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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 pre-existing 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, low birth weight, and admission to the NICU after birth, especially for boys.

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1. 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 (e.g. 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 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 than 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 have typically 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 low birth weight (birth weight less than 2500 grams, hereafter LBW), and whether the infant was admitted to the neonatal intensive care unit (NICU) after birth. 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 alternative control areas, to the exclusion of births after 9/11 (so that only births to mothers pregnant before and during 9/11 are included), and to instrumenting post-9/11 area of residence with pre-9/11 residency.

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 2 discusses background information about previous studies of pollution from 9/11 and the greater susceptibility of males to many types of health insults. Section 3 provides an overview of our data and methods. Section 4 presents the results, and a discussion and conclusion follow in Section 5.

2. 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 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 the area north of the WTC was less densely covered by big buildings, much of the heavy dust was pushed northwards. At the same time wind was blowing from the east 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 eastwards. 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.

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

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 hyper-reactivity, persistent cough, and increased risk of asthma. These health effects are in line with experimental tests which found that mice exposed to WTC dust showed short-lived pulmonary inflammations and persistent marked bronchial hyper-reactivity

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

While many previous studies have shown that there is an association between air pollution and negative infant health outcomes, economic studies have focused on determining whether the effect is causal. Chay and Greenstone (2003a,b) used exogenous variation in pollution stemming from the Clean Air Acts and economic recession respectively to show that a one-unit decline in particulates led to 5 to 8 fewer infant deaths per 100,000 live births. Other studies use naturally occurring variation in pollution and large samples of U.S. siblings subjected to different levels of pollution in utero (Currie and Neidell, 2005; Currie et al., 2009) and have found that exposure to carbon monoxide has significant negative effects on birth outcomes.

Most existing research has focused on the so-called “criterion air pollutants” which are regulated under the Clean Air Acts and there has been little research on the causal effects of other sorts of pollutants (such as many of those that appeared in the 9/11 dust cloud). One exception is Currie et al. (2013) who examine the effects of toxic emissions using openings and closures of more than 1,600 industrial plants and the universe of birth records from five large states. They found that living within a mile of such a plant increased the incidence of low birth weight by 2% relative to infants born 1–2 miles away (where economic benefits of plant operation can be assumed to be the same as for people living within a mile of a plant).

These previous studies suggest that even low levels of pollutants have negative effects on birth outcomes and that it would be quite surprising if in utero exposure to the 9/11 dust cloud was benign. Yet this is exactly the conclusion the previous studies have come to. It is possible that these null results may be explained by methodological limitations in the existing studies.

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 socio-economic status of mothers varies substantially across different neighborhoods of New York City (NYC). Thus, even if the above mentioned recruitment methods yielded representative samples, neighborhood differences in birth outcomes could confound the estimated effects of exposure to the dust cloud.

Our sample is based on the entire population of births in NYC, though in what follows we focus mainly on births to mothers residing in Manhattan. 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. For example, Berkowitz et al. (2003) include 187 births to mothers who were in the vicinity of the WTC at 9am on 9/11. These mothers were mostly self-referred in response to the researcher’s recruitment. The comparison group is composed of women delivering in the same time period at Mount Sinai hospital on the Upper East Side. The authors conclude that the incidence of poor birth outcomes was higher in the treatment group, but it is difficult to assess causality given the selected sample and a control group with different baseline characteristics.

Many existing studies do not control for the month of conception which is a potentially strong confounder for 9/11 effects. For example, Eskenazi et al. (2007) examine birth outcomes in upstate New York and in neighborhoods of NYC excluding lower Manhattan in the months following 9/11. They compare births in the week after 9/11, as well as in several later intervals, with births in the three weeks prior to 9/11. They find slightly elevated rates of low birth weight and premature births in upstate New York and NYC (excluding lower Manhattan) in the months following 9/11, and suggest that stress is the most likely explanation of this observed association.

Currie and Schwandt (2013) show using data from New York, New Jersey, and Pennsylvania, that the composition of mothers who conceive fluctuates strongly over the year and that the month of conception also affects birth outcomes independently of maternal characteristics. Since exposure to 9/11 -- especially if analyzed by pregnancy trimester -- is directly linked to the season of conception, failing to account for seasonal effects could severely bias estimates. In particular, babies conceived in February through May tend to have shorter gestation than babies conceived in November through January, suggesting that one would expect babies born in the quarter after 9/11 to have lower gestation than those born in the month prior to the attack.

Birth outcomes might also 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. In an innovative study, Lauderdale (2006) analyses births to mothers with Arabic names in California and finds that during the 6 months following 9/11 poor birth outcomes were significantly elevated for this group relative to non-Arab named mothers. She argues that Arabic-named mothers suffered particularly strong psychological stress in the aftermath of the attacks which in turn had a negative impact on their babies.

Lederman et al. (2004) study a total of 300 full-term births at three lower Manhattan hospitals dividing them into an exposed group (women who lived or worked within 2 miles of the WTC on 9/11) and an unexposed reference group. They found that the babies born to mothers in the exposed group were slightly smaller than those born to the reference group, but found that distance from the WTC had no impact on the estimated effect. Hence, they concluded that the negative effects were likely due to stress rather than exposure to dust.

Lipkind et al. (2010) compare 446 births to women enrolled in the WTC Health Registry (large self-referred in response to advertisement) to women residing more than 5 miles from the WTC and do not find any significant difference in birth outcomes. They do find that women who reported 9/11-related post-traumatic stress disorder had higher odds of LBW and preterm delivery. However, it is possible that this association is driven by third factors such as socio-economic status that might be associated with the likelihood of developing PTSD following the disaster.

Taken together these studies suggest that maternal stress related to 9/11 may have had detrimental effects on birth outcomes, but this effect is not restricted to mothers residing close to the WTC. Instead, effects have been detected independently of the region of residence, including among mothers in upstate New York and in California. In our analysis we compare mothers in the area affected by 9/11 dust to mothers in the other neighborhoods of Manhattan. Thus any stress effect that is common to mothers across areas should not result in differential effects on birth outcomes. In robustness checks we also ask whether the estimated effects change if only mothers in mid-/lower Manhattan or all mothers in NYC are included in the comparison group. If a common stress effect is stronger for mothers living closer to the WTC then the estimated effects should be smaller when including only mothers in mid-/lower Manhattan and larger when the comparison group is all NYC.

