The 9/11 Dust Cloud and Pregnancy Outcomes

A Reconsideration

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ABSTRACT

The events of 9/11 released a million tons of toxic dust into lower Manhattan, an unparalleled environmental disaster. It is puzzling, then, that the literature has shown little effect of fetal exposure to the dust. However, inference is complicated by preexisting differences between the affected mothers and other NYC mothers as well as heterogeneity in effects on boys and girls. Using all births in-utero on 9/11 in NYC and comparing them to their siblings, we show that residence in the affected area increased prematurity and low birth weight, especially for boys.

I. Introduction

The collapse of the World Trade Center (WTC) in New York City following the terrorist attacks of Sept. 11, 2001, was the largest environmental disaster ever to have befallen a U.S. metropolis, releasing a million tons of toxic dust and smoke into the air of lower Manhattan (Landrigan et al. 2004; Lioy et al. 2002; Pleil et al. 2004). The levels of mutagenic and carcinogenic air pollutants measured in the aftermath of the WTC collapse are among the highest ever reported from outdoor sources (Pleil et al. 2004).

Many previous studies have found a relationship between air pollution during pregnancy and adverse birth outcomes (for example, Black et al. 2013; Currie, Neidell, and Schmeider 2009; Currie and Walker 2011; Currie 2011, Graff Zivin and Neidell 2013). It is therefore surprising that the broad 9/11 literature has so far shown little

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consistent evidence of effects of in-utero exposure to the dust cloud on birth outcomes. Perlman et al. (2011) review the existing literature and conclude that "proximity to the WTC site on or after 9/11 does not seem to have increased the risk for low birth weight (<2500 g) or preterm deliveries."

This study reexamines the effects of the 9/11 dust cloud on pregnancy outcomes, overcoming some of the empirical challenges that have complicated inference about its effects in previous studies. First, as we will show below, mothers living in the affected areas were different from other mothers even within lower Manhattan, and were more likely to have had positive birth outcomes other things being equal. We control for this source of possible confounding by following the same mothers over time.

Second, there are issues having to do with seasonality and low statistical power in the small convenience samples that typically have been used to examine the effects of 9/11. By using all births in the affected area and elsewhere in Manhattan, we can control for the effects of seasonality, and we have larger samples sizes, and thus more statistical power than most previous studies.

Third, the larger sample size also allows us to estimate effects separately for boys and girls. Such subgroup analysis might reveal important gender differences, as a literature on "fragile males" has found that male fetuses are more vulnerable to detrimental influences in-utero than female fetuses (Kraemer 2000; Eriksson et al. 2010; Almond and Mazumder 2011; Dinkelman 2013).

We find strong effects of residence in the area affected by the 9/11 dust cloud on gestation length, the incidence of premature birth (gestation length less than 37 weeks), birth weight, and on the incidence of low birth weight (birth weight less than 2,500 grams, hereafter LBW). The effects are driven by first trimester exposure and are—in line with the literature on "fragile males"—much stronger for boys than for girls. The estimates are robust to choosing a variety of alternative definitions of the treatment and control groups both in terms of location and timing. Among other specification checks, we exclude births after 9/11 (so that only births to mothers pregnant before and during 9/11 are included), and instrument for potentially endogenous migration between the dust and the no-dust area of NYC.

These findings provide the first consistent evidence that the 9/11 dust cloud had detrimental impacts on pregnancy outcomes. Moreover, our analysis shows that it is the male offspring of mothers exposed to the dust cloud who bear the major burden in terms of health effects, which reinforces the idea that a gender-specific analysis can be useful when assessing in-utero effects of pollution and other detrimental influences.

The paper proceeds as follows: Section II discusses background information about previous studies of pollution from 9/11 and the greater susceptibility of males to many types of health insults. Section III provides an overview of our data and methods. Section IV presents the results, and a discussion and conclusion follow in Section V.

II. Background

Figure 1 shows aerial photographs of the dust cloud that resulted from the collapse of the World Trade Center towers. This dust contained a wide range of toxicants and irritants, including pulverized cement, asbestos, glass fibers, lead, dioxins,

Panel A: Collapse Cloud World Trade Center Building 2 (Approximately 10 a.m.)

Panel B: Collapse Cloud World Trade Center Building 1 (Approximately 10:30 a.m.)

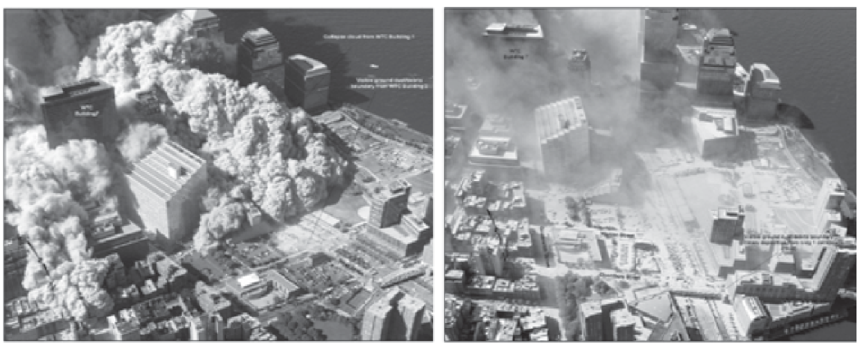


Figure 1
Aerial Photographs of the World Trade Center Collapse
Source: US Environmental Protection Agency (2005).

and polycyclic aromatic hydrocarbons (PAHs), some of which are known to be hazardous for fetal development, while the effects of many others are unknown (Pleil et al. 2004). PAHs have been identified as contributors to adverse birth outcomes in previous research. The PAH air concentrations in the days after the disaster were among the highest outdoor PAH concentrations ever reported (1.3 to 15 ng/m^3), comparable only to measurements from the Teplice coal-burning region in the Czech Republic. These initially high concentrations declined rapidly over the weeks following 9/11 (Pleil et al. 2004).

The collapse of the two towers created a zone of negative air pressure that pushed dust and smoke into the avenues surrounding the WTC site. (See Figure 1.) Since big buildings less densely covered the area north of the WTC, much of the heavy dust was pushed northward. At the same time wind was blowing from the west from the first hours to 18 hours after the collapse (Lioy et al. 2002). When the dust particles reached the open area around Warren Street, the wind started dominating the movement of the dust particles, moving them eastward. As a result of these two effects, the exposed areas include not only the area immediately adjacent to the WTC but also the areas north and east of the WTC. High levels of WTC pollutants were found in dust samples taken from Cherry and Market Streets close to the Manhattan Bridge (Lioy et al. 2002). Figure 2 shows the Neighborhood Tabulation Areas (NTAs)[1], the smallest regional areas our data identifies, which were at least partly exposed to the 9/11 dust cloud. These include Lower Manhattan, Battery Park City, SoHo, TriBeCa, Civic Center, Little Italy, Chinatown, and the Lower East Side.

Environmental exposure to the WTC dust cloud was associated with significant adverse effects on the health of adult community residents and emergency workers (Landrigan et al. 2004). The high alkalinity (pH 9.0–11.0) of WTC dust produced bronchial hyperreactivity, persistent cough, and increased risk of asthma. These health effects are in line with experimental tests that found that mice exposed to WTC dust showed short-lived pulmonary inflammations and persistent marked bronchial hyperreactivity.

