The Effect of Open-Air Waste Burning on Infant Health: Evidence from Government Failure in Lebanon*

Pierre Mouganie † Ruba Ajeeb‡ Mark Hoekstra§

March 2, 2020

Abstract

An estimated 40 percent of the world's garbage is burned in open-air fires, which are responsible for as much as half of the global emissions of some pollutants. However, there is little evidence on the health consequences of open-air waste burning. In this paper, we estimate the effect of *in utero* exposure to open-air waste burning on birth outcomes. We do so by examining the consequences of the Lebanese garbage crisis of 2015, which led to an abrupt, unanticipated increase in waste burning in residential neighborhoods in Beirut and Mount Lebanon. To identify effects, we exploit variation in exposure across neighborhoods before and after the crisis. Results indicate exposure had large impacts on birth outcomes; *in utero* exposure to at least one open-air waste burn increased premature births by 4 percentage points (50%) and low birth weight by 5 to 8 percentage points (80 – 120%). Given previous research documenting the long-run effects of prenatal shocks on adult health, human capital, and labor market outcomes, this suggests open-air waste burning imposes significant costs on populations worldwide.

JEL Classification: I18; H41

Keywords: Prenatal health; *in utero* pollution exposure; open-air waste burning

*

†American University of Beirut, Department of Economics and IZA, *Email:* pm10@aub.edu.lb

‡American University of Beirut, Department of Economics, *Email:* rja41@mail.aub.edu

§Texas A&M University, Department of Economics, NBER, and IZA, *Email:* markhoekstra@tamu.edu

1 Introduction

Open-air burning of garbage is the uncontrolled incineration of organic and inorganic waste in landfills and residential areas. Despite the risks associated with this practice, it is a popular method of waste reduction, especially in developing nations. Indeed, an estimated 40 percent of global waste is burned in open air. This practice is responsible for more than 20 percent of particulate matter (PM_{10}) and nearly 40 percent of Polycyclic Aromatic Hydrocarbons (PAH) in the atmosphere worldwide (Wiedinmyer, Yokelson, and Gullett 2014). This is of growing concern as waste production is increasing at a rapid rate. The World Bank estimates that from 2012 to 2025 the garbage produced worldwide will nearly double from 1.3 billion tons to 2.2 billion tons. Yet despite the prevalence of open-air waste burning and its role in reducing air quality worldwide, little is known about its health consequences. This is both because of data limitations in the developing countries where the practice is common, and because it is difficult to credibly distinguish effects from confounding factors.

The purpose of this paper is to document the effects of open-air waste burning on health. In particular we focus on the impact on infant health. This is partly because adults who are exposed likely only show effects years later, and this long lag makes it difficult to disentangle the effects of exposure from other factors (Currie 2013). In addition, there is significant evidence the prenatal and early childhood environments are especially important for long-run human capital formation and adult health, as discussed in reviews by Almond and Currie (2011) and Almond, Currie, and Duque (2018). We do so by studying the consequences of waste burning that occurred as a result of the Lebanese garbage crisis of 2015. The crisis was caused by the unexpected closure of a major landfill in Lebanon during the summer of 2015. This led to massive pile-ups of garbage in residential neighborhoods across Lebanon, and to an abrupt, unanticipated increase in waste burning throughout the country. We identify effects by exploiting variation in exposure across neighborhoods before and after the crisis. Specifically, we estimate the effect of exposure to at least one open-air waste fire during pregnancy, and the effect of exposure to the number of open-air waste fires during pregnancy. We do so using administrative data on every birth at the American University of Beirut Medical Center—the largest hospital in Lebanon—from 2010 to early 2017.

Results indicate that exposure to at least one incident of waste burning increased the likelihood of premature birth by roughly 4 percentage points (50 percent), and low birth weight (defined as below 2,500 grams) by 5 to 8 percentage points (80 - 120 percent). Exposure reduced overall birthweight by 61 to 98 grams (2.2 to 3.5 percent); the smaller relative effect on birthweight is consistent with much (but not all) of the previous research on prenatal shocks.[1] Results also indicate that effects increase with more exposure; we estimate that each additional waste fire to which a pregnant woman is exposed increases the probability of low birth weight by 0.6 to 1 percentage points (approximately 10 percent) and overall birthweight by 9 to 18 grams. These effects are large given the exposure of pregnant women in our sample. Among those with some exposure in our data, the median exposure during pregnancy was two waste burns, and exposure for women at the 90th percentile was eight waste burns. We also test for differential effects by trimester of exposure, and find effects are driven by exposure during the first and second trimesters.

We assess the validity of our design and the robustness of our estimates in several ways. First, we present event study figures for both of our empirical approaches and show that birth outcomes of mothers in areas subsequently exposed and less exposed to waste burns followed the same trajectory prior to the crisis. More specifically, we show that leading indicators for exposure are economically small and statistically indistinguishable from zero. This is consistent with the identifying assumption that absent waste burning, neighborhoods exposed and unexposed to burning would have had similar changes in birth outcomes. In addition, we show that exposure is uncorrelated with the number of births, and with exogenous covariates including maternal age and whether the mother has private insurance. We do find that exposure is associated with a three to four percentage point reduction in the likelihood of giving birth to a male, which we interpret as consistent with existing evidence suggesting that male fetuses are more susceptible to prenatal stress (e.g. Hansen, Møller, and Olsen 1999; Sanders and Stoecker 2015). Finally, we show that our estimates are robust to a wide range of controls including baby gender, maternal age, type of insurance, district-by-year fixed effects, neighborhood-specific linear time trends, and neighborhood-specific quadratic time trends.

In assessing the effects of waste burning exposure on birth outcomes, this paper makes two contributions to the literature. First, to our knowledge this is the first paper to look at the causal effects of open-air waste burning on health outcomes. The closest paper of which we are aware is Rangel and Vogl (2019), who examine the effects of sugarcane field burning in Brazil on birth outcomes. They find that third-trimester exposure to a one standard deviation increase in the agricultural burning of sugarcane fields in the Brazilian state of Sao Paulo is associated with a 41 percent increase in low birthweight and increases in mortality, though they find no effects from exposure in the first two trimesters. Similarly, Singh, Dey, Chowdhury, and Bali (2019) show exposure to crop burning and forest fires is associated with declines in height-at-age and weight-at-age. By comparison, the existing literature on

[1] This includes work on the impact of influenza (Schwandt 2018), income (Almond, Hoynes, and Schanzenbach 2011; Hoynes, Miller, and Simon 2015), and stress (Carlson 2015; Persson and Rossin-Slater 2018).

waste burning has to date focused on identifying the harmful pollutants emitted by waste burning, rather than analyzing their effects on individual welfare.[2] For example, Wiedinmyer, Yokelson, and Gullett (2014) estimate the quantity of worldwide pollutants that are caused by open-air waste combustion, which ranges from 5% of CO2 to 43% of organic carbon. Kodros et al. (2016) estimate that waste-combustion emissions result in 270,000 premature adult deaths each year, though they acknowledge these estimates are likely sensitive to the model and concentration-response functions used. Recent studies have found correlations between e-waste burning and health outcomes. A recent survey article by Grant et al. 2013 documents positive correlations in spontaneous abortions, stillbirths, and premature births, as well as reduced birth weight and gestational periods associated with exposure to burning of e-waste. The contribution of this paper is examine the effects on health using a quasi-experimental research design to overcome potential confounding factors, such as the concern that waste burns may occur in areas affecting lower-income people in poorer overall health.

Second, in assessing the impact of the air pollutants generated by open-air waste burning, this paper complements the large and growing literature establishing a causal link between toxicity and birth outcomes. Seminal papers by Chay and Greenstone (2003a, 2003b) show how reductions in air pollution generated by the U.S. Clean Air Act and industrial plant closings during the 1982 recession reduced infant mortality. Subsequently, researchers have documented the effect of air pollution on infant health and mortality (e.g. Currie and Neidell 2005; Currie and Walker 2011; Arceo, Hanna, and Oliva 2016; Knittel, Miller, and Sanders 2016; Currie, Davis, Greenstone, and Walker 2015).[3] Perhaps unsurprisingly given the nature of the exposure studied here, the effects we find are large relative to these other papers. Specifically, the 85 percent increase in low birthweight we observe is equivalent to exposing infants to an 80 - 90 percent increase in NO2 and associated other pollutants (Currie and Walker 2011), and is 30 times the estimated effect of living within one mile of a plant emitting toxics (Currie, Davis, Greenstone, and Walker 2015). Estimates from Almond, Hoynes, and Schanzenbach (2011) and Hoynes, Miller, and Simon (2015) suggest that it would take a 90

[2] Ashworth, Elliott, and Toledano (2014) report that no correlation between controlled waste burning–that is, waste incineration in a closed environment–and birth outcomes has been documented. However, the authors caution that results are inconclusive given difficulties overcoming confounding factors and a lack of statistical power faced by these studies.

[3] There is also a large literature examining the effect of other *in utero* shocks on infant health, including: water pollution (Currie, Graff Zivin, Meckel, Neidell, and Schlenker 2013); fetal nutrition (Almond and Mazumder 2011); maternal influenza (Schwandt 2018); income shocks and stress due to job loss (Almond, Hoynes, and Schanzenbach 2011; Hoynes, Miller, and Simon 2015; Lindo 2011; Carlson 2015); terrorist attack (Quintana-Domeque and Ródenas-Serrano 2017); death of a close relative during pregnancy (Persson and Rossin-Slater 2018); maternal smoking (Dolan-Mullen, Ramirez, and Groff 1994) and smoking bans (Hajdu and Hajdu 2018; Bharadwaj, Eberhard, and Neilson 2018); a change in the minimum legal drinking age (Barreca and Page 2015); and a change in maternity leave (Rossin 2011).

to 145 percent increase in income to offset effects of this magnitude, though we note that as in the other two comparisons, this degree of variation is well beyond that observed in the authors' data. Perhaps more telling is the increase we observe in low birthweight is roughly equivalent to the increase one would observe due to maternal smoking, based on evidence from randomized controlled trials (Dolan-Mullen, Ramirez, and Groff 1994).[4] In short, these effects are large relative to nearly any benchmark in the literature. We hypothesize this is in part due to the intensity of the treatment we study, and in part because the burning of modern urban trash releases a much wider range of toxins than the typical form of pollution studied in the literature. In addition, we believe this is particularly important given how common this practice is throughout the developing world.