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 (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. 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.

3. Data and Methods

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 pre-pregnancy 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, 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 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. Further, identifying births to the same mother makes it possible to eliminate time-constant differences between exposed and non-exposed 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 more than six months prior to 10/2001 but born after 8/2001 (born 9/2001-12/2001).[2]

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[2] 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.

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 in the dust area and the no dust area below. 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, i.e. 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 Manhattan form the control area. We explore the robustness of our results to the use of alternative areas as control groups. For example, we try assigning the Lower East Side (which may have been less exposed to the dust cloud) to the control instead of the exposed area. We also try restricting the control area to mid- and lower Manhattan. And we extend it to include all births in NYC.

We restrict attention to single births with non-missing information on gestation length and birth weight. These restrictions yield a baseline sample of 1,226,552 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. 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; 3.8% of mothers smoke and 64.5% have a prenatal care visit during the first trimester. The rates of prematurity and low birth weight are 7.9% and 6.9%, 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 afterwards. In our sample a total of 112,483 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 they are slightly younger. Rates of prematurity and low birth weight are about one percentage point lower than in the full sample. In robustness checks we present regressions using this overall NYC sample of 9/11 sibling pairs.

Our baseline regression sample, however, is restricted to the subset of these children whose mothers lived in Manhattan. Columns (3) and (4) show means for this subsample, split by whether the 9/11 sibling was born in the area affected by the dust cloud or not. A total of 2,290 births were in sibling groups where at least one infant was potentially affected by the dust cloud while the no-dust sample includes 11,273 births. This total of 13,563 births constitutes our baseline regression sample. 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; 55.3% of mothers in the affected area are Asian, compared to 6.4% in the other neighborhoods of Manhattan and 10.9% in all NYC. The other considerable difference is the fraction of mothers with more than 12 years of education which is smaller in the dust-affected area than in the no-dust area (32.5% vs. 63.1%) but similar to the rate in all NYC. Maternal behavior in terms of smoking and the number of prenatal care visits is similar across the dust and the no-dust areas and more favorable than in all NYC. An important distinction is that rates of prematurity and low birth weight are lowest in the dust area (5.1% and 3.6%, respectively), followed by the no-dust area (6.2% and 4.5%) and they are highest in the all NYC sibling sample (6.7% and 5.6%).

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 socio-economic determinants of residential sorting and they are unlikely to capture the entire extent of selection.

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 residence in areas exposed to the 9/11 dust cloud. Further, we also include sibling pairs with the 9/11 sibling born in Manhattan *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 in Manhattan outside the dust area controls for 9/11 effects that are common across neighborhoods.

Hence, the design is "difference-in-differences" with mother fixed-effects, comparing 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) $$Y_i = \alpha + \beta(N_i*T_i) + \gamma N_i + \tau + \mu + \delta X_i + \varepsilon_i,$$

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 and 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; mom age <20, 20-24, 25-29, 30-34, >34, missing; an indicator equal to one if the father information is missing).

Controlling for specific neighborhoods in the dust-exposed area deals with fixed differences between neighborhoods. Year and 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-year level to allow for correlated errors within areas. When including data for all of NYC (and hence more neighborhoods, i.e. 195 instead of only 29 in Manhattan), we cluster at the neighborhood 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) $$Y_i = \alpha + \beta_1(N_i*T1_i) + \beta_2(N_i*T2_i) + \beta_3(N_i*T3_i) + \gamma N_i + \tau + \mu + \delta X_i + \varepsilon_i,$$

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) $$Y_i = \alpha + \beta(N_i*T_i) + \theta(N_i*T_i*boy_i) + \gamma N_i + \tau + \mu + \delta X_i + \varepsilon_i,$$

where boy_i is an indicator equal to one if the newborn is a boy. Consequently, β measures the effect of 9/11 dust exposure on girls, while $\beta+\theta$ measures the 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. As for the baseline regression equation, this model can be refined to estimate gender differences of exposure effects by individual pregnancy trimesters.

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.

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 miss-assigning 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 towards 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.

Figure 3 shows a migration flow chart of all mothers who give birth in Manhattan during the three years prior to 9/11 and had a further birth anywhere in NYC in the nine months following 9/11. Almost 80% 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. Only 3.6% migrated from the dust-affected area into the no-dust area. For mothers in the no-dust area the fraction of staying mothers is higher (87%) and the fraction of those migrating into the dust area is lower (1.1%). This difference in migration rates is due mainly to the fact that the “no-dust” area is larger than the area affected by 9/11 dust. If we chose a no-dust area of a similar size, e.g. midtown and lower Manhattan, then the fraction of staying mothers is 74% and thus very similar to the dust area (see the Appendix Figure 1 for this comparison).

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 comparison area. Further, only a negligible fraction of mothers switched between the no-dust area and the area affected by 9/11 dust: Most mothers who moved out of the area went to one of the other boroughs of New York City. These considerations suggest that any bias introduced by migration of mothers between conception and birth is likely to be small.

Still, we also present a robustness check that deals with possible endogenous mobility by focusing on pregnancies in progress on or before Sept. 2011 and instrumenting residence in a dust exposed area on 9/11. Following Currie and Rossin-Slater (2013), the instrument we construct is a hypothetical indicator equal to one if the mother would have been exposed to 9/11 dust had she stayed in the first location in which we observed her. This instrument is highly correlated with actual exposure given that most mothers do not move, and it should have no effect on birth outcomes over and above the effects of actual exposure. Any fixed characteristics of mothers correlated with the first place in which we observe them will be controlled for by the inclusion of maternal fixed effects.[3]

One remaining potential issue could be that mothers in the dust zone were more likely to move out of NYC altogether and therefore do not appear in the data set after 9/11. Appendix Table 1 shows that this is not the case. 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).

4. 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 7.9 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

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[3] The corresponding first stage equation is: $N_i{*}T_i = \alpha + \beta(N0_i{*}T_i) + \gamma N_i + \tau + \mu + \delta X_i + \varepsilon_i$, 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. 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.

effect is confined to infants exposed during the first trimester of pregnancy and is even larger for this group at 6.8 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 (10.4 percentage points) than on female fetuses (3.4 percentage points). Given a baseline probability of 8.16% 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 9.6 percentage point increase in prematurity for exposed vs. unexposed boys compared to a 4.5 percentage point increase for exposed vs. unexposed girls.

