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Exposure or Income? The Unequal Effects of Pollution on Daily Labor Supply

Bridget Hoffmann (Inter-American Development Bank)

Juan Pablo Rud (Royal Holloway, University of London/IFS)

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Exposure or income?
The unequal effects of pollution on daily labor supply*

Bridget Hoffmann and Juan Pablo Rud

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Abstract

We use high-frequency data on fine particulate matter air pollution (PM 2.5) at the locality level to study the effects of high pollution on labor supply decisions and hospitalizations for respiratory disease in the metropolitan area of Mexico City. We document a negative, non-linear relationship between PM 2.5 and same-day labor supply, with strong effects on days with extremely high pollution levels. On these days, the average worker experiences a reduction of around 7.5% of working hours. Workers partially compensate for lost hours by increasing their labor supply on days that follow high-pollution days. Informal workers reduce their labor supply less than formal workers on high-pollution days and also compensate less on the following days. This suggests that informal workers may experience greater exposure to high pollution and greater reductions in labor supply and income. We provide evidence that reductions in labor supply due to high pollution are consistent with avoidance behavior and that income constraints may play an important role in workers' labor supply decisions.

1 Introduction

Air pollution is the largest environmental risk to health with approximately 3 million lives lost to ambient air pollution in a single year (WHO, 2016). A vast medical and economics literature has documented the causal effects of pollution on respiratory and other diseases (Currie and Neidell, 2005; Graff Zivin and Neidell, 2013; Guarnieri and Balmes, 2014; Zhang et al., 2017), subsequent hospitalizations (Moretti and Neidell, 2011; Schlenker and Walker, 2015), and mortality (Chay and Greenstone, 2003; Arceo et al., 2016; Anderson, 2019; Deryugina et al., 2019). Can workers avoid the harmful effects of high levels of air pollution? On these days workers may face a trade-off between health and income, as performing their usual income-generating activities may increase their exposure to pollution. This trade-off is particularly acute for workers whose income is closely linked to the daily number of hours worked. These are usually lower-income, informal workers.

In this paper, we study the daily response of labor supply to same-day particulate matter in the metropolitan area of Mexico City, and its heterogeneity by worker type. We also estimate the effects of particulate matter on hospitalizations for respiratory disease and present evidence consistent with a trade-off between income and health on high-pollution days. We focus on high-frequency measures of fine particulate matter (PM 2.5), which has been documented to have severe short-term and long-term health impacts (see, for example, Guarnieri and Balmes (2014) and Deryugina et al. (2019)). More precisely, we use hourly air pollution data from ground monitoring stations combined with the WHO's air quality thresholds to capture peaks in air pollution across days

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and localities. We combine the air pollution data with daily hospital admissions data from the Automated System of Hospital Expenditures for 2010-2016 and detailed labor market data from the National Survey of Occupation and Employment (ENOE) for 2005-2016. ENOE is a rolling panel that contains daily hours worked for each day in the reference week, socio-demographic information, and labor market characteristics, such as formality status, sector of employment, and type of position.

We estimate a panel model of labor supply and hospitalizations for respiratory disease. We include a comprehensive set of time-varying weather controls, variables to control for demographic and labor market characteristics, and a rich set of fixed effects to address unobserved, time-invariant and time-varying factors that could affect both air pollution and labor supply or hospitalizations for respiratory disease.

We find economically and statistically significant evidence that the relationship between particulate matter and daily labor supply is large, negative, and non-linear. Using alternative air quality thresholds, we first show that the marginal effect of pollution is larger at higher levels of pollution. The effects are sizeable: we find that on an average day of extremely high PM 2.5 the probability of working on that day is reduced by more than 5 percentage points, which implies an average reduction of same-day hours worked of 7.5%. This amounts to a loss of around 280,000 person-days of labor on a high-pollution day in the metropolitan area of Mexico City during the period analyzed. Our results are robust to using PM 10 and a variety of specification checks, including an instrumental variables approach using wind speed and direction as a predictor of localized pollution levels.

The granularity of the data allows us to explore whether workers engage in intertemporal or intra-household substitution of labor supply to compensate for hours of labor supply lost due to high pollution. Using lags of pollution over a 6-day period, we document that workers compensate for same-day decreases in labor supply by *increasing* their hours worked in the following days. Aggregating daily hours worked to the household level, we find that the decrease in average household daily hours worked per working household member is comparable to the decrease in daily hours worked at the worker level. This suggests that responses to pollution shocks are highly correlated within the household and that workers' ability to reallocate labor hours across working household members is limited.

We find that effects of high pollution on labor supply are heterogeneous. Informal workers reduce their contemporaneous labor supply by significantly less than formal workers on high-pollution days. This is consistent with the idea that informal workers, who are less likely to be salaried or high-income workers, cannot engage in as much avoidance behavior as their formal counterparts.[1] Furthermore, we show that, in addition to reducing their contemporaneous labor supply by less than formal workers on high-pollution days, informal workers also compensate less than formal workers with smaller increases to their labor supply in the following days. As a consequence, overall weekly hours worked decreases more for informal workers than for formal workers in weeks with high levels of PM 2.5. This heterogeneous response implies that different types of workers experience different impacts of PM 2.5 on health and income. Compared to formal workers, informal workers are likely to suffer worse health impacts on contemporaneous days and work fewer hours (i.e., lose more income) over the 6-day period.

Next, we explore the potential mechanisms that could link air pollution and labor supply. First, we demonstrate that work commitments and income constraints are likely to play a role in workers' labor supply decisions. Workers reduce their labor supply in response to PM 2.5 more on days in which neither of the previous two days had high levels of PM 2.5. In contrast, on high-pollution days in which both of the previous two days also had high levels of PM 2.5, workers return to their normal working hours. These results suggest that avoidance is a more plausible explanation than cumulative negative health impacts or lower productivity, i.e., a lower opportunity cost of missing work, as these effects should not subside after consecutive days of high pollution.[2] Further, if income constraints and work commitments play a particularly important

[1]This result can be rationalized in a context where changes to the marginal utility of consumption are sufficiently large, i.e., for low income levels as in Aragón et al. (2021) and Camerer et al. (1997). Evidence of a lower elasticity of labor supply for low-income workers has also been found in other contexts, such as rural India (Jayachandran, 2006).

[2]A decrease in labor productivity on high pollution days could reduce labor supply through a substitution effect, i.e., by reducing the opportunity cost of leisure. This effect has been documented in both indoor and outdoor settings

role in informal workers' labor supply decisions, since short-term changes in their labor supply is more likely to lead to changes in income, then income constraints and work commitments could explain the heterogeneity in labor supply responses that we observe.

Second, we explore the differential labor supply responses across sectors and use official air quality alerts to show that public sector restrictions and temporarily heightened attention to pollution cannot be the only mechanisms linking air pollution and labor supply. We explore differences in labor supply responses to PM 2.5 across private and public sector workers (including education and healthcare) and find that public sector workers reduce hours worked less than their private sector counterparts. This indicates that labor supply reductions on high-pollution days reflect workers' decisions rather than public policy. Our results hold when excluding weeks in which official alerts were issued, indicating that temporarily heightened attention to air pollution is not driving our main results.[3] Further, focusing on weeks in which official alerts were issued, we show that differential pollution information between formal and informal workers and public sector closures is unlikely to fully explain the heterogeneity in labor supply responses that we observe.

Subsequently, we investigate how particulate matter affects contemporaneous hospital admissions for respiratory disease and present evidence consistent with a trade-off between income and health. We find a positive, non-linear relationship between PM 2.5 and hospital admissions for respiratory diseases that mirrors the relationship between PM 2.5 and labor supply.[4] We run patient-level specifications and show that, controlling for a variety of individual characteristics, the probability of being admitted to hospital with a respiratory disease is substantially higher on polluted days, particularly in areas with high levels of informality. In addition to contemporaneous health impacts, we also document cumulative impacts of PM 2.5 on hospitalizations for respiratory disease. Together with the heterogeneity in labor supply response, these results suggest that informal workers likely experience worse income reductions and health effects due to high PM 2.5 than formal workers.

Our results are consistent with other studies across different contexts (including richer and poorer countries) in four strands of literature that: (i) identify the short-term causal relationship between particulate matter and labor outcomes (Hanna and Oliva, 2015; Aragón et al., 2017; Kim et al., 2017; Borgschulte et al., 2020; Chan et al., 2021); (ii) estimate (non-labor-market-related) avoidance behavior on highly polluted days (Neidell, 2004; Currie et al., 2009; Bharadwaj et al., 2017); (iii) document an increase in daily hospitalizations due to respiratory diseases (Moretti and Neidell, 2011; Schlenker and Walker, 2015); and (iv) find stronger health effects of air pollution for households or individuals with lower socio-economic status (Arceo et al., 2016; Jans et al., 2018; Zhang et al., 2018).

We unite the four stands of literature above to make two novel contributions. First, our paper is unique in its focus on the trade-off that workers face between health and income on a daily basis. Further, we extend the literature by documenting heterogeneity in the effects of PM 2.5 on labor supply by workers' characteristics that can be associated with a particularly acute health-income trade-off. In particular, we find that informal workers adjust less, exposing themselves to more pollution on high-pollution days while also under-compensating for labor supply losses on subsequent days. As a consequence, both their health and their income are likely to suffer more than formal workers'. Second, our rich, high-frequency data allow us to contribute new results to the literature linking air pollution to labor supply. Specifically, we demonstrate strong non-linear effects of PM 2.5 on labor supply and document intertemporal substitution in labor supply in response to high levels of PM 2.5. Both of these effects could be disguised when using temporal aggregates, such as weekly averages. Importantly, weekly aggregates could disguise the greater impact of pollution on informal workers, which contributes to existing inequality.

The remainder of the paper proceeds as follows. Section 2 provides background on the context and presents an analytical framework that models workers' labor supply decision on high pollution

(Graff Zivin and Neidell, 2012; Chang et al., 2016; Chang et al., 2019). There is additional evidence that pollution reduces productivity in other settings, such as performance on exams or cognitive abilities more generally (Stafford, 2015; Ebenstein et al., 2016; Roth, 2019; Zhang et al., 2018).

[3]In our sample, there were only 40 days with official alerts.

[4]We also find evidence that high pollution increases the likelihood that a deceased person died of a respiratory disease.

days. Section 3 describes the data used in the analysis. In Section 4, we discuss the empirical strategy, and in Section 5, we present the main set of results, including mechanisms, robustness checks and falsification tests. Section 6 explores the effects of pollution on health, and Section 7 concludes.

2 Background

2.1 Context

Particulate matter is an important air pollutant in Mexico City. This is reflected in Mexico City residents' concerns about local air quality. In a 2019 survey of 1,869 households in lower-income neighborhoods of Mexico City, nearly 95% reported that air pollution was a "problem" or a "big problem" in Mexico City (Hanna et al., 2021).[5]

Particulate matter impacts visibility, and some particles are large or dark enough to be visible to the naked eye (EPA, 2009). Unlike other commonly regulated pollutants, particulate matter is not a single pollutant, but a mixture of many types of particles of different shapes, sizes, and chemical compositions. For regulatory purposes, particulate matter is monitored and regulated according to the size of particles. Two of the most commonly monitored types of particulate matter are inhalable particulate matter with a diameter of less than 10 μm (PM 10) and fine particulate matter with a diameter of less than 2.5 μm (PM 2.5). Therefore, PM 2.5 is a subset of PM 10.

Particulate matter is causally linked to respiratory and cardiovascular diseases and mortality in the health literature (EPA, 2009). Many studies provide evidence that short-term exposure to high levels of ambient particulate matter leads to negative health impacts on the day of exposure and the following days (Lin et al., 2002; Tertre et al., 2002). Short-term exposure to particulate matter can cause irritation of eyes, nose, throat, and lungs, coughing, sneezing, running nose, shortness of breath. More seriously, short-term exposure to particulate matter can cause acute bronchitis, exacerbate asthma, causing asthma attacks, increase susceptibility to respiratory infections, and worsen heart conditions (EPA, 2010; New York State Department of Health, 2021). Long-term exposure to particulate matter leads to severe negative health impacts, including mortality (Anderson et al., 2011; Cesaroni et al., 2014; Crouse et al., 2015).

In the metropolitan area of Mexico City, the principal sources of PM 2.5 and PM 10 are emissions from gasoline and diesel powered vehicles, re-suspension of particles from paved and unpaved roads, construction, residential combustion (such as, liquefied petroleum gas), and industrial processes, particularly in the chemicals, minerals, cement, and power sectors (Mugica et al., 2009; Molina et al., 2010; Mancera et al., 2014). In addition, air pollution levels are affected by wildfires, wind speed and direction, air temperature, humidity, precipitation, thermal inversions, and vegetation (Beckett et al., 2000; Hien et al., 2000; Secretaria del Medio Ambiente, 2005; Janhäll, 2015).

We focus on PM 2.5 in our main specifications for two reasons. First, the fine particulates that comprise PM 2.5 have stronger health impacts and cause a broader range of health impacts than coarser particulate matter. The fine size of PM 2.5 allows these particles to penetrate into the lungs and into the bloodstream, which allows them to travel to other organs (Bell et al., 2004; Pope and Dockery, 2006). Second, its small size allows ambient PM 2.5 to more readily permeate buildings than ambient PM 10, making it more difficult to avoid exposure (Tracy and Layton, 1995; Vette et al., 2001; Pope and Dockery, 2006; CARB, 2021).[6]

2.2 Analytical Framework

In this section, we develop a simple framework to examine the channels through which high levels of pollution can affect labor supply on a given day.

Assume individuals choose the optimal labor supply to maximize a one-day horizon utility function that depends on consumption c and health h and, for simplicity is additive and separable,

[5]The (translated) survey question is: "In general, do you think air pollution is a problem in Mexico City?" and the response categories are "No, it is not a problem", "It is a problem to some extent", "It is a problem", and "It is a very big problem".

[6]https://ww2.arb.ca.gov/resources/inhalable-particulate-matter-and-health

i.e., $U(c;h) = v(c)+u(h)$.[7] Daily hours (T) are spent either working (L) or in leisure (l), i.e., $T = L+l$. Consumption is a function of an individual's fixed income y and of a variable income that depends on hours worked on that day, L, and a measure of the return to working an additional hour, $w(p)$. This variable is decreasing in excess pollution p, accounting for the fact that labor productivity is lower on days with pollution that exceeds recommended guidelines, as in Graff Zivin and Neidell (2012), Chang et al. (2016), Chang et al. (2019) and Shihe Fu and Zhang (2017).[8] Health h is a function of individual characteristics a, leisure l, and pollution p.[9] The utility and the health functions have standard properties.

The first order condition yields an optimal labor supply $L(p, y, a)$, that is a function of pollution, non-wage income, and individual characteristics. Differentiating with respect to pollution gives us the following expression

$$\frac{dL}{dp} = \frac{\overbrace{w_p[v_c + v_{cc}wL]}^{\text{Productivity effect}} + \overbrace{u_{hh}h_p h_l + u_h h_{pl}}^{\text{Avoidance effect}}}{v_{cc}w^2 + u_{hh}h_l^2 + u_h h_{ll}} \tag{1}$$

From equation 1, we can identify two main channels through which pollution affects labor supply. First, there is an avoidance effect: the health reducing effect of pollution may be countered by increasing leisure time (i.e., reducing labor supply). The magnitude of this response will depend on the concavity of the utility function with respect to health, on the marginal responses of health to leisure and pollution and on whether pollution reduces the marginal health effect of leisure, i.e., the cross-derivative h_{lp}.

Second, there is a productivity effect: pollution reduces the opportunity cost of work, suggesting a flatter budget constraint and lower labor supply. The strength of this response also depends on the concavity of utility with respect to consumption. In cases where consumption levels are very low, i.e., higher concavity of the utility function, the productivity channel (in the absence of strong health effects) may induce an increase in labor supply.[10]

From this analysis, we can draw a number of implications for the empirical analysis. First, labor supply will decrease when pollution exceeds recommended guidelines either if avoidance and productivity effects of pollution move together or if the avoidance effect dominates an opposed productivity effect. Second, those workers for whom income effects are strong (e.g., workers whom are at low consumption levels or for whom daily variable income is large relative to fixed income y), will reduce their labor supply on high pollution days by less. Third, health outcomes will be relatively worse for individuals who respond less to high levels of pollution, conditional on their characteristics a.

3 Data

We combine data from four sources to create a data set of labor market outcomes, hospital admissions, air pollution, and weather data for the metropolitan area of Mexico City.

We use detailed labor market data for 2005-2016 from the National Survey of Occupation and Employment (ENOE) collected by the National Institute of Statistics and Geography (INEGI). ENOE is a rolling panel that is conducted quarterly, with an individual interviewed in up to 5 consecutive quarters before being replaced in the sample. The survey collects information on days worked and hours worked per day during the reference week. The reference week is the full week, starting on Monday, prior to the interview date. Daily hours worked is coded as 0 on days of the reference week in which the worker did not work. The survey also collects information on formality status, sector of employment, and type of position. In addition, ENOE contains

[7]See Camerer et al. (1997) for a similar treatment of daily labor supply among cab drivers in New York City.

[8]Other papers find lower productivity in the longer run, such as He et al. (2019) and Aragón and Rud (2016).

[9]This is consistent with existing evidence that longer hours of work are detrimental to workers' health (Cygan-Rehm and Wunder, 2018; Lepinteur, 2019). Avoiding pollution can also reduce other related effects, such as crime (Bondy et al., 2020) or traffic accidents (Sager, 2019).

[10]The condition for this to happen is similar to results found in Aragón et al. (2021) and Camerer et al. (1997), namely if $-\frac{v_{cc}}{v_c} > \frac{1}{wL}$, or if the income effect dominates the substitution effect.

socio-demographic data, including gender, age, education level, and household composition data, and locality of residence.

We obtained air pollution and weather variables, i.e., hourly air pollution, temperature, wind speed, and wind direction data from the Secretary of the Environment's (SEDEMA) website. These data are collected by more than 40 ground monitoring stations across the metropolitan area. We create an hourly air pollution and weather series for each locality in the ENOE sample by weighting the data from each monitoring station within 20 km of the locality in proportion to the inverse of the distance between the centroid of the locality and the monitoring station. We use daily gridded precipitation data from the Climate Hazards Group InfraRed Precipitation with Station Data (CHIRPS) at the University of California Santa Barbara. CHIRPS incorporates 0.05-degree resolution satellite imagery with station data to create a gridded rainfall daily time series, which we average at the municipality level.

We match the air pollution and weather data to the labor market data by locality or municipality of each worker's residence. Figure 1 shows the geographical reach of the data we use for our analysis of labor supply. These include all localities in Mexico City (in pink) and in Estado de Mexico (in purple) with a centroid that are within 20 kilometers of at least one pollution monitoring station, represented by the red dots.

