AIR POLLUTION AND INFANT HEALTH:

LESSONS FROM NEW JERSEY

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Motivation

- Pollution abatement is often justified as something that will promote health yet little is known about the specific health effects of pollution levels around current air quality thresholds.

- And while there is a good deal of literature about “environmental justice” which focuses on the fact that some groups are more likely that others to be exposed to pollution, it is not known whether some groups are more vulnerable than others to the effects of pollution.

- This paper addresses these questions by examining the impact of air pollution on infant health in New Jersey over the 1990s.

- Infants are of interest for three reasons. First, policy makers and the public are highly motivated to protect these most vulnerable members of society. Second, in the case of infant health, the link between cause and effect is immediate, whereas for adults, diseases today may reflect pollution exposure that occurred many years ago. Third, there is increasing evidence of long-term effects of poor infant health on future outcomes (see Currie (2008) for a summary of this research).

Our work offers several innovations over the existing literature.

1. Most studies assign exposure by approximating location as the centroid of a geographic area or by computing the average pollution levels across all measures of pollution within a geographic area (e.g. a county). In our data we know the exact addresses of mothers, enabling us to focus on mothers located close to air quality monitors.

2. Air quality is not randomly assigned and is capitalized into housing prices (Chay and Greenstone, 2003) so families with higher incomes or preferences for cleaner air are likely to sort into locations with better air quality.

In addition to controls for pollution exposure, we control for weather, child age, observable characteristics of the mother and child, and time and monitor fixed effects. *In addition, because we can link mothers over time, we can control for mother fixed effects.*

3. We ask whether pollution has a greater effect on more vulnerable infants, where vulnerability can be proxied by: whether the mother smoked during pregnancy, low income, high maternal age, and low maternal education.

Previous research has suggested that smoking might exacerbate the effect of air pollution by increasing inflammatory responses and airway reactivity (Wang and Xu, 1998).

Also, Sven Cnattingius (1997) show (using 1,000,000+ Swedish births) that effects of smoking are greater in older women, suggesting that effects of pollution might also be greater in women at higher risk of negative birth outcomes.

To our knowledge, this is the first study of whether pollution has such different effects.

We find that:

- Air pollution has a significant effect on fetal health even at the relatively low levels of pollution experienced in recent years.
- Air pollution also effects on infant mortality, conditional on measures of health at birth.
- Although previous studies focus on particulates and ozone, we find large effects of CO, which in urban areas is produced mainly by motor vehicles.
- In particular, a one unit change in mean carbon monoxide (CO) during the last trimester of pregnancy would increase the risk of low birth weight by 9 percent and would increase the risk of infant mortality by one percent relative to baseline levels.
- The effects of air pollution on infant health at birth are two to four times larger for smokers than for nonsmokers, and greater for disadvantaged mothers and older mothers.

BACKGROUND

Previous literature suggests that CO, particulates, ozone, may affect health:

- Carbon Monoxide is an odorless, colorless gas which is poisonous at high levels. CO bonds with hemoglobin more easily than oxygen, so that it reduces the body's ability to deliver oxygen to organs and tissues. Because infants are small, and many have respiratory problems in any case, CO may be particularly harmful to them.

- In the U.S. 77 percent of CO comes from transportation sources and in cities, as much as 90 percent of CO comes from motor vehicle exhaust (Environmental Protection Agency, January 1993, 2003b). Among smokers, cigarettes are a major source of CO, and smokers have higher baseline levels of CO in the blood than non-smokers (Environmental Protection Agency, 2000).

Particulate matter can take many forms, including ash and dust, and motor vehicle exhaust is a major source. The most damage comes from the smallest particles since they are inhaled deep into the lungs [Environmental Protection Agency, 2003b]. The mechanisms through which particles harm health are controversial. A leading theory is that they cause an inflammatory response which weakens the immune system [Seaton, et al. 1995].

Ozone (the major component of smog) damages tissue, reduces lung function, and sensitizes the lungs to other irritants. Exposure to ozone during exercise reduces lung functioning and causes symptoms such as chest pain, coughing, and pulmonary congestion. Ozone is formed through reactions between nitrogen oxides and volatile organic compounds (which are found in auto emissions, among other sources) in heat and sunlight.

A link between air pollution and infant health has long been suspected. But we know little about what levels of pollutants cause health problems either to fetuses in the womb or newborns.

- Many previous studies focus on much higher pollution levels (e.g. the "London fog").

- Epidemiological research has produced inconsistent results. E.g. Ritz and Yu (1999) report that CO exposure in the last trimester of pregnancy increased the incidence of low birth weight (defined as birth weight less than 2,500 grams), while Ritz et al. (2000) report that CO exposure in the six weeks before birth has effects on gestation only in some areas. Alderman et al. (1987) found that CO in the last trimester had no effect on low birth weight once maternal education and race were controlled. Ritz et al. (2000) report that PM10 exposure 6 weeks before birth increases preterm birth, while Mainsonet et al. (2001) find that PM10 has no effect on low birth weight.

Results of studies of the effects of pollution on infant mortality are also mixed. For example, Woodruff et al. (1977) report that infants with high exposure to PM10 are more likely to die in the post neonatal period.

But Lipfert, Zhang, and Wyzga (2000) find that although they can reproduce some earlier results showing effects of county-level pollution measures on infant mortality, the results are not robust to including controls for maternal characteristics.

Most of these studies control for only a very limited number of observable characteristics.

Families with higher incomes or greater preferences for cleaner air may be more likely to sort into neighborhoods with better air quality. These families may also invest more in their children in other ways, producing better outcomes.

Economic studies attempt to control for omitted confounders.

Chay and Greenstone: The Clean Air Act of 1970 and the recession of the early 1980s induced special variation in pollution levels that is likely to be exogenous. They find that a one unit decline in total suspended particles led to a 5 to 8 fewer deaths per 100,000 infants.

However, the levels of particulates studied by Chay and Greenstone are much higher than those prevalent today, and only particulates were measured during the time period they examine, so that it was not possible for them to examine the effects of other pollutants.

Currie and Neidell: Use within-postal code variation in pollution levels and find that reductions in CO and particulates over the 1990s in California saved over 1,000 infant lives. However, they were unable to find any consistent evidence of pollution effects on health at birth.

This paper improves on Currie and Neidell (2005) by using more accurate measures of pollution exposure, controlling for mother fixed effects, and investigating the interaction between air pollution, smoking and other risk factors.

DATA

- data on pollution comes from stationary air quality monitors.
- unfortunately, many monitors measure only one pollutant. Hence, we estimate the impact of each pollutant separately.
- For the pollutants of interest, the daily measures we use are the 8-hour maximums of CO, O3 and the 24-hour average of PM10. These measures are averaged up to the weekly or the trimester level.
- Weather data come from the National Climatic Data Center and is measured at the county level.
- Data on infant births and deaths come from the New Jersey Department of Health birth and infant death files for 1989 to 2004. Vital Statistics records cover all births and deaths. Publicly available birth records have detailed information about health at birth and a good deal of background information about the mother (such as race, education, and marital status).

- We were able to travel to Trenton New Jersey in order to use a confidential version of the data with the mother's address, name, and birth date.
- The use of this data allowed us to match mothers to pollution monitors, and also to identify siblings born to the same mother.
- Births were linked to the air pollution measures taken from the closest monitor. It was also possible to link birth and death records so as to identify infants who died in the first year of life.