Table 3 shows estimates from equations (1), (2), and (3) where the dependent variables are gestation in weeks, low birth weight, 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, 1^{st} trimester exposure to the dust is associated with a reduction in gestation of a third of a week, and column (3) shows that it is mostly boys who are impacted. Similarly, there is an increase in low birth weight of 5.0 percentage points among boys, as well as an increase of 7.6 percentage points in the probability that male infants are admitted to the neonatal intensive care unit. These effects on low birth weight and admission to the NICU are large relative to the means shown in Table 1, representing increases of 79.4% and 90.5%, respectively. Thus, it appears that 9/11 roughly doubled the incidence of these outcomes among prenatally exposed male infants.

Granted that exposure to the 9/11 dust seems to have had a negative effect on birth outcomes, it is possible that some of the negative effect is via changes in maternal behaviors rather than via a "biological" effect of exposure. 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 married at the time of delivery or on the woman's self-reported pre-pregnancy weight. Column (3) shows that first trimester exposure negatively affects pregnancy weight gain if the newborn is a boy, potentially due to the negative effect on gestational length (-0.51 weeks or -3.58 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 smoking for third-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 are also plausible, since 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. 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 second 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.

Robustness Checks

Our estimation method relies on comparing mothers in the dust-affected area to mothers in another "control" area. In order to investigate whether our estimates are sensitive to the choice of control area, we present estimates based on several alternative choices in Table 5. The first three columns show models based on a sample in which the lower east side of Manhattan is moved from the dust to the no-dust category. Since the lower east side was on the boundary of the affected area, it is possible that not all of it was affected. However, comparing estimates based on this reclassification to the baseline, which is reproduced in columns (4) to (6), shows that the estimates are quite similar.

Columns (7) to (9) show estimates restricting the sample to the area shown in Figure 2, that is, to mid- and lower Manhattan. Again, the estimates are very similar to the baseline. Finally, the last three columns of Table 5 show estimates using all of New York City (rather than only Manhattan) as the sample. Once again, the estimates are quite similar to those of the baseline. We conclude that the choice of control area has very little effect on the estimates.

Table 6 shows estimates that exclude 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 under-estimate of the true health effect. Table 6 shows that in fact the estimates are larger when babies conceived after September 2001 are excluded, suggesting that there may indeed have been a permanent maternal health effect.

Table 7 continues to focus on the sample of births excluding babies conceived after September 2001, and implements the instrumental variables strategy described above. The estimates are a little larger than in Table 6, though the standard errors also increase modestly so that we cannot reject the null hypothesis that the estimates are similar to those in Table 6.

5. 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 New York City, and there is a great deal of accumulated 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, they were less likely to have poor birth outcomes, other things being equal. When we control for these pre-existing differences by following the same mothers over time, we find large effects of exposure to the dust cloud. Another piece of the puzzle falls into place given that there is heterogeneity in the effects: 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 (which was 7.75% for girls and 8.16% for boys) and had similarly large effects on the probability of low birth weight and admission to the NICU.

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. We find surprisingly little effect on these behaviors suggesting that the estimated effects of living in a dust-affected area on infant health most likely reflect a biological response to pollution exposure.

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 2 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, low birth weight, and NICU admission. 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 truly detrimental effects of 9/11 on infant health at birth.

We can also place these estimates in perspective by comparing them to previous estimates of the effects of air pollution on fetal health. 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 high way toll plazas. They find that these reductions in pollution resulted in a 10% reduction in the incidence of low birth weight and prematurity. In contrast to the relatively small 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.

References

Almond, Douglas and Bhashkar Mazumdar. 2011. "Health capital and the prenatal environment: The effect of Ramadan observance during pregnancy", *American Economic Journal: Applied Economics,* Vol. 3. No. 4. pp.56-85.

Berkowitz, Gertrud S., Mary S. Wolff, Teresa M. Janevic, Ian R. Holzman, Rachel Yehuda, and Philip J. Landrigan. 2003. "The World Trade Center disaster and intrauterine growth restriction." *JAMA - Journal of the American Medical Association*. 290(5):595-596.

Black, Sandra, Aline Bütikofer, Paul Devereux, Kjell Salvanes. "This Is Only a Test? Long-Run Impacts of Prenatal Exposure to Radioactive Fallout," NBER Working Paper #18987, April 2013.

Catalano, R., Bruckner, T., Marks, A. R., & Eskenazi, B. (2006). Exogenous shocks to the human sex ratio: the case of September 11, 2001 in New York City. *Human Reproduction*, *21*(12), 3127-3131.

Catalano, R., Bruckner, T., Gould, J., Eskenazi, B., & Anderson, E. (2005). Sex ratios in California following the terrorist attacks of September 11, 2001. *Human Reproduction*, *20*(5), 1221-1227.

Chay, K. Y., & Greenstone, M. (2003a). The Impact Of Air Pollution On Infant Mortality: Evidence From Geographic Variation In Pollution Shocks Induced By A Recession. *Quarterly Journal of Economics*, *118*(3).

Chay, K. Y., & Greenstone, M. (2003b). Air quality, infant mortality, and the Clean Air Act of 1970. NBER Working Paper #10053, October 2003.

Childs, B. (1965). Genetic origin of some sex differences among human beings. *Pediatrics*, *35*(5), 798-812.

Currie, J. (2011). Inequality at Birth: Some Causes and Consequences. *The American Economic Review*, *101*(3), 1-22

Currie, J., Davis, L., Greenstone, M., & Walker, R. (2013). Do housing prices reflect environmental health risks? Evidence from more than 1600 toxic plant openings and closings. NBER Working Paper #18700, January 2013.

Currie, J., & Neidell, M. (2005). Air Pollution and Infant Health: What Can We Learn from California's Recent Experience? *The Quarterly Journal of Economics*, *120*(3), 1003-1030.

Currie, J., Neidell, M., & Schmieder, J. F. (2009). Air pollution and infant health: Lessons from New Jersey. *Journal of Health Economics*, *28*(3), 688-703.

Currie, J & Rossin-Slater, M. (2013). "Weathering the Storm: Hurricanes and Birth Outcomes," Journal of Health Economics, 32 #3, May, 487-503.