The results in this study have important implications for both human health and public policy. While we cannot observe the long-run trajectories of infants born between 2015 and 2017, there is a large literature documenting the importance of early lifetime interventions on later life outcomes (e.g. Cunha and Heckman 2007). In particular, there is a consensus on the long-term negative impact of birth weight on future outcomes such as adult health, schooling attainment, and wages (Black, Devereux, and Salvanes 2007; Bharadwaj, Eberhard, and Neilson 2018; Figlio, Guryan, Karbownik, and Roth 2014; Bharadwaj, Lundborg, and Rooth 2018). Moreover, recent work has directly documented how exposure to pollution leads to worsened outcomes, including educational achievement (Sanders 2012), human capital accumulation and subsequent cancer risk and mortality (Ball 2018), and labor market participation and earnings (Isen, Rossin-Slater, and Walker 2017; Ball 2018). Collectively, this literature suggests the aggregate consequences of open-air waste burning are likely to be economically large. It also suggests a straightforward channel for improving human health: proper waste collection and disposal that does not involve open-air burning.

2 Background

2.1 Open-Air Waste Burning and Potential Impacts on Infant Health

Open-air waste burning is a common phenomenon worldwide. Wiedinmyer, Yokelson, and Gullett (2014) estimate that as much as 1.1 billion tons of waste, or 40 percent of total global waste, is burned in open piles. This practice is especially common in developing countries,

[4] If we instead consider birth weight, rather than low birth weight, the 60 to 100 gram reduction in birthweight we observe is about half the impact of living in the most- versus least-polluted areas of Great Britain in 1946, and is equivalent to a four-month disruption in fetal nutrition (Almond and Mazumder 2011).

and has significantly contributed to the rise in global air pollutants that World Health Organization (WHO) models estimate increases the risk of critical health conditions such as tuberculoisis, asthma, cataracts, low birth weight, and prenatal mortality (World Health Organization 2005). The full list of pollutants from open-air waste burning, reproduced from Wiedinmyer, Yokelson, and Gullett (2014), is shown in Appendix Table A1.[5] Open-air waste burning is estimated to be responsible for a relatively small proportion of global emissions of carbon dioxide (5%), methane (1%), and carbon monoxide (7%). However, it is responsible for high proportions of particulate matter (19% of PM2.5 and 24% of PM10), which are believed to affect risks of lung cancer, respiratory disease, heart failure and, notably for our study, birth outcomes. Burning is also estimated to be responsible for 11% of black carbon emissions and 43% of organic carbon emissions. In addition, an estimated 29-58% of hydrochloric acid emissions, 25% of benzene emissions, and 39% of polycyclic aromatic hydrocarbons (PAH) are estimated to be due to open burning. These pollutants are believed to be responsible for cancers and respiratory and eye problems. In short, the uncontrolled burning of waste emits a wide variety of pollutants believed to be bad for human health, and is estimated to be responsible for a large proportion of overall concentrations of these pollutants in the air.

Importantly, the pollutants generated by open-air waste burning are also believed to have impacts on infant health through *in utero* exposure. These biological channels are described in detail by Kannan, Misra, Dvonch, and Krishnakumar (2006) and Kelly (2003). Specifically, both polycyclic aromatic hydrocarbons (PAHs) and benzene can cross the placenta, directly harming the fetus through oxidative stress. We expect this channel to be potentially important in this context relative to others, given the significant amount of these toxins emitted from open-air waste burning. In addition, there are several mechanisms through which particulate matter can affect infant health. While particulate matter does not cross the placenta, maternal exposure to it can affect infant health by causing oxidative stress and DNA damage to cells, or by having direct effects on blood, blood pressure, or endothelial function, which could affect the transfer of nutrients to the fetus.

2.2 Lebanon and the Garbage Crisis of 2015-16

In the summer of 1992, Lebanon—still recovering from the end of a 15 year civil war—held its first parliamentary election in over 20 years. The newly elected government was tasked with rebuilding the country and a large number of its institutions under a power-sharing sectarian system. This system—known as the Taif agreement—was put in place to provide

[5] We compute the fraction of total global emissions based on estimates from Wiedinmyer, Yokelson, and Gullett (2014).

the basis for the ending of the civil war and the return to political normalcy in Lebanon. It involved the sharing of power among the 18 different Christian (mainly Maronites) and Muslim (mainly Sunnis and Shiites) sects represented in Lebanon. A consequence of that system is that many public employees are given jobs according to sectarian distributions, quotas and allocations. Sectarian leaders argue this system maintains the balance that helps avoid civil war, which they contend is especially important given the volatility of the region. However, critics argue the system facilitates widespread corruption (Lebanon ranks as the 44th most corrupt nation in the world, out of 180, according to Transparency International), and enabled politicians to weaken state institutions such as garbage and electricity "in favor of parallel networks of firms they set up or benefit from to provide major services" (Reuters 2015).

Soon after the formation of the new government, it formulated a plan for the various municipalities around Lebanon. Accordingly, in 1994, Sukleen, a privately owned company that was funded by the Lebanese government and had connections to at least one national politician, was formed and tasked with the management of waste in the Beirut and Mount Lebanon governorates. The Beirut governorate, home to the capital of Lebanon, is the smallest geographically of Lebanon's eight governorates and occupies approximately 7.7 square miles of space.[6] However, Beirut and Mount Lebanon are the most populated governorates with over 2 million residents, around half of the Lebanese population.

Prior to the formation of Sukleen and up until 1997, all solid wastes from Beirut and Mount Lebanon were disposed of at the Bourj Hammoud landfill. However, amidst continuous complaints and protests from the residents of Bourj Hammoud, a new plan was proposed by Sukleen and approved by the Lebanese government. This plan involved establishing two new waste treatment incinerators; one located in Karantina for sorting, fermenting, burning and pressing waste with a capacity of 1,100 tons per day, and the other located in Amroussieh with capacity of 600 tons per day (Boutros 2015). The Bourj Hammoud landfill was completely closed as of July 20, 1997. However, the residents of Amroussieh refused to have an incinerator in their city. The government then permitted Sukleen to transfer waste to a temporary landfill on a state-owned property in Al Maramel area, until the Amroussieh plant was equipped to meet proper health standards (Boutros 2015).

Following increased pressure from the public who demanded a permanent solution to the problem, the government announced the opening of two new landfills. These were to be located in Naameh and Bsalim and were to be used exclusively by Sukleen. However, the Naameh landfill was the only one eventually used to store waste from Beirut and Mount

[6] The total geographical size of Lebanon is 10,452 square kilometers (4,000 square miles), which is smaller than the state of Connecticut. See the map of Lebanon in Figure A1 of the online appendix.

Lebanon after environmental studies showed that the Bsalim area was not a viable choice. In 1998, the municipality of Naameh agreed to store all waste in the Naameh landfill for a period of 6 years. This would give the Lebanese government ample time to construct a satisfactory long-term solution for solid waste management. However, solid wastes were disposed of in the Naameh landfill well past the initially agreed six year period. It was not until July 17, 2015 that the Naameh landfill was ordered to be closed, under judicial orders, after dangerously exceeding capacity.

Unfortunately, the Lebanese government had no contingency plan for dealing with the solid waste generated by households and companies in Beirut and Mount Lebanon. As a result, the closing of this landfill in the summer of 2015 generated trash pile-ups throughout Beirut and Mount Lebanon, and soon thereafter, the open-air burning of that trash. An image of the pile-up in Beirut is shown in Figure 1. Vile odors, insects and rodents started to appear in all residential areas plagued with garbage pileups. In response, open-air burning of these organic and inorganic wastes became the norm soon after July 17, 2015, as citizens and municipality workers attempted to decrease the accumulation of garbage in residential neighborhoods. The practice of dumping and burning trash in seemingly random unauthorized areas became popular and contributed to unsanitary and dangerous conditions (Hilal, Fadlallah, Jamal, and El-Jardali 2015). Anecdotally, the consequences of the fires were severe. One woman living in Sin el Fil in Beirut described the waste burning near her apartment in the following way: ”It starts with the smell. And then this white smoke begins rising, and it encircles our building. The burning usually starts at night and lasts until dawn. I immediately run to the balcony, take in the laundry, and lock all the windows, all the doors. But the smell, the smoke, it stays there. We can’t turn on the air conditioning. We can’t sleep. We stay awake until the morning and we [feel like we are] suffocating. This happened last night, starting at midnight. It’s too much. Even when I leave the area it’s as if the smoke is still inside my lungs” (Human Rights Watch 2017).

The crisis spawned widespread protests in the streets of Beirut in what came to be known as the 2015-2016 “YouStink protests” that demanded the government find a permanent solution for the trash crisis. These protests quickly grew in size and scope to include demands such as immediate reforms, an end to endemic corruption, and calls for the government to step down. While these protests eventually faded out in 2016, their presence foreshadowed larger protests that erupted in the fall of 2019 that again demanded an end to the corruption and incompetence many viewed at the heart of government and its failure to provide basic sewer, solid waste removal, and electricity systems. Sectarian leaders warned then, and again in 2019, that the protests risked upsetting a fragile balance in the shared government necessary to preserve peace. Critics argued that the garbage crisis exemplified a system in which "lucrative contracts are routinely fought over by firms allied to the politicians," and that sectarian leaders had "made the institutions dysfunctional under the pretext of preserving stability" (Reuters 2015).