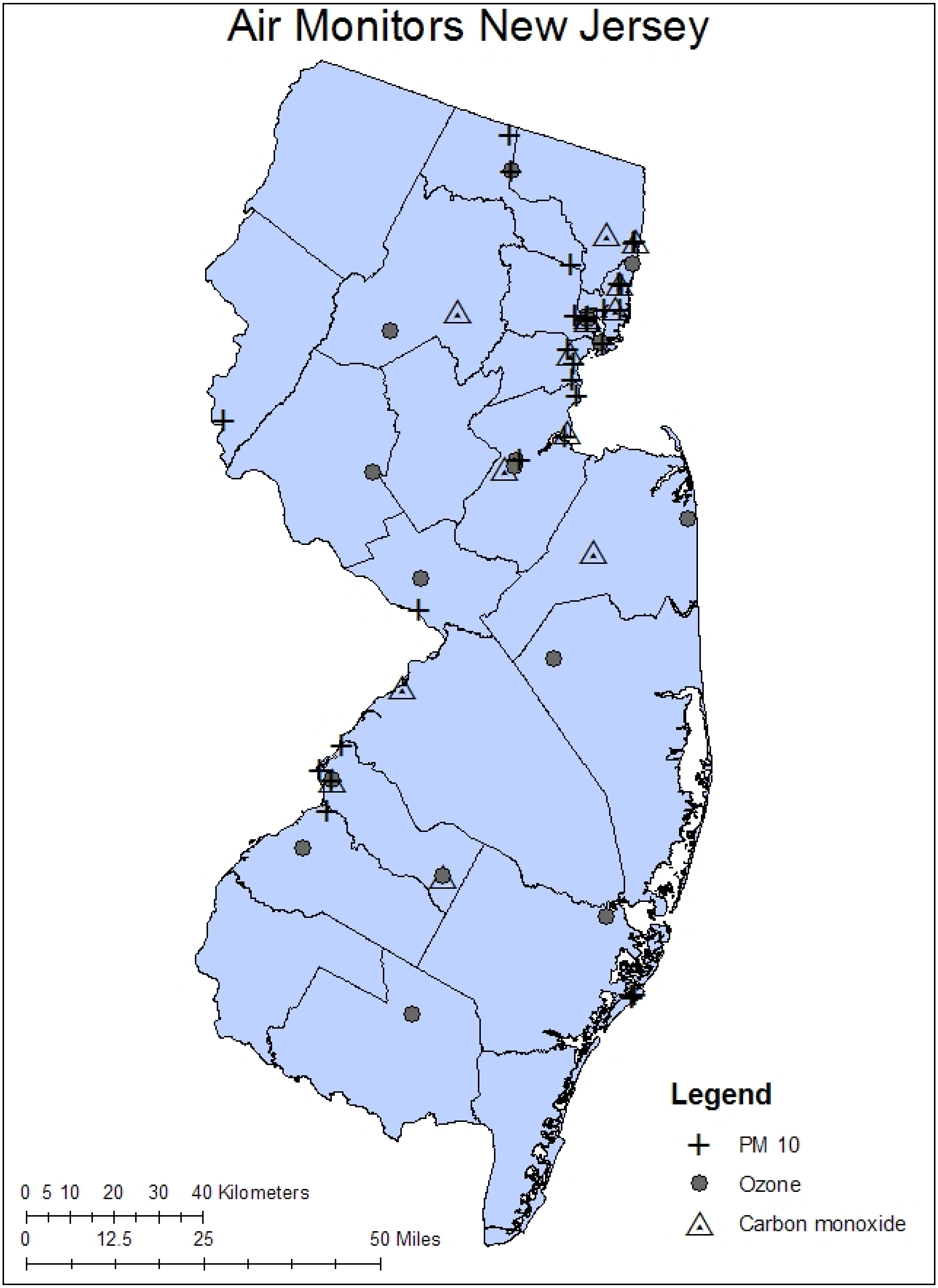

Air Monitors New Jersey
Legend
PM 10
Ozone
Carbon monoxide
0 5 10 20 30 40 Kilometers
0 12.5 25 50 Miles

Table 1: Sample Means

	[1]	[2]	[3]	[4]	[5]
	All	<10km monitor	<10km monitor & smoking	like (2) but >=1 sibling	like (3) but >=1 sibling
Number of observations	1511180	629953	62068	283882	21116
Panel A: Outcomes					
Birth weight in Grams	3319.7	3267.37	3054.71	3236.51	2937.58
	[615.58]	[650.54]	[656.04]	[660.54]	[682.10]
Infant death	0.0069	0.0077	0.0099	0.0086	0.0128
Gestation	38.83	38.71	38.28	38.55	37.84
	[2.30]	[2.47]	[2.89]	[2.64]	[3.21]
Low birth weight	0.076	0.088	0.157	0.106	0.210
Panel B: Pollution Measures 1-3 Months Before Birth					
Ozone (8 hour moving average in .01 ppm)		3.60	3.61	3.60	3.57
		[1.49]	[1.52]	[1.50]	[1.52]
CO (8 hour moving average in ppm)		1.64	1.55	1.60	1.51
		[0.79]	[0.77]	[0.76]	[0.73]
PM10 (24 hour moving average in 10 ug/m3)		2.99	2.99	2.97	3.01
		[0.74]	[0.74]	[0.74]	[0.75]

Table 1: Sample Means	[1]	[2]	[3]	[4]	[5]
	All	<10km monitor	<10km monitor & smoking	like (2) but >=1 sibling	like (3) but >=1 sibling
Number of observations	1511180	629953	62068	283882	21116
Panel C: Control Variables					
Mother Age in Years	29.23	28.25	27.44	27.75	26.92
	[6.00]	[6.16]	[5.99]	[6.00]	[5.65]
Mother African American	0.19	0.30	0.41	0.35	0.54
Mother Hispanic	0.18	0.23	0.14	0.20	0.10
Mother Years of Education	13.28	12.79	11.77	12.74	11.46
	[2.64]	[2.68]	[1.95]	[2.57]	[1.84]
Multiple Birth	0.032	0.029	0.026	0.060	0.069
Mother married	0.72	0.61	0.36	0.59	0.29
Birth parity	1.98	2.00	2.46	2.44	3.33
	[1.15]	[1.19]	[1.61]	[1.29]	[1.86]
Child Male	0.51	0.51	0.51	0.51	0.51
Mother smoking	0.09	0.10	1.00	0.12	1.00
Number of cigarettes per day	1.01	1.03	10.06	1.16	10.35
	[3.90]	[3.91]	[7.62]	[4.10]	[7.57]
Median family income census	4.66	4.05	3.53	3.97	3.25
tract 1989 ($10,000)	[1.77]	[1.59]	[1.38]	[1.62]	[1.31]
Fraction poor in census tract 1989	0.09	0.13	0.17	0.14	0.20
	[0.10]	[0.13]	[0.14]	[0.13]	[0.14]
Mean precipitation in previous	13.02	13.05	13.11	12.98	13.03

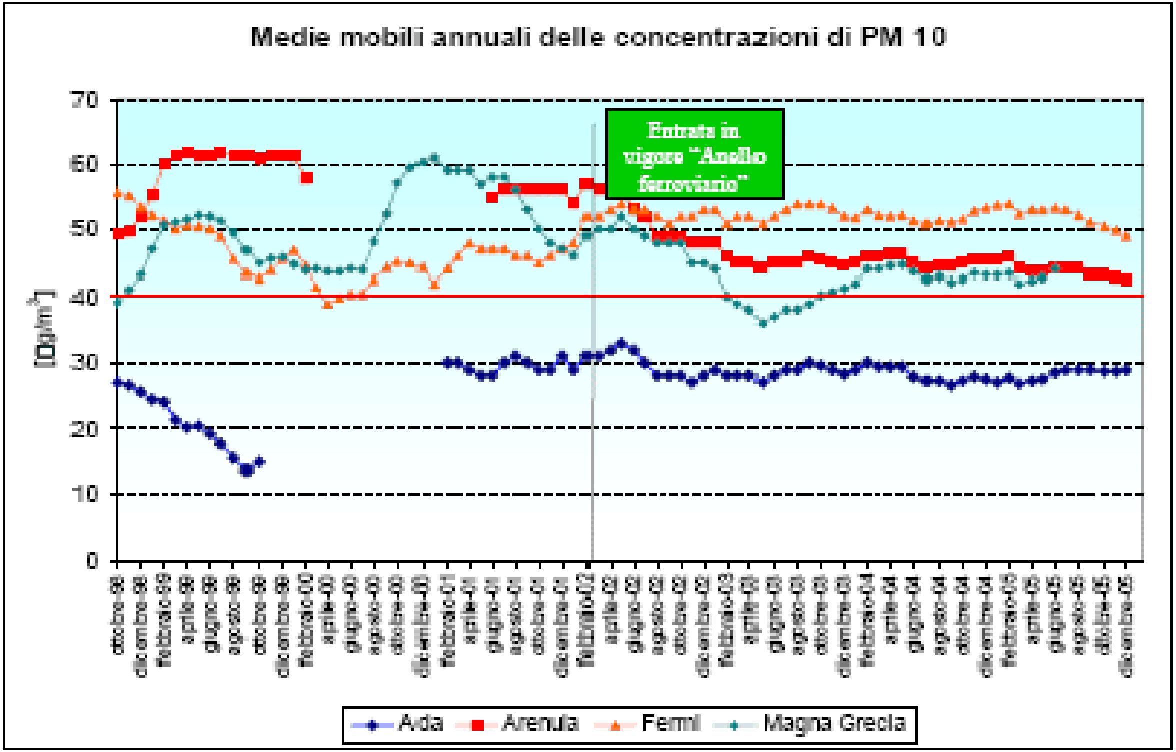
90 days	[4.21]	[4.15]	[4.16]	[4.08]	[4.07]
Mean of daily max temperature	63.69	64.09	64.42	64.10	64.67
previous 90 days	[14.65]	[14.74]	[14.70]	[14.74]	[14.74]
Mean of daily min temperature	21.33	22.04	22.25	21.87	22.43
previous 90 days	[15.19]	[15.16]	[15.11]	[15.18]	[15.12]

Notes: Standard deviations in brackets.