A. Previous Estimates of the Effects of Pollution on Newborns and of the Effects of 9/11

Many previous studies have shown that there is an association between air pollution and negative infant health outcomes (Chay and Greenstone 2003a, b; Currie and Neidell 2005; Currie et al. 2009). However most existing research has focused on pollutants that are regulated under the Clean Air Acts and there has been little research on the causal effects of many of the pollutants that appeared in the 9/11 dust cloud. One exception is Currie et al. (2015) who find that living within a mile of an industrial plant increased the incidence of low birth weight by 2 percent relative to infants born one to two miles away.

Existing studies of the effects of 9/11 on the health of newborns generally recruited samples of mothers either from individual hospitals in Lower Manhattan and/or via media publicity (Berkowitz et al. 2003; Lederman et al. 2004; Herbstman et al. 2010; Lipkind et al. 2010). Such recruitment processes might lead to unrepresentative samples, for example, if health problems during pregnancy affect mothers' willingness to participate in such studies. A further issue is selection of mothers into neighborhoods that were differentially exposed to 9/11 dust. As we show below, the socioeconomic status of mothers varies substantially across different neighborhoods of New York City (NYC).

Our sample is based on the entire population of births in NYC. In order to control for differences in the characteristics of mothers across neighborhoods, we follow the same women over time by including mother fixed effects. These fixed effects control for all characteristics of the mother that are constant between births. Using this relatively large sample of births is advantageous in that a larger sample size implies greater statistical power than many existing studies. We also control for month of conception, which is a potentially strong confounder for 9/11 effects (Currie and Schwandt 2013).

1. NTAs are aggregations of census tracts that are subsets of New York City's 55 Public Use Microdata Areas.

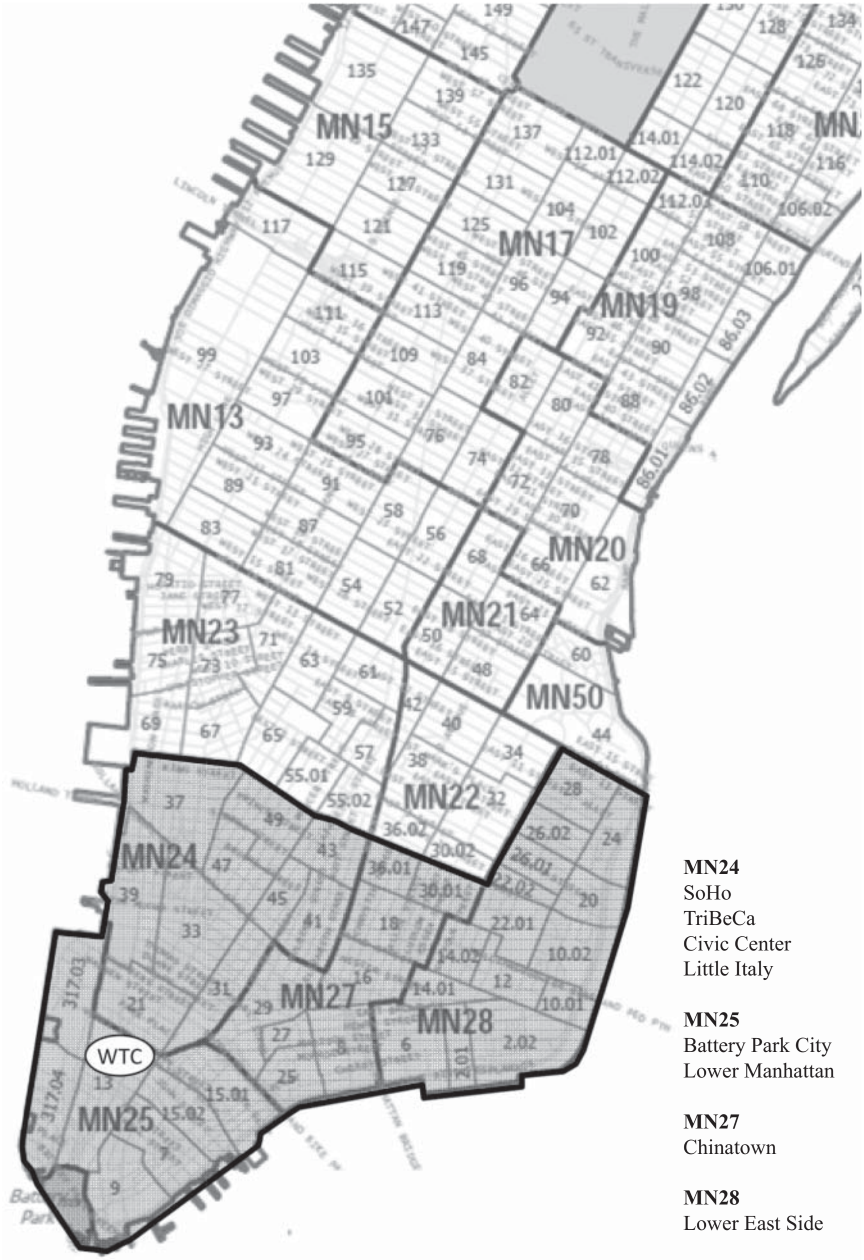


Figure 2

Neighborhood Tabulation Areas in Lower Manhattan Affected by the 9/11 Dust Cloud

Source: Population Division of the New York City Department of City Planning. URL: http://www.nyc.gov/html/dcp/pdf/census/census2010/ntas.pdf. Shaded areas, neighborhood names and World Trade Center (WTC) marker added.

Birth outcomes also might have been affected by 9/11 independent of the dust cloud, through maternal stress and post-traumatic stress disorder (PTSD), and many of the existing studies focus on this channel (for example, Lauderdale 2006; Lederman et al. 2004; Lipkind et al. 2010). These studies suggest that maternal stress related to 9/11 may have had detrimental effects on birth outcomes but that this effect is not restricted to mothers residing close to the WTC. In our analysis we compare mothers in the area affected by 9/11 dust to mothers in the other neighborhoods of New York City.

B. Fragile Males

We will show below that the 9/11 dust seems to have had much larger negative effects on male fetuses than female fetuses. This finding is in line with a broad literature about "fragile males" in epidemiology and medicine (Kraemer 2000; Eriksson et al. 2010). Fetal deaths are more common in boys (Childs 1965; Mizuno 2000), suggesting that the same environmental insults imply greater damage for male fetuses. Lower male to female sex ratios have been observed for mothers who smoke (Fukuda et al. 2002) as well as for those who experience psychological stress due to severe life events (such as severe health diagnoses of family members) or natural disasters during pregnancy (Fukuda et al. 1998; Hansen et al. 1999). Catalano et al. (2005) and Catalano et al. (2006) find that sex ratios in California and New York City respectively were slightly lower in the nine months following 9/11 than during the same season in the years before and after. They argue that maternal stress related to 9/11 might have led to more miscarriages for male than for female fetuses. Our estimates of the effects of exposure to the 9/11 dust cloud on the ratio of male to female infants born is negative but not statistically significant, suggesting that we may not have enough power to detect an effect on fetal losses though we will be able to assess markers of the health of surviving infants.[2]

III. Data and Methods

A. Data

The birth data for this paper come from individual birth records covering all births in New York City (NYC) from 1994 to 2004. New York City has its own Vital Statistics Natality system for collecting and recording information from the certificate of live birth. Data for these certificates come from two worksheets. One is completed by the mother and asks information about her circumstances and behaviors (such as marital status, smoking during pregnancy, and prepregnancy weight). The other worksheet is completed by the medical facility where the birth takes place using medical records. This worksheet includes information about prenatal care visits, risk factors for the pregnancy,

2. Aside from fetal losses, surviving male infants suffer higher rates of perinatal brain damage (Lavoie et al. 1998), cerebral palsy, and congenital deformities (Singer et al. 1968) than female infants when born prematurely. However, these conditions are much rarer than prematurity or low birth weight and even in our large sample we do not have the power to make determinations about the effects of 9/11 on these outcomes.

complications of labor and delivery, and newborn health. We start with all live singleton births in New York City between 1994 and 2004, approximately 1.2 million records.