Currie, J., & Schwandt, H. (2013). Within-mother analysis of seasonal patterns in health at birth. *Proceedings of the National Academy of Sciences*, *110*(30), 12265-12270.

Currie, J., & Walker, R. (2011). Traffic Congestion and Infant Health: Evidence from E-ZPass. *American Economic Journal: Applied Economics*, *3*(1), 65-90.

Dejmek, J. Selevan, S.G., and Sram, R.J. "The Environment, Life Style, and Pregnancy Outcome," Cas Lek Cesk, Aug 21, 135 #16, 510-515.

Dinkelman, Taryn. "Mitigating long-run health effects of drought: Evidence from South Africa," Dartmouth, NBER Working Paper #19756, 2013.

Eriksson, JG, Kajantic E, Osmond C, Thornburg K, Barker DJP. "Boys Live Dangerously in the Womb," Am J Hum Biol, 2010, 22, 330-335.

Eskenazi, B., Marks, A. R., Catalano, R., Bruckner, T., & Toniolo, P. G. (2007). Low birthweight in New York City and upstate New York following the events of September 11th. *Human Reproduction*, *22*(11), 3013-3020.

Fukuda, M., Fukuda, K., Shimizu, T., & Møller, H. (1998). Decline in sex ratio at birth after Kobe earthquake. *Human reproduction*, *13*(8), 2321-2322.

Fukuda, M., Fukuda, K., Shimizu, T., Andersen, C. Y., & Byskov, A. G. (2002). Parental periconceptional smoking and male: female ratio of newborn infants. *The Lancet*, *359*(9315), 1407-1408.

Graff Zivin, Joshua, and Matthew Neidell. 2013. "Environment, Health, and Human Capital." *Journal of Economic Literature*, 51(3): 689-730.

Hansen, D., Møller, H., & Olsen, J. (1999). Severe periconceptional life events and the sex ratio in offspring: follow up study based on five national registers. *Bmj*, *319*(7209), 548-549.

Kraemer, S. (2000). The fragile male. *BMJ: British Medical Journal*, *321*(7276), 1609.

Landrigan, P. J., Lioy, P. J., Thurston, G., Berkowitz, G., Chen, L. C., Chillrud, S. N., ... & Small, C. (2004). Health and environmental consequences of the world trade center disaster. *Environmental Health Perspectives*, *112*(6), 731.

Lauderdale, D. S. (2006). Birth outcomes for Arabic-named women in California before and after September 11. *Demography*, *43*(1), 185-201.

Lavoie, M. E., Robaey, P., Stauder, J. E., Glorieux, J., & Lefebvre, F. (1998). Extreme prematurity in healthy 5-year-old children: a re-analysis of sex effects on event-related brain activity. *Psychophysiology*, *35*(6), 679.

Lederman, S. A., Rauh, V., Weiss, L., Stein, J. L., Hoepner, L. A., Becker, M., & Perera, F. P. (2004). The effects of the World Trade Center event on birth outcomes among term deliveries at three lower Manhattan hospitals. *Environmental Health Perspectives*, *112*(17), 1772.

Lioy, P. J., Weisel, C. P., Millette, J. R., Eisenreich, S., Vallero, D., Offenberg, J., ... & Chen, L. C. (2002). Characterization of the dust/smoke aerosol that settled east of the World Trade

Center (WTC) in lower Manhattan after the collapse of the WTC 11 September 2001. *Environmental Health Perspectives*, *110*(7), 703.

Lipkind, H. S., Curry, A. E., Huynh, M., Thorpe, L. E., & Matte, T. (2010). Birth outcomes among offspring of women exposed to the September 11, 2001, terrorist attacks. *Obstetrics & Gynecology*, *116*(4), 917-925.

Mizuno, R. (2000). The male/female ratio of fetal deaths and births in Japan. *The Lancet*, *356*(9231), 738-739.

Perlman, S. E., Friedman, S., Galea, S., Nair, H. P., Erős-Sarnyai, M., Stellman, S. D., ... & Greene, C. M. (2011). Short-term and medium-term health effects of 9/11. *The Lancet*, *378*(9794), 925-934.

Pleil, J. D., Vette, A. F., Johnson, B. A., & Rappaport, S. M. (2004). Air levels of carcinogenic polycyclic aromatic hydrocarbons after the World Trade Center disaster. *Proceedings of the National Academy of Sciences of the United States of America*, *101*(32), 11685-11688.

Singer, J. E., Westphal, M., & Niswander, K. R. (1968). Sex differences in the incidence of neonatal abnormalities and abnormal performance in early childhood. *Child development*, 103-112

US Environmental Protection Agency (2005). Mapping the spatial extent of ground dust and debris from the collapse of the World Trade Center buildings. Appendix A, Figures. *US Environmental Protection Agency, EPA/600/R-03/018.*

Zivin, J. G., & Neidell, M. (2013). Environment, Health, and Human Capital. *Journal of Economic Literature*, 51(3), 689-730.