Comparison of Pollution in Beijing and New Jersey

Pollutant	US Standard	NJ-mean 3 mo. before birth	Beijing annual avg. 2006
Ozone	.08ppm	.036ppm	*
CO	13.05 ug/m3	2.38 ug/m3	2.1 ug/m3
PM10	150 ug/m3	29.9 ug/m3	161 ug/m3

- The Beijing monitoring system does not track Ozone, though some studies find levels 5 times above the WHO standard.
- Investments in cleaner air over in Beijing over the past 7 years total 120 billion yuan.
- There have been significant drops in SO_2 and NO_2.



Medie mobili annuali delle concentrazioni di PM 10
70
60
50
40
30
20
10
0
Entrata in vigore "Anello ferroviario"
Aida
Arenula
Fermi
Magna Grecia

METHODS

Air pollution may have different effects before and after birth. Hence, our analysis proceeds in two parts:

In order to examine the effect of pollution on health at birth, we restrict the sample to women who lived within 10 kilometers of a monitor and estimate baseline models of the following form:

(1) $O_{ijmt} = P_{mt}\,\beta_1 + w_m\beta_2 + x_{ijmt}\beta_3 + Y_t + \varepsilon_{ijmt},$

where O is an outcome and i = the individual, j = the mother, m = the nearest monitor, and t = time periods. P_{mt} = average pollution measures in the 1st, 2nd, & 3rd trimesters of pregnancy from the closest monitor. w_m = average, minimum and maximum temperature and precipitation measures over each trimester of the pregnancy. The vector Y_t includes dummy variables for the month of the year and for the year.

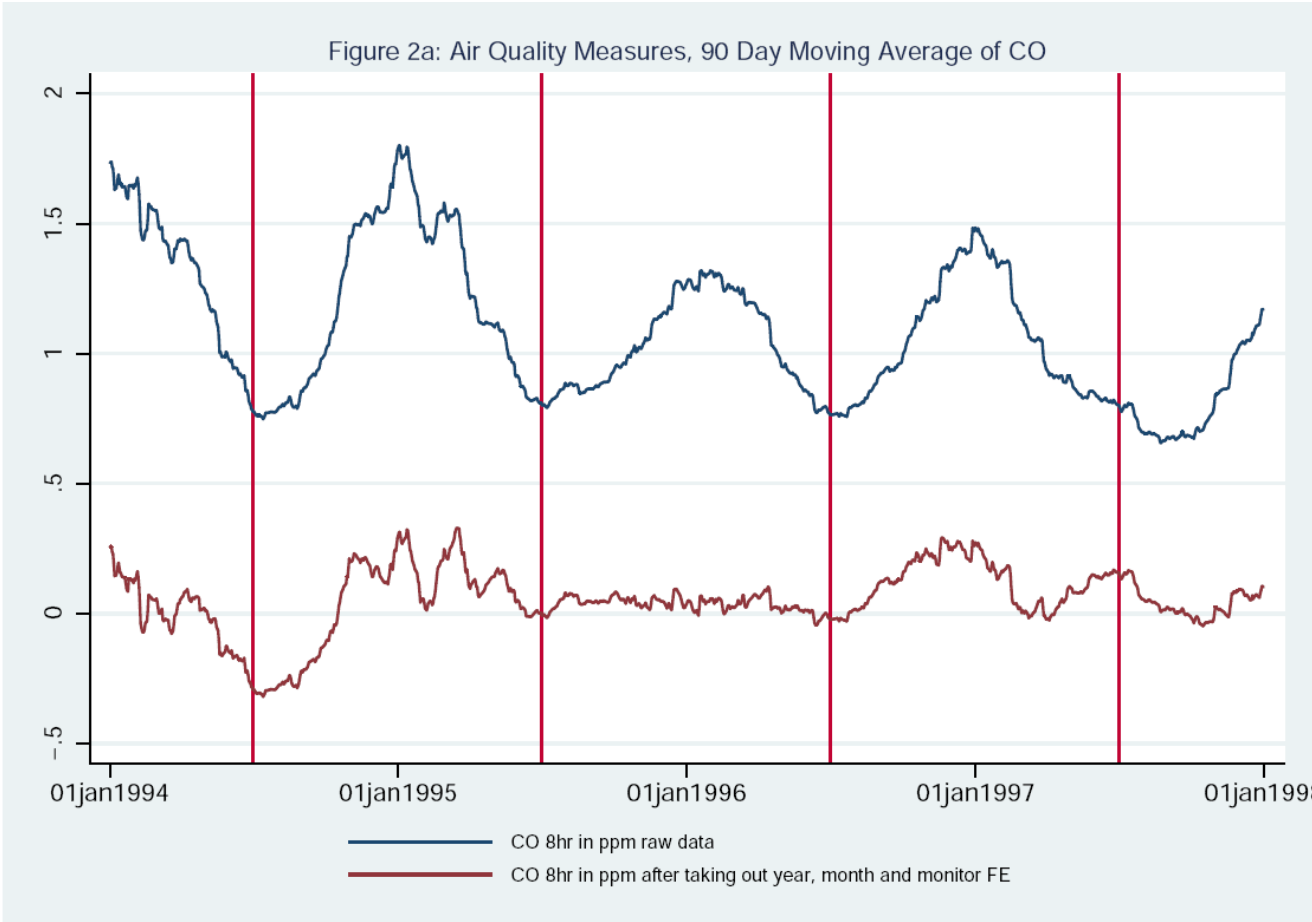


Figure 2a: Air Quality Measures, 90 Day Moving Average of CO
2
1.5
1
.5
0
−.5
01jan1994
01jan1995
01jan1996
01jan1997
01jan1998
CO 8hr in ppm raw data
CO 8hr in ppm after taking out year, month and monitor FE

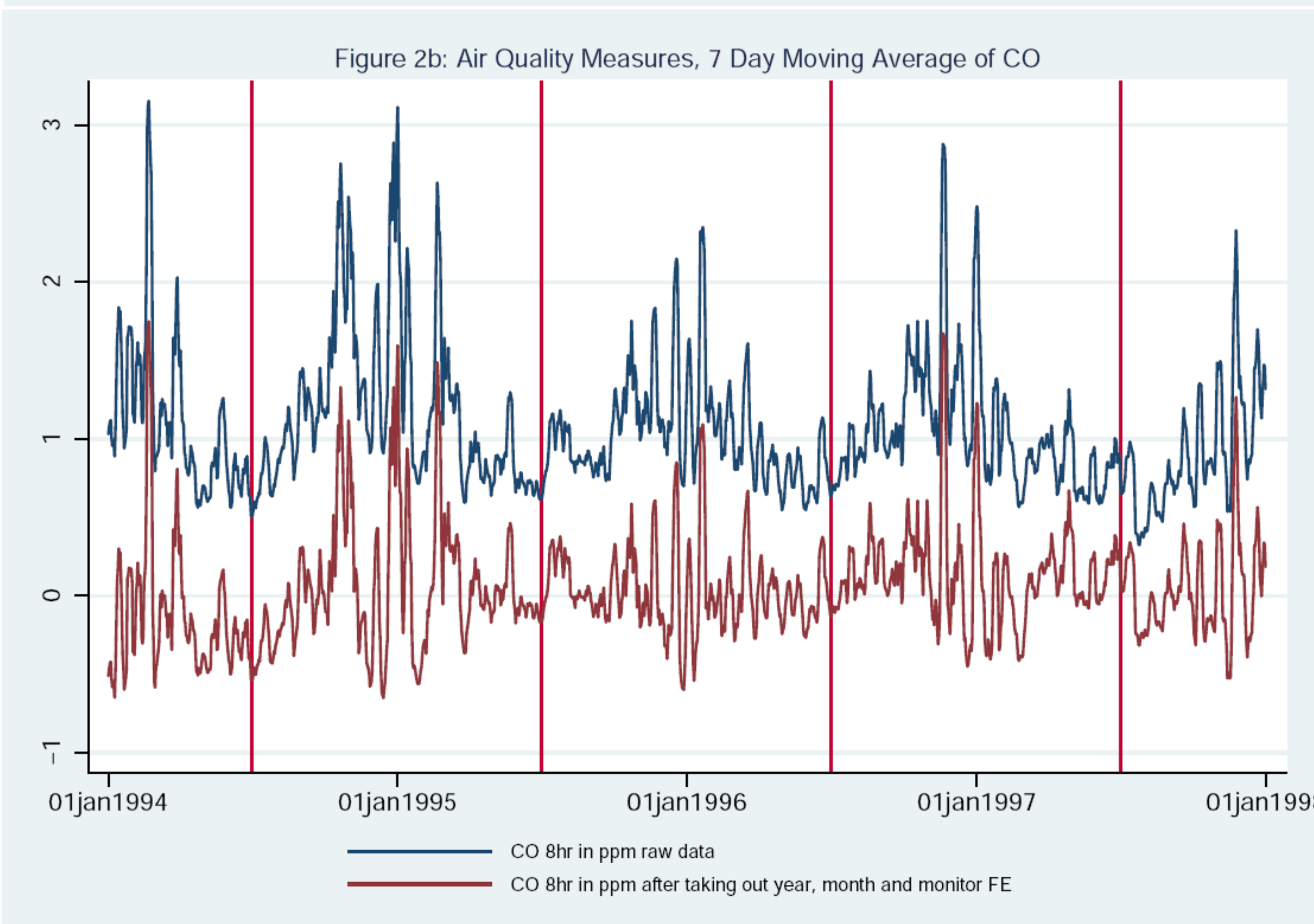


Figure 2b: Air Quality Measures, 7 Day Moving Average of CO
3
2
1
0
−1
01jan1994
01jan1995
01jan1996
01jan1997
01jan1998
CO 8hr in ppm raw data
CO 8hr in ppm after taking out year, month and monitor FE