The data also includes information about the mother's neighborhood at birth (at the NTA level) and a code that allows us to match births to the same mother. This data set makes it possible to overcome many of the limitations of previous studies of the effects of 9/11 dust exposure on birth outcomes. (See discussion above.) Including all births in NYC circumvents sample selection due to endogenous study participation. Furthermore, identifying births to the same mother makes it possible to eliminate time-constant differences between exposed and nonexposed mothers. Third, the large sample size enables us to control effectively for seasonality as well as to analyze heterogeneity in the effects of exposure by gender and trimester of exposure.

We identify exposure to 9/11 by individual trimester of pregnancy. Babies conceived within three months prior to 10/2001 were exposed during their first trimester (born 12/2001–7/2002, in our sample). Conceptions between three and six months prior 10/2001 imply second trimester exposure (born 9/2001–4/2002). Third trimester exposure applies to all babies conceived between six and nine months prior to 10/2001 and born in September 2001 or later (born 9/2001–12/2001).[3] Babies conceived in that time period but born prematurely before September 2001 are not counted as exposed to 9/11. As explained below, this mechanical relationship of gestation length and exposure status might impart some bias. Following Currie and Rossin-Slater (2013), we therefore show robustness checks in which we instrument actual exposure with an indicator of potential exposure that is one if the baby would have been exposed had the pregnancy lasted for nine months.

Information on the mothers' neighborhood of residence is provided at the date of birth but not at the date of conception. We use the residence at birth as a proxy for the residence at conception. In order to assess the precision of this proxy we investigate migration patterns of mothers initially residing in the dust area and in a similarly sized region outside the dust area. We also test whether mothers giving birth prior to 9/11 in the dust area are less likely to be observed with an additional birth after 9/11 than mothers in the no dust area, which would indicate that women might have migrated out of NYC in response to the dust cloud exposure.

As discussed in the previous section we include in the exposure area all neighborhoods that were at least partly exposed to the 9/11 dust cloud. These are Lower Manhattan, Battery Park City, SoHo, TriBeCa, Civic Center, Little Italy, Chinatown, and Lower East Side (Figure 2). Births in all the remaining neighborhoods of NYC form the control area. We explore the robustness of our results to the use of alternative areas as treatment and control groups. For example, we show regressions excluding Chinatown, a neighborhood in the dust area with specific demographics, as well as neighborhoods adjacent to the dust area. We also try restricting the control area to Manhattan instead of all of New York City.

We restrict attention to single births with nonmissing information on key maternal and birth characteristics, such as gestation length and birth weight. These restrictions yield a baseline sample of 981,462 births in all of NYC between 1994 and 2004. Table 1, Column 1 shows the means of mother characteristics and birth outcomes for this sample.

3. Birth dates are reported by year and month of birth while gestation is reported in weeks. We calculate the date of conception by subtracting the number of gestation weeks from the week (as counted by a running number from the beginning of the sample period) that covers the 15th of the month of birth.

Table 1
Descriptive Statistics

	All NYC Births (1)	Sibling pairs, with one sibling in-utero on 9/11 and born in Manhattan: Anywhere in NYC (2)	Dust area (3)	No-dust Area (4)
Mother characteristics				
White, non-Hispanic	0.263	0.329	0.206	0.500
Hispanic	0.344	0.322	0.204	0.317
Black (and other)	0.274	0.237	0.048	0.115
Asian	0.117	0.110	0.541	0.067
Age	28.04	27.36	28.08	30.32
	(6.29)	(5.93)	(5.65)	(6.21)
>12 years of education	0.411	0.381	0.333	0.650
Married	0.525	0.584	0.693	0.698
Weight gain	30.62	29.81	29.38	30.80
	(12.68)	(12.39)	(10.57)	(11.49)
Prepregnancy weight	142.5	142.3	129.0	137.2
	(32.94)	(32.99)	(28.07)	(28.86)
Hypertension	0.014	0.011	0.006	0.011
Smoking	0.037	0.031	0.018	0.019
PCV during first trimester	0.661	0.669	0.663	0.762
Birth outcomes				
Prematurity (< 37 weeks)	0.074	0.064	0.051	0.058
Prematurity, boys	0.076	0.068	0.058	0.063
Prematurity, girls	0.072	0.060	0.043	0.052
Low birth weight (< 2500g)	0.064	0.053	0.034	0.042
Low birth weight, boys	0.058	0.049	0.036	0.038
Low birth weight, girls	0.070	0.058	0.032	0.047
Gestation length (weeks)	38.93	39.00	39.07	38.97
	(1.97)	(1.83)	(1.59)	(1.69)
Gestation length, boys	38.90	38.97	38.98	38.92
	(1.98)	(1.86)	(1.62)	(1.71)
Gestation length, girls	38.95	39.04	39.16	39.01
	(1.96)	(1.80)	(1.55)	(1.66)

(*continued*)

Table 1 (*continued*)

		Sibling pairs, with one sibling in-utero on 9/11 and born in Manhattan		
	All NYC Births (1)	Anywhere in NYC (2)	Dust area (3)	No-dust Area (4)
Birth weight (g)	3,294	3,323	3,338	3,348
	(559)	(537)	(483)	(514)
Birth weight, boys	3,349	3,381	3,399	3,410
	(568)	(548)	(490)	(523)
Birth weight, girls	3,237	3,262	3,275	3,281
	(543)	(518)	(468)	(496)
Neonatal IC unit	0.076	0.062	0.030	0.065
Neonatal IC unit, boys	0.080	0.066	0.042	0.068
Neonatal IC unit, girls	0.072	0.057	0.017	0.063
Baby is a boy	0.512	0.509	0.509	0.515
Birth of sibling observed	0.46	1.00	1.00	1.00
N total births	981,462	87,864	1,932	9,335

Notes: Sample period: 1/1994–12/2004. The 9/11 dust area includes Lower Manhattan, Battery Park City, Soho, Tribeca, Civic Center, Little Italy, Chinatown, and Lower East Side. (See Figure 2.) PCV refers to prenatal care visits. Standard errors in parentheses.

One third of mothers are Hispanic, white, and black mothers make about a quarter of the sample each, and the remaining tenth are Asian. Average age is 28 years and almost half of the sample is unmarried; 3.7 percent of mothers smoke and 6.1 percent have a prenatal care visit during the first trimester. The rates of prematurity and low birth weight are 7.4 percent and 6.4 percent, respectively. For about half of the newborns we observe the birth of one or more siblings in our sample.

Our empirical strategy focuses on newborns in-utero on 9/11, comparing those born in the dust and no dust area with their siblings born before and afterward. In our sample a total of 87,864 births are part of sibling pairs in which one sibling was in-utero on 9/11. Column 2 shows the mean characteristics of this subsample. Compared to the overall sample, mothers in the 9/11 sibling sample are more likely to be white and are slightly younger. Rates of prematurity and low birth weight are about one percentage point lower than in the full sample.

