Preliminary Draft
Please do not cite
Last updated 8-25-15

Can Increases in Local Air Quality Lead to Higher Labor Productivity?

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For presentation at IZA Workshop: Labor Market Effects of Environmental Policies
Berlin, Germany August 27-28, 2015

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[1] Disclaimer: The views expressed herein are those of the author(s) and do not necessarily represent those of the U.S. Environmental Protection Agency. In addition, although the research described in this paper may have been funded entirely or in part by the U.S. Environmental Protection Agency, it has not been subjected to the Agency's required peer and policy review. No official Agency endorsement should be inferred.

Abstract

In this paper, we estimate the impact of changes in local air quality on labor productivity. We do this by combining hourly data on ambient concentration levels of specific air pollutants – particulate matter ($PM_{2.5}$), ozone (O_3), sulfur dioxide (SO_2), nitrous oxides (NOx) – with high frequency data on indoor labor productivity at supermarkets in a western U.S. metropolitan area. The nascent literature on immediate impacts of different levels of air pollution on contemporaneous productivity has generally found that contemporaneous worker productivity on days with higher pollution levels is lower, but these studies are few, and focus on outdoor work or indoor settings in highly polluted areas. Though $PM_{2.5}$ is capable of infiltrating buildings, amounts may be reduced by the use of air conditioning indoors. Our initial results indicate that there is no statistical relationship between ambient air pollution and productivity of supermarket cashiers, suggesting that indoor workers in climate controlled environments may be relatively protected from outdoor air pollution, when compared to outdoor workers or indoor workers without air conditioning.

1. Introduction

In this paper, we estimate the impact of changes in local air quality on indoor labor productivity. We do this by combining hourly data on ambient concentration levels of specific air pollutants – particulate matter ($PM_{2.5}$), ozone (O_3), sulfur dioxide (SO_2), nitrous oxides (NOx) – with high frequency data on indoor labor productivity at supermarkets in a western U.S. metropolitan area, using a dataset from Mas and Moretti (2009). This is an important issue because benefit-cost analysis of environmental regulations attempts to measure improvements in social welfare due to environmental policies, and improvements in labor productivity may be associated with improvements in air quality. For example, EPA's Regulatory Impact Analysis for the Clean Power Plan[2], includes a table listing quantified and unquantified social benefits. One of the unquantified benefits listed is "outdoor worker productivity" for ozone, which is instead assessed qualitatively due to data and resource limitations (EPA 2015a).

Most of the previous literature has looked at the impacts of long-term exposure to pollution on health. However, the immediate impacts of different levels of air pollution on contemporaneous productivity

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[2] EPA Clean Power Plan, Regulatory Impact Analysis: http://www2.epa.gov/sites/production/files/2015-08/documents/cpp-final-rule-ria.pdf, see Table ES-6 "Quantified and Unquantified Benefits" on p. ES-12.

have not been well studied. The nascent literature to which we propose to contribute has generally found that contemporaneous worker productivity is lower on days with higher pollution levels, but these studies are few, and the one peer-reviewed paper we are aware of focuses on outdoor work. Given that manufacturing, an almost entirely indoor activity, in the United States employs approximately 12.4 million workers (approximately 9% of U.S. employment[3]) accounts for approximately 12.5% of GDP[4], retail trade – also almost entirely indoors as well, accounts for 5.9% of GDP[5] (approximately 11% of U.S. employment[6]), and the service sector accounts for 68.4% of GDP[7], most production taking place indoors (approximately 71% of U.S. employment[8]), more research on indoor workers is necessary. Given recent environmental regulations aimed at improvements in local air quality (e.g. EPA's National Ambient Air Quality Standards proposed revisions for Ozone (2014), and final revisions for PM (2012)) how ambient air quality may affect labor productivity is currently an extremely important policy issue.

Health is a significant type of human capital. Improvements in health can improve labor productivity via increasing workers' physical capabilities (e.g. strength and stamina), as well as their mental capabilities (e.g. the ability to think and reason).[9] Thus pollution may affect labor productivity, indirectly through health impacts and more directly through contemporaneous impacts to work performance. There has been much research linking decreases in pollution to improvements in health (e.g. EPA (2011), and Graff Zivin and Neidell (2013)), and research that links improvements in health to improvements in human capital and labor productivity (Grossman 1972, 2000). However, the detailed data required to isolate the more direct impact of pollution on contemporaneous labor productivity, separately from overall impacts on health, poses a significant barrier to research.