Figure 3a: Air Quality Measures, 90 Day Moving Average of OZ

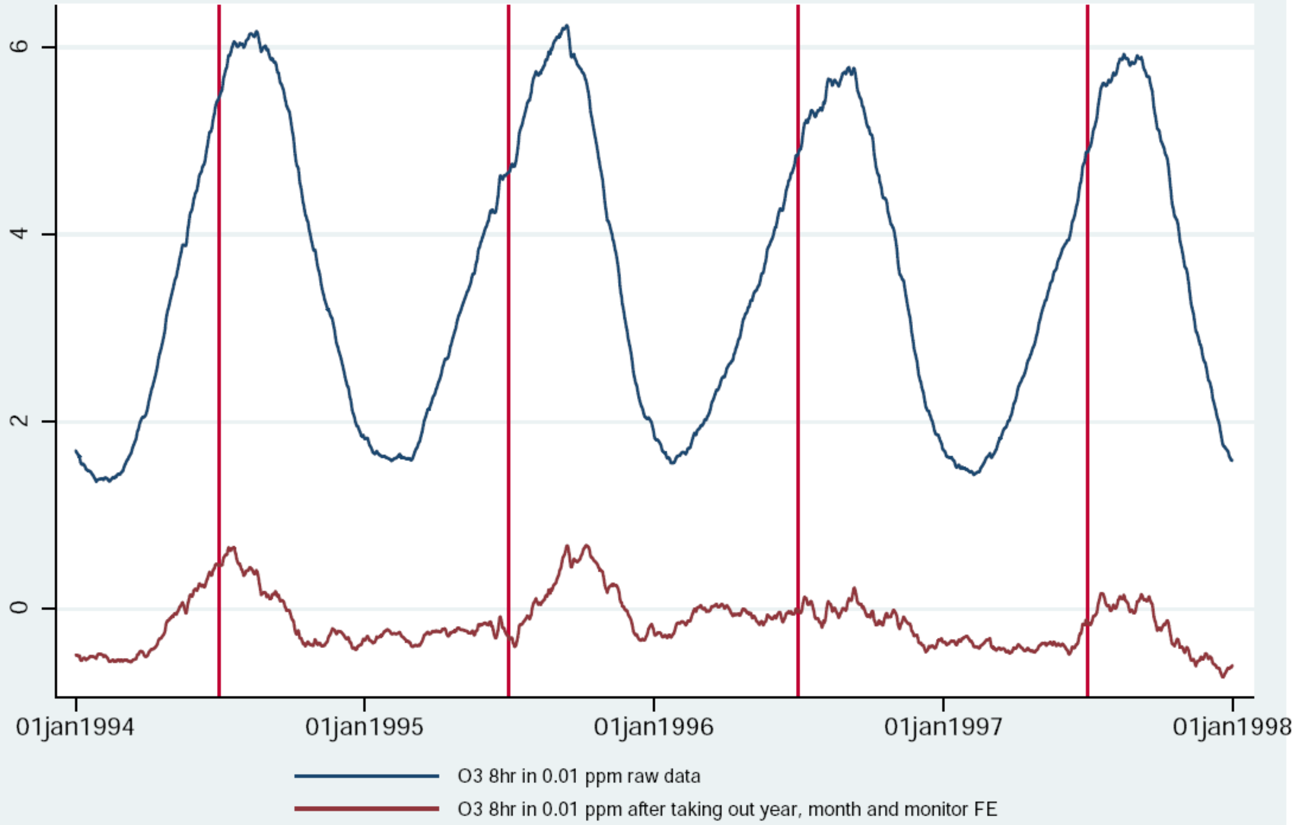
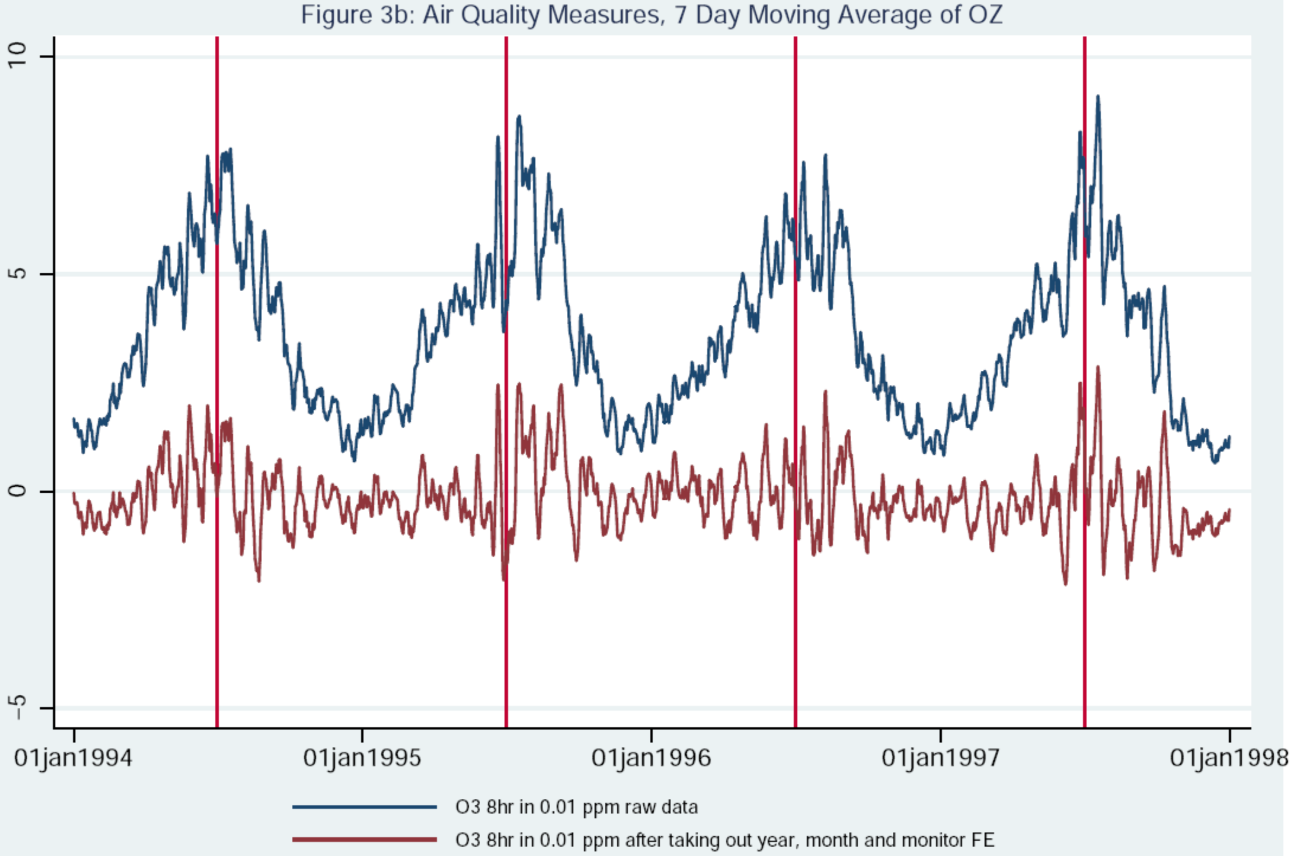