Column 3 shows means for the "treatment" sample. These are sibling pairs in which one sibling was in-utero on 9/11 and born in the dust area. A total of 1,932 births were in sibling groups where at least one infant was potentially affected. The racial composition of mothers living in the area affected by the dust is very different from the remaining sample, due to the high fraction of Asian mothers in Manhattan's Chinatown; 54.1

percent of mothers in the affected area are Asian, compared to 11.4 percent in all NYC. Education levels are similar to those in the overall sample while mothers in the dust area are slightly older and less likely to smoke or to suffer from hypertension. Prematurity and low birth weight rates in the dust area are about one and two percentage points lower compared to overall NYC, respectively. Column 4 of Table 1 shows means for sibling pairs in Manhattan outside the 9/11 dust area. Key maternal characteristics such as the racial composition, average age, or education levels are more distinct from the dust area characteristics than in the overall NYC sample, which is why we choose the overall NYC area as the baseline sample. However, we also show regressions restricting the sample to mothers living in Manhattan only.

It is important to note that we measure the effects of potential exposure, which is a noisy indicator of actual exposures. Some pregnant women resident in lower Manhattan might have been elsewhere on the morning of 9/11 whereas the dust might have affected other pregnant women resident in other parts of New York. Hence, the estimated effects we find may well represent lower bounds on the true effects of exposure.

B. Methods

Table 1 shows that there are strong socioeconomic differences between mothers who give birth in different neighborhoods of NYC. One reason mothers select into different neighborhoods has to do with racial or ethnic clusters such as Chinatown in lower Manhattan. Another driver might be differences in housing prices and skill-specific labor demand. A straightforward way to control for time-constant differences in mother characteristics across neighborhoods would be to include neighborhood fixed effects. However, the selection of mothers into different neighborhoods might change over time and in response to a disaster like 9/11. In this case, any changes in birth outcomes within neighborhoods might be entirely driven by changes in the composition of mothers over time. A way to account for time-changing regional selection is to include observable maternal characteristics in multivariate regression models. But variables such as age, race, and years of education are relatively crude proxies for the socioeconomic determinants of residential sorting, and they are unlikely to capture the entire extent of selection. As Pischke and Schwandt (2015) show, the inclusion of covariates might be of little help in reducing omitted variable bias if they are noisy or poor proxies of the true underlying confounders.

To control for both observed and unobserved mother characteristics that are constant across births (such as maternal background) we include mother fixed effects. This means we compare siblings born to the same mother at different points in time, with and without exposure to the 9/11 dust cloud. Further, we also include sibling pairs with the 9/11 sibling born in NYC *outside* the dust area to control for potential effects of 9/11 on birth outcomes unrelated to the 9/11 dust cloud. As discussed above, some papers have suggested that 9/11-related maternal stress and post-traumatic stress disorders lead to adverse birth outcomes, irrespective of where in NYC mothers lived (Lederman et al. 2004; Lauderdale 2006; Eskenazi et al. 2007; Lipkind et al. 2010). Including sibling pairs outside the dust area controls for 9/11 effects that are common across neighborhoods.

Hence, we compare the difference in birth outcomes between sibling pairs with one sibling in-utero on 9/11 and exposed to the dust cloud to the difference between sibling pairs with one sibling in-utero on 9/11 but not exposed to the dust cloud. We estimate linear regression models of the following form

$$(1) \quad Y_i = \alpha + \beta(N_i{}^* T_i) + \gamma N_i + \tau + \mu + \delta X_i + \varepsilon_i,$$

where i indexes the newborn, Y_i is a birth outcome, N is an indicator for dust exposed neighborhoods and T is an indicator variable for pregnancy on 9/11. The vector τ includes year*month of conception fixed effects, μ are mother fixed effects, and X_i are controls for time-varying maternal and child characteristics that are known to affect birth outcomes (gender; birth order 1, 2, 3, >3, missing; mother's age <20, 20–24, 25–29, 30–34, >34, missing; an indicator equal to one if the father information is missing).

Indicators for year*month of conception fixed effects control for time-varying characteristics common to births in all neighborhoods and for the effects of seasonality on birth outcomes. Mother fixed effects capture unmeasured maternal characteristics that are constant between births. Errors are clustered at the neighborhood level to allow for correlated errors within areas. When restricting the data to neighborhoods in Manhattan (29 instead of 195 neighborhoods), we cluster at the neighborhood-year level.

The key coefficient of interest is β, which measures whether infants who were in the affected neighborhoods at the critical time have worse outcomes. The model can be refined to estimate effects of exposure by individual pregnancy trimesters.

$$(2) \quad Y_i = \alpha + \beta_1(N_i{}^* T1_i) + \beta_2(N_i{}^* T2_i) + \beta_3(N_i{}^* T3_i) + \gamma N_i + \tau + \mu + \delta X_i + \varepsilon_i,$$

where $T1_i$, $T2_i$, and $T3_i$ are indicators for first, second, and third trimester pregnancy at 9/11/2001. This specification allows us to test whether estimated effects are driven by particular periods of pregnancy, such as the first trimester, when the fetus may be particularly sensitive to environmental insults (Lee et al. 2003).

In order to test for differential effects by child gender, we further estimate models with gender interaction terms:

$$(3) \quad Y_i = \alpha + \beta_1(N_i{}^* T1_i) + \theta_1(N_i{}^* T1_i{}^* boy_i) + \beta_2(N_i{}^* T2_i) + \theta_2(N_i{}^* T2_i{}^* boy_i) + \beta_3(N_i{}^* T3_i) + \theta_3(N_i{}^* T3_i{}^* boy_i) + \gamma N_i + \gamma N_i{}^* boy_i + \tau + \tau^* boy_i + \mu + \delta X_i + \varepsilon_i,$$

where boy_i is an indicator equal to one if the newborn is a boy. Consequently, β_1 measures the effect of first trimester 9/11 dust exposure on girls while $\beta_1 + \theta_1$ measures the first trimester effect on boys. An estimate of θ that is significantly different from zero thus indicates that there is a statistically significant difference between the effects of in-utero dust exposure on male and female fetuses.

A further way to test for gender differences is to estimate Equations 1 or 2 separately for boys and girls. Such gender-specific regressions are less restrictive as they allow all parameters in the model to differ by gender. At the same time they are more restrictive with respect to the data that is included. Since we control for mother fixed effects, such separate regressions essentially compare pairs of brothers and sisters, respectively, excluding mixed sibling pairs from the analysis.

C. Measurement error

One caveat to our analysis is that we observe mothers' neighborhoods only at birth and not at the time of conception. Some mothers might migrate to a different neighborhood between conception and birth and this could be particularly relevant in the aftermath of 9/11. The question is whether and how different potential migration patterns would bias the estimated effects of the 9/11 dust cloud on birth outcomes? If mothers migrate between dust-affected and no-dust areas independently of the degree to which they were affected by 9/11, then misassigning location at the time of conception will attenuate our estimates. Some treated mothers will be erroneously assigned to the control group and some control mothers will be erroneously assigned to the treatment group, biasing the difference between the two groups toward zero. This attenuation bias will be stronger if there is a greater tendency to migrate out of the dust area among mothers who are more affected, and vice versa.