In November 2015, the Minister of Health sent a letter to the Ministry of Interior asking municipalities to cease burning waste, which the Ministry of Interior forwarded to municipalities. As a temporary solution to this public health hazard, the government opened two new temporary landfills in Costa Brava and Bourj Hammoud in mid-2016, estimated to last for around 4 years. The introduction of these new landfills lead to a reduction in waste burning in the governorates of Beirut and Mount Lebanon near the end of 2016, though some burning continued into 2017. According to the Civil Defense authorities, the number of open-air waste burning cases reported in Mount Lebanon were 330 and 250 percent higher in 2015 and 2016 compared to before 2015. In Beirut, the number of cases were 50 and 75 percent higher in 2015 and in 2016 compared to pre-crisis numbers. However, reports of burning declined significantly in 2017 for both Beirut and Mount Lebanon. It is this variation in waste burning, the timing of which is also described in online appendix Figure A.2, that we use to identify health effects. Importantly, we focus only on births by women in the Beirut and Mount Lebanon governorates. We do so because these were the markets covered by Sukleen, and thus those that were potentially affected by the crisis. This enables us to compare across neighborhoods and over time within these urban neighborhoods for which we have birth data and data on the location and timing of open-air waste burning.[7] Due to historical reasons, and despite its large size, Beirut is simultaneously defined as a governorate, district and municipality. Unofficially, however, Beirut is subdivided into 12 quarters and 59 sectors, or neighborhoods. Mount Lebanon is divided into 6 districts and 303 municipalities. Eleven of these municipalities are large, and thus are divided in half. We refer to these smaller units, plus the other 292 municipalities, as neighborhoods. Together with the 59 sectors/neighborhoods in Beirut, this gives us a sample of 373 neighborhoods.

3 Data

3.1 Waste Burning Data

We obtained data on waste burning from the Lebanese Civil Defense's website, which covers all neighborhoods of Lebanon.[8] Accordingly, we construct a new dataset of waste

[7] In contrast, we do not have birth data for rural areas, where open-air burns were common before, during, and after the crisis. Even if data were available for those areas, we would worry about their similarity in both levels and trends to the urban areas of Beirut and Mount Lebanon.

[8] http://www.civildefense.gov.lb/

burning sites in Lebanon. These data contain the date and location of all fires related to waste burning. To our knowledge this is the only comprehensive data set of these fires. It contains every fire the civil defense was able to get to. To the extent that the civil defense did not reach all waste fires, the resulting measurement error will likely lead to attenuated estimates from our model measuring the extensive margin of exposure. The effect of undercounting on results from our exposure intensity model is less clear, as it depends on the spatial correlation between observed and unobserved fires.

The increase in open-air waste fires due to the garbage crisis is shown in Figure 2. It shows that while there were effectively zero waste burns in the first six months of 2015, the number increased to an average of nearly 100 fires in July, August, and September. The number of fires then fell to around 40 per month from October 2015 through November 2016. By December of 2016, the number of fires fell to around 10. As a result, we expect to see the largest health effects for women who were exposed to at least one fire in the late summer of 2015.

Unfortunately, to our knowledge there is no consistent and comprehensive record of particular air pollutants measured in the air in Beirut and Mount Lebanon. Thus, while we expect that the increase in waste fires shown in Figure 2 caused an increase in the air pollutants documented in Table 1, the lack of monitors in the area means we cannot precisely measure the increase. The limited evidence we have on air quality comes from Baalbaki et al. 2016, who show increases in polycyclic aromatic hydrocarbons (PAH) and particulate matter (PM) levels in Lebanon during the garbage crisis. Specifically, air sampling was conducted at the rooftop of a four story residential building near an open dump burning site in east Beirut. Real time PM measurements were obtained from October 5 to 22, 2015. Daily averages of $PM_{2.5}$ ranged between 14 and 67 $\mu g/m^3$. For most days, this exceeded the WHO 24-hour safe guideline value of 25 $\mu g/m^3$ and the yearly average of 30 $\mu g/m^3$ in the 3 years preceding the crisis. However, these levels are substantially lower than the average daily readings of 500 – 720 $\mu g/m^3$ during the Great London Smog or in modern Beijing and India (Ball 2018). However, the Lebanese researchers also record extreme spikes of $PM_{2.5}$ levels, with 10 minute averages reaching 665 and 1126 $\mu g/m^3$ on October 5 and October 17. Pollution levels were even higher for PM_{10} where daily averages ranged between 70.8 and 187.8 $\mu g/m^3$. These levels were well above the WHO safety guideline of 50 $\mu g/m^3$. They are also well above the yearly average of 45 $\mu g/m^3$ recorded 3 years before the crisis, which was similar to the level studied in California by Currie and Neidell (2005) of 39.5 $\mu g/m^3$. Remarkably, during the days of October 5 and October 17, 10 minute averages in east Beirut reached a high of 356 and 778 $\mu g/m^3$. Finally, Baalbaki et al. 2016 collected four samples of PAH —three of which were recorded on burning days. They find that the total concentration of 16 measured PAHs averaged 55 ng/m^3 compared to a concentration of 24.1 ng/m^3 measured during a day of no burning. Using a model of cancer risk, they estimate that this increase may have contributed to a twenty-fold increase in 2-year incremental cancer risks.

3.2 Birth Outcome Data

Data on birth outcomes come from patients at the American University of Beirut Medical Center (AUBMC). Established in 1902, AUBMC is considered the main medical center in Lebanon and the region. It is also the teaching hospital for the Faculty of Medicine at the American University of Beirut. AUBMC operates 382 beds and serves over 40,000 inpatients annually, making it the largest hospital in Lebanon. The outpatient facilities receive 431,380 outpatient visits annually (345,574 private, 29,952 outpatient department, and 55,854 emergencies). The maternity care unit is a high volume department with approximately 1,500 births a year. Relative to other hospitals in the region, AUBMC is quite advanced. It was the first medical institution in the Middle East to have earned five international accreditations of Joint Commission International (JCI), Magnet, College of American Pathologists (CAP), Joint Accreditation Committee for EBMT and ISCT, Europe (JACIE), and ACGME-I. This reflects the fact that AUBMC uses state-of-the-art equipment to measure birth outcomes such as birth weight, which results in very precise measurements.

We collected detailed medical information for all newborns delivered at the maternity care unit at AUBMC. The data consist of the date of birth, weight, height, head circumference, gestational age and gender of all babies born between May 2010 and February 2017.[9] We also have data on the neighborhood and municipality of residence, gestational age at delivery, maternal age, and insurance type for all mothers who gave birth during this period.[10] Given that AUBMC is located in central Beirut, most of our sample consists of women living in the Beirut or Mount Lebanon governorates—where most of the post-crisis burning took place. Finally, we match both datasets using neighborhood of residence in order to construct treatment. In total, we observe women in 373 distinct neighborhoods of residence in our data. We define treatment as either an indicator for whether the neighborhood in which the woman resided had a waste fire during the nine months of her pregnancy, the number of waste fires in her city during her pregnancy, or indicators for exposure to one fire, two or three fires, and four or more fires.

One potential concern with examining births in Lebanon over this time period is the

[9]We note there are very few individual-level data sets of any kind available in Lebanon, as Lebanon does not run even a single census or labor force survey. In this case we assembled the data by receiving anonymized, individual medical charts accessed through a specialized portal after more than a year of negotiation with the hospital and IRB.

[10]We note that Lebanon does not use official addresses for most of its residents.

large influx of Syrian refugees. According to United Nations estimates, there have been 130,000 births among Syrian refugees in Lebanon since 2011. The United Nations High Commissioner for Refugees (UNHCR) covered on average 3,126 deliveries per month (at 75% of hospitalization costs) at 53 contracted hospitals. Notably, AUBMC was not one of these contracted hospitals, which reduces the likelihood of this problem for our analysis. Further, it is unlikely refugees would have been able to cover the costs of delivery at AUBMC, which is considered one of the more expensive hospitals in Lebanon. In particular, our discussions with doctors at AUBMC indicate that they did not ever recall witnessing a refugee delivery at a AUBMC maternity ward. More broadly, one might be concerned that there is a shift in the composition of mothers giving birth in a way that is systematically correlated with the variation in open-air burns used to identify effects. We discuss this concern in depth in the following section.

Summary statistics are shown in column 1 of Table 1. Average age for mothers in our sample is 31 years, and approximately 44 percent of mothers have private insurance. Just under half of births over this time period are male (49.5%). Average birthweight is 3,218 grams and average weeks of gestation was 38.25. Across the whole time period, 7.9 percent of babies were born underweight (i.e., less than 2,500 grams), while 9.4 percent of babies were classified premature due to being born prior to 37 weeks. In addition, in columns 2 - 5 we show these summary statistics for both treated and control neighborhoods, before and after the crisis, where treated neighborhoods are defined as those that experienced at least one waste burn during the crisis. There, we note that 8.2 percent of births in the treatment group prior to the crisis were premature, while 6.1 percent of births were low birthweight. These outcomes are somewhat better than for all of Lebanon, where 7.8 percent of all births were low birthweight (Vital Data Observatory (VDO) 2012-14). Birth outcomes at AUBMC prior to the crisis also compare favorably to those in the U.S., which has premature and low birthweight and premature rates of 10.0 percent and 8.3 percent, respectively (Center for Disease Control 2019).

The data in columns 2 - 5 also offer an approximation of our difference-in-differences research design. While we emphasize it is a crude approximation given that not all affected neighborhoods experienced continuous fires, the means do preview our main findings. In short, while birth weight, gestational age, and the rate of premature and underweight births stayed roughly constant in control neighborhoods from before the crisis began to after, the overall pattern for treatment areas appears different. Specifically, columns 2 and 3 suggest that there was an overall decline in birth weight (3,231 to 3,147 grams) and gestational age (38.34 to 37.96 weeks) and overall increases in the rates of premature and underweight births (8.2 to 14.3 and 6.1 to 14 percent, respectively). While this is suggestive, we now turn to estimating a model that uses all of the within-neighborhood variation in exposure to open-air waste burns.