Figure 3b: Air Quality Measures, 7 Day Moving Average of OZ



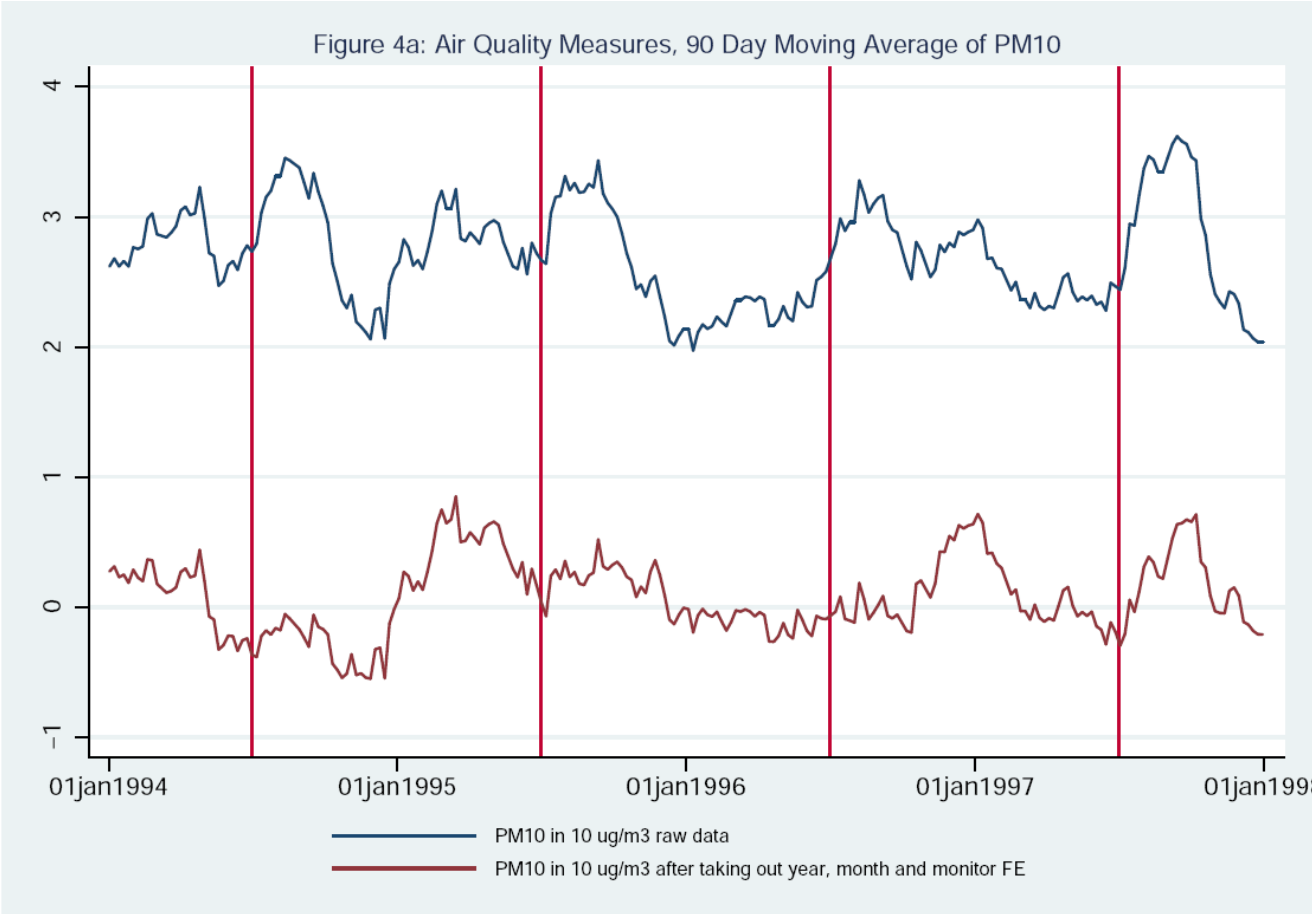


Figure 4a: Air Quality Measures, 90 Day Moving Average of PM10
4
3
2
1
0
−1
01jan1994
01jan1995
01jan1996
01jan1997
01jan1998
PM10 in 10 ug/m3 raw data
PM10 in 10 ug/m3 after taking out year, month and monitor FE

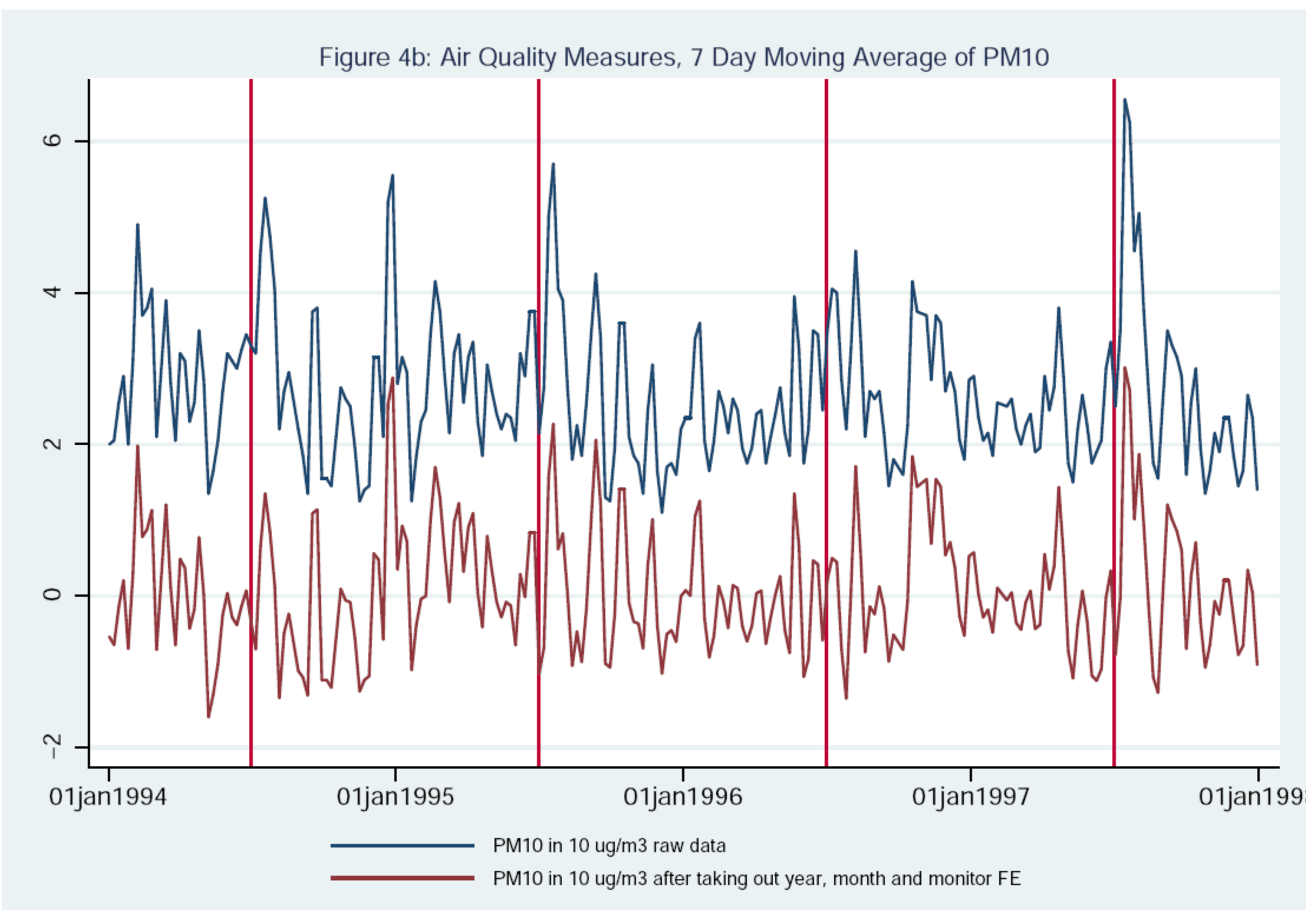


Figure 4b: Air Quality Measures, 7 Day Moving Average of PM10
6
4
2
0
−2
01jan1994
01jan1995
01jan1996
01jan1997
01jan1998
PM10 in 10 ug/m3 raw data
PM10 in 10 ug/m3 after taking out year, month and monitor FE

x_{ijmt} includes mother and child specific characteristics taken from the birth certificate.

These characteristics include:
- dummy variables for the mother's age (19-24, 25-34, 35+),
- education indicators (12, 13-15, or 16+ years),
- an indicator for whether it is a multiple birth,
- controls for birth order (2^{nd}, 3^{rd}, 4^{th} or higher),
- indicators for whether the mother is married,
- whether the child is male,
- whether the mother is African-American, Hispanic, and other or unknown race,
- an indicator for whether the mother smokes, and the number of cigarettes if she smokes.
- median family income in the Census block group.