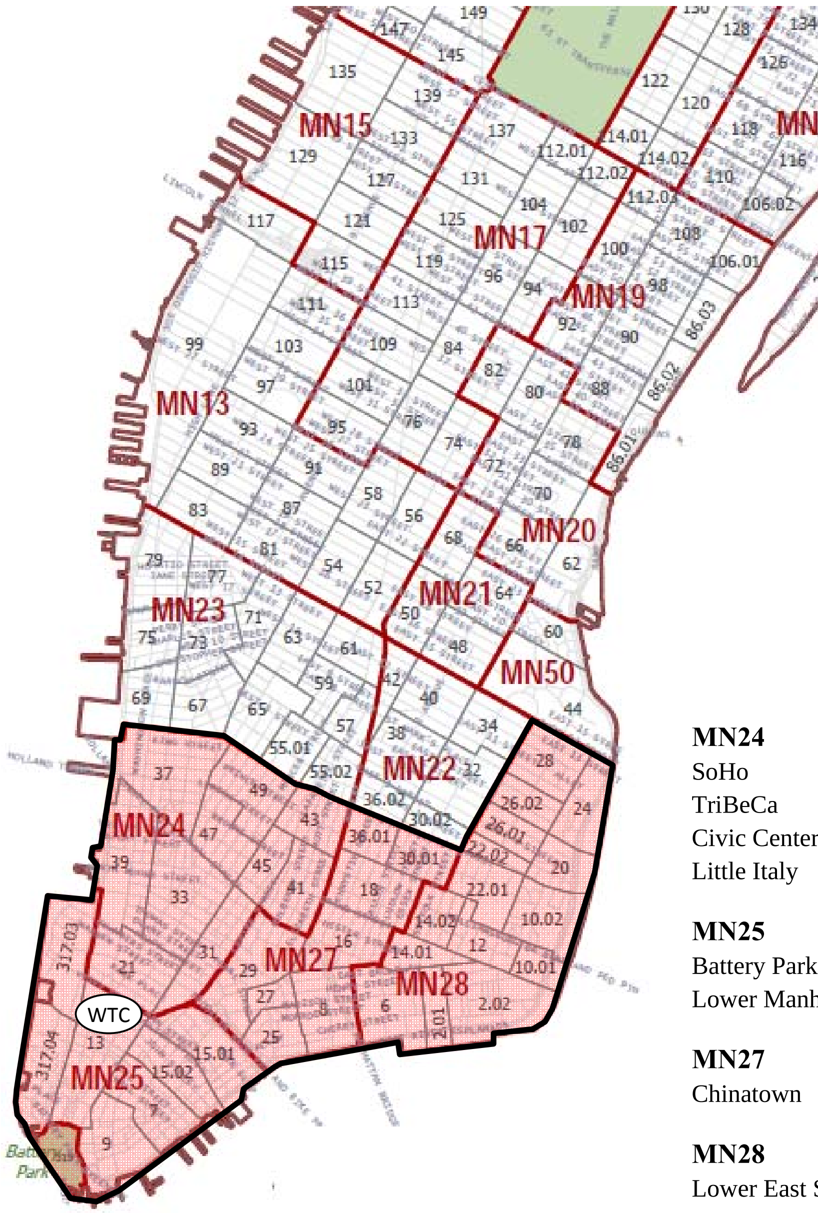
Figure 1: Aerial photographs of the WTC collapse

(A) Collapse cloud WTC building 2 (approx. 10am)

(B) Collapse cloud WTC building 1 (approx. 10:30am)

Source: US Environmental Protection Agency (2005).

Figure 2: Neighborhood Tabulation Areas in Lower Manhattan affected by the 9/11 dust cloud.



MN24
SoHo
TriBeCa
Civic Center
Little Italy

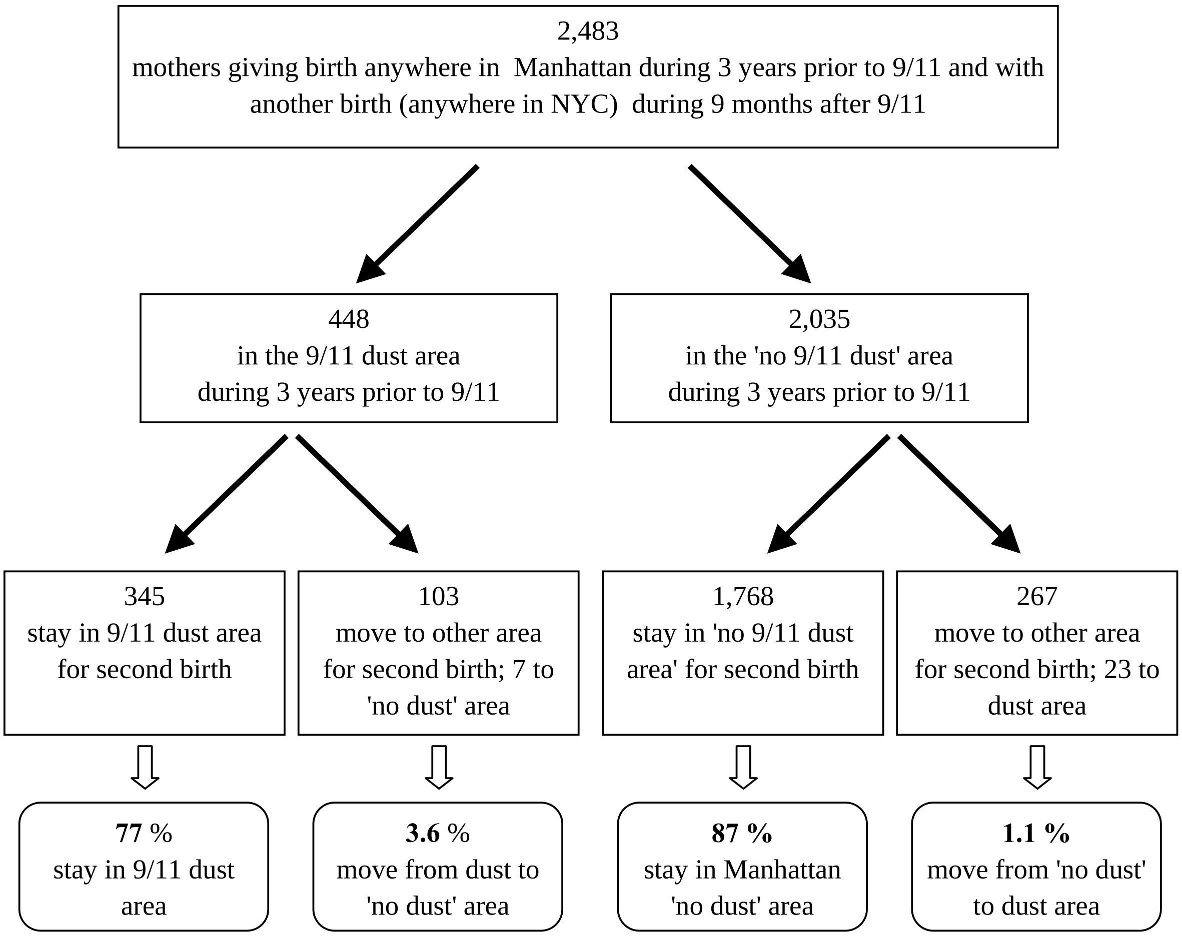
MN25
Battery Park City
Lower Manhattan

MN27
Chinatown

MN28
Lower East Side

Source: http://www.nyc.gov/html/dcp/pdf/census/census2010/ntas.pdf. Shaded areas, neighborhood names and WTC marker added.