Appendix Figure 1 shows a flow chart of the migration behavior of mothers who gave birth in the dust area in the years before 9/11. As a comparison, we also show the corresponding migration flows out of the rest of Lower/Mid-Manhattan excluding the dust-affected area, which is an area of similar size as the dust-affected area. Almost 80 percent of mothers who gave birth in the dust-affected area in the three years prior to 9/11 stayed in the same area for the subsequent birth. In other words, most mothers did not migrate out of the dust area into other areas of NYC even though the prime child bearing ages are times of relatively high mobility and we are looking at a period of almost four years. However, the migration rate still might be higher than in other parts of NYC as a response to the events of 9/11. The right-hand side of the flow chart shows that this is not the case. Mothers in the neighborhoods between the dust area and Central Park, a region of similar size as the dust area, were actually slightly more likely to migrate into another area during the same time period. One might wonder, whether those mothers who migrated out of the dust area did so in response to 9/11 moving into the adjacent neighborhoods, while in return those from the receiving neighborhoods were pushed into the dust area. However, only a negligible fraction of 2–2.5 percent switched between these two regions, the majority diffused into other areas of NYC. This analysis indicates that there was less migration out of the affected area of lower Manhattan than one might have expected, and that the extent of migration was similar to that in a similarly sized adjacent comparison area.

Another potential issue is that we only observe mothers who give birth to another child somewhere in NYC. If mothers in the dust zone were less likely to have a further child or were more likely to move out of NYC altogether, they would not appear in the data set after 9/11. Appendix Table 1 shows that this type of selection is negligible. Pre-9/11 children born in the dust area are as likely to have a post-9/11 sibling in the data as those born in the no-dust Manhattan area (Column 1) or in all of the remaining parts of NYC (Column 2).

A remaining source of potential bias is that exposure to 9/11 depends to some extent on gestation length. For example, a child conceived in January 2001 is only exposed in the third trimester if the birth occurs in September or later. Hence, babies with longer gestation are mechanically more likely to be exposed.

Currie and Rossin-Slater (2013) deal with both this endogenous timing issue and endogenous migration by instrumenting actual exposure with a hypothetical potential exposure indicator equal to one if the child would have been exposed to 9/11 dust had the mother stayed in the same location we initially observe her, and had the pregnancy lasted for exactly nine months. This instrument is highly correlated with actual exposure, given that most mothers do not move and most pregnancies are full term and it has no effect on birth outcomes over and above the effects of actual exposure. Moreover, any fixed characteristics of mothers that are correlated with the first place in which we observe them are controlled for by the inclusion of maternal fixed effects.[4] We show estimates using this instrumental variables strategy below.

IV. Results

Table 2 shows estimates of the effect of dust exposure on the incidence of premature delivery. The first column shows the estimate of β from Equation 1. There is a 2.2 percentage point increase in the probability of prematurity among infants exposed to 9/11 dust in-utero. This is a large effect relative to the incidence of prematurity in NYC of 7.4 percent. The second column shows estimates of Equation 2, which breaks the estimated effects down by the trimester of pregnancy when the exposure occurred. These estimates suggest that the effect is confined to infants exposed during the first trimester of pregnancy and is even larger for this group at 6.2 percentage points.

Column 3 of Table 2 shows estimates of Model 3, which includes gender interactions. The estimates suggest that exposure had a much greater impact on male fetuses (9.6 percentage points) than on female fetuses (2.8 percentage points). Given a baseline probability of 7.6 percent for boys, exposure to the dust cloud more than doubled the probability of premature delivery for that group. Columns 4 and 5 show sibling comparisons separately for boys and girls. As discussed above, these samples throw out mixed-sex sibling pairs and compare exposed children only to their unexposed same-sex siblings. These models yield very similar estimates of a 10.5 percentage point increase in prematurity for exposed vs. unexposed boys compared to a 4.8 percentage point increase for exposed vs. unexposed girls.

Table 3 shows estimates from Equation 3 where the dependent variables are gestation in weeks, low birth weight, birth weight in grams, and an indicator equal to one if the infant was admitted to the neonatal intensive care unit. The estimated effects are similar to those discussed above. When gestation is measured in weeks, first trimester exposure to the dust is associated with a reduction in gestation of almost half a week (3.045 days) for boys but there is no significant effect for girls. Similarly, there is an increase in low birth weight of 5.7 percentage points among boys, as well as a decrease in average birth weight of 83.17 grams among male infants. There is no significant effect on the likelihood of NICU admission, even though the point estimates for male infants suggest a strong (given that NICU is a relatively rare event) albeit imprecisely estimated effect. Similar to the effect on prematurity, the estimated impact on low birth weight is large relative to the means shown in Table 1. It appears that 9/11 roughly doubled the incidence of these outcomes among prenatally exposed male infants.

4. The corresponding first stage equation is: $N_i{*}T_i = \alpha + \beta(N0_i{*}T_i) + \gamma N0_i + \tau + \mu + \delta X_i + \varepsilon_i$, where $N0_i$ is an indicator equal to one if the first location in which we observe the mother (at her pre-9/11 birth) is part of the area later exposed to 9/11 dust and T_i equals one if the nine months following conception include 9/11. In our data the estimated first stage coefficient β is 0.958 with a standard error of 0.011, indicating that the instrument is highly predictive.

Table 2
Effect of 9/11 dust exposure on premature delivery

Dependent variable:	All births			Boys	Girls
Gestation < 37 weeks	(1)	(2)	(3)	(4)	(5)
Dust exposure (any trim)	0.022** (0.006)				
1st trimester dust exposure		0.062** (0.008)	0.028** (0.010)	0.105** (0.022)	0.048** (0.013)
1st trimester dust exposure*boy			0.068** (0.022)		
2nd trimester dust exposure		–0.011 (0.008)	0.000 (0.031)	–0.005 (0.023)	–0.024 (0.076)
2nd trimester dust exposure*boy			–0.023 (0.053)		
3rd trimester dust exposure		0.009 (0.015)	–0.007 (0.020)	0.002 (0.020)	–0.021 (0.023)
3rd trimester dust exposure*boy			0.033 (0.025)		
N		87,864		27,144	25,547

Notes: Coefficients from mother fixed effects regressions of premature births (gestation < 37 weeks) on 9/11 dust exposure during pregnancy are displayed. Dust exposure is the interaction of pregnancy during 9/11 and birth in the 9/11 dust area. The 9/11 dust area includes Lower Manhattan, Battery Park City, Soho, Tribeca, Civic Center, Little Italy, Chinatown, and Lower East Side. First trimester dust exposure is the interaction of the exposure variable with 1st trimester pregnancy during 9/11 (respectively for second and third trimester). "*boy" is the interaction with child gender. The sample in Columns 1–3 consists of all sibling pairs born between 1994 and 2004, with one sibling in-utero on 9/11. In Column 4 and 5, the sample is further restricted to brother pairs and sister pairs, respectively. All regressions include fixed effects for the mother, the conception year*month, the dust area, child gender, birth order, and mothers' age group. The regression in Column 3 additionally controls for conception year*month*boy fixed effects and a dust area*boy indicator. Robust standard errors in parenthesis are clustered at the neighborhood level. * Significance level at $p < 0.05$; ** Significance level at $p < 0.01$.