An additional effect of environmental regulation may well be increased labor productivity, working through the channel of improved air quality leading to healthier workers. However, until quite recently there was virtually no peer-reviewed empirical literature specifically estimating the impact

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[3] U.S. Bureau of Labor Statistics (CES): manufacturing, May 2015: 12,333,000 employees. Total non-farm U.S. employment May 2015: 141,625,000; http://www.bls.gov/web/empsit/ceseeb1a.htm.

[4] Manufacturing as a percent of GDP: 2015:Q1; ; https://research.stlouisfed.org/fred2/series/VAPGDPMA

[5] Retail trade as a percent of GDP: 2015:Q; https://research.stlouisfed.org/fred2/series/VAPGDPR

[6] U.S. Bureau of Labor Statistics (CES): retail trade, May 2015: 15,631,200 employees.

[7] Private services-producing industries as a percent of GDP: 2015:Q1; https://research.stlouisfed.org/fred2/series/VAPGDPSPI

[8] U.S. Bureau of Labor Statistics (CES): private service-providing industries, May 2015: 100,157,000 employees.

[9] Bloom and Canning (2005) use adult survival rates as their measure of health and find that an increase in adult survival rates by one percentage point increases labor productivity by roughly 2.8 percent."

of changes in local air quality on labor productivity. There is good reason to think pollution, in particular $PM_{2.5}$, could reduce short-term worker productivity via increases in blood pressure, minor headaches, respiratory irritation and irritation to the eyes, ears, nose and throat (Pope, 2000; Ghio, Kim and Devlin, 2000; Auchincloss et al, 2008).[10] These milder symptoms can begin quickly (possibly as soon as a few hours) after exposure, especially for individuals with pre-existing cardiovascular and respiratory conditions. Moreover, fine particles can also affect people for several days after being exposed. $PM_{2.5}$ is extremely small; these “fine particles” have diameters smaller than 2.5 micrometers (approximately 1/30 the diameter of a human hair) and can persist in the air for prolonged periods of time.[11] $PM_{2.5}$ can enter buildings with little difficulty with penetration rates from 70–100 percent (Thatcher and Layton, 1995; Ozkaynak et al., 1996; and Vette et al., 2001). This, unlike other pollutants that do not easily penetrate buildings or dissipate quickly once inside a building, makes $PM_{2.5}$ extremely hard to avoid even by retreating indoors. However, $PM_{2.5}$ may be removed by air conditioning or air ventilation systems with filters that can capture such small particles. (Riley et al, 2002, and EPA, 2009)[12] Ozone, on the other hand, due to its chemical composition (with NOx and VOC precursors) and dependence on sunlight, may be less of an issue in indoor environments. Exposure to ozone can affect lung function, and potential impacts can vary greatly across individuals.[13] An average outdoor worker may experience moderate lung function effects and possibly lung injury and inflammation during an 8-hour exposure to high ambient levels of ozone. On the other hand, people resting for most of the day in an air-conditioned building with little air turnover would suffer few effects (EPA 2015b).

Our paper is closest in spirit to Chang et al (2014).[14] We examine the effect of ambient air quality on contemporaneous indoor labor productivity at a set of supermarkets in the same metropolitan area of

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[10] Increased hospitalization rates for respiratory illness associated with $PM_{2.5}$ provides further evidence that fine particles can cause impact the respiratory system – Stafoggia et al (2013), Dominici et al (2008) and Bell et al (2006) – though these studies focus on older individuals.

[11] Particulate Matter: Basic Information http://www.epa.gov/pm/basic.html

[12] “Ozone concentrations indoors typically vary between 20% and 80% of outdoor levels depending upon whether windows are open or closed, air conditioning is used, or other factors such as indoor sources. People with the greatest cumulative exposure are those heavily exercising outdoors for long periods of time when ozone concentrations are high… People with the lowest cumulative exposure are those resting for most of the day in an air-conditioned building with little air turnover.” [http://www.epa.gov/apti/ozonehealth/population.html] Currently we only include ozone levels as a control variable, but in the next version of this paper we plan to do a much more careful analysis of the potential impact of ozone on worker productivity.