We code daily air pollution variables as the number of hours above the WHO air quality guideline (AQG) and 3 Interim Targets (IT1-IT3) for 24-hour concentrations of particulate matter (WHO, 2005). The interim targets are intended to be used in high-pollution areas to progressively reduce air pollution. The annual air quality guideline for PM 2.5 represents the lowest level of air pollution at which total lung and cardiopulmonary cancer mortality have been shown to increase in response to long-term exposure to PM 2.5 with 95% confidence, and the annual air quality guideline for PM 10 is defined as twice the PM 2.5 concentration. The 24-hour air quality guidelines are based on the relationship between the 24-hour and annual concentrations of particulate matter. Interim Targets 1 are the levels that represent a 5% higher short-term mortality risk than the AQG based on multi-center studies and meta-analysis (WHO, 2005). In between PM 2.5 IT1 and PM 2.5 AQG are Interim Targets 2 and 3.

During our study period 2005-2016, across all localities and days in our sample, pollution in Mexico City and surrounding localities is high. Figure 2 shows the distribution of the highest hourly PM 2.5 reading per locality-day, relative to the World Health Organization's Air Quality Guideline (AQG) and 3 Interim Targets (IT1-IT3) for 24-hour concentrations of particulate matter (WHO, 2005). The distribution has wide support with a large share of days experiencing at least one hour above the recommended pollution levels. Table 1 shows the targets, the share of hours in all locality-days above each target and the share of days that have at least one hour above the target. In more than 40% of all hours and in almost 2 out of 3 days between 2005 and 2016, residents in Mexico City and surrounding localities experienced levels of pollution above the air quality guidelines for PM 2.5. The latter share increases to almost 80% for PM 10. Pollution has also exceeded the least ambitious of Interim Targets (IT1) in almost 6% of days for PM 2.5 and more than 12% for PM 10.[11] The variation in PM 2.5 levels across days allows us to estimate the non-linear effects of PM 2.5 and the impact of consecutive high-pollution days.

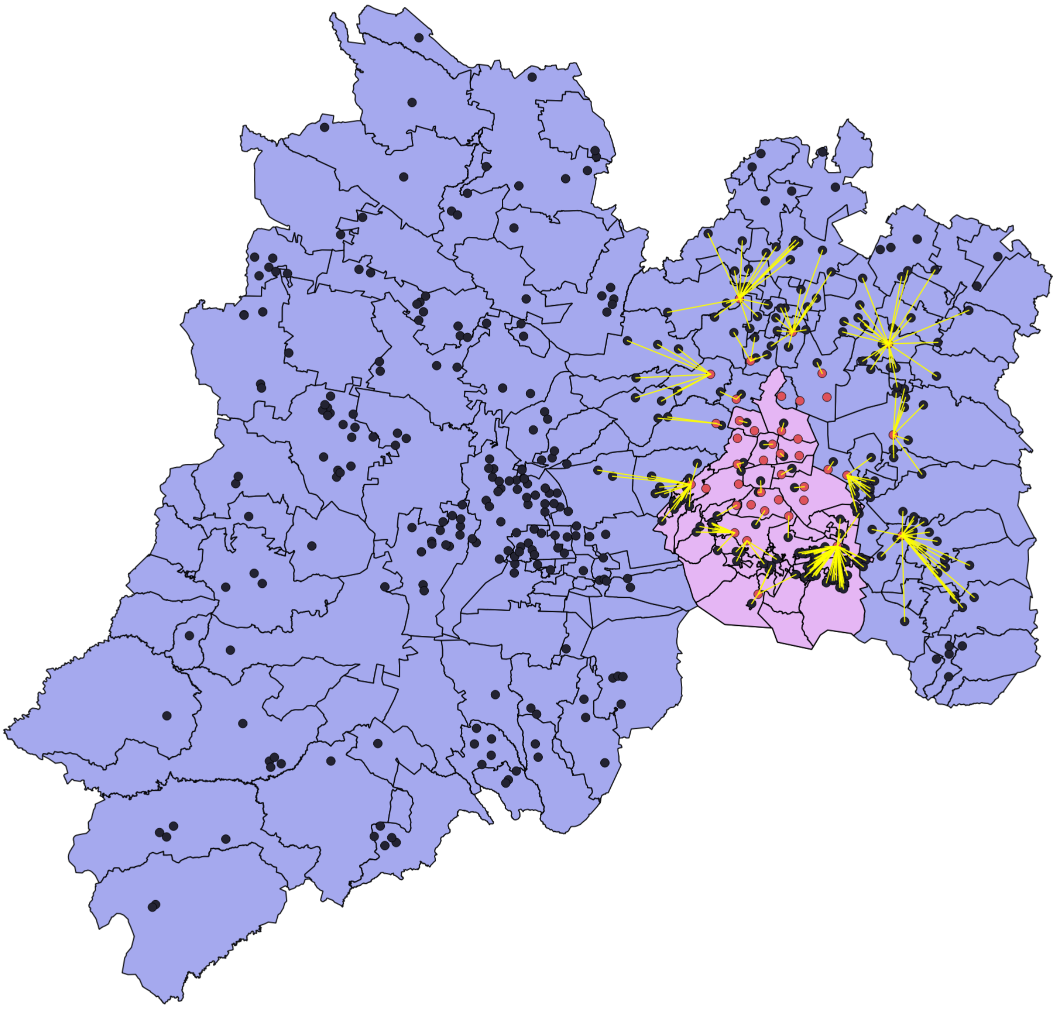
Table 1: WHO Air Quality Guidelines and Targets and Pollution Incidence in Mexico City and Surroundings (2005-2016)

	PM 2.5			PM 10		
	Target	Hours-locality (%)	Days-locality (%)	Target	Hours-locality (%)	Days-locality (%)
Interim Target 1 (IT1)	75	0.95	5.60	150	1.26	12.04
Interim Target 2 (IT2)	50	6.06	24.65	100	6.41	34.87
Interim Target 3 (IT3)	37.5	16.27	44.76	75	15.77	55.65
Air Quality Guideline (AQG)	25	40.24	63.92	50	37.90	79.60

Notes: PM 2.5 and PM 10 are measured in $\mu g/m^3$ (WHO, 2005).

[11] In Figure B1 we show that there is substantial variation across localities and across time within localities.

Figure 1: Monitoring Stations and Sample Localities

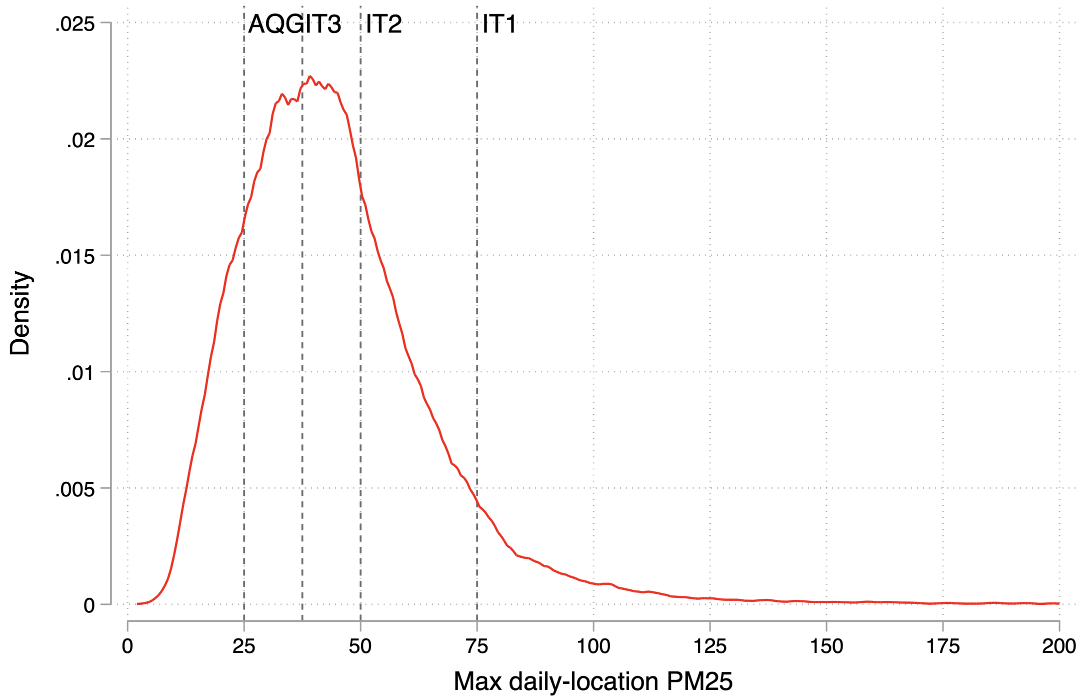


Note: The figure displays a map of Ciudad (pink) and Estado (purple) de Mexico regions. The red dots are air pollution monitoring stations and yellow lines link them to the centroid of the localities that are within 20km and included in the ENOE sample.

Our measures of daily air pollution leverage our high-frequency air pollution data to capture peaks in air pollution. Relative to the literature that studies daily or weekly average levels of particulate matter, which smooth peaks in air pollution, our measures represent an improvement for studying the non-linear relationship between labor supply and health outcomes and PM 2.5 and estimating the impact of extreme levels of PM 2.5 on labor supply and health outcomes.

Finally, we use data on daily hospital admissions for 2010-2016 from the Automated Subsystem of Hospital Expenditures (Subsistema Automatizado de Egresos Hospitalarios) available from the Secretary of Health. The data set contains data on the reason for admission to public hospitals run by the Secretariat of Health and provides information related to individuals' hospitalization (e.g., diagnoses, discharges, procedures, etc.). Health conditions for hospital admissions are coded using the International Statistical Classification of Diseases and Related Health Problems (ICD-10). The data also contains basic demographic information about patients, including age,

Figure 2: Distribution of Maximum Daily-Locality PM 2.5



Note: The figure displays the distribution of the daily maximum PM2.5 hourly-location readings for 2005-2016 and the World Health Organization's (WHO) air quality guidelines (AQG) and interim targets (IT1-IT3).

sex, indigenous heritage, and type of insurance.

In Table 2, we provide summary statistics for the main variables that we use in the empirical analysis. In Panel A, we summarize the average worker in our sample: around 39 years old with more than 10 years of schooling, has a 59% probability of being male and a 53% probability of being informal. In Panel B, we match workers' daily observations with air pollution and weather information. Workers work around 6.3 hours per day on 76% of days (i.e., more than 5 days a week). Note that on an average day, PM2.5 levels are above the AQG threshold for more than 10 hours, while the average number of hours above the highest threshold (IT1) is about 0.17 (equivalent to 10 minutes a day). In Panel C, we show hospitalization data. The average age of individuals admitted to hospital is 37.5 years, with almost an equal number of men and women. There are 15 daily hospital admissions on average, out of which around 1 (7%) is due to a respiratory disease.

4 Empirical Strategy

Our objective is to identify the short-term causal effect of PM 2.5 on labor supply and hospitalizations for respiratory disease. There may be unobserved time-invariant determinants of both local air pollution and labor supply or hospitalizations for respiratory disease, such as the local level of economic activity, or time-varying factors that affect both air pollution and labor supply or hospitalizations for respiratory disease, such as weather conditions or local trends in contagion. To address these concerns, our empirical specifications include a comprehensive set of time-varying weather controls, variables to control for demographic and labor market characteristics, and a rich set of fixed effects.

We estimate the impact of particulate matter on the probability of working the contemporaneous day and on hours worked on the contemporaneous day. As our baseline labor supply specification,

Table 2: Summary Statistics - Employment and Environment

	N	Mean	Standard Deviation	Min	Max
A. Individual characteristics					
Age	317,844	39.2	13.5	12	98
Male (%)	317,844	0.59	0.49	0	1
Years of schooling	317,844	10.5	4.2	0	24
Informal (%)	317,844	0.53	0.50	0	1
Self-employed (%)	317,844	0.23	0.42	0	1
Wage employee (%)	317,815	0.57	0.50	0	1
Works in retail or services (%)	317,844	0.78	0.42	0	1
B. Daily observations					
Hours Worked	2,232,239	6.3	4.0	0	15
Days Worked (%)	2,232,239	0.76	0.43	0	1
Hours Above PM2.5 IT1 Threshold	2,232,239	0.17	0.96	0	22
Hours Above PM2.5 IT2 Threshold	2,232,239	1.39	2.90	0	24
Hours Above PM2.5 IT3 Threshold	2,232,239	4.10	5.19	0	24
Hours Above PM2.5 AQG Threshold	2,232,239	10.2	7.7	0	24
Maximum Temperature (C)	2,232,239	23.3	3.06	7.7	33.8
Rainfall (mm)	2,232,239	1.95	4.52	0	69.7
C. Daily hospitalizations					
Age	1,286,439	37.5	21.9	1	90
Male (%)	1,286,439	0.49	0.50	0	1
Uninsured (%)	1,286,439	0.31	0.46	0	1
Respiratory disease (%)	1,286,439	0.07	0.25	0	1
Total daily	49,925	14.8	17.10	1	125
Respiratory daily	49,925	0.98	1.49	1	15

we estimate the impact of contemporaneous particulate matter on labor supply using the following regression:

$$y_{ilm,tw} = \alpha_m + \phi_w + \eta_d \beta PM2.5_{lm,tw} + \gamma X_{ilm,tw} + \epsilon_{ilm,tw} \tag{2}$$

where the unit of observation is individual i who resides in locality l of municipality m on day t that falls within week w. The outcome $y_{ilm,tw}$ an indicator variable that equals 1 if individual i reported working on day t and 0 otherwise or the number of hours that individual i reported working on day t. $PM2.5_{lm,tw}$ is the number of hours in which fine particulate matter exceeded the WHO's IT1, IT2, IT3, or AQG in locality l of municipality m on day t in week w. $X_{ilm,tw}$ is a vector of time-varying weather and demographic controls that consists of maximum temperature in locality l on day t, precipitation in municipality m on day t and its square, age of individual i and its square, gender of individual i, and years of schooling completed by individual i and its square. α_m is a set of municipality fixed effects to control for time-invariant unobserved determinants of labor supply that are common to a municipality. η_d is a set of day of the week fixed effects that controls for any unobserved patterns in labor supply across days of the week. ϕ_w is a set of week fixed effects to control for any unobserved determinant of labor supply that varies over time but is common to all individuals in Mexico City, such as seasonality in the labor market. We estimate robust standard errors.[12]

We augment the baseline specification for labor supply in multiple ways to address additional concerns about potential sources of endogeneity. First, we include additional control variables consisting of type of job and position, formality status, and sector of employment to control for labor market characteristics. Second, we include household fixed effects, which controls for time-invariant unobserved factors at the household level, such as preference for residing in a low-pollution neighborhood. Finally, we include individual fixed effects, which controls for time-invariant unobserved factors at the individual-level, such as individual preference for air pollution, health status, and working conditions. We focus on the parsimonious specification because our results are consistent with those of these additional specifications.

As described in Section 5.5, we corroborate our results using an instrumental variables strategy to overcome concerns associated with confounding factors that vary over time within a locality. A primary concern in estimating the contemporaneous or short-term effects of air pollution on labor supply is that local vehicle traffic or the level and type of economic activity in a specific area could determine both labor supply and air pollution levels. We use wind direction and wind speed as instruments for particulate matter. This instrumental variables identification strategy provides evidence that our results are not driven by confounding factors.

As our baseline specification to estimate the impact of contemporaneous particulate matter on hospital admissions for respiratory disease, we use the following regression:

$$y_{hm,tcy} = \alpha_m + \phi_{cy} + \beta PM2.5_{lm,tcy} + \epsilon_{hm,tcy} \tag{3}$$

where the unit of observation is a hospital admission. Therefore, we estimate the effect of particulate matter on the likelihood of a hospitalization for respiratory diseases relative to admissions due to other causes. We restrict our sample to hospital admissions unrelated to pregnancy or child-birth.

The outcome variable $y_{hlm,tcy}$ is an indicator variable that equals one for a hospital admission for a respiratory disease in hospital h in locality l in municipality m on day t of month c and year y and 0 for hospital admissions related to other diseases. $PM2.5_{lm,tw}$ is the number of hours in which fine particulate matter exceeded the WHO's IT1, IT2, IT3, or AQG in locality l of municipality m on day t of month c in year y. α_m is a set of municipality fixed effects to control for time-invariant unobserved determinants of respiratory hospitalizations that are common to a municipality. ϕ_{cy} is a set of month × year fixed effects to control for any unobserved determinant of respiratory disease that varies over time but is common to all individuals in Mexico City, such as seasonality in weather or contagion. Standard errors are clustered at the locality level to capture the potential correlation of shocks between neighboring hospitals.

We augment the baseline specification for hospitalizations in multiple ways. First, we include additional variables to control for weather and patient demographic characteristics that could

[12] The results are robust to clustering at the locality level, that may matter in the presence of heterogeneous results after the inclusion of locality fixed effects (Abadie et al., 2017).

partially determine the likelihood of hospitalization for a respiratory disease. Specifically, we include the maximum hourly temperature in the locality in which the hospital is located, daily precipitation and its square at the municipality level and individual patients' age, age squared, sex, type of health insurance, and indigenous heritage as control variables. Second, we include a set of locality fixed effects, which controls for time-invariant unobserved factors at the locality-level such as localized incidence of certain types of diseases, and day of the week fixed effects, which controls for any unobserved determinant of admissions across days of the week, such as potential day of the week preferences for admissions among patients or doctors. Finally, we include a larger set of controls by augmenting the prior patient characteristics controls with the natural logs of patients' height and weight, available only for a sub-sample of hospitalized individuals. Similarly to the labor supply analysis, we focus on the parsimonious specification because our results are consistent with those of these additional specifications.

5 Results

5.1 Non-Linear Effects of PM 2.5 on Contemporaneous Labor Supply

In this section, we document that PM2.5 has a negative non-linear relationship with labor supply by estimating equation 2 using the number of hours above each WHO threshold as alternative measures of air pollution.

Figure 3 plots the coefficients and 90% confidence intervals from separate regressions for each WHO threshold. The effect of PM 2.5 on the probability of working the contemporaneous day is shown in Panel A and the effect of PM 2.5 on contemporaneous daily hours worked is shown in Panel B.

We find that an hour above the WHO Air Quality Guideline or the WHO Interim Target 3 has a very small effect on the probability of working that day and on daily hours worked. This is not surprising, as Table 1 shows that around 64% of days have at least one hour above the Air Quality Guideline threshold and almost 45% of days have at least one hour above the lowest interim target. This would suggest that days with levels of PM 2.5 above either of those targets are the norm.

Workers start to respond when pollution exceeds the upper two thresholds. An hour above the WHO Interim Target 2 decreases the probability of working that day by 0.2%, and an hour above the WHO Interim Target 1 decreases the probability of working that day by 1.8%. Similarly, an hour above the WHO Interim Target 2 results in a 0.020-hour reduction in same day hours worked and an hour above the WHO Interim Target 1 implies a 0.155-hour (9.3 minutes) reduction in same day hours worked. The magnitude of the effect is sizeable. The point estimate represents around 2.5% of the hours worked on an average day. Considering that on days with at least an hour above IT1, the average number of hours exceeding the threshold is 3, this implies that on these days the number of hours is reduced by 7.5% (i.e., around half an hour).[13]

The marginal effect of PM 2.5 on labor supply is larger at higher levels of pollution, i.e., an additional hour of pollution above the WHO Air Quality Guidelines decreases labor supply more at higher levels of PM2.5. Based on these non-linear effects of pollution on labor supply and to exploit the advantage of our high-frequency data in capturing peaks in air pollution levels, we focus on WHO Interim Target 1 for the remainder of the paper.