Granted that exposure to the 9/11 dust seems to have had a negative effect on birth outcomes, it is interesting to explore possible pathways via some of the variables about maternal behaviors and condition that are listed on the birth certificate. In order to investigate this hypothesis, Table 4 estimates models examining a wide variety of maternal behaviors and conditions that are noted on the birth certificates. Columns 1 and 2 show that exposure to 9/11 dust had no effect on whether mothers were smoking during pregnancy or on the woman's self-reported prepregnancy weight. Column 3 shows that first trimester exposure negatively affects pregnancy weight gain if the

Table 3
Effect of 9/11 dust exposure on additional birth outcomes

Dependent variable	Gestation Length in Weeks (1)	Low Birth Weight (<2500g) (2)	Birth Weight in Grams (3)	Neonatal Intensive Care Unit (4)
1st trimester dust exposure	0.049	–0.019	47.28	0.022
	(0.075)	(0.033)	(42.97)	(0.020)
1st trimester dust exposure*boy	–0.484**	0.076*	−130.46**	0.047
	(0.167)	(0.032)	(39.93)	(0.039)
2nd trimester dust exposure	0.097	–0.011	34.99	–0.002
	(0.175)	(0.011)	(73.1)	(0.027)
2nd trimester dust exposure*boy	0.073	0.005	3.65	–0.008
	(0.372)	(0.010)	(100.05)	(0.029)
3rd trimester dust exposure	0.199	–0.010	41.12	–0.025
	(0.103)	(0.016)	(39.32)	(0.024)
3rd trimester dust exposure*boy	–0.164	0.042	–99.42	0.022
	(0.215)	(0.025)	(61.13)	(0.015)
N	87,864	87,864	87,864	86,053

Notes: * Significance level at $p < 0.05$; ** Significance level at $p < 0.01$. Further comments as in Table 1.

newborn is a boy, potentially due to the negative effect on gestational length (–0.43 weeks or −3.045 days, see Table 3).

Column 4 indicates a positive effect of first trimester exposure on hypertension both for boys and girls. Since inflammation is associated with hypertension, it is possible that this result captures one of the physiological pathways for exposure to 9/11 dust to affect preterm birth and other birth outcomes. There is also a slightly significant effect on whether mothers were married at the time of delivery for second-trimester exposure (Column 5). This might just be sampling variation, given the large number of estimated coefficients. Column 6 shows, though, that women who were exposed during the first trimester were more likely to have a prenatal care visit in the first trimester, suggesting that perhaps they sought out medical care as a response to the exposure to the dust cloud. As one would expect, this positive behavioral response does not depend on child gender, which is usually unknown during the first trimester. Insignificant effects for higher trimester exposure also are plausible because second or third trimester exposure should not affect the likelihood that a woman had a prenatal care visit during the first trimester.

All things considered and combined with the previous evidence regarding migration out of the affected area, there is little evidence of large detrimental behavioral changes in the mothers who were potentially exposed to 9/11 dust during pregnancy. If anything prenatal care increases among mothers who were exposed during the first trimester.

Table 4
Effect of 9/11 dust exposure on mother characteristics and behaviors

Dependent Variable	Mother Smokes (1)	Prepregnancy Weight (2)	Maternal Weight Gain (3)	Maternal Hypertension (4)	Mother Is Married (5)	Prenatal care visit in 1st trimester (6)	Baby Is a Boy (7)
1st trimester dust exposure	0.009	1.498	–0.013	0.022**	–0.032	0.112*	–0.013
	(0.007)	(0.971)	(0.937)	(0.006)	(0.043)	(0.045)	(0.937)
1st trimester dust exposure*boy	–0.011	–2.473	–2.238*	–0.018	0.032	–0.116	
	(0.013)	(1.969)	(0.976)	(0.020)	(0.043)	(0.101)	
2nd trimester dust exposure	0.012	–0.958	0.577	0.007	–0.062*	0.074	0.577
	(0.021)	(0.666)	(1.051)	(0.009)	(0.024)	(0.078)	(1.051)
2nd trimester dust exposure*boy	0.003	–0.376	–1.699	–0.015	0.105	–0.049	
	(0.020)	(3.715)	(1.063)	(0.011)	(0.058)	(0.051)	
3rd trimester dust exposure	0.008	1.600	–0.171	0.010	–0.018	0.038	–0.171
	(0.005)	(1.966)	(1.494)	(0.011)	(0.026)	(0.028)	(1.494)
3st trimester dust exposure*boy	–0.012	–2.184	–1.062	–0.007	0.012	–0.086	
	(0.014)	(2.714)	(1.489)	(0.017)	(0.040)	(0.070)	

Notes: $N = 87{,}864$ in all columns. Maternal weight gain and prepregnancy weight are measured in pounds. * Significance level at $p < 0.05$; ** Significance level at $p < 0.01$. Further comments as in Table 1.

These findings lend support to the hypothesis that the negative effects on birth outcomes we observe are primarily due to the effect of exposure to pollution during pregnancy.

Column 7 shows our estimate of the effect of the 9/11 dust on sex ratios. Although the point estimate for exposure in the first and third trimesters is negative, neither is close to statistical significance. Thus, unlike some previous research we find no effect on sex ratios perhaps because fetal death is a rarer outcome than the birth outcomes we examine and we do not have sufficient power to detect it. A more direct way to test for effects on miscarriages is to regress the overall number of conceptions resulting in live births on 9/11 exposure during the different trimesters for the dust and the nondust areas. Appendix Table 2 reports the results from such a regression for the overall number of conceptions as well as separately for male and female births. The point estimates for male conceptions are negative but not significantly different from zero, in line with the estimates in Column 7 of Table 4.

A. Robustness Checks

Our estimation method relies on comparing mothers in the dust-affected "treatment" area to mothers in another "control" area. In order to investigate whether our estimates are sensitive to the choice of the treatment and control area, we present estimates based on several alternative choices in Table 5. The first three columns show models based on a sample that excludes Chinatown. Chinatown is particularly distinct in terms of demographics from the rest of Manhattan. At the same time, it makes up almost a third of the treatment sample, so that one might worry that estimates could be driven by the distinct demographics in that area. However, comparing estimates based on this reclassification to the baseline in Table 2 shows that the estimates are quite similar.

In our analysis we treat the exposed and unexposed areas as if separated by hard boundaries but immediately adjacent areas also might have received some exposure that might lead to a downward bias. Columns 4–6 show that this is not the case, reporting estimates excluding neighborhoods adjacent to the dust area. If anything, these estimates are slightly smaller than the baseline effects.

Columns 7–9 show estimates restricting the sample to Manhattan. Again, the point estimates are very similar to the baseline. We conclude that the choice of the control area has very little effect on the estimates.

Table 6 shows estimates using several alternative timing specifications. Columns 1–3 report results for a sample that excludes conceptions that occurred after September 2001. The rationale for this sample restriction is that if a mother's health was permanently impaired by 9/11 dust exposure, then this could have an effect on subsequent pregnancies as well as on the pregnancies that were in progress on 9/11. Hence, comparing an exposed baby to a sibling born later might result in an underestimate of the true health effect. The results in Columns 1–3 show that point estimates are very similar when babies conceived after September 2001 are excluded though standard errors are slightly increased, which is not surprising, given the reduction in sample size. The similarity of these estimates to the baseline estimates suggests that there may not have been a permanent negative maternal health effect in line with the evaluation of potential long-run effects of moderate 9/11 dust exposure on adult health in the medical literature (Pleil et al. 2004).