[13] http://www.epa.gov/apti/ozonehealth/population.html

[14] Our paper is also similar to Li et al (2015), but in their paper $PM_{2.5}$ levels are orders of magnitude higher than in our sample, making it difficult to compare our results.

a Western U.S. state. To do this, we use a quasi-experimental design that exploits a panel data set consisting of all transactions performed by cashiers from six stores of a national supermarket chain for two years, for dates between 2003 and 2006. We have scanner-level data on the number of items scanned and the length of each transaction, measured in seconds, which allows us to obtain a precise, high-frequency measure of productivity for each cashier.

We measure hourly concentration levels of each of O_3, $PM_{2.5}$, SO_2, and NOx at two air quality monitors located near our sample of supermarkets. We link each supermarket to the closest ambient air quality monitor for each of these pollutants – all our grocery stores link to two monitors. Having monitors in two locations in the metro area provides us with rich variation in air quality across space as well as time, whereas previous research had to rely solely on variation over time. Our empirical strategy, exploits the high-frequency fluctuations across time and space in ambient concentrations of O_3, $PM_{2.5}$, SO_2, and NOx.

Our preliminary results indicate that there is no statistically significant decline in indoor productivity due to increases in ambient concentrations of $PM_{2.5}$ or any of our other pollutants. We have done several sensitivity analyses allowing $PM_{2.5}$ to have various non-linear effects on productivity, using logs of $PM_{2.5}$ levels and productivity, and examining different lagged values of $PM_{2.5}$ levels (e.g. 1-hour, 3-hours, and 48 hours), but our results are robust to any of these variations. We have also estimated labor supply specifications, based on the intensive margin: hours worked, and similarly find no statistically significant relationship between ambient concentrations of $PM_{2.5}$ or any of our other pollutants. So unlike Chang et al (2015), who find relatively large negative indoor productivity effects of $PM_{2.5}$, our findings using very detailed productivity measures and higher frequency measures of ambient $PM_{2.5}$ concentrations in an air-conditioned setting, suggest that $PM_{2.5}$, does not have statistically significant, nor economically substantial, negative impacts on productivity.

Our paper is organized as follows: Section 2 reviews the brief literature which examines the impact of ambient pollution levels on worker productivity. In section 3 we discuss the data and empirical methodology. Section 4 presents our preliminary results, followed by concluding remarks and next steps in section 5.

2. Ambient Pollution and Productivity

The question of how environmental regulation affects some economic outcomes has been studied extensively. There is an wide-ranging literature that investigates how the costs of complying with EPA regulations affects productivity (e.g., Färe, Grosskopf and Pasurka 1986, Boyd and McClelland 1999, Berman and Bui 2001a, Gray and Shadbegian 2002, Shadbegian and Gray 2005, Shadbegian and Gray 2006), investment (e.g., Gray and Shadbegian 1998), and environmental performance (e.g., Magat and Viscusi 1990, Gray and Shadbegian 2003, Shadbegian and Gray 2006). There is also a growing literature which examines the impact of environmental regulations on employment (e.g., Berman and Bui 2001b, Greenstone 2002, Morgenstern, Pizer and Shih 2002, Cole and Elliott 2007, Walker 2011, Walker 2013, Gray and Shadbegian 2013, Curtis 2014, Gray, Shadbegian, Wang and Meral 2014, and Ferris, Shadbegian, and Wolverton 2014).

There is a small, nascent empirical literature that uses very detailed labor and air quality data, along with innovative quasi-experimental techniques to examine the linkage between pollution and productivity. This new research has found some evidence that there could be statistically and economically significant increases in contemporaneous worker productivity, both outdoors and indoors, when work site ambient air quality improves. For example, Graff Zivin and Neidell (2012) match detailed worker-level productivity data from 2009 and 2010 for a large California farm with local air quality monitoring data. Their quasi-experimental design allows them to identify the impact of daily variation in ozone levels on labor productivity. Graff Zivin and Neidell find "that ozone levels well below federal air quality standards have a significant impact on productivity: a 10 parts per billion (ppb) decrease in ozone concentrations increases worker productivity by 5.5 percent." Chang et al (2014) examine the impact of outdoor air pollution on the productivity of indoor workers at a pear-packing factory, noting that estimating the effects of pollution on indoor worker productivity is very important, since most output in the wealthiest countries is produced in indoor settings. They note that the factory is not air conditioned. Using a detailed panel dataset on the daily productivity of workers at a single pear-packing plant in Northern California, during the 2001, 2002, and 2003 packing seasons, they find that an increase in outdoor levels of $PM_{2.5}$, a harmful pollutant that easily penetrates indoor settings, leads to a statistically and economically significant decrease in pear-packing productivity, with effects occurring at levels well below current air quality standards.[15]