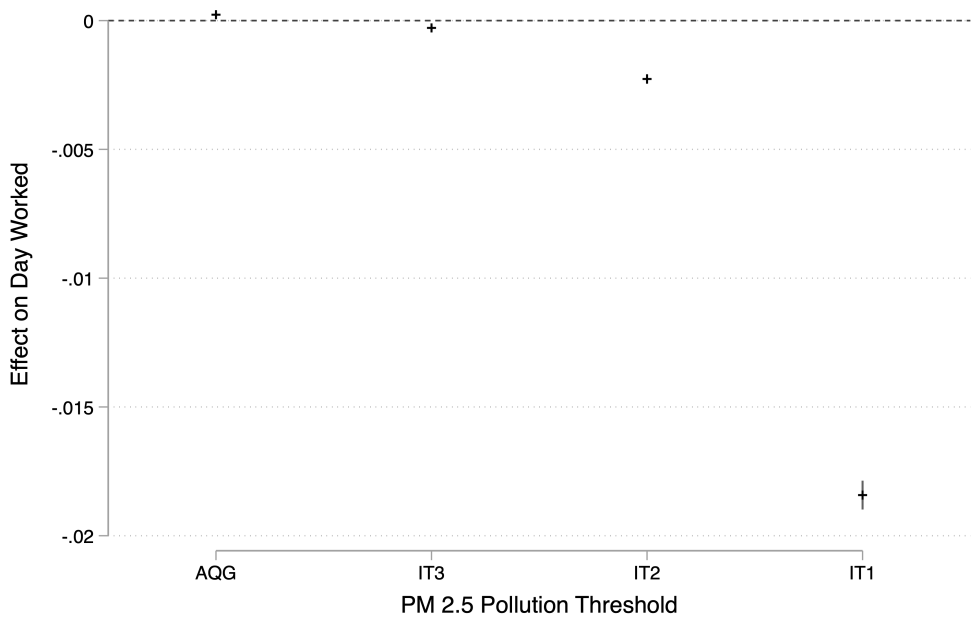
5.2 Impact of High PM 2.5 on Contemporaneous Labor Supply

In this section, we document that the effect of high PM 2.5 on the probability of working and daily hours worked are large, negative, and consistent across specifications. These results are consistent with the first implication of the analytical framework, which states that labor supply decreases with PM 2.5 if avoidance and productivity effects of pollution move together or if the avoidance effect dominates an opposed productivity effect. We also document that workers with lower and more uncertain income reduce their hours worked by less than workers with higher and more

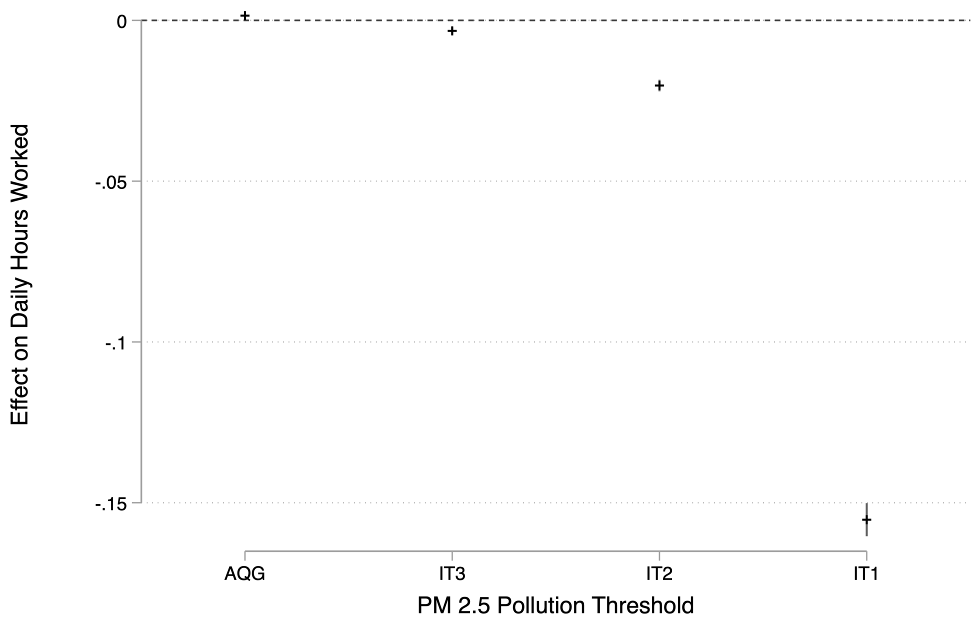
[13]Coefficients and standard errors are displayed in Appendix Table A1. In addition, we estimate the non-linear relationship between PM 2.5 and the semi-elasticity of daily hours using the natural logarithm of 1+ daily hours worked as the outcome variable in equation 2. The results shown in Appendix Figure B3 follow a similar pattern.

Figure 3: Daily Number of Hours Above WHO Thresholds and Worked Day and Daily Hours Worked

Panel A: Worked Day



Panel B: Daily Hours Worked



Coefficients and 90% confidence intervals are plotted from equation 2 for the number of hours above the WHO air quality threshold for PM 2.5. A separate regression is run for each threshold. Panel A shows the impact on working that day and Panel B shows impact on hours worked that day.

stable income on days with high levels of PM 2.5. These results support the second implication of the analytical framework, which states that workers at low consumption levels or for whom daily variable income is large relative to fixed income (i.e., those for whom income effects are strong) make smaller reductions to their labor supply on days with high PM 2.5.

5.2.1 Effects on Days Worked and Daily Hours Worked

Table 3 shows that the impact of an hour of PM 2.5 above the WHO IT1 threshold on the probability of working the contemporaneous day (Panel A) and on contemporaneous daily hours worked (Panel B) are very consistent across alternative specifications. Column (1) displays the results of the baseline specification, already discussed in relation to Figure 3. We augment our baseline specification in three ways. Column (2) presents the results of the baseline specification controlling for a worker's type of job and position, formality status, and sector of employment. We find that that the effects on the probability of working that day (Panel A) and on contemporaneous daily hours worked (Panel B) are almost identical to column (1). Columns (3) and (4) present the results of the baseline specification using household fixed effects and individual fixed effects, respectively, and show that the effects are slightly larger in magnitude.[14]

Table 3: The Effect of PM 2.5 on Day Worked and Daily Hours Worked

	Panel A: Day Worked			
	(1)	(2)	(3)	(4)
Hours Above PM2.5 IT1 Threshold	-0.018***	-0.018***	-0.019***	-0.019***
	(0.000)	(0.000)	(0.000)	(0.000)
Method	Baseline	Occupation Controls	HH FE	Individual FE
N	2,232,239	2,232,239	2,232,231	2,232,204
R2	0.331	0.337	0.383	0.426
	Panel B: Daily Hours Worked			
	(1)	(2)	(3)	(4)
Hours Above PM2.5 IT1 Threshold	-0.155***	-0.155***	-0.159***	-0.161***
	(0.003)	(0.003)	(0.003)	(0.003)
Method	Baseline	Occupation Controls	HH FE	Individual FE
N	2,232,239	2,232,239	2,232,231	2,232,204
R2	0.285	0.308	0.391	0.476

Notes: Robust standard errors in parenthesis. * denotes significance at the 10% level, ** denotes significance at the 5% level, and *** denotes significance at the 1% level. Equation 2 is the baseline specification shown in column (1). Column (2) includes type of job and position, formality status, and sector of employment as additional controls. Column (3) adds household fixed effects to the baseline specification. Column (4) adds individual fixed effects to the baseline specification.

We also estimate the semi-elasticity of daily hours worked to an hour above the WHO IT1 threshold for PM 2.5. Appendix Table A2 shows the results of estimating equation 2 using the natural logarithm of 1 + daily hours worked as the outcome variable. An hour of PM 2.5 above the WHO IT1 threshold decreases daily hours worked by 4.1%-4.2% depending on the specification.

These effects are substantial and imply that reductions in labor supply due to high levels of fine particulate matter have a significant economic cost. In our preferred specification (column (1) in Table 3, the effect of an additional hour above the IT1 threshold would reduce hours worked

[14] In Figure B2 we show that pollution levels above IT1 are, on average, more intense between 5 and 9 a.m. This is suggestive of the idea that people are likely aware of high pollution realizations in the morning, when they decide whether or not to go to work.

by around 2.5%. On a day above the WHO IT1 threshold, a locality would experience around 3 hours of extremely high pollution. Using the estimate from our baseline specification for a back-of-the-envelope calculation, this implies that reducing fine particulate matter to levels below this threshold could increase an individual's labor supply by approximately 7.5% hours, i.e., almost half an hour, on polluted days. If we consider that our sample includes around 3.5 million workers in Ciudad de Mexico and surroundings, our results imply that on a high-pollution day there would be a loss of 1.75 million hours or an average of around 280 thousand worker-days, evaluated at the sample mean of 6.3 hours of work per day.

In addition, we explore whether the effect of particulate matter on labor supply is driven by the extensive margin, the intensive margin, or both. We find a strong negative relationship between high levels of PM 2.5 and same day hours worked but this measure of labor supply conflates the intensive and extensive margins (panel B of Table 3). We find large and statistically significant effects of high levels of PM 2.5 on the extensive margin (columns (1)-(3) of Appendix Table A3). In contrast, we find weaker evidence of an effect of high levels of PM 2.5 on the intensive margin. To investigate the intensive margin, we estimate the impact of PM 2.5 on hours worked in the sample of individuals who worked that day. Our results are suggestive because we may have selection, due to pollution, in the sample of workers who work each day. While the point estimates are negative across specifications, we find no economically or statistically significant effect in our baseline specification or when including occupational controls (columns (4) and (5) of Appendix Table A3), but the result becomes significant when using individual fixed effects. In that case, an additional hour above the WHO Interim Threshold 1 for PM 2.5 reduces hours worked by 0.003 hours (0.18 minutes) (column (6) of Appendix Table A3). Although we find suggestive evidence that the largest effect of PM 2.5 on labor supply is through the extensive margin, in the remainder of the analysis, we focus on daily hours worked as the outcome of interest because this variable captures adjustments in labor supply on both margins and avoids selection into the sample.

These results indicate that workers reduce their same-day labor supply on high-pollution days. This could be due to contemporaneous negative health impacts of PM 2.5, negative productivity shocks, or workers engaging in avoidance behavior. In later sections, we examine the role that these channels play to the extent possible in our data.

5.2.2 Heterogeneous Effects of PM 2.5

As discussed in Section 2.2, we expect that workers with high variable income relative to fixed income or with low consumption levels will experience stronger income effects of pollution on labor supply. This implies that workers with highly variable income and low consumption levels will make smaller reductions to labor supply on high-pollution days.

In this section, we use a variety of indicators that may capture these circumstances, such as informality or reporting income in a low-income bracket, to explore whether labor supply responses differ across types of workers. To document the heterogeneous effects of fine particulate matter on contemporaneous daily hours worked, we augment our baseline specification, equation 2, by adding indicators for employment and earnings characteristics and fully interacting these characteristics with the number of hours above the WHO IT1 threshold and controls. Table 4 presents the results.

Column (1) of Table 4 shows that informal workers' labor supply is up to 20% less responsive to elevated levels of PM 2.5 than formal workers. For each hour above the WHO IT1 threshold, formal workers reduce daily hours worked by 0.174 hours (10.5 minutes) while informal workers reduce daily hours worked by 0.142 hours (8.5 minutes). Accounting for these different responses, and considering that 53% of workers in the sample are informal, the aggregate effect on labor lost to pollution on high-pollution days is around 260 thousand worker-days.

Column (2)-(5) display a similar pattern for self-employed, non-wage employees, workers with low educational attainment, and low-income workers.[15]

Appendix Table A5 corroborates the heterogeneity results by showing heterogeneity in the semi-elasticity of daily hours worked to an hour of fine particulate matter above the WHO IT1

[15] Appendix Table A4 presents the results of adding only the indicator for employment or earnings characteristic and the interaction between this characteristic and the number of hours above the WHO IT1 threshold to the main specification. The results are robust to this alternative specification.

Table 4: Heterogeneous Effects of PM 2.5

	Daily Hours Worked				
	(1)	(2)	(3)	(4)	(5)
Hours Above PM2.5 IT1 Threshold	-0.174***	-0.164***	-0.161***	-0.165***	-0.157***
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Characteristic x Hours Above IT1	0.032***	0.036***	0.012**	0.016***	0.019***
	(0.006)	(0.007)	(0.006)	(0.006)	(0.006)
Characteristic	Informal	Self-employed	Non-wage employee	Low Education	Low Income
N	2,232,239	2,232,239	2,232,032	2,232,239	1,960,838
R2	0.314	0.307	0.300	0.294	0.298

Notes: Robust standard errors in parenthesis. * denotes significance at the 10% level, ** denotes significance at the 5% level, and *** denotes significance at the 1% level. Results of estimating the baseline equation 2, allowing for interactions between characteristics and controls and using the number of daily hours worked as the outcome variable. ENOE classifies as informal those workers in unregistered economic activities; self-employed are those workers who work on their own or with the support of unpaid family members; non-wage employees are those whose earnings are not fixed (e.g. depend on commissions or sales); Low education refers to workers with an educational attainment below 9 years; Low income workers are those usually earning less than 3 minimum wages.

threshold by worker characteristics. Informal and self-employed workers reduce their labor supply by about 1% less than formal and non-self-employed workers in response to an hour of PM 2.5 above the WHO IT1 threshold. Similarly, non-wage employees, and workers with low education levels reduce their daily hours worked by 0.6%-0.7% less than wage employees and workers with higher incomes and education levels.

Consistent with the analytical framework and with evidence from labor markets in other settings (e.g., rural India in Jayachandran (2006)), the evidence presented in this section shows that workers with lower and more uncertain income make smaller reductions to their labor supply than other workers when PM 2.5 is elevated.

5.3 Reallocations of Labor Supply

In this section, we exploit two key features of our data to explore whether workers or households mitigate contemporaneous labor supply shocks by reallocating labor across time or household members. First, we make use of the temporal granularity of the data to explore whether high PM 2.5 has implications for labor supply in subsequent days and to explore the impacts of high PM 2.5 on cumulative labor supply. We also draw on the labor supply data for all household members to explore the possibility that households smooth labor supply by reallocating labor across workers, presumably with different characteristics or types of jobs, within the household.

We find that workers partially mitigate negative labor supply shocks on days with high PM 2.5 by increasing their labor supply on the following days. However, we show that households engage in limited reallocation of their labor supply across household members in response to high levels of PM 2.5.

5.3.1 Inter-Temporal Substitution

We investigate workers' inter-temporal substitution of labor supply by augmenting our baseline specification with 5 days of lagged air pollution measures. Figure 4 shows that workers reallocate their labor supply across days in response to high PM 2.5. The largest reallocations in labor supply occur on the day of high PM 2.5 and the following 1 to 4 days. Panel A displays the impact of contemporaneous and lagged PM 2.5 on daily hours worked.[16] Workers decrease hours worked on days with high PM 2.5 and partially compensate by increasing hours worked in the following days. Specifically, summing the positive coefficients for the 5 lagged days results in an increase in hours worked of 0.12 compared to a same day decrease of 0.15 hours worked, implying that high PM 2.5 decreases cumulative hours worked over the 6-day period.[17]

Panel B displays workers' inter-temporal substitution in response to high PM 2.5 by formality status. Consistent with the prior results showing that informal workers have a less flexible labor supply than formal workers, informal workers are less responsive to contemporaneous PM 2.5 and engage in less inter-temporal substitution of labor supply across days in response to high PM 2.5. Further, informal workers spread their reallocations of labor supply more equally across 5 days compared to formal workers who concentrate their reallocations in the first four days after high PM 2.5.

Formal workers decrease contemporaneous daily hours worked by 0.16 hours in response to an hour of PM 2.5 above the WHO IT1 threshold compared to a total increase of 0.14 hours worked in response to an hour of PM 2.5 above the WHO IT1 threshold over the following 5 days. For informal workers, an hour of PM 2.5 above the WHO IT1 threshold decreases the contemporaneous hours worked by 0.15 hours compared to a total increase of 0.10 hours worked in response to an hour above the WHO IT1 threshold over the following 5 days.[18]

Informal workers decrease their probability of working and their hours worked less than formal workers on days with high PM 2.5, but they also compensate less than formal workers with smaller increases in their probability of working and hours worked in the following days. This inflexibility leads to larger cumulative decreases in labor supply over the 6-day period for informal workers than for formal workers.

Table 5: Weekly Air Pollution and Weekly Hours Worked

	Full Sample		Formal Workers		Informal Workers	
	(1)	(2)	(3)	(4)	(5)	(6)
Hours Above PM2.5 IT1 Threshold	-0.073***	-0.085***	-0.058*	-0.078**	-0.088**	-0.093***
	(0.025)	(0.025)	(0.035)	(0.034)	(0.035)	(0.035)
Method	Baseline	Occupation Controls	Baseline	Occupation Controls	Baseline	Occupation Controls
N	339,432	339,432	159,348	159,348	180,084	180,084
R2	0.013	0.022	0.009	0.023	0.019	0.025

Notes: Robust standard errors in parenthesis. * denotes significance at the 10% level, ** denotes significance at the 5% level, and *** denotes significance at the 1% level. Results of estimating the baseline equation 2 in each subsample.

We corroborate the result that cumulative labor supply decreases due to high PM 2.5 using air pollution and labor supply data at the weekly level. Columns (1) and (2) of table 5 present the results. Columns (3)-(6) provide additional suggestive evidence that informal workers' relatively inflexible labor supply leads them to suffer greater cumulative losses of labor supply due to high PM 2.5 than formal workers, although we cannot reject equality of the coefficients.