Table 5
Alternative Area Specifications

Dependent Variable:	Excluding Chinatown			Excluding Adjacent Areas (MN 22, MN 23 and MN 50)			Manhattan Only		
Gestation <37 weeks	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Dust exposure (any trimester)	0.026**			0.021**			0.028**		
	(0.008)			(0.006)			(0.008)		
1st trimester dust exposure		0.065**	0.023*		0.060**	0.029**		0.074**	0.046*
		(0.009)	(0.011)		(0.009)	(0.010)		(0.013)	(0.019)
1st trimester dust exposure*boy			0.082**			0.062*			0.056
			(0.024)			(0.025)			(0.033)
2nd trimester dust exposure		–0.015	–0.013		–0.011	0.001		–0.003	0.016
		(0.010)	(0.041)		(0.008)	(0.032)		(0.012)	(0.033)
2nd trimester dust exposure*boy			–0.005			–0.024			–0.040
			(0.065)			(0.053)			(0.054)
3rd trimester dust exposure		0.023	0.007		0.010	–0.007		0.008	–0.013
		(0.013)	(0.019)		(0.015)	(0.021)		(0.016)	(0.019)
3rd trimester dust exposure*boy			0.033			0.034			0.043
			(0.040)			(0.025)			(0.028)
N		87,148			87,267			11,267	

Notes: Regressions in Columns 1–3 exclude births in Chinatown while adjacent areas are excluded in Columns 4–6. In Columns 7–8 the sample is restricted to sibling pairs with one sibling exposed in-utero to 9/11 and born in Manhattan (instead of entire NYC). Standard errors are clustered at the neighborhood-year level in Columns 7–8 and at the neighborhood level in Columns 1–6. * Significance level at $p < 0.05$; ** Significance level at $p < 0.01$.

Table 6
Alternative Timing Specifications

Dependent Variable:	Excluding Post-9/2001 Conceptions			Excluding 9/2001 Births			Potential Exposure IV		
Gestation <37 weeks	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Dust exposure (any trimester)	0.037**			0.018**			0.019**		
	(0.011)			(0.005)			(0.004)		
1st trimester dust exposure		0.071**	0.046*		0.062**	0.025*		0.066**	0.025*
		(0.015)	(0.019)		(0.008)	(0.010)		(0.008)	(0.010)
1st trimester dust exposure*boy			0.053			0.075**			0.083*
			(0.037)			(0.023)			(0.037)
2nd trimester dust exposure		0.008	0.058		–0.010	–0.004		0.003	0.015
		(0.011)	(0.031)		(0.008)	(0.035)		(0.006)	(0.019)
2nd trimester dust exposure*boy			–0.094			–0.015			–0.018
			(0.053)			(0.059)			(0.033)
3rd trimester dust exposure		0.033	0.006		–0.007	–0.014		–0.010	–0.031
		(0.028)	(0.039)		(0.010)	(0.020)		(0.016)	(0.022)
3rd trimester dust exposure*boy			0.056			0.016			0.039*
			(0.044)			(0.024)			(0.018)
N		68,659			81,505			88,148	

Notes: In Columns 1–3, the sample is restricted to conceptions prior to September 2001. In Columns 4–6, births in September 2001 are excluded. Columns 7–9 show estimates from two-stage least square regressions in which we instrument for actual exposure using a hypothetical indicator equal to one if the child would have been exposed to 9/11 dust had the mother stayed in the first location in which we observe her and had the pregnancy lasted at least for nine months. * Significance level at $p<0.05$; ** Significance level at $p<0.01$. Further comments as in Table 1.

Columns 4 to 6 present results excluding births that occurred during September 2001. Those born before 9/11 were not exposed to the dust cloud and thus are misclassified if September births are included. Because the data does not contain the exact date of birth, we test for the role of this misclassification excluding these births and their corresponding sibling pairs. Results change very little, however, when using this restricted sample.

In Columns 7 to 9 we implement the instrumental variables strategy described above. Notice that the sample size is about 300 observations larger compared to the baseline regressions, due to sibling pairs with one sibling who would have been exposed to 9/11 had the pregnancy been full-term. These sibling pairs were not included in the baseline sample (because under the baseline, neither sibling was exposed). The first trimester effects in these instrumental variable regressions are very similar to the baseline estimates, suggesting that our first trimester estimates are not driven by endogenous location.

Interestingly, there is a statistically significant estimated effect of exposure in the third trimester effect for boys, which is what one would expect if the baseline third trimester results were attenuated by a mechanical relationship between length of gestation and exposure. The point estimate of 0.039 is similar in size to the corresponding coefficients in the other regression models though the standard error is smaller. These estimates suggest that exposure in the third trimester also may have had a negative effect, perhaps by directly triggering preterm labor as some of the prior literature on the effect of chemicals like PAHs has suggested.

V. Discussion and Conclusions

Previous research into the health impacts of in-utero exposure to the 9/11 dust cloud on birth outcomes has shown little evidence of consistent effects. This is a puzzle given that 9/11 was one of the worst environmental catastrophes to have ever befallen a U.S. metropolis, and there is a great deal of prior evidence that even low levels of pollution are associated with negative birth outcomes.

Our work suggests a simple resolution of this puzzle, which is that the women who lived in neighborhoods exposed to the 9/11 dust cloud were quite different than women in other parts of New York City. In particular, the latter group was less likely to have poor birth outcomes, other things being equal. When we control for these preexisting differences by following the same mothers over time, we find large effects of exposure to the dust cloud. The impacts are especially pronounced for fetuses exposed in the first trimester, and for male fetuses. We estimate that in this group, exposure to the dust cloud more than doubled the probability of premature delivery and had similarly large effects on the probability of low birth weight. Our work also improves on past efforts by utilizing a relatively large sample of births, controlling for seasonal effects, and examining the impact of 9/11 on various observable maternal behaviors, including migration.

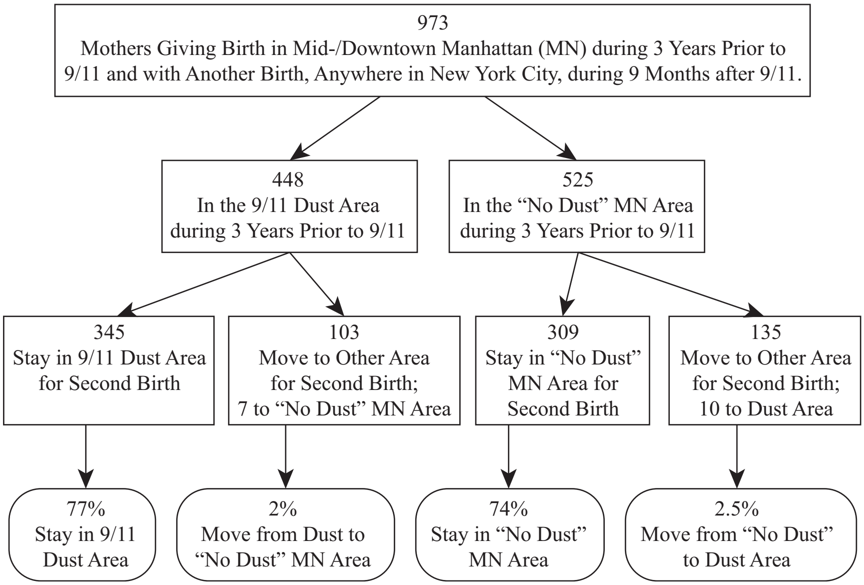
One might wonder whether a simple difference-in-difference estimate that does not rely on the comparison of siblings born to the same mother would deliver similar results. We report such difference-in-difference regressions for premature birth in the first two columns in Appendix Table 3. These estimates do not resemble the effects that we find when using mother fixed effects. Moreover, as the balancing regressions in Columns 3–8 show there is evidence of selection on observable characteristics suggesting that a simple difference-in-difference design might be confounded by unobservable characteristics.