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[15] However, if they exclude observations from the weeks with air quality alerts because of the massive Biscuit wildfire their estimate is not statistically significant, but it is of similar magnitude.

More specifically, they find that a 1 microgram per cubic meter (µg/m3) increase in $PM_{2.5}$ reduces worker productivity by $0.04 per hour (roughly 0.6%). In contrast, increases in levels of pollutants that do not easily travel indoors, such as ozone, have no estimated statistical impact.[16] This is the first evidence that outdoor pollution can affect the productivity of indoor workers. Li, Liu, and Salvo (2015), is another recent study which examines the impact of outdoor air quality on indoor worker productivity. Using a panel of 98 workers from a manufacturing plant in the Hebei province of China, they find large reductions in contemporaneous indoor worker productivity (on the order of 15%) associated with the first 200 µg/m3 increase in concentrations of fine particles ($PM_{2.5}$).

There is some initial evidence that air conditioning may play a protective role, in reducing the amount of outdoor air pollution that indoor workers may be exposed to. Particularly for $PM_{2.5}$, recent research indicates that while $PM_{2.5}$ is able to enter buildings easily, air conditioning and filtration systems (e.g. HVAC) can effectively reduce $PM_{2.5}$ in indoor settings (EPA, 2009)[17], but measurements of indoor and outdoor concentrations of $PM_{2.5}$ can vary, even in retail stores with air conditioning and filtrations systems (Chan et al 2012). The effectiveness of $PM_{2.5}$ removal depends on building types, the types and use of air conditioning and filtration systems, in particular, the effectiveness rating of the air filter (Riley et al 2002). Because the filters remain in place and can continue to capture fine particles, even when air conditioning systems are used in ventilation mode, they can continue to effectively remove $PM_{2.5}$ even when the systems are not cooling the air. (Bennett et. al., 2012 and Zaatari et. al., 2014)

3. Data and Empirical Methodology

The goal of this paper is to estimate the impact of $PM_{2.5}$ on indoor worker productivity. To do this we combine data on the productivity of supermarket cashiers in a national chain, using a data set used by Mas and Moretti (2009) with ambient air quality data. The Mas and Moretti data includes transactions level data for all sales that transpired at a set of six grocery stores of a national supermarket chain over a two year period between 2003 and 2006. Even though the data set includes only two years of data for each store the dataset spans four calendar years since the starting dates differ by store. All the stores are located in the same metropolitan area of a state in the Western

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[16] "Ozone concentrations indoors typically vary between 20% and 80% of outdoor levels depending upon whether windows are open or closed, air conditioning is used, or other factors such as indoor sources." (EPA 2015b)

Census region. In total, the data includes observations on 394 cashiers. One extremely useful aspect of their data set is that in the grocery store environment they were able to use scanner-level data to construct an extremely high-quality measure of productivity. More specifically, for each store we observe the number of items scanned by each cashier during every transaction, along with precise length of the transaction for a period of two years. In our paper, we define individual productivity as the natural log of the number of items scanned per second during times spent in transactions over one hour intervals.[18] Unlike much of the previous literature, which had to rely on less precise measures of productivity (e.g. monetary or daily output measures), our measure of labor productivity is precise, worker-specific, and varies instantaneously.