4 Identification Strategy

In order to identify effects, we need to address the possibility that women from neighborhoods exposed to the fires would have had different birth outcomes even absent the exposure. This is a general concern when identifying effects of pollution, as exposure to adverse environmental conditions during pregnancy is generally correlated with other factors that may affect birth outcomes. For instance, (Currie 2011) documents that infants born in polluted areas have younger mothers with less education and are less likely to ask for or receive prenatal care. Such differences and other unobserved factors could explain the poor outcomes of newborns living in heavily polluted areas. To distinguish the effect of exposure to open-air waste burning from confounding factors, we employ a staggered difference-in-differences research design that exploits within-neighborhood variation induced by the fact that certain neighborhoods were exposed to waste burning while others were not during the 2015-2017 crisis period. Our identifying assumption requires that neighborhoods exposed to waste burning would have had experienced the same changes in birth outcomes as those not exposed, absent the waste burning crisis. Formally, we estimate the following equation:

$$Y_{irdym} = \alpha + \tau exposure_{rdym} + \delta X_{irdym} + \gamma_y + \rho_r + \lambda_m + \zeta_{dy} + \theta_r year_{rt} + \epsilon_{irdym} \qquad (1)$$

where i denotes pregnant mothers, r denotes neighborhood of residence, d denotes district of residence, y denotes year of birth and m denotes month of birth. Y_{irdym} is the outcome of interest representing the birth outcomes of newborns. The variable $exposure_{rdym}$ is a measure of either whether a newborn's mother was exposed to at least one open-air waste burn during pregnancy, or the number of burns during pregnancy to which the mother was exposed. X_{irdym} controls for confounding factors that may vary at the neighborhood level over time. γ_y is a year fixed effect that controls for common shocks affecting children born in the same year. ρ_r is a neighborhood fixed effect that controls for the most obvious confounder, the endogenous sorting of mothers across neighborhoods based on unobserved factors. λ_m is a month of birth fixed effect that controls for any month specific birth characteristics common to all infants. ζdy is a district-by-year fixed effects that controls for any district-specific shocks changing over time. We also add to equation (1) neighborhood-specific linear time trends($\theta_r * year_{rt}$) and (in another specification) quadratic neighborhood-specific time trends to control for any unobserved regional changes over time. Finally, ϵ_{irdym} represents the error term, composed of individual, area, year and month specific random elements. Standard errors are clustered at the neighborhood level.

The coefficient of interest is τ, which measures the effect of exposure to at least one waste burn during pregnancy. We note that in our data, the mean (median) number of fires during pregnancy for women exposed to at least one was 3.43 (2). In order to measure the effect of higher intensity exposure to open-air waste burns, we also estimate equations where the main treatment variable of interest is either the number of open-air waste fires to which the mother was exposed during the nine month pregnancy, or indicators for exposure to one burn, two or three burns, or four or more burns. These measures capture both the intensive and extensive margins of exposure.

As stated above, the identifying assumption of this approach is that the difference in birth outcomes between treatment and control neighborhoods would have remained the same after the crisis as it was before, absent the exposure to open-air waste burning. One way we examine this assumption is to ask whether the birth outcomes of these two groups remained constant prior to the crisis. We do so by estimating a dynamic difference-in-difference specification that allows for separate estimates of the divergence of outcomes between the groups in each year prior to and after the first open-air waste burn following July 17, 2015.

One potential threat to this research design is if exposure to fires changed the composition of births in the affected cities in unobserved ways from before to after the crisis. This could be a problem if the crisis affected the type of women who became pregnant, or if the exposure to open-air burns affected the propensity of women to give birth at AUBMC. While the function and capacity of the medical center itself was not affected by any waste burns, there is still potential for a shift in the type of women giving birth there. To address these potential concerns, we do several things. First, we explicitly test for the effect of open-air burns on the number of births at AUBMC. To the extent that births are affected, we might worry that the composition of births (and thus birth outcomes, even absent exposure) would also be affected. Second, we also empirically test for differences in exogenous covariates that are known predictors of birth outcomes, including maternal age and likelihood of having private insurance. Along similar lines, we show estimates with only the minimum set of fixed effects, and then show estimates conditional on all exogenous characteristics. To the extent that changes in composition are driving our estimates, adding these controls should reduce the magnitude of the estimates. On the other hand, if there are no shifts in composition based on observed characteristics, estimates should remain unchanged when including these covariates.

A related possibility is that exposure to open-air waste burning itself changes the composition of births through miscarriages and stillbirths. While we were unable to acquire data on infant mortality, we note that the tests above also address the possibility of changes in composition for this reason.[11] In addition, we also test for a shift in gender. We do so because previous research suggests that male fetuses are more susceptible to prenatal shocks than female ones (e.g. Hansen, Møller, and Olsen 1999; Sanders and Stoecker 2015).

5 Results

5.1 Balance Tests

Before estimating effects of the garbage crisis and the associated open-air waste burning on birth outcomes, we first test for whether exposure affected the number of births or the composition of mothers giving birth, as proxied by mother characteristics. Results are shown in Table 2. In column 1, we show results for our most basic model in which we control only for year fixed effects, neighborhood fixed effects, and month fixed effects. In columns 2 - 4, we add individual level controls, district-by-year fixed effects, neighborhood-specific linear time trends, and neighborhood-specific quadratic time trends, respectively.

Results in Panel A indicate that exposure to at least one burn had no effect on the log number of births in the city. Coefficients range from -0.001 to 0.026, none of which is significant at conventional levels. Similarly, results in Panels B and C show no correlation between maternal age and the likelihood the mother has private insurance when we condition on year, month, and neighborhood fixed effects.

In the second row of each panel, we perform the same exercise with our treatment intensity measure. In panels A and B, we find some evidence in columns 1 and 2 that exposure to more waste burns is associated with older maternal age. The largest estimate implies that exposure to an additional waste burn during pregnancy is associated with the mother being 0.13 years older at birth. The estimate in column 1 is significant at the five percent level, while the estimate in column 2 is significant only at the 10 percent level. Estimates in columns 3 and 4 are not significant at conventional levels. Importantly, of the 24 estimates shown in Panels A - C of Table 2, these are the only two that are significant at conventional levels, which is consistent with chance.

Finally, in Panel D we test whether infant gender is correlated with our two measures of exposure. Point estimates for ever being exposed to a waste burn suggest a negative correlation. Coefficients range from -0.043 to -0.034, though none are significant at conventional

[11] To our knowledge, AUB does not keep records of prenatal or postnatal deaths linked to mothers. The one possible exception is for stillbirths, though they are unwilling to share the individual-level data with us. In addition, there are very few reported stillbirths each year.

levels. These estimates are somewhat larger than effects found due to the Great London Smog, or to a one standard deviation change in air pollution generated by the U.S. Clean Air Act (Ball 2018; Sanders and Stoecker 2015) We interpret these coefficients as suggestive that perhaps exposure led to some miscarriages of male fetuses, who have been shown to be more susceptible to prenatal shocks. However, we find relatively little correlation between baby gender and the number of waste burns exposed to during pregnancy, as shown in the second row of Panel D. In our subsequent main analysis, we will test whether our estimates of the effect on birth outcomes are robust to the inclusion of infant gender as well as maternal age and private insurance status.

5.2 Main Results

We begin by showing our main results in graphical form. Figures 3 - 5 show results for our main outcomes of interest, including the likelihood of being low birthweight, log birth weight, and the likelihood of being born prematurely. For each figure, we present results from each of the two main approaches we use. In panel A, we define treatment as exposure during pregnancy to at least one waste burn in one's city, while in panel B we define it as the number of waste burns in one's city during pregnancy.

Figure 3 shows results for the likelihood of low birth weight. Importantly, in each panel we see little to no divergence between treatment and control groups *before* treatment. Rather, the estimated divergence—measured relative to the difference in the two groups six or more years before treatment—estimates are close to zero, and all of them are statistically indistinguishable from zero. This is consistent with the identifying assumption. After exposure to the first waste burn in one's city, however, we observe a large and significant increase of five to ten percentage points in Figure 3a. The effect is somewhat smaller one to two years after the first fire, which is consistent with the pattern in Figure 2 that shows the intensity of the fires peaked in the first year of the crisis.

Figure 4 shows a similar pattern for log birth weight in that there is no evidence of divergence between the two groups in the five years prior to treatment. However, we do observe an abrupt reduction of nearly five percent following exposure to the first waste burn in one's city. In both models this reduction is statistically different from zero, and suggests that average birth weight is significantly reduced as a result of exposure to open-air waste burning.

Finally, Figure 5 shows results for premature births. Figure 5a shows that there is little divergence in the rate of premature births for babies born in areas that will and will not be exposed to waste burning during the crisis. This is consistent with the identifying assumption. However, we find more than a 10 percentage point increase immediately after first exposure, indicating that waste burning leads to significant increases in the rate of premature births relative to mothers who lived in areas that were less exposed. Figure 5b shows a slight increase in premature births from five to two years prior to the crisis, though none of the estimates are statistically different from zero. We also see an increase of around 0.005 to 0.01, suggesting that each additional fire to which one is exposed during the crisis leads to a half to full percentage point increase in the likelihood of premature birth.

We now turn to formally estimating effects using our generalized difference-in-differences model. Results for the specification in which treatment is defined as exposure to at least one waste burn during pregnancy are shown in Table 3. The format of Table 3 follows that of the balancing tests in Table 2 in that the first column controls only for year, neighborhood, and month fixed effects. In the second column we add controls for baby gender, maternal age, type of insurance and district-by-year fixed effects, while in the third and fourth column we add neighborhood-specific linear time trends and neighborhood-specific quadratic time trends.