These results imply that informal workers' relatively more inflexible labor supply could lead them to suffer from fine particulate matter more than formal workers for two reasons. First, informal workers' smaller reductions in contemporaneous labor supply implies that they may be more exposed to same-day pollution, which could have negative short- and long-term health impacts. Second, informal workers' increase their labor supply by smaller amounts than formal

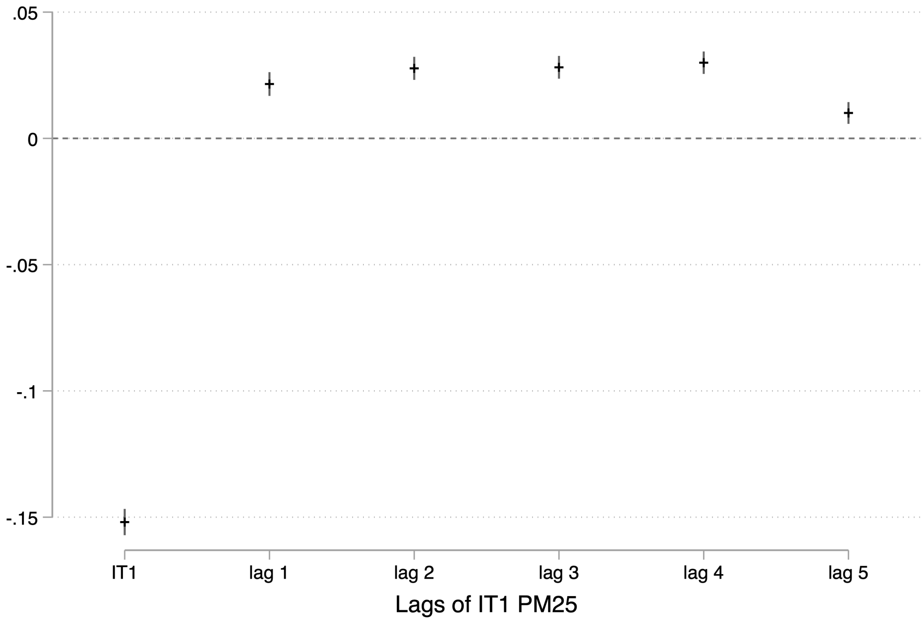
[16]Coefficients and standard errors for both worked day and daily hours worked outcomes are shown in Appendix Table A6.

[17]Panel A of Appendix Figure B4 shows that the effects of contemporaneous and lagged PM 2.5 on the probability of working each day follows a similar pattern.

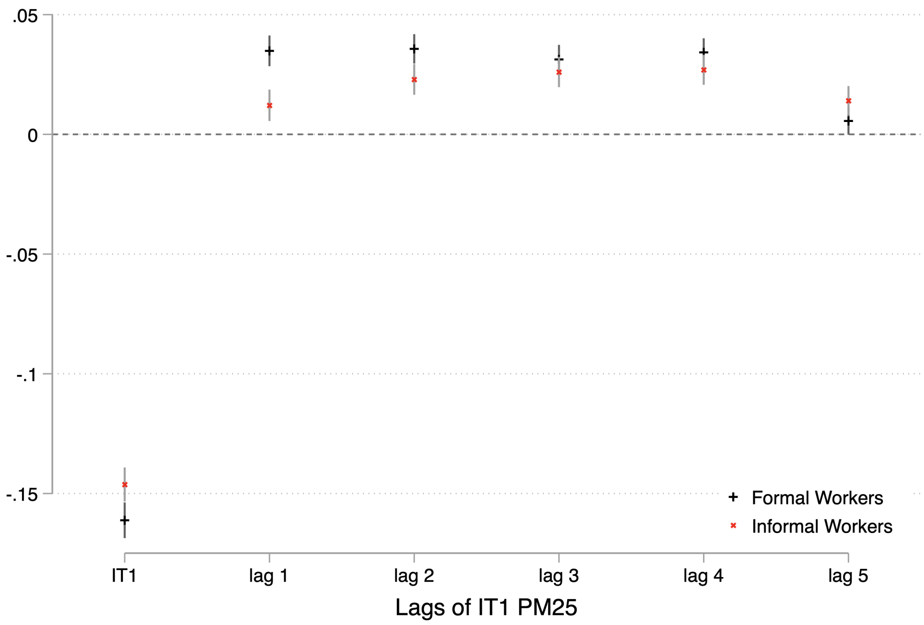
[18]Panel B of Appendix Figure B4 shows that the effects of contemporaneous and lagged PM 2.5 on the probability of working each day follows a similar pattern for formal and informal workers.

Figure 4: Impact of Same-Day and Lagged PM 2.5 on Daily Hours Worked

Panel A: Full Sample



Panel B: By Formality Status



Coefficients and 90% confidence intervals are plotted from equation 2 augmented by five days of lagged PM2.5 measures. Panel A shows the impact on hours worked that day in the full sample and Panel B shows impact on hours worked that day separately in the samples of formal workers and informal workers.

workers on the days following high-pollution days, implying that informal workers' cumulative labor supply decreases more than formal workers. Combined with income streams that are more

Table 6: The Effect of PM 2.5 on Daily Hours Worked at the Household Level

	Total Hours	Average Hours					
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Hours Above PM2.5 IT1 Threshold	-0.271***	-0.160***	-0.171***	-0.147***	-0.174***	-0.153***	-0.157***
	(0.008)	(0.004)	(0.006)	(0.005)	(0.006)	(0.007)	(0.006)
Household Sample	All	All	Single Worker	Multi- Worker	All Formal	Mixed	All Informal
N	1,291,397	1,291,397	640,224	651,173	491,210	281,209	518,978
R2	0.180	0.327	0.291	0.387	0.486	0.433	0.190

Notes: Robust standard errors in parenthesis. * denotes significance at the 10% level, ** denotes significance at the 5% level, and *** denotes significance at the 1% level. Results of estimating the baseline equation 2 in each subsample.

likely to be directly linked to hours worked than formal workers, this implies that informal workers will experience greater drops in income in response to PM 2.5 than formal workers.

5.3.2 Intra-Household Substitution

Households may substitute labor within the household on days with elevated levels of PM 2.5 to protect household members who are more exposed to PM 2.5 at work or more vulnerable to PM 2.5. If labor is substituted across workers in the household, then total household labor supply, and household income, may increase or decrease on days with high levels of PM 2.5.

Table 6 shows that households' total daily hours worked (column (1)) decreases with high levels of PM 2.5. The decrease in households' total daily hours worked suggests that households are likely to experience reductions in household income on days with elevated levels of fine particulate matter. Column (2) shows that the average hours worked per working household member decreases in response to high pollution. The magnitude of this effect is very similar to the effect at the individual level in Table 3, indicating that there is limited intra-household substitution of labor supply.

Columns (3) and (4) show the impact of elevated PM 2.5 on average daily hours worked for households with only a single worker and for households with multiple workers. In single-worker households, there is no possibility for intra-household substitution of labor supply and daily average household hours worked is equal to the worker's daily hours worked. The coefficient in column (4) is smaller than that in column (3), suggesting that households have some capacity to smooth labor supply shocks through intra-household substitution. Together, columns (2), (3), and (4) suggest that although pollution shocks are highly correlated within the household and likely lead to drops in household income, households have some capacity to smooth responses to high pollution across their members.

Columns (5)-(7) show the impact of elevated PM 2.5 on average daily hours worked for households in which all workers are formal workers, there is a mix of formal and informal workers, and all workers are informal. The average daily hours worked for the household decreases more for households in which all workers in the household are formal than for households in which some or all workers are informal. Consistent with the heterogeneous effects at the individual level presented in Section 5.2.2, these results provide additional evidence that informal workers and households have less flexible labor supply.

5.4 Mechanisms

In this section, we explore several mechanisms that could link air pollution and labor supply and could explain the differential effects for formal and informal workers. First, we provide evidence that income constraints and work commitments likely play a role in workers' labor supply adjustments. This suggests that workers' reductions in labor supply more plausibly reflect avoidance behavior and are not fully explained by reductions in labor supply due to contemporaneous negative health impacts or lower productivity due to PM 2.5. Further, if income constraints and work commitments play a particularly strong role in informal workers' labor supply decisions, this channel could also explain their lower response to high PM 2.5 compared to formal, higher-income workers. Second, we use official air quality alerts to show that temporarily heightened attention to pollution and public sector restrictions cannot be the only mechanisms linking air pollution and labor supply. We explore differences across private and public sector workers to show that labor supply reductions on high-pollution days reflect workers' decisions rather than reductions to labor demand. Further, focusing on weeks in which official alerts were issued, we show that differential pollution information between formal and informal workers and public sector closures cannot fully explain the heterogeneity in labor supply responses that we observe.

5.4.1 Role of Income Constraints and Work Commitments

We investigate the impact of PM 2.5 on labor supply on consecutive days with high levels of PM 2.5. The presumption is that, while workers' response may be strong on a sudden high-pollution day, when there are consecutive days of high pollution, income loss may start to constrain labor supply responses, particularly if they are related to avoidance behavior. Therefore, if workers' reductions in labor supply were partially due to avoidance behavior, income constraints and work commitments would imply that the impacts of PM 2.5 would decrease across consecutive days of high PM 2.5.[19] However, if workers' reductions to labor supply were completely due to negative short-term health impacts or reduced productivity due to PM 2.5, we would not expect these impacts to subside on consecutive days with high pollution. Income constraints and work commitments are likely to play a particularly important role in informal workers' labor supply decisions since their short-term changes in labor supply are more likely to lead to changes in income.

We investigate the role of income constraints and work commitments by estimating our baseline specification, equation 2, in the sample of all days in which both of the prior two days had zero hours with PM 2.5 above the WHO IT1 threshold, the sample of all days in which the prior day had zero hours of PM 2.5 above the WHO IT1 threshold, the sample of days in which the prior day had at least one hour above the WHO IT1 threshold, and the sample of days in which both of the prior two days had at least one hour of PM 2.5 above the WHO IT1 threshold.

Figure 5 shows that workers' adjustments to daily hours worked is very different depending on the levels of PM 2.5 on the prior days.[20] On days in which the prior two days did not have elevated levels of PM 2.5, an hour of PM 2.5 above the WHO IT1 threshold results in a reduction in daily hours worked of 0.191 hours. The reduction to daily hours worked is slightly smaller when we restrict the sample to the days in which only the prior day did not have any hours with PM 2.5 above the WHO IT1 threshold. However, on days in which the prior day had at least one hour of PM 2.5 above the WHO IT1 threshold, an hour of PM 2.5 above the WHO IT1 threshold results in a reduction in daily hours worked of 0.081 hours. When both of the prior two days had at least one hour of PM2.5 above the WHO IT1 threshold, workers reduce their daily hours worked by 0.019 hours. The bottom line is that if high levels of pollution persist, workers reduce their response. We find that after two consecutive days of high pollution, workers return to work. If health deterioration due to continuous exposure to high levels of pollution was the reason why workers reduced their working hours, then we would expect a somewhat different pattern, for example with reduced working hours persisting across consecutive high pollution days. This result suggests that a sudden occurrence of high pollution generates avoidance behavior that cannot be sustained if pollution remains high in consecutive days.

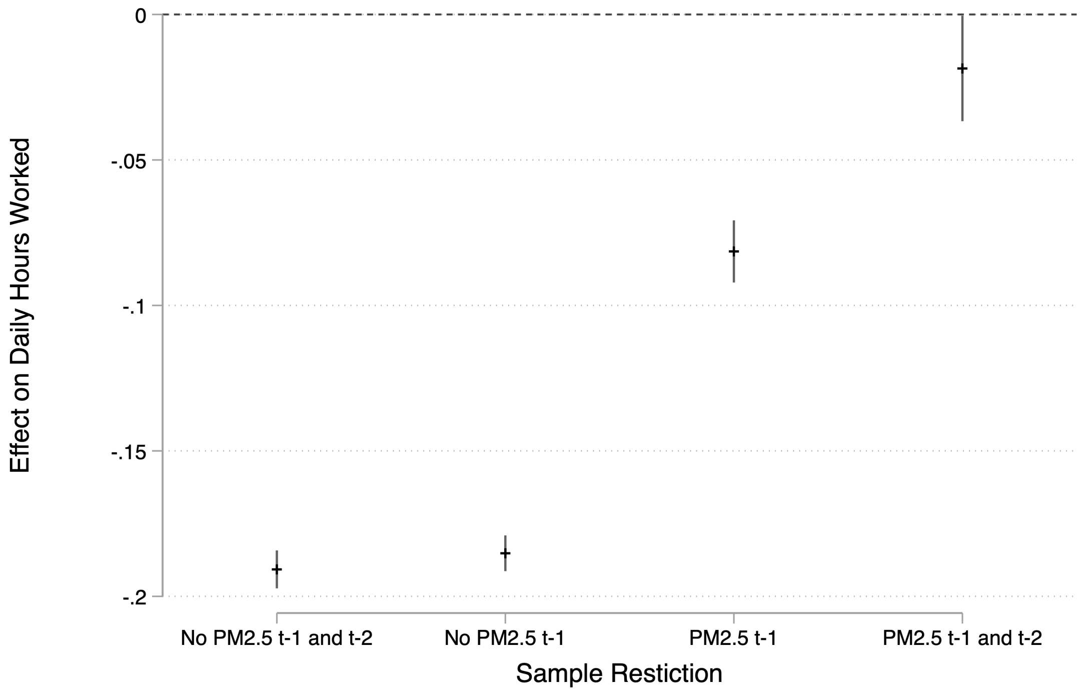
Figure 6 shows the effects by formality and income status.[21] Panel A shows these coefficients separately in the sample of formal workers and in the sample of informal workers. The pattern of results is very similar for formal and informal workers. The coefficients for informal workers imply smaller reductions to labor supply in each sample but we cannot reject that the effects are the same for formal and informal workers in any of the samples. Panel B shows the effects separately in the sample of high- and low-income workers. Low income is defined as less than 2

[19]In Figure B7 in the Appendix we show that, if anything, hospitalizations due to respiratory diseases increase when high pollution persists over a few days.

[20]The coefficients and standard errors are displayed in Appendix Table A7.

[21]The coefficients and standard errors are displayed in Appendix Table A8.

Figure 5: Impact of Same-Day PM 2.5 on Daily Hours Worked by Prior Days' PM 2.5



Coefficients and 90% confidence intervals are plotted from separate regressions of equation 2 in the sample of days in which each of the prior two days did not have any hours with PM 2.5 above the WHO IT1 threshold, the sample of days in which the prior day did not have any hours with PM 2.5 above the WHO IT1 threshold, the sample of days in which the prior day had at least one hour with PM 2.5 above the WHO IT1 threshold, and the sample of days in which each of the prior two days had at least one hour of PM 2.5 above the WHO IT1 threshold.

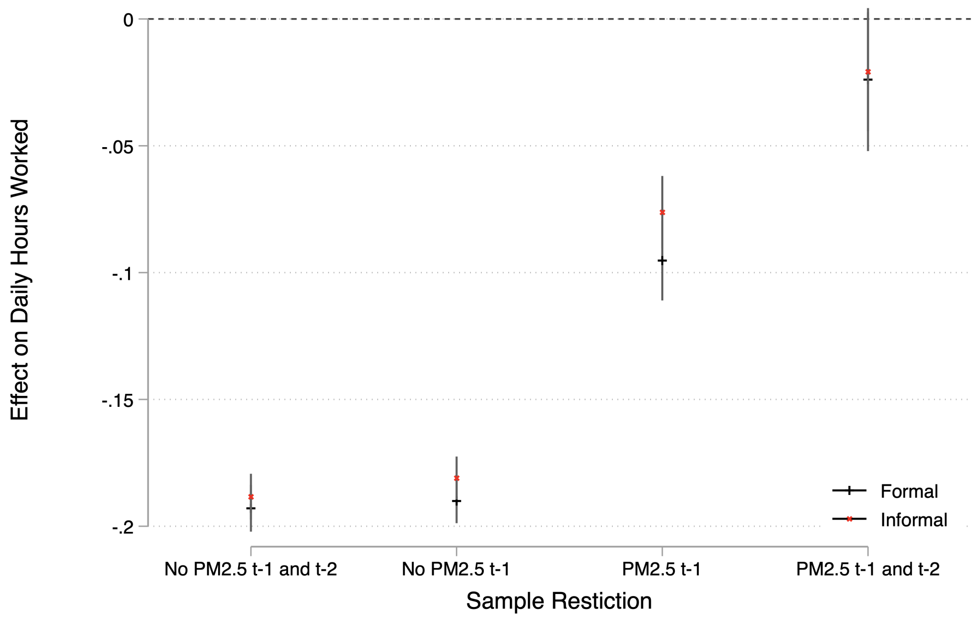
times the minimum wage. Both high-income and low-income workers adjust their labor supply less on consecutive days with high PM 2.5, demonstrating the importance of income effects and work commitments. Although the results suggest that low-income workers may reduce their daily hours worked less than higher income workers on the first days with high levels of PM 2.5 and on consecutive days with elevated PM 2.5, we cannot reject that the effect size is equal to that for high-income workers.[22]

Figure 5 demonstrates that workers reduce their daily hours worked in response to high levels of PM 2.5 most on days in which the prior days did not have high levels of fine particulate matter. Figure 6 suggests that informal and lower income workers may make smaller adjustments in their labor supply in response to high levels of PM 2.5, particularly on the first days with high PM 2.5. Contrary to the pattern of effects that we find in Figures 5 and 6, if workers' reductions to labor supply in response to high levels of PM 2.5 were completely due to short-term negative health impacts, we would expect to see increasing health impacts and therefore larger reductions in labor supply on consecutive days with high PM 2.5. Although our data does not allow us to rule out that the contemporaneous decrease in labor supply in response to PM 2.5 that we find is due to negative health shocks, these results provide suggestive evidence that workers reduce their labor supply at least partially as avoidance behavior. From this perspective, these results suggest that income constraints play an important role. Further, income constraints may be the reason that workers with lower and more uncertain income have a relatively inflexible labor supply since their income is more likely to be directly related to hours worked.

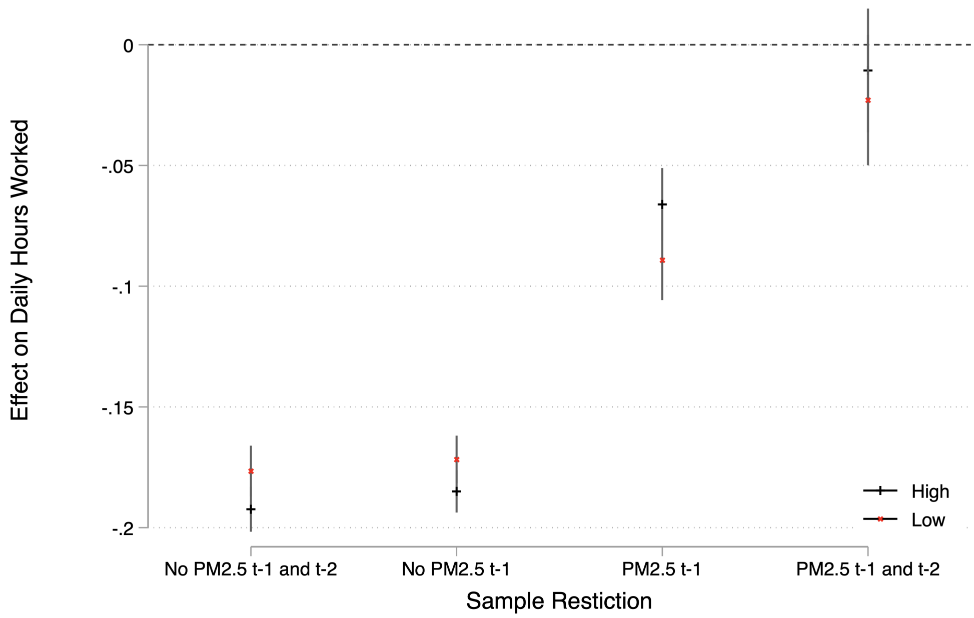
[22]Appendix Figure B5 show that the results by wage status follow a similar pattern to those by income and formality status.