To the productivity data we add ambient air quality data and weather data from the closest monitors to each store. We measure hourly concentration levels of each of O3, $PM_{2.5}$, SO_2, and NOx at two outdoor air quality monitors located near our sample of supermarkets. We link each supermarket to the closest ambient air quality monitor for each of these pollutants – there are multiple air quality monitors in this region and all six of our grocery stores link to one of two monitors. Having monitors in two locations in the metro area provides us with rich variation in air quality across space as well as time, whereas previous research had to rely solely on variation over time. Our empirical strategy exploits the high-frequency fluctuations across time and space in ambient concentrations of O3, $PM_{2.5}$, SO_2, and NOx. The two air quality monitors nearest our sample of supermarkets only have hourly $PM_{2.5}$ data available for years 2004 and 2005. We assume that hourly fluctuations in $PM_{2.5}$ and the other pollutants in our study are exogenous. We believe this is a reasonable assumption as they not affected by grocery store sales (since grocery stores are only very minor emitters of these pollutants) and fluctuations in ambient pollution concentrations can be caused by sources hundreds of miles away from the monitor. We also control for hourly temperature, humidity, wind speed, and solar radiation.

To assess the impact of $PM_{2.5}$ on indoor worker productivity we estimate the following equation:

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[18] Specifically, we sum the number of items that a worker scanned over one hour. We divide this number by the total number of seconds that the worker was in a transaction, where a transaction is defined as the time between when the first item is scanned to when the payment is completed and the receipt for the transaction is given to the customer.

$$(1)\quad Ln(\text{Labor Productivity}_{iscdt}) = \alpha_0 + \alpha_1 PM2.5_{mdt} + \alpha_2 O3_{mdt} + \alpha_3 SO2_{mdt} + \alpha_4 NO2_{mdt} + \alpha_5 CO_{mdt} + \alpha_6 Temp_{cdt} + \alpha_7 (Temp_{cdt})^2 + \alpha_8 Humidity_{cdt} + \alpha_9 Wind_{cdt} + \alpha_{10} Solar_{cdt} + \alpha_{11} Transactions_{scdt} + \beta_i Worker_i + \delta_{dt} \text{Hour-Day-Store}_{dt} + \zeta_{ym} \text{Year-Month}_{ym} + \varepsilon_{iscdt}$$

Labor productivity is the log of the average productivity of cashier *i* in the hourly time interval, working in store *s*, in county *c*, on date *d*, and time *t*. Our main explanatory variable of interest is ambient concentration level of $PM_{2.5}$, which is measured as an hourly average at monitor m, on date d, at time t. Likewise our other measures of ambient pollution O3, SO_2, NO_2, and CO are also hourly averages at monitor m, on date d, at time t. Similarly temperature, humidity, wind speed, and solar radiation. We also control for the number of hourly transactions at each store, worker fixed effects, hour of day-day of week-store fixed effects, as well as year-month fixed effects.

It is also possible that ambient air quality may affect whether a cashier works and how many hours he or she chooses to work.[19] As Chang et al (2014) note, this presents us with one potential difficulty of estimating the effect of $PM_{2.5}$ on worker productivity, isolating the changes in productivity that are not confounded with changes in labor supply. If the decision of the number of hours worked responds to changes in $PM_{2.5}$ levels, then the estimated effect of $PM_{2.5}$ on productivity could be biased due to sample selection. Moreover, like Chang et al, we want to separate the direct effects of $PM_{2.5}$ on productivity from a worker's decision to work and the number of hours they work.

The cashiers submit their preferences for hours and shifts two weeks before a shift, thus the within-day timing of entry and exit of workers due to shift changes is arguably exogenous to ambient air quality. This allows us to test for the possibility of sample selection bias due to labor supply responding to levels of $PM_{2.5}$. To do this we estimate a regression using hours worked in the day as our outcome variable and including all the explanatory variables from equation (1). We do not find any statistical evidence that $PM_{2.5}$ or the other pollutants affect labor supply, measured on this intensive margin hours worked. Therefore we expect that any estimated effect $PM_{2.5}$ on productivity will not be confounded with changes in the labor supply.

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[19] Hanna and Oliva (2015) provide evidence that pollution levels can impact labor supply using variation in sulfur dioxide (SO_2) emissions from the closing of a large oil refinery in Mexico City. They find that the closing of the refinery led to a nearly 20% reduction in SO_2 emissions in the area around the plant leading to a 3.5% increase in hours worked per week.