Results in Panel A of Table 3 indicate that exposure to at least one open-air waste burn is associated with a 5.2 (column 1) to 8.4 (column 4) percentage point increase in the probability of being born at low birthweight. This is a large effect and represents an 85 to 138 percent increase relative to the pre-crisis mean of 6.1 percent. All four estimates are statistically significant at the five percent level, and three are significant at the one percent level. Panels B and C show similar effects for birth weight levels and log birth weight. Estimates of the effect of exposure on birth weight range from 61 to 98 gram reductions; effects on log birth weight are reductions of 1.9 to 3.0 percent. Again, all estimates in Panels B and C are statistically significant at the five percent level, and estimates in columns 2 - 4 are significant at the one percent level.

Panel D of Table 4 shows results for gestational age, and reveals statistically significant reductions of 0.22 to 0.26 weeks. Finally, Panel E shows results for premature birth. Estimates range from 3.8 to 4.6 percentage points, which represent relative increases of 46 to 56 percent given the baseline level of 8.2 percent as shown in Table 2. Estimates in columns 1 and 2 are significant at the five percent level, and estimates in columns 3 and 4 are significant at the 10 percent level.

In summary, Table 3 shows that consistent with Figures 3a - 5a, there is strong evidence that exposure to at least one open-air waste burn is associated with economically large, statistically significant reductions in infant health. We estimate that exposure to at least one waste burn during pregnancy is associated with a 1.9 to 3.0 percent reduction in birthweight, 85 to 138 percent increases in the likelihood of being born with low birth weight, and a 46 to 56 percent increase in the likelihood of being born premature.

5.3 Effects by Intensity of Exposure

One limitation of the approach used to estimate effects in Table 3 is that it is focused on the extensive margin of exposure. In reality, the intensity of exposure varied significantly both across and within neighborhoods that all experienced at least one waste burn due to the crisis. While we are unable to obtain data on the size or duration of each fire—or, ideally, the concentration of airborne toxins present in each neighborhood over time—we were able to acquire a count of fires in each neighborhood at any given point in time. As a result, our second analysis focuses on the effect of exposure intensity on infant health by examining how exposure to additional fires during pregnancy affected birth outcomes. The advantage of this approach is we can use the substantial variation in exposure intensity. As noted earlier, while the median number of fires to which a mother was exposed during pregnancy was two, the average was 3.43, and the 90th percentile was eight. We note that because we only observe the number of fires, and not the size of the fire or the concentration of airborne toxins emitted by each fire, we do not attempt to use this variation to estimate how the marginal impact of exposure changes with the level of exposure. Rather, we view this analysis as a test of whether the greatest reductions in infant health occur after the greatest exposure to open-air waste burning.

We do so in two ways. We begin by estimating the effect of the number of waste burns to which women were exposed during pregnancy. Results for this analysis are shown in Table 4, which has a similar format to Table 3. Estimates indicate that exposure to an additional waste burn results in a 0.6 to 1 percentage point increase in the probability of being low birthweight. Similarly, we estimate exposure to an additional fire during pregnancy causes a 9.5 to 18.5 gram reduction in birth weight, which translates to a 0.3 to 0.6 percent reduction. All 12 estimates on birth weight outcomes shown in Panels A - C of Table 4, are statistically significant at the ten percent level, and 9 of 12 are significant at the 5 percent level.

We note that these estimates lead to large differences in risk across pregnancies. For example, among women exposed to at least one waste burn during pregnancy, the 10th percentile of exposure was one waste burn during pregnancy, and the 90th percentile was eight burns. The estimate from column 2 of Panel A in Table 5 indicates that this increased inframarginal exposure leads to an increase in the likelihood of a low birthweight baby by 4.8 to 8 percentage points, or 80 to 133 percent. Thus, it is clear that there is substantial heterogeneity in the intensity of treatment, and that more intense exposure is associated with significantly higher risk.

Results in Panel D show evidence of reductions in gestational age as well, and indicate that each additional burn to which a pregnant women is exposed is associated with a 0.04 to 0.05 week reduction in gestational age. Results in Panel E show suggestive evidence of an effect of exposure intensity on the likelihood of premature birth. Estimates range from 0.4 to 0.6 percentage points, though only two of four estimates are significant at the 10 percent level.

In addition, we also estimate the effect of exposure intensity using an alternative specification in which we estimate the effect of exposure to one fire, two to three fires, and four or more fires during pregnancy. The advantage of this approach is that we relax the linearity assumption of the previous analysis; the disadvantage is we lose statistical power. Results are shown in Table 5. Estimates suggest that exposure to these three levels of exposure are associated with increases in low birthweight of 5.1, 6.6, and 10.2 percentage points, respectively. Similarly, estimated effects on birth weight, log birth weight, and gestational age (columns 2 - 4) also show larger effects from additional exposure. Estimates in column 4 indicate that exposure to one fire reduces gestational age by a statistically insignificant 0.13 weeks, whereas exposure to 2 - 3 and 4+ reduces gestational age by 0.28 and 0.41 weeks, respectively. Finally, columns 5 shows estimates for the likelihood of premature birth. In contrast to the birthweight and gestational age measures, effects on premature birth are similar across exposure at 4.6, 4.7, and 4.5 percentage points, respectively.

In summary, Tables 4 and 5 show strong evidence that exposure to more waste burns during pregnancy significantly reduced gestational age, birth weight, and the probability of being born with low birthweight. Results indicate that exposure to an additional fire is associated with a 0.6 to 1 percentage point increase in low birth weight, a 9.5 to 18.5 gram reduction in birthweight, and a 0.04 to 0.05 week reduction in gestational age. Pregnant mothers who were exposed to 4+ fires—approximately 25 percent of the treated mothers in our sample—give birth to babies that weigh 4.4 percent less, are born 0.42 weeks earlier, and are 10 percentage points (167 percent) more likely to be low birthweight.

5.4 Heterogeneous Effects

Next, we turn to the question of whether exposure to open-air waste burns had differential effects based on the trimester of exposure. Results for the impact of exposure to at least one waste burn are shown in Table 6, where each specification controls for year, neighborhood, month, and district-by-year fixed effects as well as individual controls. Estimates for the effect on low birthweight are similar across all three trimesters at 3.2, 2.8 and 3.2 percentage points, respectively, none of which are significant at conventional levels.

However, estimates for birthweight, log birthweight, gestational age, and to a lesser extent premature birth are significantly larger for exposure during trimesters one and two, rather than the third trimester. For example, the estimated effect of exposure during the first and second trimesters on log birthweight is -1.9% and -1.9%, respectively. By comparison, the estimated effect of exposure during the third trimester is only -0.3%. Similarly, while we estimate 0.20 and 0.17 week reductions in gestational age due to exposure in the first and second trimesters, respectively, we estimate only a 0.04 week reduction due to exposure in the third trimester. We note, however, that estimates of exposure during the first and second trimester are not statistically different from those in the third semester. As a result, we interpret the results as suggesting that effects are perhaps more driven by exposure during the first two trimesters, though we cannot reject the null hypothesis that effects are constant across the pregnancy.

5.5 Robustness Checks

As discussed earlier, a major threat to identification of effects in this context is a potential change in the composition of mothers giving birth during the garbage crisis. For example, if affluent women from neighborhoods affected by waste burning were to move and give birth elsewhere during the crisis, that could potentially drive the effects we observe in Tables 3 and 4. Results presented earlier provide some evidence this is unlikely to be the case. Specifically, we showed in Table 2 that exposure was not associated with a change in the overall number of births, or with maternal age or insurance status, the latter of which is a proxy for family income. Similarly, in Tables 3 and 4 we show that if anything estimates are larger, not smaller, when we control for maternal age, insurance status, and child gender. In addition, we note the hospital itself was not affected by the waste burning. Nevertheless, a potential concern could be that the composition of births is changing in a way that does not generate a statistically detectable shift in the number of births, and in a way that is not correlated with maternal age or insurance status.

To address this possibility, in this section we show results for the sample of mothers who gave birth in the nine months after July 17, 2015, when the garbage crisis started. In this way, we avoid any selection issues potentially caused by changes in fertility over this time period. In addition, we exploit the abrupt and unforeseeable timing of the shock, which was precipitated by a judicial order to close the existing landfill. In addition, focusing on this very short time horizon further minimizes opportunities for pregnant women to move. Restricting the sample to these births leaves us with 5,581 births from May 2010 to April 2016.

Table 7 summarizes findings from this exercise, which are consistent with results in Tables 3 and 4 in showing that exposure is associated with a worsening of birth outcomes. All 10 estimates are statistically significant at the five percent level, and 6 of 10 are significant at the one percent level. Panel A shows results of any exposure, which are even larger than the main estimates shown in Tables 3 and 4. For example, the estimate in column 1 of Panel A of Table 7 suggests that exposure is associated with a 10.2 percentage point increase in low birthweight, compared to a 6.9 percentage point effect shown in column 2 of Table 3. Similarly, estimates in Table 7 indicate exposure is associated with a decline of 3.8 percent for overall bodyweight and 0.39 weeks for gestational age, compared to 2.6 percent and 0.26 weeks in Table 3, respectively. Estimates of the effect of exposure to the number of fires (i.e., our measure of treatment intensity) shown in Panel B are also somewhat larger than those in Table 4. In particular, we estimate that exposure to an additional waste burn is associated with a 1.6 percentage point increase in low birthweight, a 0.8 percent decline in overall birthweight, and a 0.10 week reduction in gestational age. These estimates compare to effects of 0.1 percentage point increase in low birthweight, a 0.5 percent reduction in overall birthweight, and a 0.05 week reduction in gestational age. The larger estimates in Table 7 could be due in part to the fact that the burning was more severe in the early months of the crisis, as shown in Figure 2. This could be because there were more fires, as shown in Figure 2, or that the fires early in the crisis were larger or closer to especially populous residential areas. Alternatively, it is also possible that as the crisis went on, residents were better able mitigate their exposure to the toxic smoke. While we are unable to assess these explanations empirically, what is clear from Table 7 is that results are not driven by any changes to fertility, or to any longer-term shifts in residential mobility.