One way to assess the size of the estimated effects is to compare the effect of 9/11 exposure to the differences in health at birth between disadvantaged and advantaged mothers. The first two columns of Appendix Table 4 show mean birth outcomes for unmarried, black mothers with less than 12 years of schooling (disadvantaged) and for married, white mothers with more than 12 years of schooling (advantaged). As the comparison of columns 4 and 5 shows, the estimated effect of first trimester dust cloud exposure on boys is of similar magnitude to the difference between disadvantaged and advantaged mothers for prematurity and low birth weight. In other words, the male newborn of an advantaged mother who was exposed to the 9/11 dust cloud during the first trimester would have birth outcomes similar to the newborn of a disadvantaged mother who was not exposed. This comparison highlights the importance of controlling adequately for the baseline characteristics of the mothers, in order to uncover the detrimental effects of 9/11 on infant health at birth.

We also can place these estimates in perspective by comparing them to previous estimates of the effects of air pollution on fetal health. Many previous epidemiological studies of areas with high pollution suffer from some of the methodological weaknesses discussed above, notably, a lack of controls for possible confounders. One study of the Teplice coal mining region of northern Bohemia, which had high pollution in winter due to both coal-burning and atmospheric inversions found that rates of prematurity and low birth weight were twice as high in Teplice as in a nearby district with much lower pollution levels. However, the authors note that both the ethnic makeup of the mothers and smoking behaviors differed between the two regions, which could account for some of this difference (Dejmek, Selevan, and Sram 1996).

More recent studies of low levels of pollution also find negative effects. For example, Currie and Walker (2011) found that the implementation of EZ-Pass electronic toll collections in New Jersey and Pennsylvania reduced automobile exhaust in the vicinity of highway toll plazas. They find that these reductions in pollution resulted in a 10 percent reduction in the incidence of low birth weight and prematurity. In contrast to the relatively small though permanent changes in pollution wrought by EZ-Pass, 9/11 was an environmental catastrophe of unparalleled magnitude. It seems reasonable then that properly measured, the effects of 9/11 are much larger.

Appendix



Appendix Figure 1

Migration Behavior of Mothers in Mid-/Downtown Manhattan with Births before and after 9/11.

Notes: The 9/11 dust area includes Lower Manhattan, Battery Pk City, SoHo, TriBeCa, Civic Center, Little Italy, China Town and Lower East Side (see Figure 2). The "no-dust" in Mid-/Downtown Manhattan consists of all neighborhoods south of Central Park not contained in the dust area.

Appendix Table 1
Effect of Pre-9/11 Location on Likelihood of Post-9/11 Birth

Dependent Variable:	Sample: All Pre-9/11 Births in	
Sibling Appears in Post-9/11 Period, Anywhere in NYC	Manhattan (1)	Entire NYC (2)
Born in dust area (pre-9/11 births only)	0.009 (0.016)	–0.014 (0.015)
Constant	0.134** (0.007)	0.157** (0.003)
N	115,512	858,320

Notes: Coefficients from OLS regressions are displayed. The sample in Column 1 and 2 are all births born prior to 9/11 in Manhattan and the entire NYC, respectively. The dependent variable is a dummy that equals 1 if the sample child has a sibling that is born after 9/11, anywhere in NYC. The explanatory variable is a dummy that equals 1 if the sample child is born in the 9/11 dust area. The 9/11 dust area includes Lower Manhattan, Battery Park City, Soho, Tribeca, Civic Center, Little Italy, Chinatown, and Lower East Side. Robust standard errors in parenthesis are clustered at the neighborhood-year level. * Significance level at $p < 0.05$; ** Significance level at $p < 0.01$.

Appendix Table 2
Effect of 9/11 Dust Exposure on the Log Number of Conceptions Resulting in Live Birth

Dependent Variable: Log number of Conceptions Resulting in Life Birth	All births (1)	Boys (2)	Girls (3)
1st trimester dust exposure	0.017 (0.080)	–0.075 (0.072)	0.036 (0.101)
2nd trimester dust exposure	–0.041 (0.077)	–0.078 (0.069)	–0.082 (0.113)
3rd trimester dust exposure	0.014 (0.118)	–0.002 (0.182)	–0.044 (0.084)
N	239	239	239

Notes: The sample consists of all conceptions in NYC between 1994 and 2004 resulting in live birth. The data is collapsed by conception year * conception month * dust area (vs. rest of NYC). In columns 2 and 3, the sample is restricted to male and female births, respectively. All regressions control for the main effects: dust area and year*month fixed effects. Standard errors are clustered by year*month and observations are weighted by the number of births in each year × month × area cell. * Significance level at $p < 0.05$; ** Significance level at $p < 0.01$.

Appendix Table 3
Difference-in-Difference Estimates, No Mother Fixed Effects

	Dependent Variable							
	Gestation < 37 weeks		Mother Is White		Mother Is Asian		Mother's Education	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1st trimester dust exposure	0.007	–0.008	–0.009	0.000	0.002	0.025	–0.091	–0.143*
	(0.006)	(0.011)	(0.019)	(0.013)	(0.025)	(0.022)	(0.102)	(0.062)
1st trimester dust exposure*boy		0.032**		–0.018		–0.047**		0.107
		(0.012)		(0.015)		(0.011)		(0.175)
2nd trimester dust exposure	–0.025**	–0.009	0.021	0.008	0.033	0.058*	–0.060	–0.095
	(0.008)	(0.016)	(0.013)	(0.022)	(0.024)	(0.028)	(0.140)	(0.061)
2nd trimester dust exposure*boy		–0.032		0.026		–0.050		0.070
		(0.017)		(0.037)		(0.031)		(0.304)
3rd trimester dust exposure	–0.004	0.002	0.033**	0.021**	0.025*	0.043	0.014	–0.149
	(0.010)	(0.011)	(0.010)	(0.007)	(0.013)	(0.023)	(0.145)	(0.166)
3rd trimester dust exposure*boy		–0.010*		0.024		–0.035		0.321
		(0.004)		(0.024)		(0.040)		(0.275)
N	981,462		981,462		981,462		981,462	

Notes: Coefficients from OLS regressions of prematurity and mother characteristics on 9/11 dust exposure during pregnancy are displayed. The sample includes all children born between 1994 and 2004. No mother fixed-effects are included. Further comments as in Table 1. * Significance level at $p < 0.05$; ** Significance level at $p < 0.01$.

Appendix Table 4
Comparison of Mean Birth Outcomes by SES with the Estimated Effect of 1st Trimester Dust Cloud Exposure

	Low SES Edu < 12; Unmarried; Black	High SES Edu > 12; Married; White	Difference Low-High	Estimated 1st Trim Dust Effect
Prematurity (< 37 weeks)	0.126	0.048	0.078	0.062**
Prematurity, boys	0.126	0.051	0.075	0.096**
Prematurity, girls	0.126	0.045	0.081	0.028**
Low birth weight (< 2500g)				
Low birth weight, boys	0.111	0.033	0.078	0.057*
Low birth weight, girls	0.134	0.041	0.094	–0.019

Notes: Sample means of birth outcomes are displayed by socioeconomic status in Column 1 and 2. Column 3 shows the difference between the two. Column 4 shows the estimates reported in Tables 2 and 3. * Significance level at $p < 0.05$; ** Significance level at $p < 0.01$.

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