In order to control for omitted characteristics of neighborhoods and for differential seasonal effects in these characteristics (for example, beach towns experience much less economic activity in winter than in summer), we estimate models of the form:

$$(2)\quad O_{ijmt} = P_{mt}\,\beta_1 + w_m\beta_2 + x_{ijmt}\beta_3 + Y_t + \varphi_{mt*}Y_t + \varepsilon_{ijmt},$$

where now φ_{mt} is a fixed effect for the closest air pollution monitor and $\varphi_{mt*}Y_t$ is an interaction between the monitor effect and the quarter of calendar time. In this specification, we compare the outcomes of children who live in close proximity to each other to capture average neighborhood amenities to the extent they are similar within a fixed distance from the monitor.

Finally, we estimate:

(3) $O_{ijmt} = P_{mt}\,\beta_1 + w_m\beta_2 \; + x_{ijmt}\beta_3 + \; Y_t + \varphi_{mt*}Y_{t.} + \zeta_j + \varepsilon_{ijmt}$,

where ζ_i is a mother-specific fixed effect. These models control both for characteristics of neighborhoods near monitors, and for omitted characteristics of mothers.

In (3) the effect of pollution is identified from variation in pollution levels across siblings with the same mother. Much of this variation is driven by changes in pollution levels over time and within the year. Air quality improvements over time are largely due to air quality regulations, and variation within the year (after controlling for seasonal effects and weather) are largely due to unpredictable variations in human activity. For the most part, the identification of pollution in our study stems from the birth spacing of siblings, which is unlikely to be related to air quality regulations or short term variations in pollution levels.

To examine infant mortality conditional on health at birth, we estimate a hazard model with time-varying covariates to account for a varying probability of survival and levels of pollution over the infants' first year of life.

To do this, we treat an infant who lived for n weeks as if they contributed n person-week observations to the sample. The dependent variable is coded as 1 in the period the infant dies, and 0 in all other periods. Each time-invariant covariate (such as birth parity) is repeated for every period, while the time-varying covariates (such as pollution and weather) are updated each period.

We then estimate a model in which the probability of death D_{izt} is specified as:

(4) $D_{imt} = \alpha(t) + P_{mt}\,\beta_1 + w_m\beta_2 + x_{imt}\beta_3 + O_{imt}\beta_4 + Y_t + \varphi_{mt*}Y_{t.} + \zeta_i$,

where $\alpha(t)$ is a measure of duration dependence and is specified as a linear spline in the weeks since the infant's birth, with breaks after 1, 2, 4, 8, 12, 20, and 32 weeks. These break points were chosen to capture the shape of the actual empirical hazard.

Because infant death might be affected by pollution before birth as well as by pollution after birth, we add birth weight as a measure of infant health outcomes at birth (O_{imt}) to the list of independent variables. To the extent that birth weight is a sufficient statistic for health at birth, β_1 from equation (4) will capture the effect of pollution after birth conditional on health at birth.

This model can be thought of as a flexible, discrete-time, hazard model that allows for time-varying covariates, non-parametric duration dependence, monitor-specific time trends and mother fixed effects. Allison [1982] shows that estimates from models of this type converge to those obtained from continuous time models.

This procedure yields a very large number of observations since most infants survive all 52 weeks of their first year. In order to reduce the number of observations, we focus on mothers who lost at least one child. These families may have other characteristics (besides pollution exposure) that lead to a higher risk of infant death. But in the mother fixed effects specification that we wish to focus on, families with no deaths will not tell us anything about the effect of pollution on deaths in any case.

Table 2: Effects of Air Pollution on Health at Birth - All Mothers < 10 km from a Monitor

Models of Birth Weight

	CO	CO	CO	Ozone	Ozone	Ozone	PM10	PM10	PM10
Mean pollutant 1-3 months	-12.73	-14.98	-18.07	7.003	-2.667	-3.701	-1.364	0.149	-2.979
before birth	[5.393]*	[6.505]*	[6.690]*	[2.828]*	[3.938]	[3.966]	[2.499]	[2.960]	[3.016]
Mean pollutant 4-6 months	10.90	-0.990	4.912	0.685	-2.417	-8.455	-3.799	-0.986	-2.090
before birth	[6.453]	[7.236]	[7.396]	[3.329]	[4.039]	[4.138]*	[2.487]	[3.095]	[3.131]
Mean pollutant 7-9 months	-0.701	-5.431	-5.664	4.827	2.013	-3.757	-4.249	-0.821	-2.846
before birth	[5.180]	[6.273]	[6.429]	[2.879]	[3.833]	[3.933]	[2.439]	[2.919]	[2.936]
Observations	301577	301577	301577	257502	257502	257502	272933	272933	272933

Models of Low Birth Weight (Coefficients and standard errors multiplied by 100)

	CO	CO	CO	Ozone	Ozone	Ozone	PM10	PM10	PM10
Mean pollutant 1-3 months	0.512	0.710	0.832	-0.396	-0.112	0.121	0.0616	-0.00717	0.0715
before birth	[0.253]*	[0.307]*	[0.359]*	[0.137]*	[0.192]	[0.217]	[0.120]	[0.144]	[0.163]
Mean pollutant 4-6 months	-0.385	-0.181	-0.374	-0.116	-0.0998	-0.0737	0.0874	0.104	0.0785
before birth	[0.303]	[0.341]	[0.397]	[0.162]	[0.198]	[0.226]	[0.120]	[0.149]	[0.169]
Mean pollutant 7-9 months	-0.0306	0.0853	0.519	-0.0291	0.206	0.389	0.164	0.150	0.390
before birth	[0.243]	[0.298]	[0.345]	[0.138]	[0.186]	[0.215]	[0.116]	[0.139]	[0.159]*
Observations	302012	302012	302012	257920	257920	257920	273420	273420	273420

Models of Gestation (Coefficients and standard errors multiplied by 100)

	CO	CO	CO	Ozone	Ozone	Ozone	PM10	PM10	PM10
Mean pollutant 1-3 months	-4.377	-5.409	-7.737	3.159	-1.224	-0.531	2.044	3.431	1.956
before birth	[2.292]	[2.776]	[3.012]*	[1.224]*	[1.726]	[1.814]	[1.066]	[1.268]*	[1.375]
Mean pollutant 4-6 months	3.188	-0.237	3.990	0.427	-3.279	-3.713	-2.534	-0.808	-1.523
before birth	[2.737]	[3.085]	[3.331]	[1.454]	[1.760]	[1.893]*	[1.069]*	[1.344]	[1.428]
Mean pollutant 7-9 months	0.270	-0.721	-3.778	4.237	0.884	-1.440	-1.944	0.596	-0.521
before birth	[2.182]	[2.669]	[2.894]	[1.239]*	[1.649]	[1.801]	[1.051]	[1.268]	[1.339]
Observations	297079	297079	297079	253664	253664	253664	267701	267701	267701

The estimates in Table 2 suggest that a one unit increase in the mean level of CO during the last trimester (where the mean is 1.64 and a standard deviation is .79) would reduce average birth weight by 18.07 grams on a base of 3,267 grams, a reduction of about a half a percent.

The proportional effects are greater for low birth weight where a one unit change in mean CO would lead to an increase in low birth weight of .0083 on a base of .088. This is a nine percent increase in the incidence of low birth weight.

Finally, a one unit change in mean CO is estimated to reduce gestation by .08 weeks on a mean of 38.71 weeks for a reduction in mean gestation of .2 percent.

Table 3: Effects of Smoking on Health at Birth - All Smoking Mothers < 10 km from a Monitor. Coefficients from models that included CO

Models of Birth Weight	**[1]**	**[2]**	**[3]**
Mother smokes	-165.4	-165.0	-42.57
	[6.515]*	[6.513]*	[6.645]*
# Cigarettes per day	-4.907	-4.939	-2.159
	[0.492]*	[0.492]*	[0.481]*
# Observations	301577	301577	301577
Models of Low Birth Weight (Coefficients and standard errors multiplied by 100)			
Mother smokes	4.949	4.916	0.714
	[0.357]*	[0.357]*	[0.357]*
# Cigarettes per day	0.191	0.190	0.126
	[0.0282]*	[0.0282]*	[0.0259]*
# Observations	302012	302012	302012
Models of Gestation (Coefficients and standard errors multiplied by 100)			
Mother smokes	-32.25	-31.78	-2.842
	[2.911]*	[2.908]*	[2.998]
# Cigarettes per day	-1.144	-1.150	-0.604
	[0.224]*	[0.224]*	[0.218]*
# Observations	297079	297079	297079
Monitor * Quarter Fixed Effects	no	yes	yes
Mother Fixed Effects	no	no	yes

Compare to the effects of smoking: Table 3 shows that smoking has extremely negative effects on infant health in models that do not include maternal fixed effects. For example, being a smoker is reduces birth weight by 152.5 grams in models that include monitor fixed effects, and each additional cigarette smoked reduces birth weight by 4.9 grams, for a total reduction of approximately 200 grams at the mean of 10 cigarettes per day.