Figure 3: Migration behavior of mothers in 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 area' in consists of all neighborhoods in Manhattan not contained in the dust area. The difference in migration rates between dust and 'no-dust' area mothers is due to the fact that the 'no-dust' area is larger than the area affected by 9/11 dust (25 vs. 4 neighborhoods). See Appendix Figure 1 for migration patterns between areas of similar size.

Table 1: Descriptive Statistics

		Sibling pairs, with one sibling in utero on 9/11		
		9/11 sibling born	9/11 sibling born in Manhattan	
	All NYC births	anywhere in NYC	no dust area	dust area
	(1)	(2)	(3)	(4)
Mother characteristics				
White, non-hispanic	0.257	0.325	0.483	0.206
Hispanic	0.343	0.321	0.325	0.192
Black (and other)	0.280	0.244	0.126	0.048
Asian	0.114	0.109	0.064	0.553
Age	27.93	27.22	30.15	28.10
	(6.32)	(5.94)	(6.25)	(5.62)
>12 yrs of education	0.383	0.359	0.631	0.325
Married	0.512	0.572	0.678	0.693
Weight gain	30.59	29.78	30.87	29.34
	(12.71)	(12.45)	(11.57)	(10.65)
Prepregnancy weight	142.8	142.8	137.7	129.0
	(33.2)	(33.4)	(29.3)	(28.0)
Hypertension	0.022	0.018	0.017	0.009
Smoking	0.038	0.031	0.021	0.019
PCV during first trimester	0.645	0.660	0.759	0.656
Birth outcomes				
Prematurity (< 37 weeks)	0.079	0.067	0.062	0.051
Prematurity, boys	0.082	0.070	0.066	0.055
Prematurity, girls	0.077	0.063	0.058	0.047
Low birth weight (< 2500g)	0.069	0.056	0.045	0.036
Low birth weight, boys	0.063	0.052	0.040	0.038
Low birth weight, girls	0.075	0.061	0.051	0.035
Gestation length (weeks)	38.89	38.99	38.94	39.05
	(2.06)	(1.88)	(1.73)	(1.63)
Gestation length, boys	38.87	38.96	38.90	38.99
	(2.08)	(1.91)	(1.76)	(1.63)
Gestation length, girls	38.91	39.02	38.97	39.11
	(2.05)	(1.84)	(1.70)	(1.61)
Birth weight (g)	3,282	3,314	3,345	3,335
	(571)	(543)	(521)	(485)
Birth weight, boys	3,337	3,372	3,408	3,398
	(581)	(555)	(532)	(490)
Birth weight, girls	3,225	3,254	3,279	3,270
	(555)	(523)	(502)	(471)
Neonatal IC unit	0.081	0.064	0.066	0.029
Neonatal IC unit, boys	0.084	0.068	0.068	0.040
Neonatal IC unit, girls	0.077	0.060	0.065	0.017
Baby is a boy	0.512	0.509	0.515	0.510
Birth of sibling observed	0.45	1	1	1
N total births	1,226,552	112,483	11,273	2,290

Notes: Sample period: 1/1994-12/2004. 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' area includes the remaining neighborhoods in Manhattan. Standard errors in parentheses.

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

Dependent variable:	Sample				
	All births			Boys	Girls
Gestation < 37 weeks	(1)	(2)	(3)	(4)	(5)
Dust exposure (any trim.)	0.022***				
	(0.008)				
1st trimester dust exposure		0.068***	0.034**	0.096***	0.045*
		(0.014)	(0.016)	(0.037)	(0.023)
1st trim. dust exposure*boy			0.070***		
			(0.022)		
2nd trimester dust exposure		-0.011	-0.003	-0.014	-0.018
		(0.012)	(0.020)	(0.027)	(0.047)
2nd trim. dust exposure*boy			-0.017		
			(0.028)		
3rd trimester dust exposure		0.004	-0.008	0.004	-0.013
		(0.014)	(0.020)	(0.020)	(0.028)
3rd trim. dust exposure*boy			0.025		
			(0.022)		
N		13,563		4,143	3,781

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 Pk City, SoHo, TriBeCa, Civic Center, Little Italy, China Town and Lower East Side. 1st trimester dust exposure is the interaction of the exposure variable with 1st trimester pregnancy during 9/11 (respectively for 2nd and 3rd trimester). "*boy" is the interaction with child gender. The sample in columns (1) to (3) consists of all sibling pairs born between 1994 and 2004, with one sibling in utero on 9/11 and born in Manhattan. In column (4) and (5) the sample is further restricted to brother pairs and sister pairs, respectively. All regressions control separately for pregnancy during 9/11 by trimester, the dust region, child gender, birth order, mothers' age group, and fixed effects for conception year, conception month and for each mother. Robust standard errors in parenthesis are clustered at the neighborhood-year level. * Significance level at p<0.10; ** Significance level at p<0.05; *** Significance level at p<0.01.

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

	Dependent Variable								
	Gestation (in weeks)			Low birth weight (<2500g)			Neonatal intensive care unit		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Dust exposure (any trim.)	-0.047			0.009			0.010		
	(0.061)			(0.011)			(0.014)		
1st trimester dust exposure		-0.339***	-0.175		0.022	-0.005		0.048**	0.021
		(0.103)	(0.117)		(0.019)	(0.024)		(0.024)	(0.017)
1st trim. dust exposure*boy			-0.337**			0.055**			0.055*
			(0.159)			(0.025)			(0.029)
N	13,563								

Notes: Coefficients from mother fixed effects regressions of different birth outcomes 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 Pk City, SoHo, TriBeCa, Civic Center, Little Italy, China Town and Lower East Side. 1st trimester dust exposure is the interaction of the exposure variable with 1st trimester pregnancy during 9/11. "**boy*" is the interaction with child gender. The sample consists of all sibling pairs born between 1994 and 2004, with one sibling in utero on 9/11 and born in Manhattan. All regressions control separately for pregnancy during 9/11 by trimester, the dust region, child gender, birth order, mothers' age group, and fixed effects for conception year, conception month and for each mother. Robust standard errors in parenthesis are clustered at the neighborhood-year level. * Significance level at p<0.10; ** Significance level at p<0.05; *** Significance level at p<0.01.