Figure 6: Impact of Same-Day PM 2.5 on Daily Hours Worked by Prior Days' PM 2.5: By Formality Status and By Income

Panel A: By Formality Status



Panel B: By Income



Coefficients and 90% confidence intervals are plotted from separate regressions of equation 2 in the sample of days in which each of the prior two days did not have any hours with PM 2.5 above the WHO IT1 threshold, the sample of days in which the prior day did not have any hours with PM 2.5 above the WHO IT1 threshold, the sample of days in which the prior day had at least one hour with PM 2.5 above the WHO IT1 threshold, and the sample of days in which each of the prior two days had at least one hour of PM 2.5 above the WHO IT1 threshold. Panel A shows the impact in the full sample of formal workers and in the full sample of formal workers. Panel B shows impact separately in the sample of low-income and high-income workers. Low income is defined as income less than 2 times the minimum wage.

5.4.2 Role of Public Information and Public Sector Restrictions

Next, we turn to the possibility that the reduction in working hours associated with PM 2.5 is explained by pollution alerts issued by the environmental authority in Mexico City. We first note that in the period 2005-2016 these alerts were activated fewer than 40 times overall.

In columns (1)-(3) of Table 7, we exclude weeks in which an alert was issued. We exclude the entire week because any increase in attention to air pollution caused by alerts could persist in the following days. Columns (1)-(3) provide evidence that our prior results documenting the effects of same-day pollution and lags of pollution on daily hours worked and documenting formal-informal differences in response hold when excluding weeks with alerts. These results show that the response of daily hours worked to pollution described above is not explained by alerts, implying that heightened attention to air pollution or public sector closures due to alerts cannot be the only mechanisms linking high pollution and labor supply.

In contrast, in columns (4) to (6) of Table 7, we use the same specifications but restrict the sample to weeks in which at least one alert was issued. Local media, including newspapers, radio, and television, and official media, including the AIRE CMDX app, official websites, and social networks, are mandated by law to publish the alerts (Aguilar-Gomez, 2020). This indicates that the population is likely to be aware of alerts and that it is less likely that formal, higher-income workers and informal, lower-income workers have differential access to pollution information on days with alerts. Therefore, if the heterogeneity that we observe in labor supply responses across formal and informal workers persists in the sample of alerts, then this indicates that differential access to pollution information is unlikely to be the only mechanism driving the heterogeneity that we observe in labor supply reductions on high-pollution days.

In the sample of weeks with alerts, the point estimates are larger in magnitude both for same-day and lagged pollution (columns (4) and (5)). Note that on alert weeks, the average number of hours above the IT1 threshold almost triples (from 0.16 to 0.45). Therefore, we cannot distinguish whether the stronger response during alert weeks is due to the higher level of pollution or the information disseminated by the alerts, which could encourage additional avoidance behavior.[23] Interestingly, the difference in labor supply response between formal and informal workers almost doubles in magnitude implying that differential access to information is not the only mechanism driving the heterogeneity that we observe (column (6)). Unfortunately, we cannot determine whether the larger differences between formal and informal workers during alert weeks is due to the higher level of pollution, differential probabilities of responding to alerts between formal and informal workers or regulations associated with official alerts that could affect the labor demand of formal workers more than informal workers.

We further investigate the role that public sector decisions to close or reduce work in its offices, schools or hospitals on high pollution days could play in our main results. It is plausible that public sector workers are not deciding to reduce their labor supply on high-pollution days but instead that their workplace is closed or operating at reduced capacity. Further, because more than 80% of workers in these occupations in our sample are formal (and they represent more than 30% of formal workers overall), this could explain the larger reduction in labor supply that we observe for formal workers.

Our results in Table 8 show that the labor supply response is stronger among private sector workers than public sector workers, even on weeks with officially issued alerts. In column (1), we find that public sector workers work more hours than private sector workers on high-pollution days. The result is statistically significant and large in magnitude (i.e., public sector workers' response is around one third smaller). Column (2) shows that this pattern holds when restricting the sample to formal workers only. Further, in columns (3) and (4) of Table 8, we explore whether public sector closures in response to official alerts can explain the reductions in labor supply that we observe. As in Table 7, point estimates are larger on alert weeks (column 4), but the pattern is the same as in weeks with no pollution alerts (column 3) with public sector workers reducing their labor supply significantly less than private sector workers. These results suggest that labor supply reductions reflect worker's decisions rather than public sector closures that reduce labor demand. Further, these results indicate that public sector closures are not driving the heterogeneity in labor

[23] Aguilar-Gomez (2020) shows evidence consistent with avoidance, as on high alert days in Mexico City for the period 2013-2016 people reduce car trips. Alerts, however, do not seem to be associated with a reduction in air pollution.

Table 7: Labor Responses and Official Pollution Alerts

	Weeks with no alert days			Weeks with alert days		
	(1)	(2)	(3)	(4)	(5)	(6)
Hours Above PM2.5 IT1 Threshold	-0.140***	-0.138***	-0.158***	-0.239***	-0.245***	-0.271***
	(0.003)	(0.003)	(0.005)	(0.008)	(0.009)	(0.011)
Lag 1 IT1 PM2.5		0.015***			0.056***	
		(0.003)			(0.008)	
Lag 2 IT1 PM2.5		0.024***			0.043***	
		(0.003)			(0.008)	
Lag 3 IT1 PM2.5		0.023***			0.073***	
		(0.003)			(0.008)	
Lag 4 IT1 PM2.5		0.023***			0.085***	
		(0.003)			(0.009)	
Lag 5 IT1 PM2.5		0.008***			0.010	
		(0.003)			(0.009)	
Informal x Hours Above IT1			0.029***			0.056***
			(0.006)			(0.014)
N	2,105,582	2,097,737	2,105,582	126,657	125,228	126,657
R2	0.285	0.285	0.314	0.280	0.278	0.308

Notes: Robust standard errors in parenthesis. * denotes significance at the 10% level, ** denotes significance at the 5% level, and *** denotes significance at the 1% level. Results of estimating the baseline equation 2 in each subsample.

supply reductions that we observe across formal and informal workers.

In contrast to Aragón et al. (2017), we show that school closures or caring for children who become ill on high-pollution days are not driving our main results. Column (2) of Appendix Table A9 shows that women who have children reduce their daily hours by less than women who do not have children on high-pollution days. Column (4) shows that there is no difference in labor supply responses on high-pollution days between workers in households with and without children.

In brief, we find no evidence suggesting that alerts or public sector closures are driving the reduction in working hours on high-pollution days. Instead, these results suggest that labor supply reductions on high-pollution days are due to workers' labor supply decisions. Further, our results suggest that public sector closures and differential access to pollution information between formal and informal workers cannot fully explain the lower labor supply reductions of informal workers on high-pollution days.

5.5 Robustness

In this section, we demonstrate the robustness of our main results linking PM 2.5 to changes in labor supply. First, we demonstrate that we find consistent results when restricting the sample to weekdays and using alternative measures of particulate matter. Column (1) of Table 9 shows the results of our baseline specification in the sample restricted to weekdays. In columns (2) and (3), we use the number of hours with pollution above the WHO Interim Threshold 1 when using PM 10 as our measure of air pollution. Column (2) shows the results using our baseline specification and column (3) shows the results for the specification including individual fixed effects. Columns (4) and (5) use combined measures of PM 2.5 and PM 10. Column (4) shows the results of our baseline specification using the maximum of the number of hours in which PM 2.5 is above IT1 and the number of hours in which PM 10 is above IT1 as the measure of particulate matter. Similarly, column (5) shows the results of our baseline specification using the minimum of the number of hours in which PM 2.5 is above IT1 and the number of hours in which PM 10 is above IT1 as the measure of particulate matter. Columns (1)-(5) all show a statistically significant negative

Table 8: Labor Responses of Public Sector, Education and Health Workers

	Daily Hours Worked			
	(1) All Sample	(2) Formal Workers	(3) No Alerts	(4) Alerts
Hours Above PM2.5 IT1 Threshold	-0.165***	-0.192***	-0.149***	-0.253***
	(0.003)	(0.005)	(0.004)	(0.009)
Public Sector x Hours Above IT1	0.057***	0.101***	0.044***	0.102***
	(0.008)	(0.009)	(0.008)	(0.022)
N	2,114,731	1,050,206	1,994,919	119,812
R2	0.285	0.454	0.286	0.280

Notes: Robust standard errors in parenthesis. * denotes significance at the 10% level, ** denotes significance at the 5% level, and *** denotes significance at the 1% level. Public sector workers include those working in the public administration, in educational or health institutions. Results of estimating the baseline equation 2 in each subsample.

relationship between particulate matter and same-day hours worked with similar magnitudes to our main results.

Second, we corroborate our main results using an instrumental variables strategy to overcome concerns associated with confounding factors. A primary concern in estimating the impact of air pollution on contemporaneous labor supply is that the level and type of economic activity could determine both labor supply and air pollution. A related concern is that traffic levels, which increase commuting time and increase the costs of commuting, could determine both labor supply and air pollution levels.

We use wind speed and wind direction from the network of ground monitoring stations as instruments for particulate matter to demonstrate that our results are not driven by confounding factors. We code wind speed as the daily mean wind speed and code wind direction as four indicator variables corresponding to the four compass quadrants (north, south, east, and west). We use two-stage least squares to estimate our baseline specification (column (6)) and the specification including individual fixed effects (column (7)). Consistent with our prior results, we find a negative and statistically significant impact of fine particulate matter on daily hours worked using instrumental variables.

Third, we conduct two falsification tests. As a first falsification test, we add one lead of the number of hours above the IT1 threshold to the baseline specification (column (8)). The results show that the inclusion of a measure of tomorrow's particulate matter does not substantially change the estimated impact of PM 2.5 on contemporaneous daily hours worked. Further, although the impact of tomorrow's PM 2.5 is also negative and statistically significant, the coefficient is orders of magnitude smaller than our coefficient of interest. As a second falsification test, we replace the dependent variable reported daily hours worked during the reference week with reported usual daily hours worked in our baseline specification in the sample of weekdays. As expected, the results show that there is no relationship between high levels of PM 2.5 during the reference week and usual daily hours worked (column (9)).

Table 9: Robustness and Falsification Tests for Daily Hours Worked

	Daily Hours Worked								Usual Daily Hours Worked
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Hours Above PM2.5 IT1 Threshold	-0.199***					-0.272***	-0.217***	-0.154***	0.002
	(0.004)					(0.057)	(0.047)	(0.003)	(0.007)
Hours Above PM10 IT1 Threshold		-0.085***	-0.091***						
		(0.003)	(0.003)						
Max Hours Above PM25-PM10 IT1 Threshold				-0.108***					
				(0.003)					
Min Hours Above PM25-PM10 IT1 Threshold					-0.166***				
					(0.005)				
Lead Hours Above PM2.5 IT1 Threshold								-0.006**	
								(0.003)	
Method	PM2.5	PM10	PM10 - Indiv. FE	Max IT1 PM2.5-PM10	Min IT1 PM2.5-PM10	IV	IV - Indiv. FE	Lead	Usual Hours
Sample	Weekdays	Full	Full	Full	Full	Full	Full	Full	Weekdays
N	1,593,422	2,328,400	2,328,369	2,338,133	2,338,133	2,224,744	2,224,708	2,230,682	152,784
R2	0.074	0.283	0.475	0.283	0.283	0.279	0.324	0.285	0.042

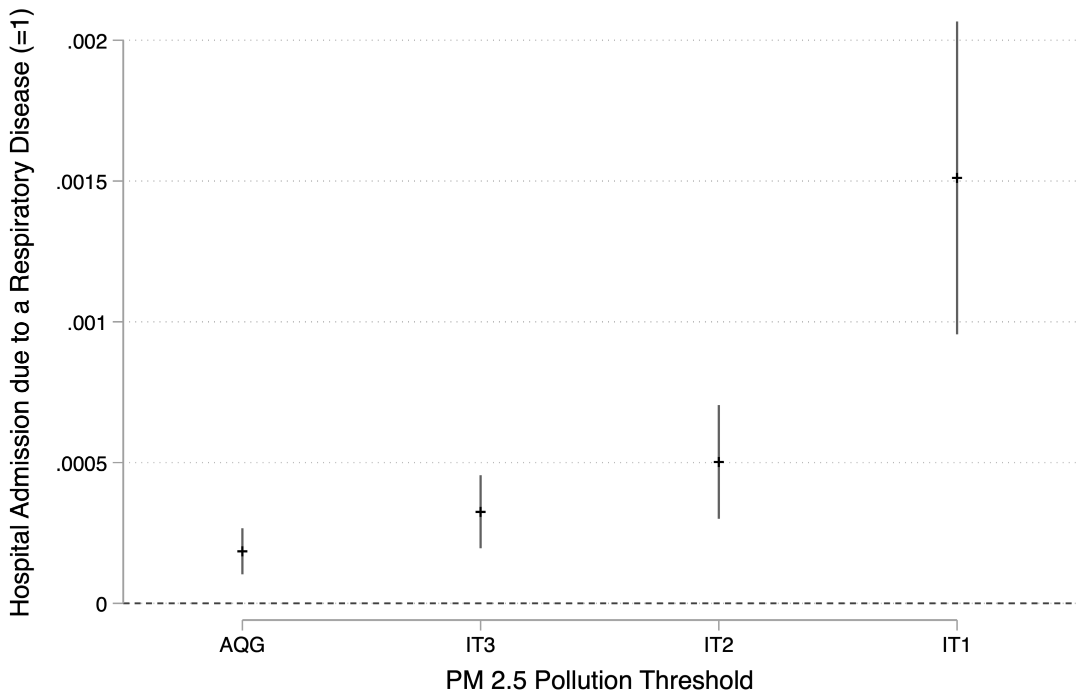
Notes: Robust standard errors in parenthesis. * denotes significance at the 10% level, ** denotes significance at the 5% level, and *** denotes significance at the 1% level. Equation 2 is the baseline specification shown in columns (1), (2), (4), (5), and (9). Column (1) restricts the sample to weekdays. Column (3) adds individual fixed effects to the baseline specification. Columns (6) and (7) uses two stage least squares to instrument PM 2.5 with wind speed and wind direction, which is coded as four indicator variables according to compass quadrant. The F-statistic for the specification in column (6) is 1,037 and the F-statistic for the specification in column (7) is 1,139. Column (8) adds the one-day lead of the number of hours above the IT1 threshold to the baseline specification. In columns (1)-(8), the dependent variable is reported actual daily hours worked during the reference week. In column (9), the dependent variable is reported usual daily hours worked and the sample is restricted to weekdays.

6 Implications for Health

In this section, we document the health implications of high levels of PM 2.5 and present evidence consistent with workers facing a trade-off between health and income on high-pollution days, since performing their usual income-generating activities can increase their exposure to air pollution, which has substantial negative health impacts. This trade-off is particularly acute for workers whose income is closely linked to the number of hours worked. These are usually lower-income, informal workers.

First, we demonstrate that elevated levels of fine particulate matter have negative contemporaneous health effects that mirror those found for labor supply. Second, we show that the negative health effects are concentrated in locations with the largest shares of workers with lower and more uncertain income. Together with the result above showing that workers with lower and more uncertain income have relatively inflexible labor supply, this suggests that they cannot engage in as much avoidance behavior as their higher-income counterparts. This is consistent with the third implication of the analytical framework, which states that, conditional on their characteristics, health outcomes are relatively worse for individuals who responded less to high levels of pollution. Third, similarly to the cumulative effects of PM 2.5 on labor supply, we show that there are cumulative effects of PM 2.5 on health. These results indicate that workers with lower and more uncertain income likely experience worse income reductions and health effects due to high PM 2.5 than their higher-income counterparts.

Figure 7: Daily Number of Hours Above WHO Thresholds and Daily Hospital Admissions for Respiratory Disease



Coefficients and 90% confidence intervals are plotted from equation 3 for the number of hours above the WHO air quality threshold for PM 2.5. A separate regression is run for each threshold. Coefficients show the impact on daily hospital admissions for respiratory disease in the sample of admissions excluding pregnancy or childbirth-related admissions.

First, we document that PM2.5 has a positive, non-linear relationship with contemporaneous hospital admissions for respiratory diseases that mirrors its relationship with labor supply. We estimate equation 3 in the sample of hospital admissions excluding admissions related to pregnancy or childbirth. Figure 7 plots the coefficients and 90% confidence intervals from separate regressions for each WHO threshold.[24] An hour above the WHO Air Quality Guideline slightly increases the likelihood of a hospital admission for respiratory diseases relative to admissions due to other causes. An hour above the WHO IT3 threshold and an hour above the WHO IT2 threshold increases the likelihood of a hospital admission for respiratory diseases by 0.03% and 0.05%, respectively, relative to other causes. An hour above the WHO IT1 threshold increases the likelihood of a hospital admission for respiratory diseases by 0.15% relative to other causes. Appendix Figure B6 shows a similar pattern for the daily deaths associated to respiratory diseases. Together the patterns of non-linear effects of PM 2.5 on labor supply and hospital admissions for respiratory disease suggests that high PM 2.5 events expose workers to negative health shocks and negative labor supply and income shocks.

To confirm that the relationship between hospitalizations for respiratory disease and contemporary levels of fine particulate matter shown in Figure 7 is not spurious, Appendix Figure B8 replicates the empirical strategy of Figure 7 replacing hospital admissions for respiratory diseases with hospital admissions for circulatory and digestive diseases as the outcome variable. There is no significant effect of fine particulate matter on hospitalizations for circulatory disease or digestive disease. Similarly, Appendix Figure B9 demonstrates that there is no significant effect of PM 2.5 on deaths due to circulatory and digestive diseases.

Appendix Table A11 shows the impact of an hour above the WHO IT1 PM 2.5 threshold on same-day hospital admissions for respiratory disease is consistent across alternative specifications and controls. Appendix Table A12 illustrates that our main results for hospital admissions due to respiratory disease are robust to alternative, but related, measures of particulate matter. Further, Appendix Table A12 displays the results of falsification tests to demonstrate that the relationship that we estimate between PM2.5 and hospital admissions for respiratory diseases is not due to another factor correlated with PM2.5 that may increase other types of hospitalizations as well.

Second, we provide evidence that indicates that workers with lower and more uncertain income have greater exposure to fine particulate matter and suffer larger health impacts. The data do not allow us to show directly that workers with lower and more uncertain income suffer greater health impacts than workers with higher and more stable income because they make smaller reductions to their labor supply on days with elevated levels of fine particulate matter. However, Table 10 provides suggestive evidence that workers with lower and more uncertain income suffer greater health impacts of PM 2.5 by showing that the increase in hospital admissions for respiratory diseases is driven by municipalities with large shares of informal workers.