While these particular supermarkets do not also report on their air conditioning and air filtration use, along with the cashier productivity measures, we estimate air conditioning use in supermarkets in the U.S. West. We examine data on air conditioning use by grocery stores and supermarkets from the U.S. Energy Information Administration 2003 Commercial Buildings Energy Consumption Survey.[20] We use the micro data with sample weights, grocery stores in the U.S. West with more than 20 employees (to focus on chain stores, rather than small shops with fewer than 5 employees). All report the use of air conditioning systems for cooling indoor air (packaged A/C or central A/C), and they report, on average, 75 percent cooling. Thus, we expect that the supermarkets in our sample likely use air conditioning and air filtration systems. Some local building codes and industry standards indicate a minimum amount of ventilation in supermarkets and grocery stores (Zaatari et al 2014, and Bennett et. al., 2012). More research is needed to understand to what extent air conditioning and ventilation systems may reduce $PM_{2.5}$ in grocery stores, if at all. Zaatari et al (2014) cite two recent studies that measured concentrations of $PM_{2.5}$, both from outdoor and indoor sources, for U.S. retail stores. Chan et al (2012) find that although the two grocery stores in their sample met the minimum requirements for ventilation, $PM_{2.5}$ concentrations were not greatly reduced indoors. In fact, while one grocery store had lower $PM_{2.5}$ concentrations indoors than measured outside, in the other grocery store they measured concentrations of indoor $PM_{2.5}$ that were higher from contemporaneous measures of outdoor $PM_{2.5}$. The second grocery store was observed to have possible indoor sources of PM, and was using less-efficient air filters (MERV 8, rather than MERV 15) than the first store in their sample. . Bennet et al (2012) find that buildings in their sample, which include two grocery stores, generally use low-efficiency air filters which are not as effective as high-efficiency filters at removing $PM_{2.5}$.

4. Preliminary Findings

Table 1 presents the summary statistics and description of all variables used in this study. In Table 2 we present our basic models which include only $PM_{2.5}$, in both levels and quartile ranges, along with the levels of O3, SO_2, NO_2, and CO. We also include worker fixed effects, hour-day-store fixed effects as well as a set of year-month dummies. Our models do reasonably well explaining the

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[20] Authors' calculations using the 2003 CBECS microdata http://www.eia.gov/consumption/commercial/data/2003/index.cfm?view=microdata

variation in labor productivity, with R^2s around 0.27, except for model (1) without worker fixed effects – worker fixed effects significantly increase the R^2 from 0.16 to 0.27, so we include them in all models. In models (1), (2), and (5) we include $PM_{2.5}$ levels and in models (3) and (6) we allow $PM_{2.5}$ to have a nonlinear impact on labor productivity by including a set of dummy variables representing $PM_{2.5}$ quartiles (the lowest quartile is the excluded group). In each linear model, except model (2), $PM_{2.5}$ has the expected negative effect on labor productivity, but this effect is never statistically significant. Moreover, even if the estimated impacts of $PM_{2.5}$ were significant, the effect would still be quite small. For example, in model (5) in which we control for other pollutants a 10 $\mu g/m^3$ (approximately a one standard deviation) increase in $PM_{2.5}$ levels would only decrease labor productivity by 0.15%. The other pollution variables all have the wrong sign.

In the models in which we allow $PM_{2.5}$ to have a nonlinear effect we still find the expected negative impact on labor productivity, but again the effect is never statistically significant. Furthermore, the estimated $PM_{2.5}$ effects have an inverted U shape, with the largest estimated impact occurring in the 3rd quartile, but again these effects are not economically meaningful. For example in model (6) $PM_{2.5}$ levels in the range of 7.8-11.4 $\mu g/m^3$ would lower labor productivity by approximately 0.14% relative to $PM_{2.5}$ levels between 2.6 and 5.4 $\mu g/m^3$. We also tested for $PM_{2.5}$ impacts at levels above the 90th percentile – models (4) and (7) – and while the effect is negative it is small and not significant.