In addition, given the large estimated effect on the likelihood of low birthweight, we also assess the robustness of that finding to alternative weight thresholds. Results are shown in Figure 6, which results using different weight thresholds. Specifically, each point represents τ from equation 1, where the outcome is whether birth weight was less than a given threshold. Figure 6 indicates that we estimate statistically significant declines for the thresholds of 2100, 2300, 2400, 2500, 2600, 2700, 2800, 2900, and 3000 grams. This suggests that the result on low birthweight is not idiosyncratic to the low birthweight threshold of 2500 grams.

6 Conclusion

In this paper, we examine the effects of exposure to open-air waste burning on birth outcomes. We do so by examining the 2015 garbage crisis in neighborhoods within Beirut and Mount Lebanon, which led to abrupt and unanticipated trash pileups that were subsequently burned. This generates the variation in exposure within neighborhoods and over time necessary to identify effects.

Results indicate that women exposed to at least one waste burn during the crisis gave birth to babies who weighed 2.2 to 3.5 percent less at birth, and were 5.2 to 8.4 percentage points (85 to 138 percent) more likely to be classified as low birthweight. We also estimate that exposure reduced gestational age by around a quarter of a week, and increased the likelihood of premature birth by four percentage points (50 percent). In addition, we also show that being exposed to more waste burns in one neighborhood also led to worse birth outcomes, especially with respect to birth weight. We estimate that women exposed to four or more fires in their neighborhoods during pregnancy gave birth to babies that were 0.4 weeks early and 10 percentage points (167 percent) more likely to be classified as low birthweight. In short, we find strong evidence that prenatal exposure to open-air waste burning leads to significantly worse birth outcomes.

These effects are large relative to the estimated impacts of other *in utero* health shocks studied in the literature.[12] The 85 percent increase in low birthweight we observe is equivalent to an 80 – 90 percent increase in NO2 and associated other pollutants (Currie and Walker 2011), or to a roughly 100 percent increase in exposure to water contamination (Currie, Graff Zivin, Meckel, Neidell, and Schlenker 2013). Indeed, given the intensity of the air pollution generated by waste burning, perhaps the most analogous setting is to compare effects to maternal smoking. Evidence from randomized control trials indicates that a 50 percent reduction in cessation reduces low birthweight by 40 percent, which suggests the effects here are roughly equivalent to maternal smoking (Dolan-Mullen, Ramirez, and Groff 1994).[13] Similarly, the magnitude is comparable to the impact of 90 to 145 percent increases in annual income (Almond, Hoynes, and Schanzenbach 2011; Hoynes, Miller, and Simon 2015), or a 54 percent increase in expected job loss (Carlson 2015).[14] The effect documented here is somewhat larger than the effect of hospitalizing the mother during pregnancy due to influenza (Schwandt 2018), and 30 times as large as the effect of living within one mile of a

[12] We note that in most if not all of the cases described below, we had to scale up the magnitude of the treatment in order to obtain estimates of the magnitude we observe in this setting. We view the fact that previous authors rarely observed variation in treatment of the type necessary to generate effects we observe as further evidence of the relative magnitude of effects of exposure to waste burning.

[13] Alternatively, the effect of open-air waste burning is roughly three times as large as the effect of maternal exposure to smoking as an employee prior to a smoking ban (Hajdu and Hajdu 2018). Bharadwaj, Eberhard, and Neilson (2018) find no effect on low birthweight from a similar ban in Norway, though they estimate a reduction in overall birthweight of 4.8 percent and very low birthweight of 74 percent, and report effects are due to a 15 percentage point reduction in maternal smoking for female employees.

[14] It is three to four times larger than the effect of a father's unemployment (Lindo 2011), four to five times as large as the effect of experiencing a death of a close relative during pregnancy (Persson and Rossin-Slater 2018), and at least an order of magnitude larger than the effect of a one-year change in the minimum legal drinking age (Barreca and Page 2015) or a one-month change in maternity leave (Rossin 2011).

plant emitting toxics (Currie, Davis, Greenstone, and Walker 2015).[15] In short, exposure to a common practice used to dispose of 40% of the world's garbage has effects that are large relative to any *in utero* shock studied previously.

The effects documented in this study have important implications for populations worldwide, and especially for those in developing countries who live in close proximity to open-air waste burns. Given projected increases in the worldwide production of garbage—especially in developing countries—the volume of waste burned in open-air fires is likely to become much larger in the future. Results here suggest that exposure to the resulting pollutants have serious implications for infant health. Moreover, effects likely extend beyond those documented here given that we only attempt to detect effects on infant health, and given a large previous literature documenting how prenatal health shocks—including air pollution—can result in long-term effects on adult health, human capital, and labor market outcomes. The policy implications of our findings are also clear in that our study shows there would be large benefits from reducing the uncontrolled open burning of waste. Importantly, this need not involve reducing the amount of garbage produced, but could rather consist of alternative disposal methods.

[15]Other studies report effects on birthweight, but not low birthweight. As described in the results section, our estimated effect on birthweight is significantly smaller at approximately 60 to 100 grams, or 2.5 percent. This is up to half as large as the estimated effect from maternal smoking (Bernabé, Soriano, Albaladejo, Juarranz, Calle, Martinez, and Dominguez-Rojas 2004), and is roughly comparable to the effect of exposure to the most-polluted air in England in 1946 compared to the least-polluted air. It is also comparable to a four-month disruption to fetal nutrition (Almond and Mazumder 2011), and is somewhat larger than the effect of being exposed to a terrorist attack (Quintana-Domeque and Ródenas-Serrano 2017).

References

Almond, Douglas, and Janet Currie. 2011. "Killing me softly: The fetal origins hypothesis". *Journal of Economic Perspectives* 25 (3): 153–72.

Almond, Douglas, Janet Currie, and Valentina Duque. 2018. "Childhood circumstances and adult outcomes: Act II". *Journal of Economic Literature* 56 (4): 1360–1446.

Almond, Douglas, Hilary W Hoynes, and Diane Whitmore Schanzenbach. 2011. "Inside the war on poverty: The impact of food stamps on birth outcomes". *The Review of Economics and Statistics* 93 (2): 387–403.

Almond, Douglas, and Bhashkar Mazumder. 2011. "Health capital and the prenatal environment: the effect of Ramadan observance during pregnancy". *American Economic Journal: Applied Economics* 3 (4): 56–85.

Arceo, Eva, Rema Hanna, and Paulina Oliva. 2016. "Does the effect of pollution on infant mortality differ between developing and developed countries? Evidence from Mexico City". *The Economic Journal* 126 (591): 257–280.

Ashworth, Danielle C, Paul Elliott, and Mireille B Toledano. 2014. "Waste incineration and adverse birth and neonatal outcomes: a systematic review". *Environment international* 69:120–132.

Baalbaki, Rima, Rachel El Hage, Julie Nassar, Jocelyne Gerard, Nada B Saliba, and Rita Zaarour. 2016. "Exposure to atmospheric PMs, PAHs, PCDD/Fs and metals near an open air waste burning site in Beirut". *Lebanese Science Journal* 17 (2): 91–103.

Ball, Alastair. 2018. "The long-term economic costs of the Great London Smog". *Working Paper.*

Barreca, Alan, and Marianne Page. 2015. "A pint for a pound? Minimum drinking age laws and birth outcomes". *Health Economics* 24 (4): 400–418.

Bernabé, Javier Valero de, Trinidad Soriano, Romana Albaladejo, Margarita Juarranz, Maria Elisa Calle, David Martinez, and Vicente Dominguez-Rojas. 2004. "Risk factors for low birth weight: a review". *European Journal of Obstetrics & Gynecology and Reproductive Biology* 116 (1): 3–15.

Bharadwaj, Prashant, Juan Pedro Eberhard, and Christopher A Neilson. 2018. "Health at birth, parental investments, and academic outcomes". *Journal of Labor Economics* 36 (2): 349–394.

Bharadwaj, Prashant, Petter Lundborg, and Dan-Olof Rooth. 2018. "Birth weight in the long run". *Journal of Human Resources* 53 (1): 189–231.

Black, Sandra E, Paul J Devereux, and Kjell G Salvanes. 2007. "From the cradle to the labor market? The effect of birth weight on adult outcomes". *The Quarterly Journal of Economics* 122 (1): 409–439.

Boutros, Joelie. 2015. *Garbage Crisis in Lebanon - 1997: Same Policy, Repeated History.* https://legal-agenda.com/en/article.php?id=3102, Last accessed on 2020-1-16.

Carlson, Kyle. 2015. "Fear itself: The effects of distressing economic news on birth outcomes". *Journal of Health Economics* 41:117–132.

Center for Disease Control. 2019. *Births: Final Data for 2018.* https://www.cdc.gov/nchs/data/nvsr/nvsr68/nvsr68_13-508.pdf, Last accessed on 2020-1-22.

Chay, Kenneth Y, and Michael Greenstone. 2003a. *Air quality, infant mortality, and the Clean Air Act of 1970.* Tech. rep. National Bureau of Economic Research.

— . 2003b. "The impact of air pollution on infant mortality: evidence from geographic variation in pollution shocks induced by a recession". *The Quarterly Journal of Economics* 118 (3): 1121–1167.

Cunha, Flavio, and James Heckman. 2007. "The technology of skill formation". *American Economic Review* 97 (2): 31–47.