We augment our main specification with individual controls and the interaction of the number of hours that PM 2.5 is above the WHO IT1 threshold and the share of workers who are informal by municipality (column (1)). The coefficient on the number of hours above the WHO IT1 threshold is now insignificant, but the coefficient on the interaction is negative and significant demonstrating that municipalities with high shares of informal workers are driving the increase in hospital admissions for respiratory diseases on days with elevated levels of PM 2.5.

Next, we augment our main specification with individual controls and the interaction of the number of hours that PM 2.5 is above the WHO IT1 threshold with indicator variables for the quartile of the distribution of the share of workers who are informal by municipality (column (2)). Similarly to column (1), the coefficient on the number of hours with PM 2.5 above the WHO IT1 threshold is not significant. Further, the coefficients on the interactions of the number of hours with PM 2.5 above the WHO IT1 threshold and the second and third quartiles of informality shares are not significant. However, the interaction of the number of hours with PM 2.5 above the WHO IT1 threshold and the top quartile of informality shares is positive and significant.

These results suggest that informal workers, and likely all workers with lower and more uncertain income, experience worse health outcomes than other workers on days with high levels of PM 2.5. If reducing labor supply is an effective avoidance behavior, then these differential health outcomes could be caused by differences in the flexibility of labor supply across different types of workers, which in turn could be caused by income constraints.

Third, we show that similarly to its effect on labor supply, PM 2.5 has a cumulative effect on health outcomes. In Table 11, we show that high PM 2.5 on the contemporaneous day and prior days increases hospital admissions for respiratory diseases. We restrict the sample to hospital

[24]See Appendix Table A10 for estimates.

Table 10: Heterogeneity of Hospital Admissions Response by Municipality Informality Share

	Admitted with Respiratory Disease (=1)	
	(1)	(2)
Hours Above PM2.5 IT1 Threshold	-0.0026	0.0004
	(0.0022)	(0.0007)
Hours Above PM2.5 IT1 Threshold x Share Informality	0.0071**	
	(0.0037)	
Hours Above PM2.5 IT1 Threshold x Share Informality (Quartile 2)		0.0012
		(0.0009)
Hours Above PM2.5 IT1 Threshold x Share Informality (Quartile 3)		0.0001
		(0.0010)
Hours Above PM2.5 IT1 Threshold x Share Informality (Top Quartile)		0.0024**
		(0.0012)
Controls	Individual	Individual
N	1,291,659	1,291,659
R2	0.040	0.040

Notes: Robust standard errors clustered by locality in parenthesis. * denotes significance at the 10% level, ** denotes significance at the 5% level, and *** denotes significance at the 1% level. The sample is restricted to hospital admissions that are not related to pregnancy or childbirth. Column (1) shows the results of estimating equation 3 augmented by the informality share by municipality interacted with the number of hours with PM2.5 above the WHO's IT1 threshold and including the daily maximum hourly temperature in the locality in which the hospital is located, daily precipitation and it's square at the municipality level and individual patients' age, age squared, sex, type of health insurance, indigenous heritage as control variables. Column (2) shows the results of estimating equation 3 augmented by the quartile of the informality share of the municipality interacted with the number of hours with PM2.5 above the WHO's IT1 threshold and including maximum hourly temperature in the locality in which the hospital is located, daily precipitation and it's square at the municipality level and individual patients' age, age squared, sex, type of health insurance, indigenous heritage as control variables.

Table 11: The Effect of Lagged and Weekly PM 2.5 on Hospital Admissions for Respiratory Diseases

	Admitted with Disease (=1)	
	(1)	(2)
Hours Above PM2.5 IT1 Threshold	0.0011***	0.0011***
	(0.0003)	(0.0003)
Hours Above PM2.5 IT1 Threshold- 1 Day Lag	0.0004	
	(0.0003)	
Hours Above PM2.5 IT1 Threshold- 2 Day Lag	0.0006**	
	(0.0002)	
Hours Above PM2.5 IT1 Threshold- 3 Day Lag	0.0002	
	(0.0003)	
Mean Hours Above PM2.5 IT1 Threshold - Prior Week		0.0030***
		(0.0011)
Method	Lags	Prior Week
N	1,287,439	1,292,219
R2	0.041	0.041

Notes: Robust standard errors clustered by locality in parenthesis. * denotes significance at the 10% level, ** denotes significance at the 5% level, and *** denotes significance at the 1% level. The sample is restricted to hospital admissions that are not related to pregnancy or childbirth. Column (1) shows the results of estimating equation 3 augmented by the number of hours of PM2.5 above the WHO's IT1 threshold for each of the prior three days and including maximum hourly temperature in the locality in which the hospital is located, daily precipitation and it's square for the contemporaneous day and the three prior days at the municipality level and individual patients' age, age squared, sex, type of health insurance, indigenous heritage as control variables. Column (2) shows the results of estimating equation 3 augmented by the average daily number of hours with PM2.5 above the WHO's IT1 threshold over the prior week and including the weekly average of the daily maximum hourly temperature in the locality in which the hospital is located, the weekly average of daily precipitation and it's square at the municipality level and individual patients' age, age squared, sex, type of health insurance, indigenous heritage as control variables.

admissions that are not related to pregnancy or childbirth. Column (1) shows the results of estimating equation 3 augmented by the number of hours of PM 2.5 above the WHO IT1 threshold in each of the prior three days and including the daily maximum of hourly temperature in the locality in which the hospital is located, daily precipitation and its square for the contemporaneous day and the three prior days at the municipality level and individual patients' age, age squared, sex, type of health insurance, and indigenous heritage as control variables. An hour of PM 2.5 above the WHO IT1 threshold increases contemporaneous daily hospital admissions for respiratory diseases by 0.11% relative to hospital admissions for other causes and an hour of PM 2.5 above the WHO IT1 threshold 2 days prior increases hospital admissions for respiratory diseases by 0.06% relative to hospital admissions for other causes.

We also use PM 2.5 and hospital admissions data at the weekly level to demonstrate the cumulative weekly impact of PM 2.5 hospital admissions for respiratory diseases. Column (2) shows the results of estimating equation 3 augmented by the average daily number of hours with PM 2.5 above the WHO IT1 threshold over the prior week and including the daily maximum of hourly temperature in the locality in which the hospital is located, daily precipitation and its square for the contemporaneous day and the three prior days at the municipality level and individual patients' age, age squared, sex, type of health insurance, and indigenous heritage as control variables. Consistent with the results presented in column (1), an hour of PM 2.5 above the WHO IT1 threshold increases contemporaneous daily hospital admissions for respiratory diseases by 0.11% relative to hospital admissions for other causes and increasing the mean number of hours of PM 2.5 above the WHO IT1 threshold by 1 hour increases hospital admissions for respiratory diseases by 0.3% relative to hospital admissions for other causes.

High pollution may present workers with a trade-off between health and income, and this trade-off is particularly acute for lower-income, informal workers whose income is closely linked to the number of hours worked. In Section 5.3.1, we documented that high PM 2.5 has a negative cumulative effect on labor supply and presented suggestive evidence that the negative effect on cumulative hours worked is larger for lower-income, informal workers. Together with the evidence shown above, these results indicate that lower-income, informal workers experience larger reductions to income and worse health effects than their higher-income, formal counterparts due to high PM 2.5.

7 Conclusion

In this paper, we document the daily response of labor supply to particulate matter in the metropolitan area of Mexico City and provide evidence that heterogeneity across workers in this response contributes to income and health inequalities.

Mexico City's high pollution levels and informal labor market make it a particularly relevant context for this study and allow our results to speak more broadly to developing countries. Similar to many other large cities in the region (such as Santiago, Lima, and Bogota) and in other developing countries, Mexico City experiences high levels of fine particulate matter and has a substantial informal labor market (IQAir, 2019; World Bank Development Indicators, 2021).[25]

Our results have two key policy implications. First, in addition to negative health impacts that have been documented extensively, reductions in labor supply are a negative externality of fine particulate matter. A back-of-the-envelope calculation based on our estimates of the effects of fine particulate matter on contemporaneous labor supply suggests that, during the time period analyzed, workers in the metropolitan area of Mexico City lost labor earnings of $1.2 million USD due to reductions in labor supply on days with particulate matter above the World Health Organization's least ambitious target. This is approximately $ 430 million USD per year. The strong non-linear relationship of PM 2.5 with labor supply and respiratory diseases indicates that policies should focus on decreasing peak levels of fine particulate matter.

Second, greater cumulative reductions in labor supply and negative health impacts of fine particulate matter for workers with lower and more uncertain income indicates that the costs of air pollution are unequally distributed across workers and that air pollution may be exacerbating income inequality within Mexico City. Further, the results suggesting that income constraints affect

[25]Informality is proxied by self-employment.

labor supply responses to air pollution indicates a role for social programs. Informal workers do not have access to public paid sick leave and are unlikely to have paid sick leave from their employers. Social programs that support informal workers on high-pollution days could allow them to avoid steep drops in income while engaging in avoidance behavior that could reduce the risk of negative health outcomes.

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A Appendix Tables

Table A1: Non-Linear Effect of PM 2.5 on Labor Supply

	Panel A: Day Worked			
	(1)	(2)	(3)	(4)
Hours Above WHO PM 2.5 Threshold	0.000***	-0.000***	-0.002***	-0.018***
	(0.000)	(0.000)	(0.000)	(0.000)
WHO Threshold	AGQ	IT3	IT2	IT1
N	2,232,239	2,232,239	2,232,239	2,232,239
R2	0.329	0.329	0.329	0.331
	Panel B: Daily Hours Worked			
	(1)	(2)	(3)	(4)
Hours Above WHO PM 2.5 Threshold	0.001***	-0.003***	-0.020***	-0.155***
	(0.000)	(0.001)	(0.001)	(0.003)
WHO Threshold	AQG	IT3	IT2	IT1
N	2,232,239	2,232,239	2,232,239	2,232,239
R2	0.283	0.283	0.284	0.285

Notes: Robust standard errors in parenthesis. * denotes significance at the 10% level, ** denotes significance at the 5% level, and *** denotes significance at the 1% level. Results of estimating 2 for the number of hours above the WHO air quality threshold for PM 2.5. A separate regression is run for each threshold. Panel A show the impact on working that day and Panel B shows impact on hours worked that day.

Table A2: Semi-Elasticity of Daily Hours Worked to PM 2.5

	Natural Log of Daily Hours Worked			
	(1)	(2)	(3)	(4)
Hours Above PM2.5 IT1 Threshold	-0.041***	-0.041***	-0.042***	-0.042***
	(0.001)	(0.001)	(0.001)	(0.001)
Method	Baseline	Occupation Controls	HH FE	Individual FE
N	2,232,239	2,232,239	2,232,231	2,232,204
R2	0.324	0.337	0.395	0.454

Notes: Robust standard errors in parenthesis. * denotes significance at the 10% level, ** denotes significance at the 5% level, and *** denotes significance at the 1% level. The outcome variable is the natural log of 1 + daily hours worked. Equation 2 is the baseline specification shown in column (1). Column (2) includes type of job and position, formality status, and sector of employment as additional controls. Column (3) adds household fixed effects to the baseline specification. Column (4) adds individual fixed effects to the baseline specification.

Table A3: The Effect of PM 2.5 on Labor Supply: Extensive and Intensive Margins

	Day Worked			Daily Hours Worked (if working)		
	(1) Extensive Margin	(2) Extensive Margin	(3) Extensive Margin	(4) Intensive Margin	(5) Intensive Margin	(6) Intensive Margin
Hours Above PM2.5 IT1 Threshold	-0.018***	-0.018***	-0.019***	-0.001	-0.002	-0.003*
	(0.000)	(0.000)	(0.000)	(0.002)	(0.002)	(0.002)
Method	Baseline	Occupation Controls	Individual FE	Baseline	Occupation Controls	Individual FE
N	2,232,239	2,232,239	2,232,204	1,686,565	1,686,565	1,685,500
R2	0.331	0.337	0.426	0.080	0.158	0.620

Notes: Robust standard errors in parenthesis. * denotes significance at the 10% level, ** denotes significance at the 5% level, and *** denotes significance at the 1% level. Equation 2 is the baseline specification shown in columns (1) and (4). Columns (2) and (5) include include type of job and position, formality status, and sector of employment as additional control variables. Columns (3) and (6) adds individual fixed effects to the baseline specification. In columns (4) to (6), the sample is restricted to those that report working that day.

Table A4: Heterogeneous Effects of PM 2.5 - Simple Interactions

	Daily Hours Worked				
	(1)	(2)	(3)	(4)	(5)
Characteristic	-0.569***	-0.624***	-0.139***	0.117***	-1.023***
	(0.005)	(0.006)	(0.005)	(0.008)	(0.006)
Hours Above PM2.5 IT1 Threshold	-0.183***	-0.168***	-0.166***	-0.169***	-0.162***
	(0.004)	(0.003)	(0.004)	(0.004)	(0.004)
Characteristic x Hours Above IT1	0.049***	0.051***	0.024***	0.027***	0.028***
	(0.006)	(0.007)	(0.006)	(0.006)	(0.006)
Characteristic	Informal	Self-employed	Non-wage employee	Low Education	Low Income
N	2,232,239	2,232,239	2,232,032	2,232,239	1,960,838
R2	0.289	0.288	0.285	0.285	0.285

Notes: Robust standard errors clustered by locality in parenthesis. * denotes significance at the 10% level, ** denotes significance at the 5% level, and *** denotes significance at the 1% level. Results of estimating the baseline equation 2 adding employment and earnings characteristics and the interactions between this characteristic and the number of hours above the WHO IT1 threshold. The outcome variable is the number of daily hours worked. ENOE classifies as informal those workers in unregistered economic activities; self-employed are those workers who work on their own or with the support of unpaid family members; non-wage employees are those whose earnings are not fixed (e.g. depend on commissions or sales); low education refers to workers with an educational attainment below 9 years; low income workers are those usually earning less than 3 minimum wages.

Table A5: Semi-Elasticity of Daily Hours Worked to PM 2.5: Heterogeneity by Worker Characteristics

	Natural Log of Daily Hours Worked				
	(1)	(2)	(3)	(4)	(5)
Characteristic	-0.107***	-0.091***	-0.019***	0.015***	-0.047***
	(0.001)	(0.001)	(0.001)	(0.002)	(0.003)
Hours Above PM2.5 IT1 Threshold	-0.047***	-0.044***	-0.043***	-0.044***	-0.054***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.004)
Characteristic x Hours Above IT1	0.011***	0.011***	0.006***	0.007***	0.006
	(0.001)	(0.002)	(0.001)	(0.001)	(0.004)
Characteristic	Informal	Self-employed	Non-wage employee	Low Education	Low Income
N	2,232,239	2,232,239	2,232,032	2,232,239	391,276
R2	0.326	0.325	0.324	0.324	0.404

Notes: Robust standard errors in parenthesis. * denotes significance at the 10% level, ** denotes significance at the 5% level, and *** denotes significance at the 1% level. Results of estimating the baseline equation 2 in each subsample using the natural log of 1 + daily hours worked as the outcome variable. ENOE classifies as informal those workers in unregistered economic activities; self-employed are those workers who work on their own or with the support of unpaid family members; non-wage employees are those whose earnings are not fixed (e.g. depend on commissions or sales); Low education refers to workers with an educational attainment below 9 years; Low income workers are those usually earning less than 3 minimum wages.

Table A6: Impact of Same-Day and Lagged PM 2.5 on Labor Supply

	Worked Day			Daily Hours Worked		
	(1)	(2)	(3)	(4)	(5)	(6)
Same-Day Hours Above PM2.5 IT1 Threshold	-0.018***	-0.019***	-0.018***	-0.152***	-0.161***	-0.146***
	(0.000)	(0.000)	(0.000)	(0.003)	(0.005)	(0.004)
1 Day Lag Hours Above PM2.5 IT1 Threshold	0.002***	0.004***	0.001***	0.022***	0.035***	0.012***
	(0.000)	(0.000)	(0.000)	(0.003)	(0.004)	(0.004)
2 Day Lag Hours Above PM2.5 IT1 Threshold	0.003***	0.004***	0.003***	0.028***	0.036***	0.023***
	(0.000)	(0.000)	(0.000)	(0.003)	(0.004)	(0.004)
3 Day Lag Hours Above PM2.5 IT1 Threshold	0.003***	0.004***	0.003***	0.028***	0.031***	0.026***
	(0.000)	(0.000)	(0.000)	(0.003)	(0.004)	(0.004)
4 Day Lag Hours Above PM2.5 IT1 Threshold	0.004***	0.004***	0.003***	0.030***	0.034***	0.027***
	(0.000)	(0.000)	(0.000)	(0.003)	(0.004)	(0.004)
5 Day Lag Hours Above PM2.5 IT1 Threshold	0.001***	0.001**	0.002***	0.010***	0.006	0.014***
	(0.000)	(0.000)	(0.000)	(0.003)	(0.003)	(0.004)
Sum of Lags	0.014	0.016	0.013	0.117	0.142	0.102
Standard Error of Lags	0.001	0.001	0.001	0.007	0.009	0.009
Sample	Full	Formal	Informal	Full	Formal	Informal
N	2,222,965	1,051,669	1,171,296	2,222,965	1,051,669	1,171,296
R2	0.331	0.503	0.222	0.285	0.445	0.201

Notes: Robust standard errors in parenthesis. * denotes significance at the 10% level, ** denotes significance at the 5% level, and *** denotes significance at the 1% level. Results of estimating the baseline equation 2 augmented by five days of lagged PM 2.5 measures.

Table A7: Impact of Same-Day PM 2.5 on Daily Hours Worked by Prior Days' PM 2.5

	Panel A: Daily Hours Worked			
	(1)	(2)	(3)	(4)
Hours Above PM2.5 IT1 Threshold	-0.191***	-0.185***	-0.081***	-0.019*
	(0.004)	(0.004)	(0.006)	(0.011)
Sample Restriction	No PM 2.5 t-1 and t-2	No PM 2.5 t-1	PM 2.5 t-1	PM 2.5 t-1 and t-2
N	2,015,816	2,104,786	125,681	37,898
R2	0.284	0.284	0.302	0.316
	Panel B: Household Total Daily Hours Worked			
	(1)	(2)	(3)	(4)
Hours Above PM2.5 IT1 Threshold	-0.326***	-0.316***	-0.153***	-0.023
	(0.010)	(0.009)	(0.017)	(0.030)
Sample Restriction	No PM 2.5 t-1 and t-2	No PM 2.5 t-1	PM 2.5 t-1	PM 2.5 t-1 and t-2
N	1,165,489	1,217,165	73,215	22,140
R2	0.179	0.179	0.205	0.229

Notes: Robust standard errors in parenthesis. * denotes significance at the 10% level, ** denotes significance at the 5% level, and *** denotes significance at the 1% level. Columns present the results of separate regressions of equation 2 in the sample of days in which each of the prior two days did not have any hours with PM 2.5 above the WHO IT1 threshold, the sample of days in which the prior day did not have any hours with PM 2.5 above the WHO IT1 threshold, the sample of days in which the prior day had at least one hour with PM 2.5 above the WHO IT1 threshold, and the sample of days in which each of the prior two days had at least one hour of PM 2.5 above the WHO IT1 threshold. Panel A show the impact in the full sample of workers using daily hours worked at the worker-level and Panel B shows impact in the full sample of households using total household daily hours worked.