Including mother fixed effects controls for unobserved characteristics of the mother. In these models, being a smoker is estimated to reduce birth weight by 42.6 grams, and each cigarette reduces it a further 2.2 grams for a total reduction of about 65 grams in infants of women who smoke 10 cigarettes per day.

Hence it would take a roughly 3.5 unit change in mean CO levels to be equivalent to having a woman start smoking 10 cigarettes per day in terms of its effects on average birth weight.

Similarly, the effect of smoking 10 cigarettes per day is roughly twice as large as the impact of a one unit change in mean CO in terms of the effect on the incidence of low birth weight.

Table 4: Effects of Air Pollution on Health at Birth - All Smoking Mothers<10 km from a Monitor

Models of Birth Weight	**CO**	**Ozone**	**PM10**
Mean pollutant 1-3 months	-39.10	-19.29	-24.41
before birth	[27.94]	[14.34]	[11.71]*
Mean pollutant 4-6 months	10.43	-32.43	-36.43
before birth	[31.29]	[15.29]*	[12.13]*
Mean pollutant 7-9 months	0.237	-15.41	3.437
before birth	[27.38]	[14.67]	[11.67]
Observations	20439	20467	20044
Models of Low Birth Weight (Coefficients and standard errors multiplied by 100)			
Mean pollutant 1-3 months	4.401	-0.255	0.429
before birth	[1.959]*	[1.005]	[0.825]
Mean pollutant 4-6 months	-4.282	1.641	1.775
before birth	[2.192]	[1.072]	[0.855]*
Mean pollutant 7-9 months	0.854	1.838	1.635
before birth	[1.918]	[1.028]	[0.822]*
Observations	20469	20504	20086
Models of Gestation (Coefficients and standard errors multiplied by 100)			
Mean pollutant 1-3 months	-42.77	-11.83	-3.211
before birth	[15.26]*	[7.748]	[6.404]
Mean pollutant 4-6 months	20.25	-18.38	-14.75
before birth	[17.09]	[8.248]*	[6.624]*
Mean pollutant 7-9 months	-14.40	-15.21	-8.280
before birth	[14.91]	[7.932]	[6.377]

Effects on smokers:

Point estimates in Table 4 > than those in Table 2, and suggest that a broader array of pollutants are harmful to the infants of smokers.

In the model for birth weight, the point estimate of -39.1 on CO in the model with mother fixed effects is twice as large as the Table 2 coefficient. Similarly, the coefficients are .04 vs. .008 for low birth weight and -.43 vs. -.07 for gestation.

Suggests that the harmful effects of a one unit increase in CO are 2-4x greater for smoking mothers than for non-smoking mothers, depending on the outcome.

Compare estimated effects of a 1 unit change in CO and smoking 10 cigarettes per day on birth weight in ounces.

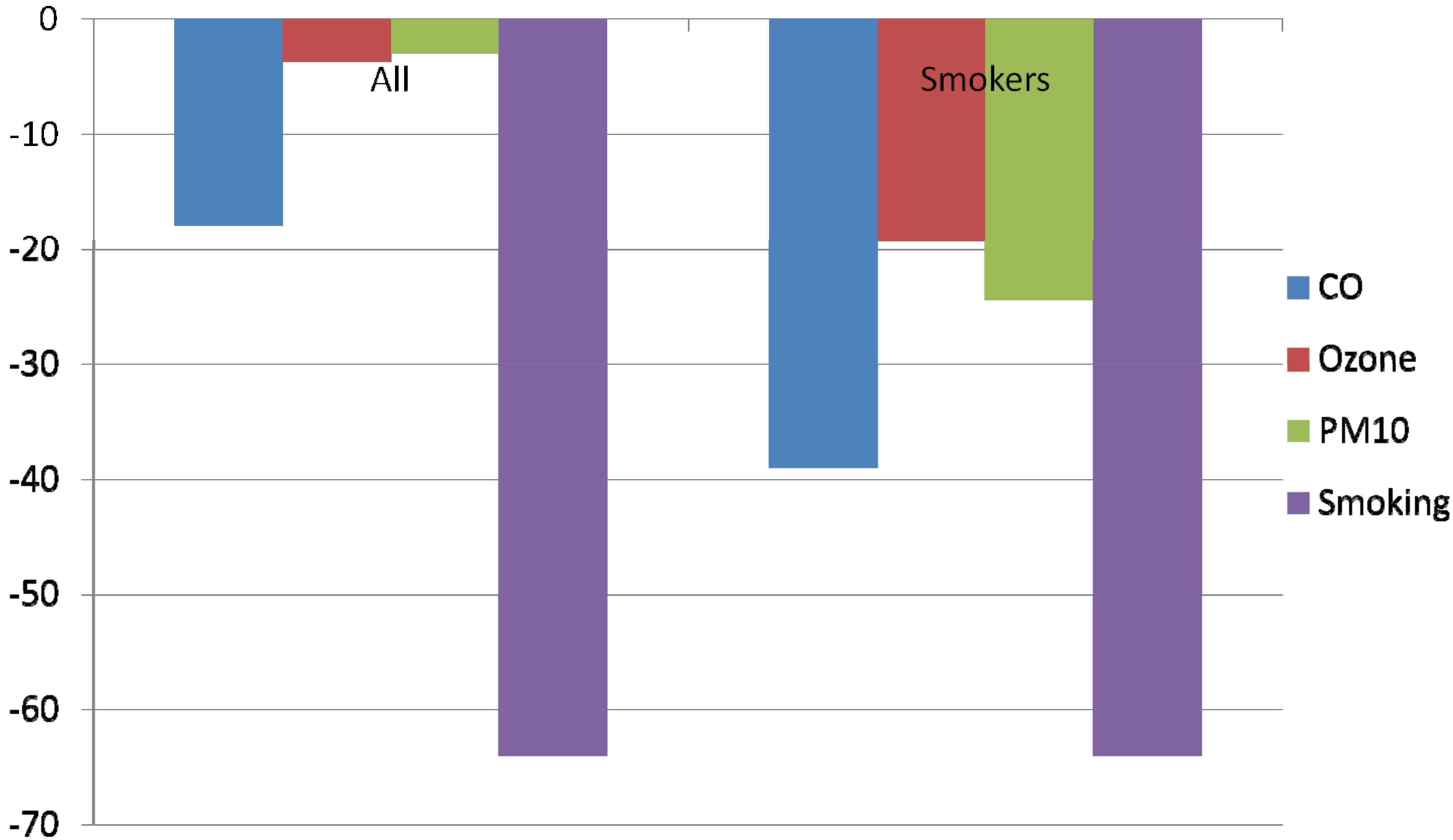


Table 5: Effects of CO on Health at Birth - Mothers from Vulnerable Groups
< 10 km From a Monitor - Models with Mother Fixed Effects

	All	<age 19	>= age 35	Risk factors for the preg.	Black	<12 yrs ed.	Income <30,000
Models of Birth Weight							
Mean CO 1-3 months	-18.07	-31.50	-75.14	-19.78	-22.96	-26.93	-38.54
before birth	[6.690]*	[63.76]	[29.09]*	[22.32]	[14.17]	[17.76]	[16.50]*
Mean CO 4-6 months	4.912	-81.10	22.94	21.62	10.50	6.670	13.08
before birth	[7.396]	[66.60]	[31.36]	[25.20]	[15.80]	[19.83]	[18.29]
Mean CO 7-9 months	-5.664	89.44	-24.77	-32.40	-12.21	0.703	-23.58
before birth	[6.429]	[59.05]	[27.24]	[21.99]	[13.74]	[17.10]	[15.87]
Observations	301577	5283	20798	48845	91003	44734	58878
Models of Low Birth Weight (Coefficients and standard errors multiplied by 100)							
Mean CO 1-3 months	0.832	1.624	3.400	2.289	1.608	2.570	1.238
before birth	[0.359]*	[4.113]	[1.636]*	[1.353]	[0.824]	[1.075]*	[0.983]
Mean CO 4-6 months	-0.374	3.500	-2.656	-2.157	-0.706	-1.960	-0.967
before birth	[0.397]	[4.295]	[1.764]	[1.528]	[0.919]	[1.200]	[1.090]
Mean CO 7-9 months	0.519	-4.665	2.501	0.945	0.424	0.652	1.666
before birth	[0.345]	[3.807]	[1.532]	[1.333]	[0.799]	[1.035]	[0.946]
Observations	302012	5287	20847	48898	91103	44781	58956
Models of Gestation (Coefficients and standard errors multiplied by 100)							
Mean CO 1-3 months	-7.737	-20.41	-31.67	-13.81	-16.48	-14.22	-9.676
before birth	[3.012]*	[34.39]	[12.04]*	[10.45]	[7.039]*	[8.650]	[8.211]
Mean CO 4-6 months	3.990	-76.52	21.26	14.70	4.918	10.72	5.611
before birth	[3.331]	[35.86]*	[13.00]	[11.78]	[7.848]	[9.649]	[9.102]
Mean CO 7-9 months	-3.778	57.08	-25.00	-13.32	-8.009	-4.240	-13.29
before birth	[2.894]	[31.72]	[11.39]*	[10.27]	[6.822]	[8.316]	[7.899]
Observations	297079	5179	20508	48483	90043	44291	58267

Notes: See Table 2.