Currie, Janet. 2011. "Inequality at birth: Some causes and consequences". *American Economic Review* 101 (3): 1–22.

— . 2013. "Pollution and infant health". *Child Development Perspectives* 7 (4): 237–242.

Currie, Janet, Lucas Davis, Michael Greenstone, and Reed Walker. 2015. "Environmental health risks and housing values: evidence from 1,600 toxic plant openings and closings". *American Economic Review* 105 (2): 678–709.

Currie, Janet, Joshua Graff Zivin, Katherine Meckel, Matthew Neidell, and Wolfram Schlenker. 2013. "Something in the water: Contaminated drinking water and infant health". *Canadian Journal of Economics/Revue canadienne d'économique* 46 (3): 791–810.

Currie, Janet, and Matthew Neidell. 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, Janet, and Reed Walker. 2011. "Traffic congestion and infant health: Evidence from E-ZPass". *American Economic Journal: Applied Economics* 3 (1): 65–90.

Dolan-Mullen, Patricia, Gilbert Ramirez, and Janet Y Groff. 1994. "A meta-analysis of randomized trials of prenatal smoking cessation interventions". *American Journal of Obstetrics and Gynecology* 171 (5): 1328–1334.

Figlio, David, Jonathan Guryan, Krzysztof Karbownik, and Jeffrey Roth. 2014. "The effects of poor neonatal health on children's cognitive development". *American Economic Review* 104 (12): 3921–55.

Grant, Kristen, Fiona C Goldizen, Peter D Sly, Marie-Noel Brune, Maria Neira, Martin van den Berg, and Rosana E Norman. 2013. "Health consequences of exposure to e-waste: a systematic review". *The Lancet Global Health* 1 (6): e350–e361.

Hajdu, Tamás, and Gábor Hajdu. 2018. "Smoking ban and health at birth: Evidence from Hungary". *Economics & Human Biology* 30:37–47.

Hansen, Dorthe, Henrik Møller, and Jørn Olsen. 1999. "Severe periconceptional life events and the sex ratio in offspring: follow up study based on five national registers". *British Medical Journal* 319 (7209): 548–549.

Hilal, N, R Fadlallah, D Jamal, and F El-Jardali. 2015. "K2P evidence summary: approaching the waste crisis in Lebanon: consequences and insights into solutions". *Beirut: Knowledge to Policy (K2P) Center.*

Hoynes, Hilary, Doug Miller, and David Simon. 2015. "Income, the earned income tax credit, and infant health". *American Economic Journal: Economic Policy* 7 (1): 172–211.

Human Rights Watch. 2017. *As If You're Inhaling Your Death: The Health Risks of Burning Waste in Lebanon.* https://www.hrw.org/report/2017/12/01/if-youre-inhaling-your-death/health-risks-burning-waste-lebanon, Last accessed on 2020-2-2.

Isen, Adam, Maya Rossin-Slater, and W Reed Walker. 2017. "Every breath you take,every dollar you'll make: The long-term consequences of the clean air act of 1970". *Journal of Political Economy* 125 (3): 848–902.

Kannan, Srimathi, Dawn P Misra, J Timothy Dvonch, and Ambika Krishnakumar. 2006. "Exposures to airborne particulate matter and adverse perinatal outcomes: a biologically plausible mechanistic framework for exploring potential effect modification by nutrition". *Environmental health perspectives* 114 (11): 1636–1642.

Kelly, Frank J. 2003. "Oxidative stress: its role in air pollution and adverse health effects". *Occupational and environmental medicine* 60 (8): 612–616.

Knittel, Christopher R, Douglas L Miller, and Nicholas J Sanders. 2016. "Caution, drivers! Children present: Traffic, pollution, and infant health". *Review of Economics and Statistics* 98 (2): 350–366.

Kodros, John K, Christine Wiedinmyer, Bonne Ford, Rachel Cucinotta, Ryan Gan, Sheryl Magzamen, and Jeffrey R. Pierce. 2016. "Global burden of mortalities due to chronic exposure to ambient PM2.5 from open combustion of domestic waste". *Environmental Research Letters* 11 (12).

Lindo, Jason M. 2011. "Parental job loss and infant health". *Journal of Health Economics* 30 (5): 869–879.

Persson, Petra, and Maya Rossin-Slater. 2018. "Family ruptures, stress, and the mental health of the next generation". *American Economic Review* 108 (4-5): 1214–52.

Quintana-Domeque, Climent, and Pedro Ródenas-Serrano. 2017. "The hidden costs of terrorism: The effects on health at birth". *Journal of Health Economics* 56:47–60.

Rangel, Marcos A, and Tom S Vogl. 2019. "Agricultural fires and health at birth". *Review of Economics and Statistics* 101 (4): 616–630.

Reuters. 2015. *Lebanon's rubbish crisis exposes political rot.*

Rossin, Maya. 2011. "The effects of maternity leave on children's birth and infant health outcomes in the United States". *Journal of Health Economics* 30 (2): 221–239.

Sanders, Nicholas J. 2012. "What doesn?t kill you makes you weaker: Prenatal pollution exposure and educational outcomes". *Journal of Human Resources* 47 (3): 826–850.

Sanders, Nicholas J, and Charles Stoecker. 2015. "Where have all the young men gone? Using sex ratios to measure fetal death rates". *Journal of Health Economics* 41:30–45.

Schwandt, Hannes. 2018. "The lasting legacy of seasonal influenza: In-utero exposure and labor market outcomes". *CEPR Discussion Paper No. DP12563.*

Singh, Prachi, Sagnik Dey, Sourangsu Chowdhury, and Kunal Bali. 2019. "Early Life Exposure to Outdoor Air Pollution: Effect on Child Health in India".

Vital Data Observatory (VDO). 2012-14. *Selected indicators of Lebanon: 2012 - 2016.* Tech. rep. Ministry of Public Health, Lebanon.

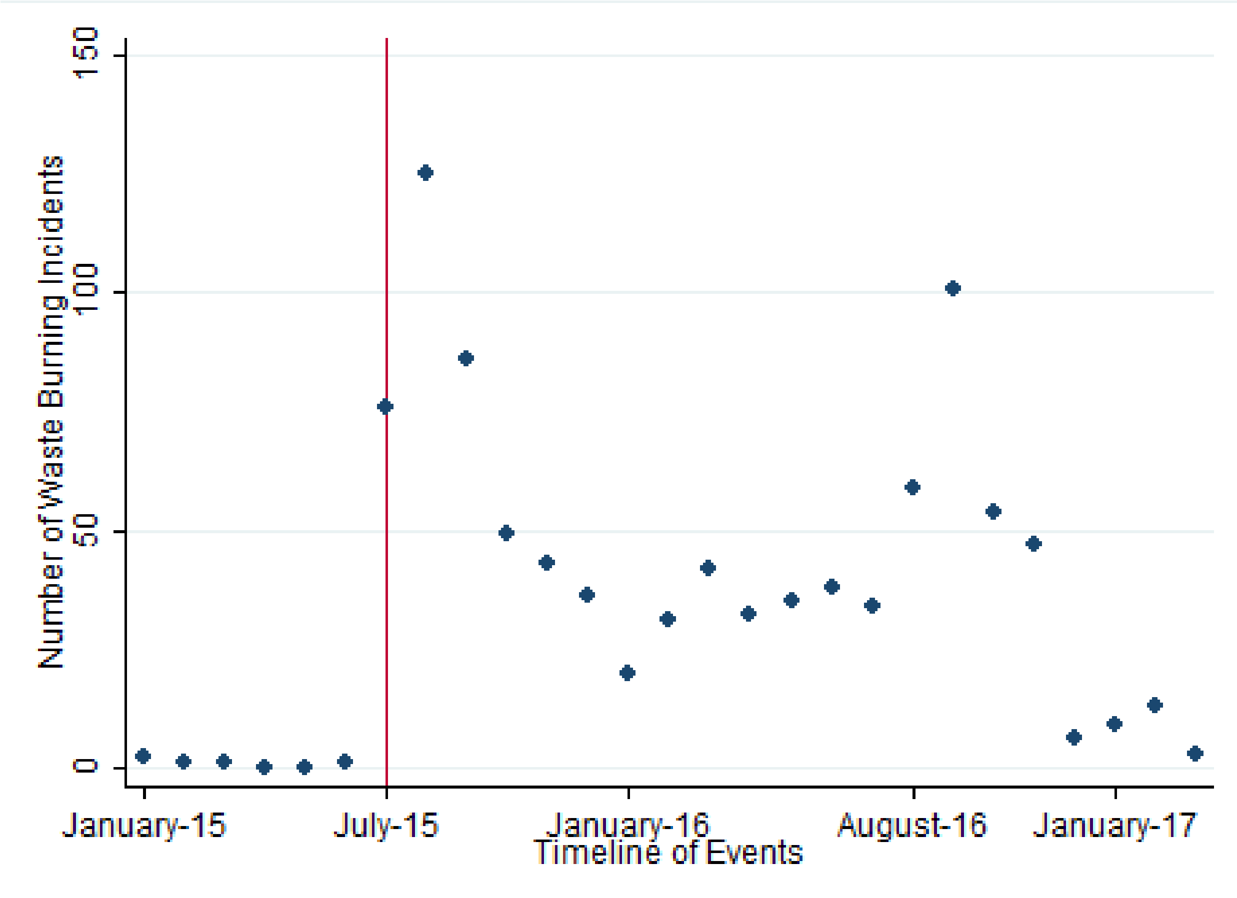
Wiedinmyer, Christine, Robert J Yokelson, and Brian K Gullett. 2014. "Global emissions of trace gases, particulate matter, and hazardous air pollutants from open burning of domestic waste". *Environmental Science & Technology* 48 (16): 9523–9530.

World Health Organization. 2005. *Effects of air pollution on children's health and development: a review of the evidence.* Tech. rep. Copenhagen: WHO Regional Office for Europe.