Table A8: Heterogeneity of the Impact of Same-Day PM 2.5 on Daily Hours Worked by Prior Days' PM 2.5

	(1)	(2)	(3)	(4)
Panel A: Formal Workers				
Hours Above PM2.5 IT1 Threshold	-0.193***	-0.190***	-0.095***	-0.024
	(0.006)	(0.005)	(0.010)	(0.017)
Sample Restriction	No PM 2.5 t-1 and t-2	No PM 2.5 t-1	PM 2.5 t-1	PM 2.5 t-1 and t-2
N	956,002	997,250	57,549	16,662
R2	0.445	0.445	0.461	0.483
Panel B: Informal Workers				
Hours Above PM2.5 IT1 Threshold	-0.188***	-0.181***	-0.076***	-0.021
	(0.005)	(0.005)	(0.009)	(0.014)
Sample Restriction	No PM 2.5 t-1 and t-2	No PM 2.5 t-1	PM 2.5 t-1	PM 2.5 t-1 and t-2
N	1,059,814	1,107,536	68,126	21,230
R2	0.200	0.200	0.221	0.235
Panel C: High Income Workers				
Hours Above PM2.5 IT1 Threshold	-0.192***	-0.185***	-0.066***	-0.011
	(0.006)	(0.005)	(0.009)	(0.016)
Sample Restriction	No PM 2.5 t-1 and t-2	No PM 2.5 t-1	PM 2.5 t-1	PM 2.5 t-1 and t-2
N	1,015,344	1,061,440	64,826	19,278
R2	0.367	0.367	0.383	0.406
Panel D: Low Income Workers				
Hours Above PM2.5 IT1 Threshold	-0.177***	-0.172***	-0.089***	-0.023
	(0.006)	(0.006)	(0.010)	(0.016)
Sample Restriction	No PM 2.5 t-1 and t-2	No PM 2.5 t-1	PM 2.5 t-1	PM 2.5 t-1 and t-2
N	751,693	785,058	47,860	15,051
R2	0.178	0.178	0.202	0.218

Notes: Robust standard errors in parenthesis. * denotes significance at the 10% level, ** denotes significance at the 5% level, and *** denotes significance at the 1% level. Columns present the results of separate regressions of equation 2 in the sample of days in which each of the prior two days did not have any hours with PM 2.5 above the WHO IT1 threshold, the sample of days in which the prior day did not have any hours with PM 2.5 above the WHO IT1 threshold, the sample of days in which the prior day had at least one hour with PM 2.5 above the WHO IT1 threshold, and the sample of days in which each of the prior two days had at least one hour of PM 2.5 above the WHO IT1 threshold. In Panel A, the sample is restricted to formal workers, and in Panel B, the sample is restricted to informal workers. In Panel C, the sample is restricted to high income workers who earn at least two times the minimum wage. In Panel D, the sample is restricted to low income workers who earn less than two times the minimum wage.

Table A9: Heterogeneity of the Impact of Same-Day PM 2.5 on Daily Hours Worked by Having Children

	Women		All Workers	
	(1)	(2)	(3)	(4)
Hours Above PM2.5				
IT1 Threshold	-0.145***	-0.157***	-0.155***	-0.164***
	(0.005)	(0.008)	(0.003)	(0.009)
Children x				
Hours Above IT1		0.019*		0.009
		(0.010)		(0.010)
Interaction		Have Children		Have Children
N	916,346	916,297	2,232,239	1,998,400
R2	0.253	0.258	0.285	0.283

Notes: Robust standard errors in parenthesis. * denotes significance at the 10% level, ** denotes significance at the 5% level, and *** denotes significance at the 1% level. The outcome variable is the number of daily hours worked in all columns. Columns (1) and (3) present the results of separate regressions of equation 2. Columns (2) an (4) present the results of estimating baseline equation 2 allowing for interactions between characteristics and controls. In columns (1) and (2) the sample is restricted to women. In column (2), the interaction variable is coded as 1 if the woman is at least 15 years old and has at least 1 child and 0 otherwise. In column (4), the interaction variable is coded as 1 if there is a woman in the household who is at least 15 years old and has a child and 0 otherwise.

Table A10: Daily Number of Hours Above WHO Thresholds and Daily Hospital Admissions for Respiratory Disease

	Admitted with a Respiratory Disease (=1)			
	(1)	(2)	(3)	(4)
Hours Above PM2.5 AQG Threshold	0.0002***			
	(0.0000)			
Hours Above PM2.5 IT3 Threshold		0.0003***		
		(0.0001)		
Hours Above PM2.5 IT2 Threshold			0.0005***	
			(0.0001)	
Hours Above PM2.5 IT1 Threshold				0.0015***
				(0.0003)
N	1,302,701	1,302,701	1,302,701	1,302,701
R2	0.0102	0.0102	0.0102	0.0102

Notes: Robust standard errors in parenthesis. * denotes significance at the 10% level, ** denotes significance at the 5% level, and *** denotes significance at the 1% level. Coefficients from equation 3 for the number of hours above the WHO threshold for PM 2.5. A separate regression is run for each threshold. Coefficients show the impact on daily hospital admissions for respiratory disease in the sample of admissions excluding pregnancy or child birth related admissions.

Table A11: The Effect of PM 2.5 on Same-Day Hospital Admissions for Respiratory Diseases

	Admitted with a Respiratory Disease (=1)			
	(1)	(2)	(3)	(4)
Hours Above PM2.5 IT1 Threshold	0.0015***	0.0013***	0.0012***	0.0012***
	(0.0003)	(0.0003)	(0.0003)	(0.0004)
Method	Baseline	Add Controls	Add Locality & DoW FE	Add Height & Weight
N	1,302,701	1,291,703	1,291,688	563,756
R2	0.0102	0.0403	0.0410	0.1371

Notes: Robust standard errors clustered by locality in parenthesis. * denotes significance at the 10% level, ** denotes significance at the 5% level, and *** denotes significance at the 1% level. The sample is restricted to hospital admissions that are not related to pregnancy or childbirth. Equation 3 is the baseline specification shown in column (1). Column (2) includes the daily maximum hourly temperature in the locality in which the hospital is located, daily precipitation and it's square at the municipality level and individual patients' age, age squared, sex, type of health insurance, indigenous heritage as control variables. Column (3) adds locality and day of the week fixed effects to the baseline specification. Column (4) adds maximum hourly temperature in the locality in which the hospital is located, daily precipitation and it's square at the municipality level and individual patients' age, age squared, sex, type of health insurance, indigenous heritage, natural log of weight, and natural log of height as control variables to the baseline specification.

Table A12: Robustness and Falsification Tests for Hospital Admissions for Respiratory Disease

	Admitted with Disease (=1)					
	(1) Respiratory	(2) Respiratory	(3) Circulatory	(4) Digestive	(5) Urinary	(6) Infection
Hours Above PM10 IT1 Threshold	0.0007*	0.0006				
	(0.0004)	(0.0004)				
Hours Above PM2.5 IT1 Threshold			0.0001	-0.0000	-0.0013	0.0001
			(0.0003)	(0.0005)	(0.0012)	(0.0002)
Method	Baseline	Controls	Controls	Controls	Controls	Controls
N	1,381,919	1,367,355	1,291,703	1,291,703	1,291,703	1,291,703
R2	0.010	0.040	0.042	0.018	0.116	0.008

Notes: Robust standard errors clustered by locality in parenthesis. * denotes significance at the 10% level, ** denotes significance at the 5% level, and *** denotes significance at the 1% level. The sample is restricted to hospital admissions that are not related to pregnancy or childbirth. Column (1) shows the results of estimating equation 3 using the number of hours above the WHO IT1 threshold for PM10 as the measure of air pollution. Column (2) uses the number of hours above the WHO IT1 threshold for PM10 as the measure of air pollution in the regression specification that includes the daily maximum hourly temperature in the locality in which the hospital is located, daily precipitation and it's square at the municipality level and individual patients' age, age squared, sex, type of health insurance, indigenous heritage as control variables. Column (3)-(6) use the number of hours with PM2.5 above the IT1 threshold as the measure of air pollution. Columns (3)-(6) show the results of estimating the specification that includes the daily maximum hourly temperature in the locality in which the hospital is located, daily precipitation and it's square at the municipality level and individual patients' age, age squared, sex, type of health insurance, indigenous heritage as control variables. The outcome variable in column (3) is an indicator that equals one if the hospital admission was due to a circulatory disease and zero otherwise. The outcome variables for columns (4)-(6) are defined analogously for digestive diseases, urinary diseases, and infections.

Table A13: Deaths Due to Respiratory Disease on High PM 2.5 days

	Death due to a Respiratory Disease (=1)			
	(1)	(2)	(3)	(4)
Hours Above PM2.5 IT1 Threshold	0.0010***	0.0010***	0.0010***	0.0015***
	(0.0003)	(0.0003)	(0.0003)	(0.0004)
Method	Baseline	Add Controls	Add Locality & DoW FE	Add Weight
N	930,008	919,092	919,092	521,275
R2	0.0029	0.0241	0.0242	0.0283

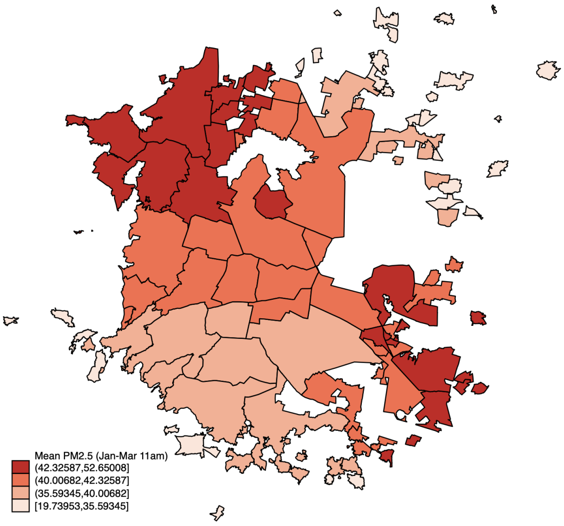
Table A14: Deaths on High PM 2.5 Days - Robustness

	Deaths due to Disease (=1)					
	(1)	(2)	(3)	(4)	(5)	(6)
	Respiratory	Respiratory	Circulatory	Digestive	Urinary	Infection
Hours Above PM10						
IT1 Threshold	0.0017***	0.0016***				
	(0.0004)	(0.0004)				
Hours Above PM2.5						
IT1 Threshold			-0.0003	-0.0000	-0.0002	-0.0002
			(0.0003)	(0.0002)	(0.0001)	(0.0001)
Method	Baseline	Controls	Controls	Controls	Controls	Controls
N	961,440	949,360	919,092	919,092	919,092	919,092
R2	0.003	0.024	0.080	0.021	0.003	0.016

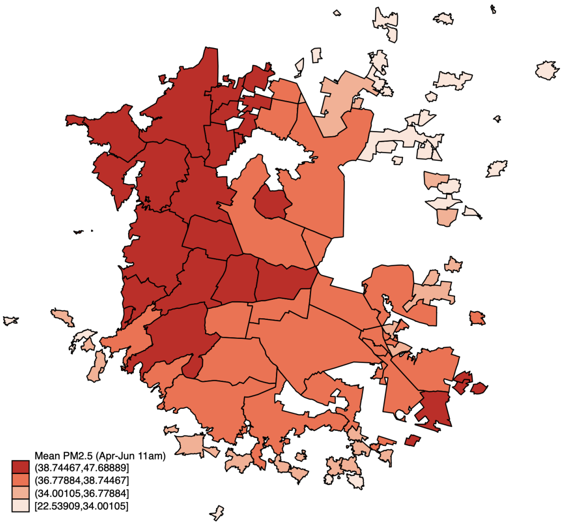
B Appendix Figures

Figure B1: Quarterly Distribution of PM 2.5 for 2004-2016 - Most Populated Localities

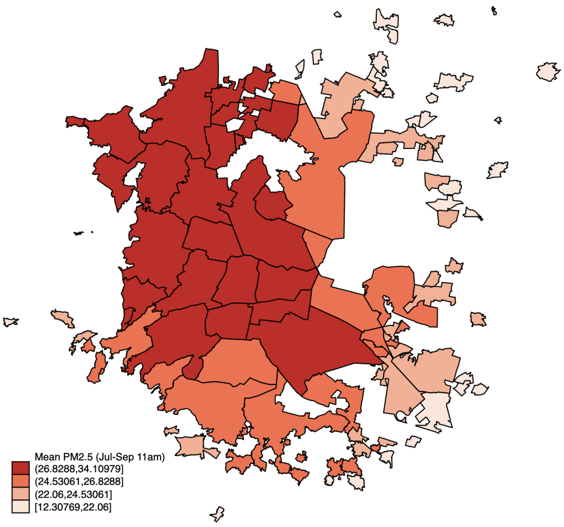
Panel A: Quarter 1 (January-March)



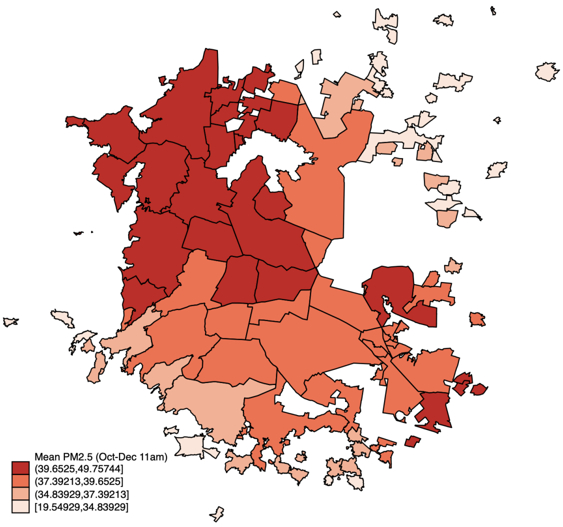
Panel B: Quarter 2 (April-June)



Panel C: Quarter 3 (July-September)

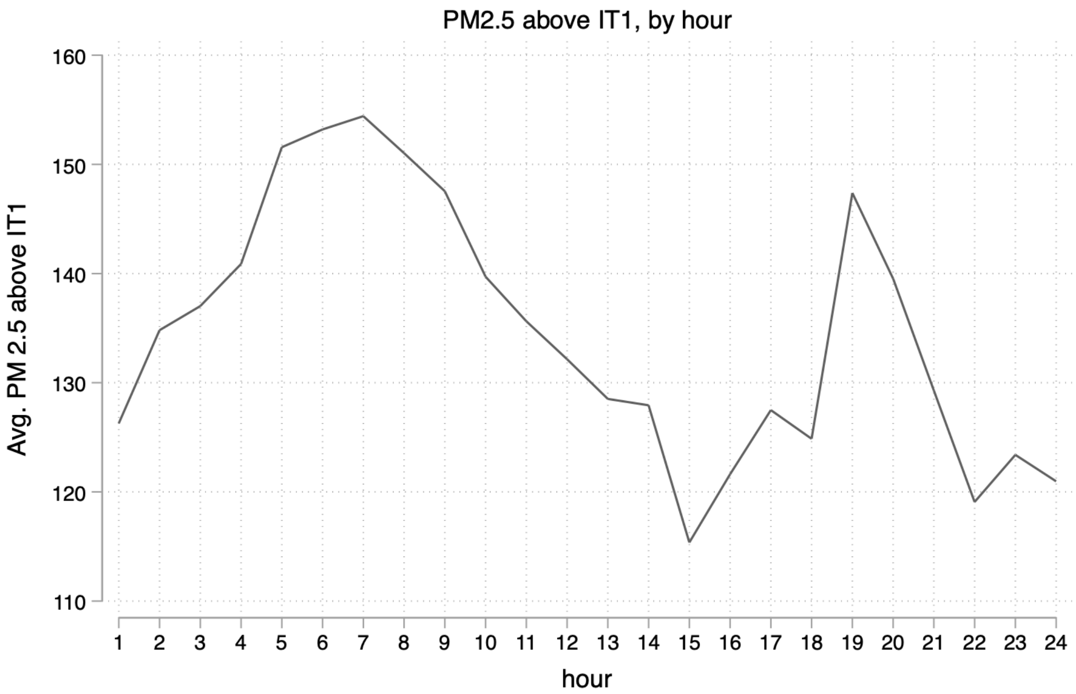


Panel D: Quarter 4 (October-December)



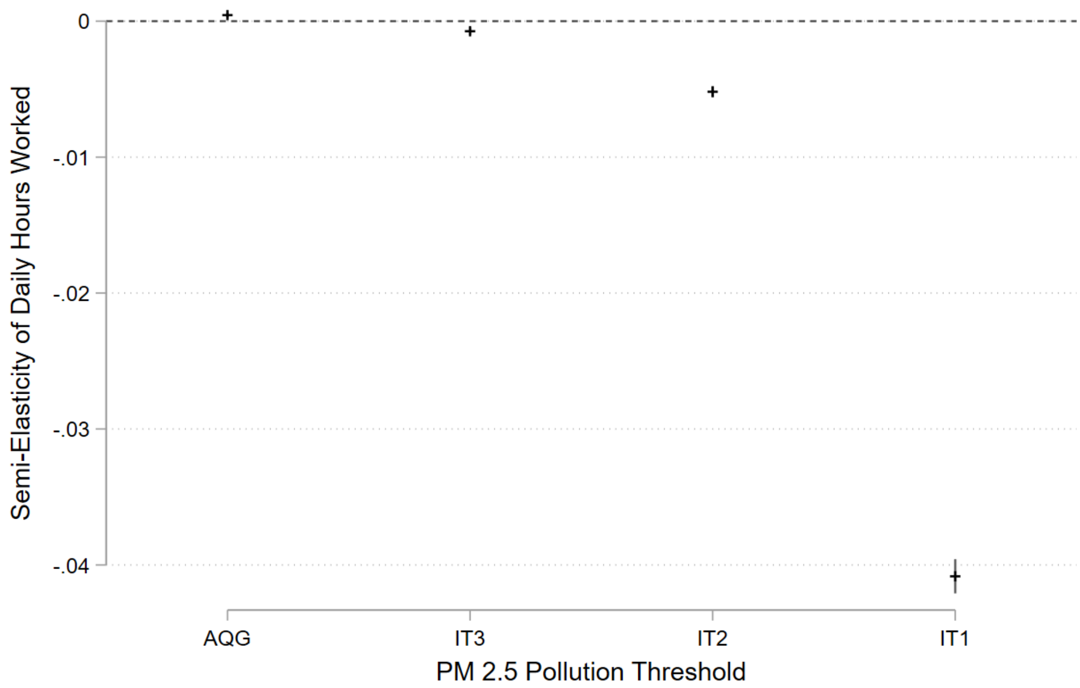
Average pollution at 11am for all days and months in each quarter for years 2004-2016.