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

Dependent Variable	Mother is married (1)	Prepregnancy weight (2)	Maternal weight gain (3)	Hypertension (4)	Mother smokes (5)	Prenat. care visit in 1st trimester (6)	Baby is a boy (7)
1st trimester dust exposure	-0.021	0.80	0.09	0.014*	0.002	0.101***	-0.019
	(0.024)	(1.05)	(0.88)	(0.008)	(0.007)	(0.038)	(0.032)
1st trim. dust exposure*boy	-0.002	-1.07	-1.84**	0.003	-0.006	-0.101	-
	(0.026)	(2.12)	(0.890)	(0.018)	(0.013)	(0.071)	-
2nd trimester dust exposure	-0.047	-1.93	0.34	-0.004	0.006	0.060	-0.026
	(0.029)	(1.42)	(0.92)	(0.009)	(0.014)	(0.063)	(0.042)
2st trim. dust exposure*boy	0.050	0.55	-1.24	-0.001	0.005	-0.023	-
	(0.032)	(2.48)	(1.19)	(0.015)	(0.014)	(0.061)	-
3rd trimester dust exposure	-0.029	1.87	-0.38	0.017	0.015*	0.027	0.020
	(0.021)	(1.22)	(0.95)	(0.012)	(0.008)	(0.042)	(0.037)
3st trim. dust exposure*boy	0.023	-1.70	-0.98	-0.007	-0.019	-0.095	-
	(0.036)	(1.72)	(0.86)	(0.013)	(0.016)	(0.065)	-
N	13,563	12,963	12,928	13,563	13,534	12,703	13,563

Notes: Coefficients from mother fixed effects regressions of birth and mother characteristics on 9/11 dust exposure during pregnancy are displayed. Robust standard errors in parenthesis are clustered at the neighborhood-year level. * Significance level at p<0.10; ** Significance level at p<0.05; *** Significance level at p<0.01. Further comments as in Table 2.

Table 5: Alternative area specifications

Dependent variable: Gestation < 37 weeks	Moving Lower E Side from dust to no-dust area (1)	(2)	(3)	Sample area: Manhattan (baseline) (4)	(5)	(6)	Mid-/Downtown Manhattan (7)	(8)	(9)	Entire New York City (10)	(11)	(12)
Dust exposure (any trim)	0.018*			0.022***			0.036***			0.020***		
	(0.009)			(0.008)			(0.010)			(0.003)		
1st trimester dust exposure		0.057***	0.022		0.068***	0.034**		0.066***	0.034**		0.058***	0.023**
		(0.018)	(0.023)		(0.013)	(0.016)		(0.017)	(0.020)		(0.009)	(0.010)
1st trim. dust exposure*boy			0.076**			0.070***			0.065***			0.075***
			(0.030)			(0.022)			(0.024)			(0.023)
N		13,563			13,563			4,705			111,920	

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. In columns (4)-(12) the 9/11 dust area includes Lower Manhattan, Battery Pk City, SoHo, TriBeCa, Civic Center, Little Italy, China Town and Lower East Side. In columns (1)-(3) Lower East Side is counted as unaffected area. Regressions in columns (7)-(9) include only areas south of Central Park, and all areas in NYC in columns (10)-(12). 1st trimester dust exposure is the interaction of the exposure variable with 1st trimester pregnancy during 9/11. "**boy*" is the interaction with child gender. The sample consists of all sibling pairs born between 1994 and 2004, with one sibling in utero on 9/11 and born in Manhattan. All regressions control separately for pregnancy during 9/11 by trimester, the dust region, child gender, birth order, mothers' age group, and fixed effects for conception year, conception month and for each mother. Robust standard errors in parenthesis are clustered at the neighborhood-year level in columns (1)-(9) and clustered at the neighborhood level in columns (10)-(12). * Significance level at p<0.10; ** Significance level at p<0.05; *** Significance level at p<0.01.

Table 6: Excluding conceptions after 9/2001

	Sample: Excluding conceptions after 9/2001				
Dependent variable:	All births			Boys	Girls
Gestation < 37 weeks	(1)	(2)	(3)	(4)	(5)
Dust exposure (any trim.)	0.040***				
	(0.011)				
1st trimester dust exposure		0.089***	0.049**	0.154**	0.074**
		(0.017)	(0.021)	(0.072)	(0.033)
1st trim. dust exposure*boy			0.085***		
			(0.033)		
N		10,988		5,636	5,352