Table 5 shows the effects of CO for other subsets of mothers who may be vulnerable to poor birth outcomes.

The point estimates are generally larger for these disadvantaged mothers relative to those for all mothers, but the standard errors are also larger.

However, we do find consistent evidence that children of older mothers are more susceptible to the effects of pollution across all three outcome measures. Along with the results for smokers, these estimates suggest that infants who are at risk for other biological reasons are also at higher risk from pollution.

Table 6: Effects of Air Pollution after Birth on the Probability of Infant Death
All Mothers < 10 km from a Monitor (Coefficients and standard errors multiplied by 100)

	CO	**Ozone**	**PM10**
Mean pollutant if 0 <= week <2	107.0	8.407	-11.13
	[37.60]*	[18.61]	[25.19]
Mean pollutant if 2 <= week <4	-22.29	4.154	-7.886
	[15.79]	[9.075]	[10.72]
Mean pollutant if 4 <= week <6	14.65	9.014	8.583
	[10.89]	[5.464]	[5.908]
Mean pollutant if 6 <= week	-5.993	2.752	-0.244
	[5.877]	[3.426]	[1.845]
Week after birth	-1720.0	-1713.1	-1775.6
	[54.89]*	[58.24]*	[63.82]*
Week after birth-1 * Indicator	1838.9	1654.5	1673.7
for week >= 1	[100.4]*	[110.8]*	[121.5]*
Week after birth-2 * Indicator	-199.8	5.859	13.92
for week >= 2	[86.22]*	[97.58]	[108.5]
Week after birth-4 * Indicator	78.48	44.53	83.77
for week >= 4	[24.09]*	[26.96]	[30.36]*
Week after birth-8 * Indicator	1.073	8.407	6.223
for week >= 8	[7.483]	[8.050]	[8.991]
Week after birth-12 *	-2.018	-4.844	-5.716
Indicator for week >= 12	[4.375]	[4.852]	[5.508]
Week after birth-20 *	1.146	2.931	0.810
Indicator for week >= 20	[1.552]	[1.696]	[2.074]
Week after birth-32 *	1.883	1.274	2.689
Indicator for week >= 32	[0.625]*	[0.672]	[0.827]*
Observations	188690	161758	130251
Number of Births	5735	5017	4490
Number of Deaths	2285	2010	1840
Number of Mothers	2207	1938	1778

In Table 6, the coefficient on CO implies that a one unit increase in CO in the previous week would increase the risk of death by 1 percentage point..

Recall, this subsample includes only children who died and their siblings, so the base risk of death is about 40% (2285 deaths divided by 5735 births). Hence, our estimate implies that a one unit increase in CO in the previous week increases the risk of death by about 2.5%.

We do not show separate estimates of the effect of pollution on deaths among infants of smokers, because restricting the sample to smokers who had at least one death in the family results in very small sample sizes.

Table 7: Effects of Air Pollution on Health at Birth - All Mothers > 10 km and < 20 km from a Monitor

	CO	Ozone	PM10
Models of Birth Weight			
Mean pollutant 1-3 months	0.847	-5.760	-9.575
before birth	[7.958]	[3.757]	[4.307]*
Mean pollutant 4-6 months	-15.90	1.114	-3.166
before birth	[8.543]	[3.852]	[4.465]
Mean pollutant 7-9 months	-18.93	-2.414	-7.470
before birth	[7.823]*	[3.662]	[4.052]
Observations	221973	242833	120347
Models of Low Birth Weight (Coefficients and standard errors multiplied by 100)			
Mean pollutant 1-3 months	0.587	0.367	0.345
before birth	[0.400]	[0.190]	[0.219]
Mean pollutant 4-6 months	0.320	-0.102	0.0222
before birth	[0.430]	[0.194]	[0.227]
Mean pollutant 7-9 months	0.418	0.160	0.435
before birth	[0.393]	[0.185]	[0.206]*
Observations	222387	243269	120588
Models of Gestation (Coefficients and standard errors multiplied by 100)			
Mean pollutant 1-3 months	-1.811	-0.480	-1.740
before birth	[3.266]	[1.546]	[1.750]
Mean pollutant 4-6 months	-0.853	-0.462	-0.353
before birth	[3.509]	[1.587]	[1.814]
Mean pollutant 7-9 months	-1.888	1.120	-2.672
before birth	[3.212]	[1.509]	[1.647]
Observations	219806	239393	118971

Table 8: Effects of Air Pollution on Health at Birth - All Mothers < 10 km from a Monitor
Models control for both CO and O3

	Birth Weight	Low Birth Weight	Gestation
Mean CO 8hr 1 to 3 months	-22.58	1.028	-9.995
before birth in ppm	[7.397]*	[0.401]*	[3.363]*
Mean CO 8hr 4 to 6 months	8.456	-0.820	5.492
before birth in ppm	[8.110]	[0.439]	[3.687]
Mean CO 8hr 7 to 9 months	-5.771	0.864	-4.926
before birth in ppm	[7.024]	[0.380]*	[3.193]
Mean O3 8hr 1 to 3 months	-6.028	0.125	-3.616
before birth in 0.01 ppm	[3.693]	[0.200]	[1.678]*
Mean O3 8hr 4 to 6 months	0.441	-0.105	-1.837
before birth in 0.01 ppm	[4.131]	[0.224]	[1.877]
Mean O3 8hr 7 to 9 months	-5.149	0.291	-0.974
before birth in 0.01 ppm	[3.776]	[0.204]	[1.716]
Observations	264814	265214	260560

Notes: See Table 2. Coefficients and standard errors are multiplied by 100 in columns 2 and 3.
All models include mother fixed effects.

Specification Checks:

1. Show that it is important to have a relatively precise measure of pollution exposure. Measures taken further away than 10 km are not informative.
2. In models with both CO and Ozone, it is CO that is important, and the CO coefficients are not changed by the addition of Ozone.

DISCUSSION AND CONCLUSIONS

- CO has negative effects on infant health both before and after birth.

- This is a new finding – the focus has been on other pollutants such as particulates and ozone which appear to have less effect on infants, at least in the concentrations found in New Jersey.

- Infants of smokers and older mothers are at much higher risk.
- Since most CO emissions come from transportation sources, these findings are germane to the current debate over proposals to further tighten automobile emissions standards. For example, the state of California's most recent proposal to increase emissions standards has been blocked by the Environmental Protection Agency. The state is currently suing the federal government over the issue. At least 16 other states are set to implement California's regulations, should the state prevail.

- Some areas in our study saw a reduction in mean CO levels from 4 ppm to 1 ppm over our sample period.
- Our estimates suggest that this reduction had an effect equivalent to getting a woman smoking 10 cigarettes a day to quit. We also find some weaker evidence of significant effects of PM10 and ozone on health at birth, particularly among smokers.
- We further find that a one unit increase in mean CO levels in the first two weeks of life increases the probability of infant death by about 2.5 percent.
- Over our sample period, average levels of CO in New Jersey declined 1.4 ppm from 2.3 to .9 ppm. Our estimates imply that this decline led to about 388 fewer deaths, about double what Currie and Neidell found using cruder pollution measures (and no fixed effects) in CA.

Caveats and directions for future research:

It is likely that our estimates are under-estimates of the true pollution effects:

- monitor data is a crude proxy for individual exposures. Noisy data means that we are more likely to falsely accept a negative null than to find an effect when there isn't any.
- The biological literature gives little guidance about whether there are particular "critical periods" when exposure to pollution may matter more, which also makes measurement error likely and tends to bias effects towards zero.
- If vulnerable fetuses are more likely to be lost when pollution is high, then mean infant health will be higher, leading to an underestimate of pollution's effects.

– It is possible that more vulnerable groups are more likely to be affected by pollution because they are less likely to practice avoidance behavior (CO is odorless and colorless, but other components of auto exhaust are detectable). Avoidance will also cause an underestimate of pollution’s effects.