Figure B2: Hourly Realizations of PM 2.5 Above IT1



Average (across days and localities) PM 2.5 level for observations above the WHO IT1 threshold by hour of the day.

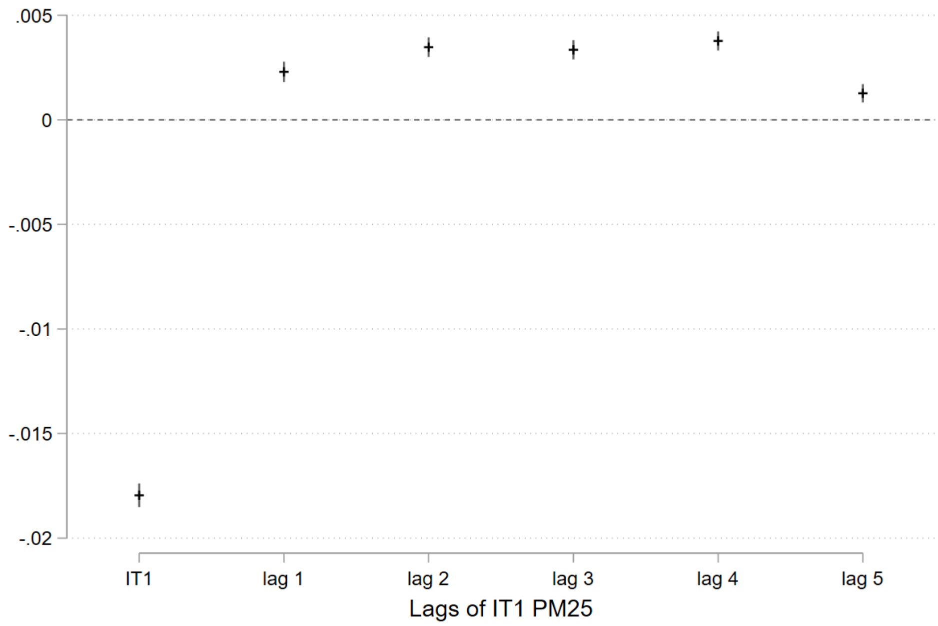
Figure B3: Semi-Elasticity of Daily Hours Worked to the Number of Hours Above WHO Thresholds for PM 2.5



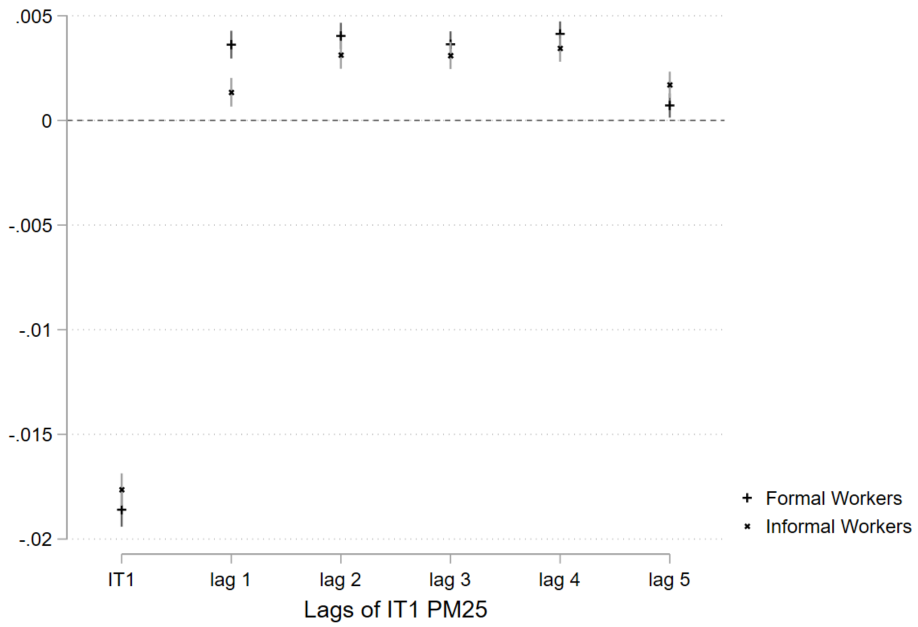
Coefficients and 90% confidence intervals are plotted from equation 2 for the number of hours above the WHO air quality threshold for PM 2.5. The outcome variable is the natural logarithm of 1 + daily hours worked. A separate regression is run for each threshold.

Figure B4: Impact of Same-Day and Lagged PM 2.5 on Probability of Working

Panel A: Full Sample



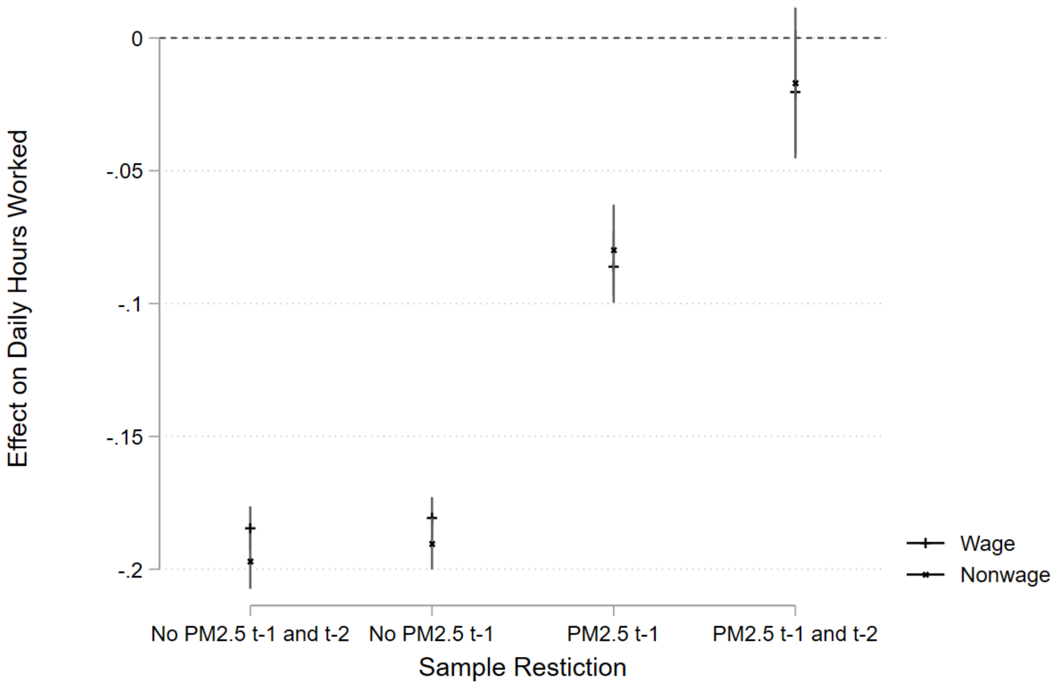
Panel B: By Formality Status



Coefficients and 90% confidence intervals are plotted from equation 2 augmented by five days of lagged PM2.5 measures. Panel A shows the impact on working that day in the full sample and Panel B shows impact on working that day separately in the samples of formal and informal workers.

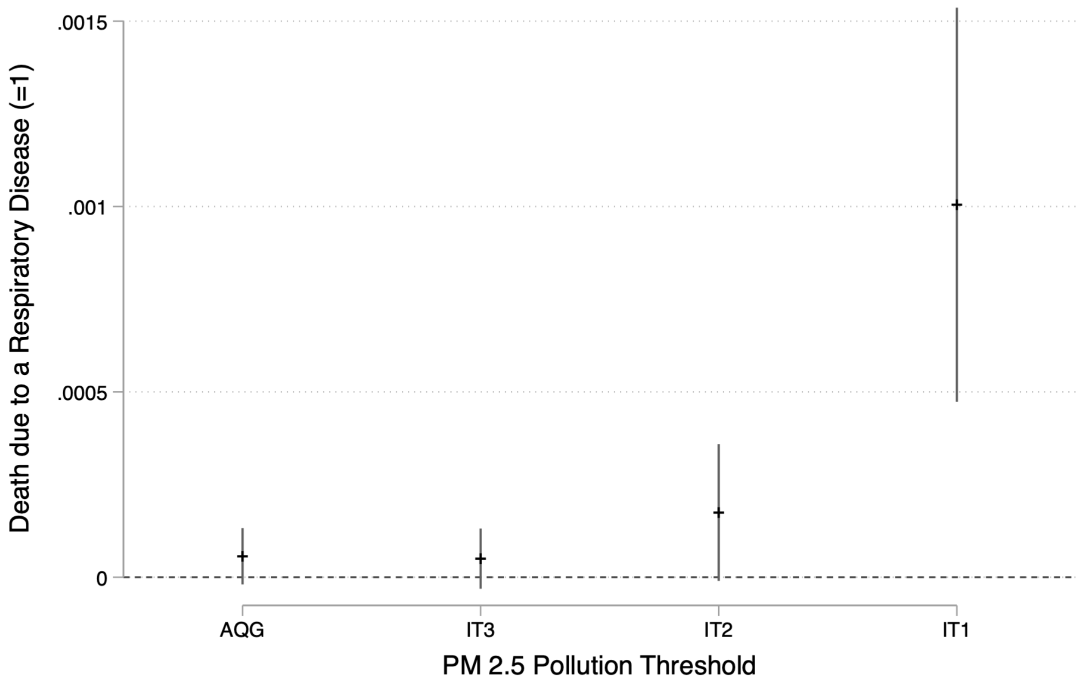
Figure B5: Impact of Same-Day PM 2.5 on Daily Hours Worked by Prior Days' PM 2.5: By Wage Status

By Wage Status



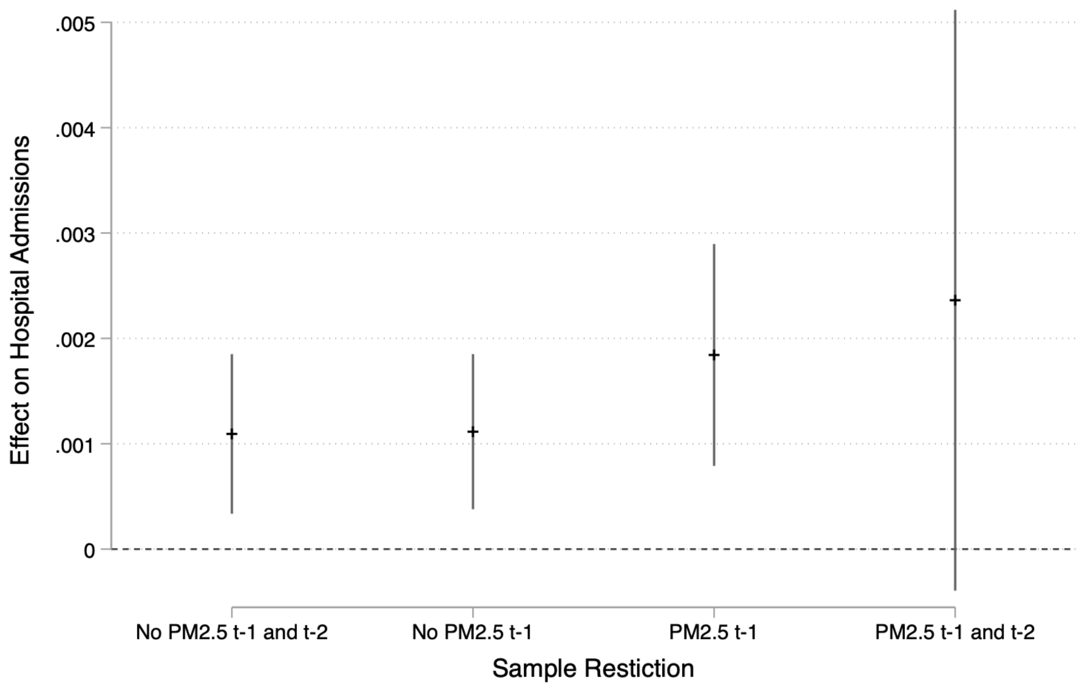
Coefficients and 90% confidence intervals are plotted from separate regressions of equation 2 in the sample of days in which each of the prior two days did not have any hours with PM 2.5 above the WHO IT1 threshold, the sample of days in which the prior day did not have any hours with PM 2.5 above the WHO IT1 threshold, the sample of days in which the prior day had at least one hour with PM 2.5 above the WHO IT1 threshold, and the sample of days in which each of the prior two days had at least one hour of PM 2.5 above the WHO IT1 threshold. Coefficients show the impact separately in the full sample of wage workers and in the full sample of non-wage workers.

Figure B6: Daily Number of Hours Above WHO Thresholds and Daily Deaths for Respiratory Diseases



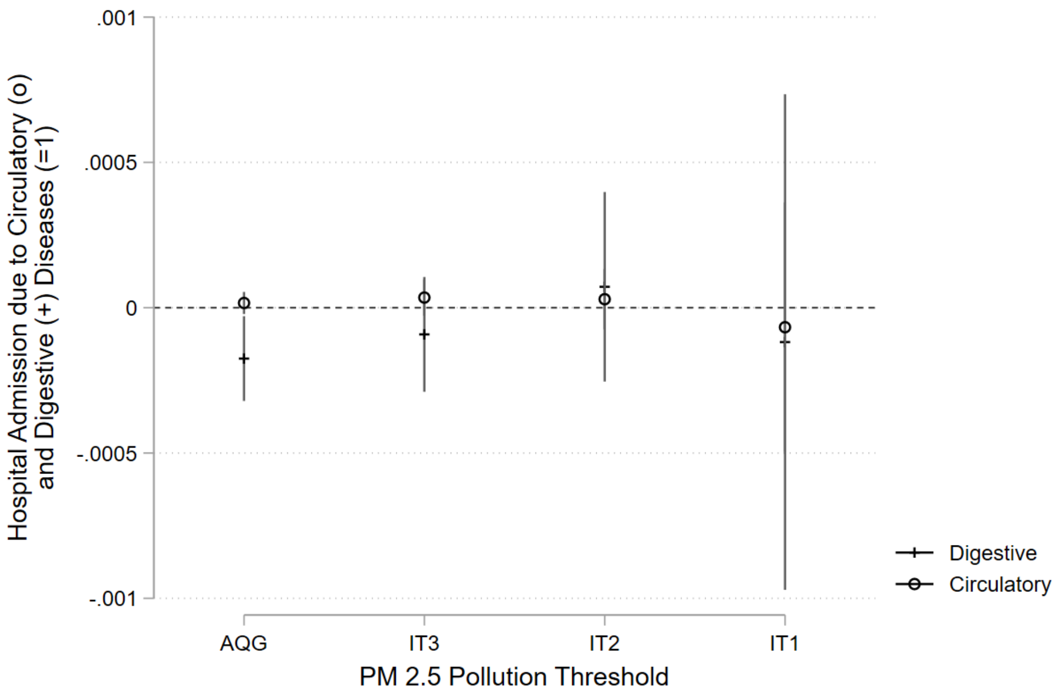
Coefficients and 90% confidence intervals are plotted from equation 3 for the number of hours above the WHO air quality threshold for PM 2.5. A separate regression is run for each threshold. Coefficients show the impact on daily deaths for respiratory diseases.

Figure B7: Impact of Same-Day PM 2.5 on Daily Hospitalizations by Prior Days' PM 2.5



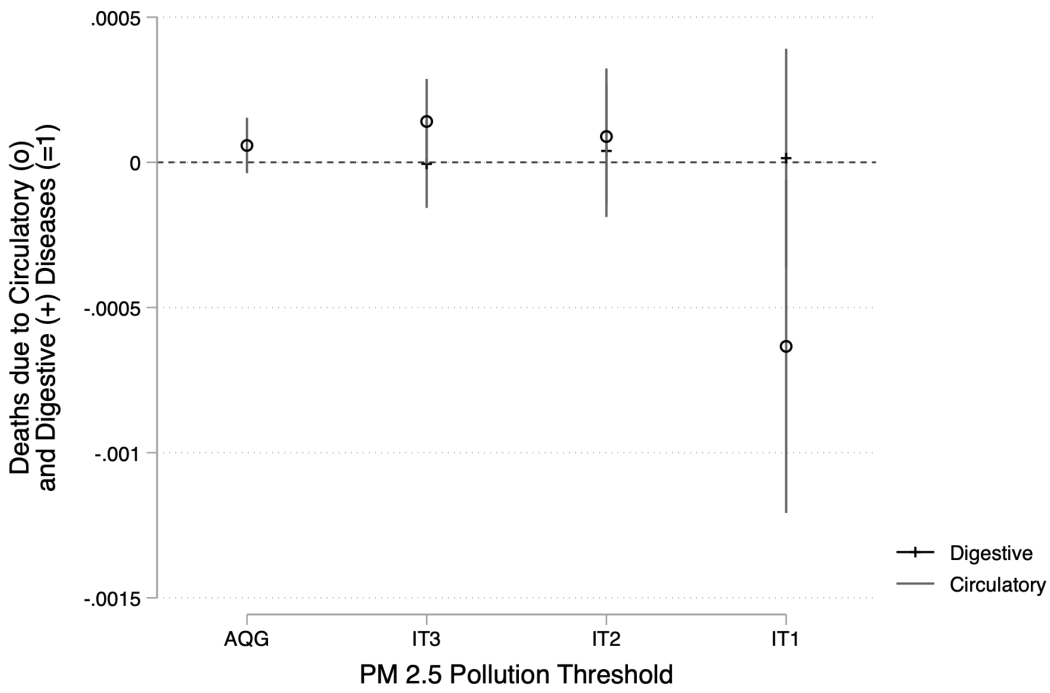
Coefficients and 90% confidence intervals are plotted from separate regressions of equation 2 in the sample of days in which each of the prior two days did not have any hours with PM 2.5 above the WHO IT1 threshold, the sample of days in which the prior day did not have any hours with PM 2.5 above the WHO IT1 threshold, the sample of days in which the prior day had at least one hour with PM 2.5 above the WHO IT1 threshold, and the sample of days in which each of the prior two days had at least one hour of PM 2.5 above the WHO IT1 threshold.

Figure B8: Daily Number of Hours Above WHO Thresholds and Daily Hospital Admissions for Digestive and Circulatory Diseases



Coefficients and 90% confidence intervals are plotted from equation 3 for the number of hours above the WHO air quality threshold for PM 2.5. A separate regression is run for each threshold. Coefficients show the impact on daily hospital admissions for digestive and circulatory diseases in the sample of hospital admissions excluding admissions related to pregnancy or child birth.

Figure B9: Daily Number of Hours Above WHO Thresholds and Daily Deaths for Digestive and Circulatory Diseases



Coefficients and 90% confidence intervals are plotted from equation 3 for the number of hours above the WHO air quality threshold for PM 2.5. A separate regression is run for each threshold. Coefficients show the impact on daily deaths for digestive and circulatory diseases.