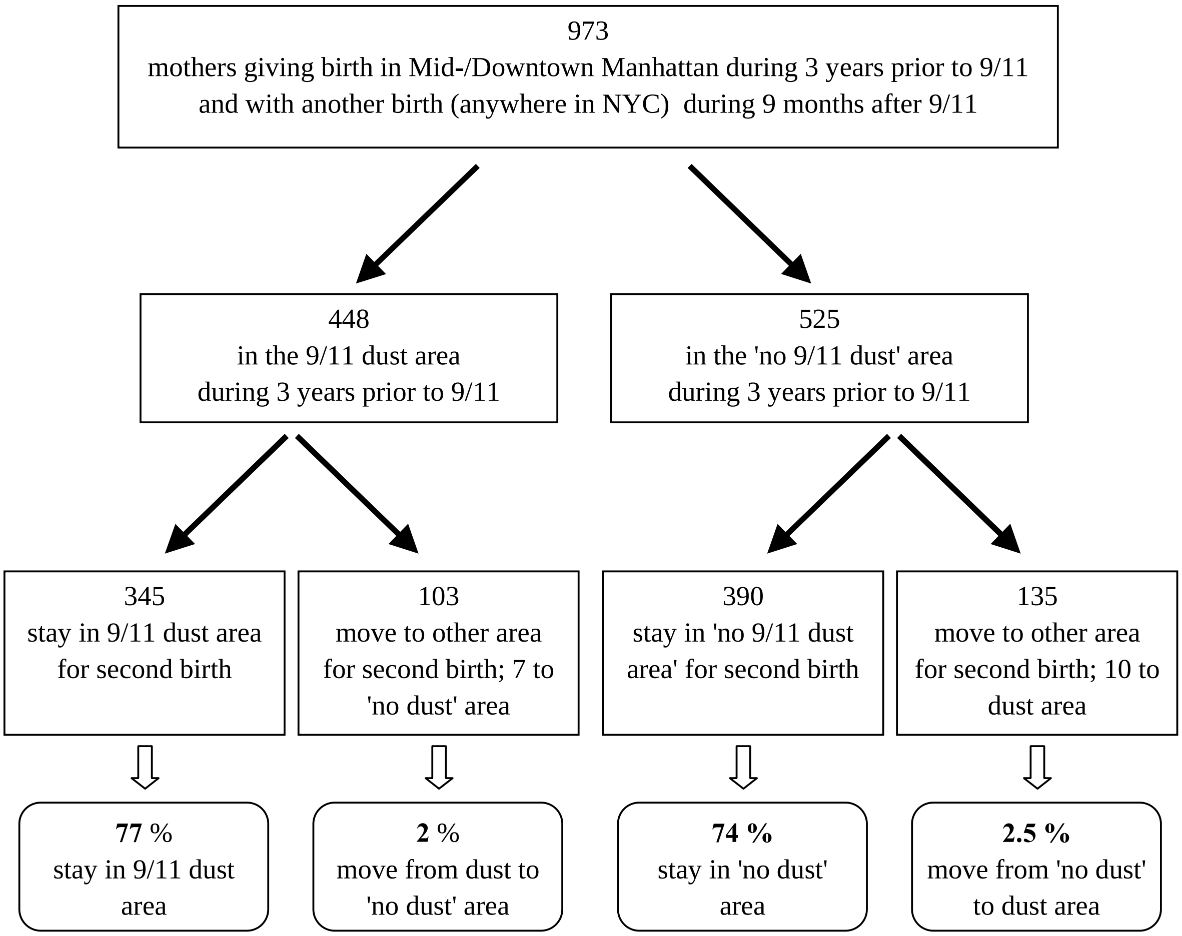
Notes: Coefficients from mother fixed effects regressions of premature births (gestation<37 weeks) on 9/11 dust exposure during pregnancy are displayed. Conceptions after 9/2001 are excluded. Dust exposure is the interaction of pregnancy during 9/11 and birth in the 9/11 dust area. The 9/11 dust area includes Lower Manhattan, Battery Pk City, SoHo, TriBeCa, Civic Center, Little Italy, China Town and Lower East Side. 1st trimester dust exposure is the interaction of the exposure variable with 1st trimester pregnancy during 9/11. "**boy*" is the interaction with child gender. The sample consists of all sibling pairs born between 1994 and May 2002, with one sibling in utero on 9/11 and born in Manhattan. All regressions control separately for pregnancy during 9/11 by trimester, the dust region, child gender, birth order, mothers' age group, and fixed effects for conception year, conception month and for each mother. Robust standard errors in parenthesis are clustered at the neighborhood-year level. * Significance level at p<0.10; ** Significance level at p<0.05; *** Significance level at p<0.01.

Table 7: IV regressions with pre-9/11 neighborhood as instrument for 9/11 neighborhood

Dependent variable:	All births			Boys	Girls
Gestation < 37 weeks	(1)	(2)	(3)	(4)	(5)
Dust exposure (any trim.)	0.041*** (0.015)				
1st trimester dust exposure		0.102*** (0.025)	0.051 (0.033)	0.185*** (0.050)	0.080* (0.043)
1st trim. dust exposure*boy			0.115** (0.046)		
N		10,988		5,636	5,352

Notes: Coefficients from IV regressions of premature births (gestation<37 weeks) on 9/11 dust exposure during pregnancy are displayed. The mothers' neighborhood at the first birth observed in the sample is used as an instrument for the neighborhood on 9/11. Conceptions after 9/2001 are excluded. 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 Pk City, SoHo, TriBeCa, Civic Center, Little Italy, China Town and Lower East Side. 1st trimester dust exposure is the interaction of the exposure variable with 1st trimester pregnancy during 9/11. "**boy*" is the interaction with child gender. The sample consists of all sibling pairs born between 1994 and May 2002, with one sibling in utero on 9/11 and born in Manhattan. All regressions control separately for pregnancy during 9/11 by trimester, the dust region, child gender, birth order, mothers' age group, and fixed effects for conception year, conception month and for each mother. Robust standard errors in parenthesis are clustered at the neighborhood-year level. * Significance level at p<0.10; ** Significance level at p<0.05; *** Significance level at p<0.01.

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 area' in Mid-/Downtwon Manhattan consists of all neighborhoods south of Central Park not contained in the dust area.

Appendix Table 1:

Dependent variable: Sibling appears in post-9/11 period, anywhere in NYC	Sample: All pre-9/11 births in	
	Manhattan	Entire NYC
	(1)	(2)
Born in dust area	0.009	-0.014
(pre-9/11 births only)	(0.016)	(0.015)
Constant	0.134***	0.157***
	(0.007)	(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 one if the sample child has a sibling that is born after 9/11, anywhere in NYC. The explanatory variable is a dummy that equals one if the sample child is born in the 9/11 dust area. The 9/11 dust area includes Lower Manhattan, Battery Pk City, SoHo, TriBeCa, Civic Center, Little Italy, China Town and Lower East Side. Robust standard errors in parenthesis are clustered at the neighborhood-year level. * Significance level at p<0.10; ** Significance level at p<0.05; *** Significance level at p<0.01.

Appendix Table 2: Comparison of mean birth outcomes by SES with the estimated effect of 1st trimester dust cloud exposure.

	Disadvantaged mothers Edu<12; unmarried; black (1)	Advantaged mothers Edu>12; married; white (2)	Diff (1)-(2) (3)	Estimated 1st trim dust effect (4)
Prematurity (< 37 weeks)	0.126	0.048	0.078	0.068***
Prematurity, boys	0.126	0.051	0.075	0.104***
Prematurity, girls	0.126	0.045	0.081	0.034**
Low birth weight (< 2500g)	0.122	0.037	0.086	0.022
Low birth weight, boys	0.111	0.033	0.078	0.05**
Low birth weight, girls	0.134	0.041	0.094	-0.005
Neonatal IC unit	0.138	0.045	0.093	0.048**
Neonatal IC unit, boys	0.141	0.049	0.091	0.076*
Neonatal IC unit, girls	0.135	0.041	0.094	0.021

Notes: Sample means of birth outcomes for the overall NYC sample are displayed by socio-economic status in column (1) and (2). Column (3) shows the difference between the two. Column (4) shows the estimates reported in Table (2) and (3).