In Table 3 we control for weather – temperature, relative humidity, wind speed, and solar radiation – and hourly transactions at the store to control for demand. None of the temperature variables have a significant effect on productivity, which may not be too surprising given grocery stores are typically climate controlled. Additionally, the set of weather variables, along with the level of hourly transactions adds virtually no explanatory power to our simpler models. Moreover, unsurprisingly including these extra controls did not change the sign, statistical significance or economic significance of the effect of $PM_{2.5}$ on labor productivity. However, the estimated impact of ozone and NOx are now consistently negative, though still not statistically significant at conventional levels. Again, even if these effects were statistically significant, they are still quite small from an economic point of view. For example, in model 13 a 1 ppm and a 10 ppb (approximately a one standard deviation) increase in ozone and NOx respectively would decrease productivity by 1.4% and 0.3%. We plan to look more carefully at the potential effects of these other pollutants, in particular ozone and NOx. Both have potential health effects, primarily respiratory, that may have short-term effects on productivity.[21]

The milder symptoms associated with $PM_{2.5}$ can begin quickly (possibly as soon as a few hours) after exposure, but not necessarily contemporaneously, and can also affect people for several days after being exposed. So in in table 4, we present results where we lag our measure of $PM_{2.5}$ by 3 hours to give the workers time to be affected by the fine particles. However, while the impact of $PM_{2.5}$ continues to be negative, the effect is never statistically significant and even if it were, its effect on productivity remains quite small.[22]

5. Preliminary Conclusions and Next Steps

We combined hourly data on ambient concentration levels of specific air pollutants – particulate matter ($PM_{2.5}$), ozone (O_3), sulfur dioxide (SO_2), nitrous oxides (NOx) – with high frequency data on indoor labor productivity at supermarkets in a western U.S. metropolitan area. Our initial results indicate that there is no statistical relationship between PM2.5 and productivity of supermarket cashiers, suggesting that indoor workers in climate controlled environments may be relatively protected from outdoor air pollution, when compared to outdoor workers or indoor workers without air conditioning. This result stands in contrast to the nascent literature on immediate impacts of different levels of air pollution on contemporaneous productivity which has generally found that contemporaneous worker productivity on days with higher pollution levels is lower. However, these studies are few, and focus on outdoor work (Graff Zivin and Neidell, 2012, Lichter et. al., 2015), indoor settings in highly polluted areas (Li et al., 2015), or indoor work in buildings without air conditioning (Chang et. al, 2014). Our initial finding of a zero impact is not unusual in the literature on employment impacts of environmental regulations, e.g. Berman and Bui (2001b). Our study, focused on supermarkets, suggests further work: if climate control and air conditioning systems are effectively protecting indoor workers from outside air pollutants, that is important and policy-relevant information, which suggests that more research is needed to gain more traction on the complex relationship between ambient air pollution and labor productivity.

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[21] See http://www.epa.gov/airquality/nitrogenoxides/health.html, and http://www.epa.gov/apti/ozonehealth/population.html

[22] We also tried a 48 hour lagged measure of $PM_{2.5}$, but it showed nearly the same effects as the 3 hour lagged version.

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Table 1 – Summary Statistics

Variables:	*Hourly data*			
	Mean	***Std. dev.***	***10th percentile***	***90th percentile***
Ln(Labor Productivity)				
Air quality: measured over 2004 & 2005at two monitors in the metro area				
PM 2.5	11.0	10.5	2	23
PM 10	18.5	9.7	8	33
Ozone (O3)	0.02	0.01	0.00	0.04
Sulfur Dioxide (SO2)	1.3	1.5	0	3
Nitrogen Dioxide (NO2)	14.0	10.2	4	30
Carbon Monoxide (CO)	0.44	0.38	0.25	0.8
Temperature	15.3	6.9	8	25
Solar radiation	207.0	293.1	0	730
Wind	3.5	2.3	0	6.4
Relative humidity	74.9	21.6	39	97

Table 2 – Impact of PM$_{2.5}$ on Labor Productivity

Model	**1**	**2**	**3**	**4**	**5**	**6**	**7**
PM2.5	-0.0000863	0.0000535			-0.0001499		
	(0.000172)	(0.0001673)			(0.00017)		
PM2.5 Quartiles:							
2.6-5.4 (Omitted)							
5.4-7.8			-0.0006471			-0.0004799	
			(0.003)			(0.003)	
7.8-11.4			-0.0032693			-0.0041634	
			(0.003)			(0.003)	
>11.4			-0.0007543			-0.0014011	
			(0.003)			(0.003)	
PM2.5 >=20				-0.0010157			-0.001951
				(0.004)			(0.004)
Other Pollutants:							
O3					0.1963627	0.2114551	0.2002099
					(0.120)	(0.119)	(0.121)
SO2					0.0009338	0.0008135	0.00086
					(0.001)	(0.0005)	(0.001)
NO2					0.0000511	0.0000691	0.0000367
					(0.000)	(0.000)	(0.000)
CO					0.0028031	0.0021967	0.0024942
					(0.005)	(0.005)	(0.005)
Worker F.E.		X	X	X	X	X	X
Hour * DOW * Store	X	X	X	X	X	X	X
Year-Month Dummies	X	X	X	X	X	X	X
Store Transactions/Hour					X	X	X
Observations	382,819	382,819	382,819	382,819	352,787	352,787	352,787
R-squared	0.16	0.27	0.27	0.27	0.27	0.27	0.27

(standard errors)

Table 3 – Impact of $PM_{2.5}$ on Labor Productivity, with Additional Controls

Model	**8**	**9**	**10**	**11**	**12**	**13**
PM2.5	-0.0000598			-0.0001289		
	(0.00017)			(0.00017)		
PM2.5 Quartiles:						
2.6-5.4 (Omidted)						
5.4-7.8		-0.0002828			-0.0004726	
		(0.003)			(0.003)	
7.8-11.4		-0.0030621			-0.0031945	
		(0.003)			(0.003)	
>11.4		0.0004103			-0.001662	
		(0.003)			(0.003)	
PM2.5 >=20			-0.0017184			-0.0026693
			(0.004)			(0.004)
Other Pollutants:						
O3	-0.0078713	-0.0064155	-0.0102918	-0.0133754	0.0024052	-0.0142861
	(0.114)	0.1146068	(0.115)	(0.113)	(0.113)	(0.114)
SO2	0.0008014	0.0007163	0.0008051	0.0004648	0.0003759	0.0004379
	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)
NO2	-0.0002842	-0.0002999	-0.0002884	-0.0002855	-0.0002753	-0.0002942
	(0.00021)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
CO	0.0086574	0.0091446	0.008666	0.0088984	0.0084756	0.0087636
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
Weather	X	X	X	X	X	X
Worker F.E.	X	X	X	X	X	X
Hour * DOW * Store	X	X	X	X	X	X
Year-Month Dummies	X	X	X	X	X	X
Store Transactions/Hour				X	X	X
Observations	352,787	352,787	352,787	352,787	352,787	352,787
R-squared	0.27	0.27	0.27	0.27	0.27	0.27

(standard errors)

Table 4 – Impact of Lagged PM$_{2.5}$ on Labor Productivity, with Additional Controls

Model	**9**	**10**	**11**	**12**	**13**	**14**
PM2.5	-0.0001353			-0.0001113		
	(0.00019)			(0.00016)		
PM2.5 Quartiles:						
2.6-5.4 (Omidted)						
5.4-7.8		0.0022162			0.0015273	
		(0.003)			(0.003)	
7.8-11.4		0.0010908			-0.000295	
		(0.003)			(0.003)	
>11.4		-0.0021184			-0.0040149	
		(0.004)			(0.004)	
PM2.5 >=20			-0.0046303			-0.00526
			(0.005)			(0.004)
Other Pollutants:						
O3	0.01116	0.0182815	0.0058438	-0.0001921	0.0265715	0.0050459
	(0.118)	0.1213342	(0.118)	(0.000)	(0.120)	(0.116)
SO2	0.0007441	0.0007618	0.000761	0.0114516	0.0003646	0.0003617
	(0.001)	(0.001)	(0.001)	(0.117)	(0.000)	(0.000)
NO2	-0.000294	-0.000283	-0.0003036	0.0003527	-0.0002692	-0.0003062
	(0.00021)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
CO	0.0097207	0.0098007	0.0099399	-0.0002941	0.0096758	0.0099003
	(0.005)	(0.005)	(0.005)	(0.000)	(0.005)	(0.005)
Weather	X	X	X	X	X	X
Worker F.E.	X	X	X	X	X	X
Hour * DOW * Store	X	X	X	X	X	X
Year-Month Dummies	X	X	X	X	X	X
Store Transactions/Hour				X	X	X
Observations	344,043	344,043	344,043	344,043	344,043	344,043
R-squared	0.27	0.27	0.27	0.27	0.27	0.27