A Figures

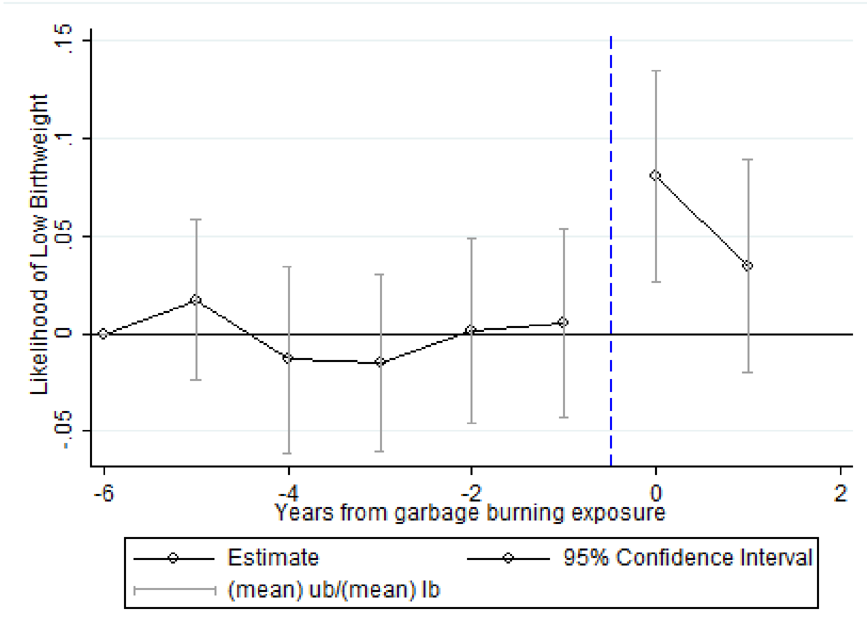
Figure 1: Incident of Trash Burning Near Residential Area in Beirut

Figure 2: Incidence of Waste Burning in Beirut and Mount Lebanon.

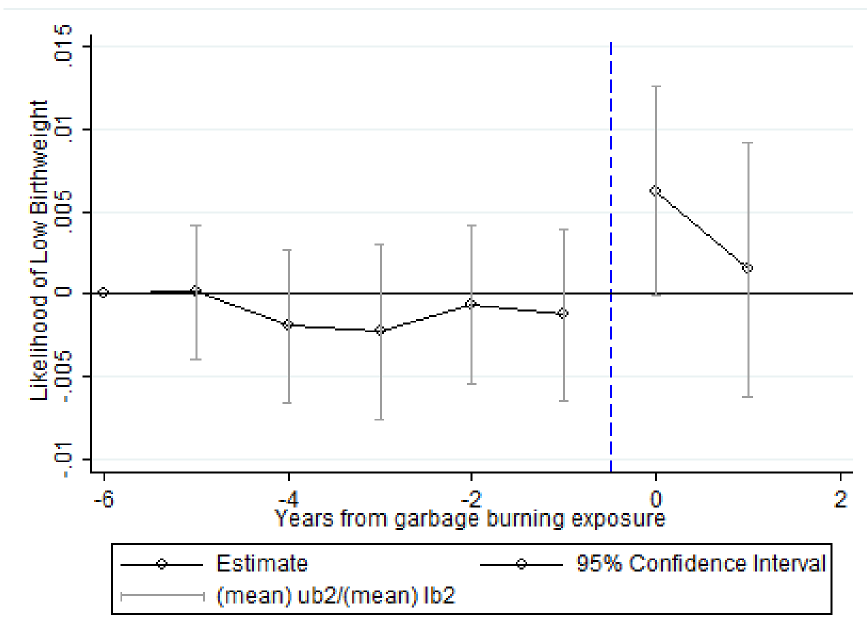


- Note: The above figure shows the number of waste burns between January 1, 2015 through March 30, 2017. Data come from the Lebanese Civil Defense unit.

Figure 3: Likelihood of Low Birth Weight



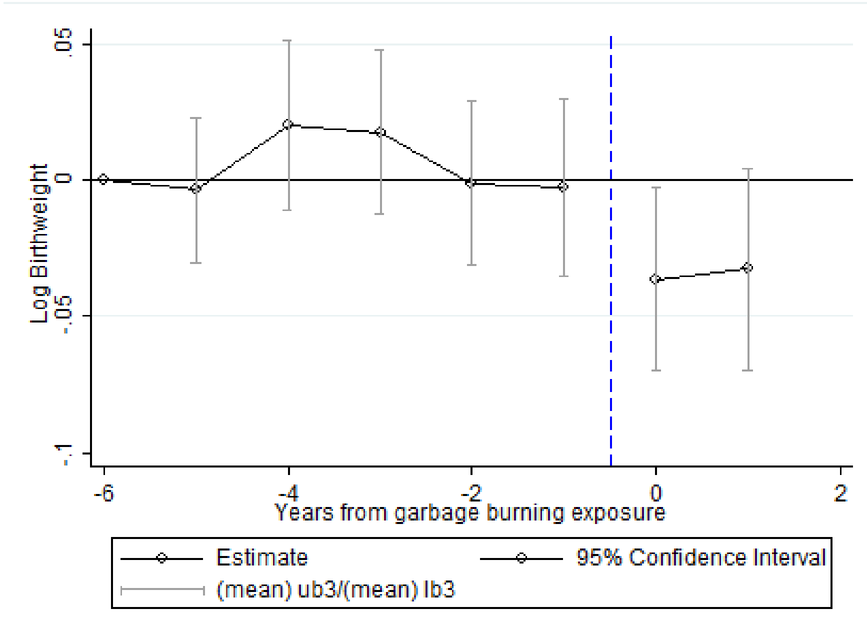
(a) Dynamic leads and lags with binary treatment



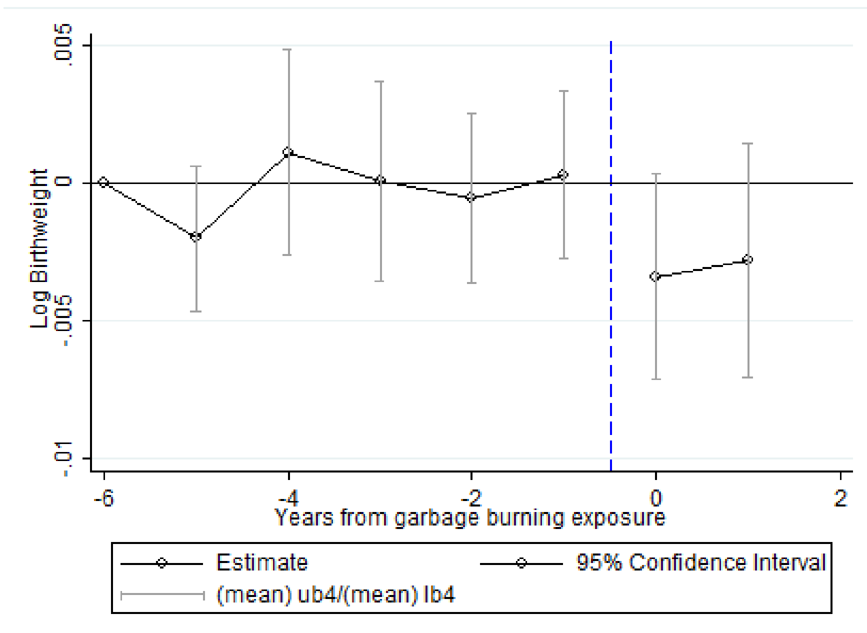
(b) Dynamic leads and lags with treatment intensity

- Notes: Each figure shows coefficients from a fully interacted generalized difference-in-difference specification that includes neighborhood and year fixed effects, and where the excluded time period is six or more years prior to the start of the crisis on July 17, 2015. Panel a shows results when treatment is defined as exposure to at least one burn, while Panel b shows results when treatment is defined as the number of fires to which one was exposed during pregnancy.

Figure 4: Log Birth Weight



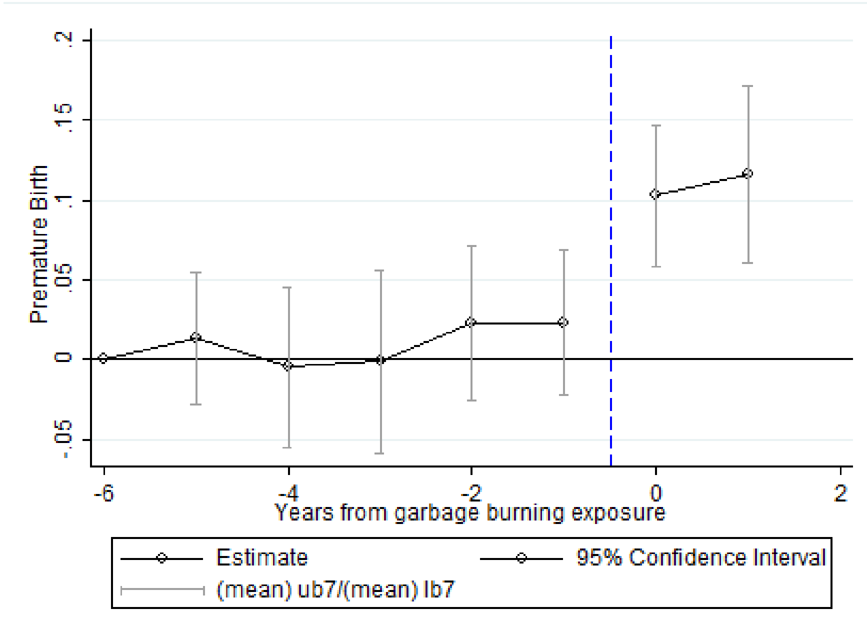
(a) Dynamic leads and lags with binary treatment



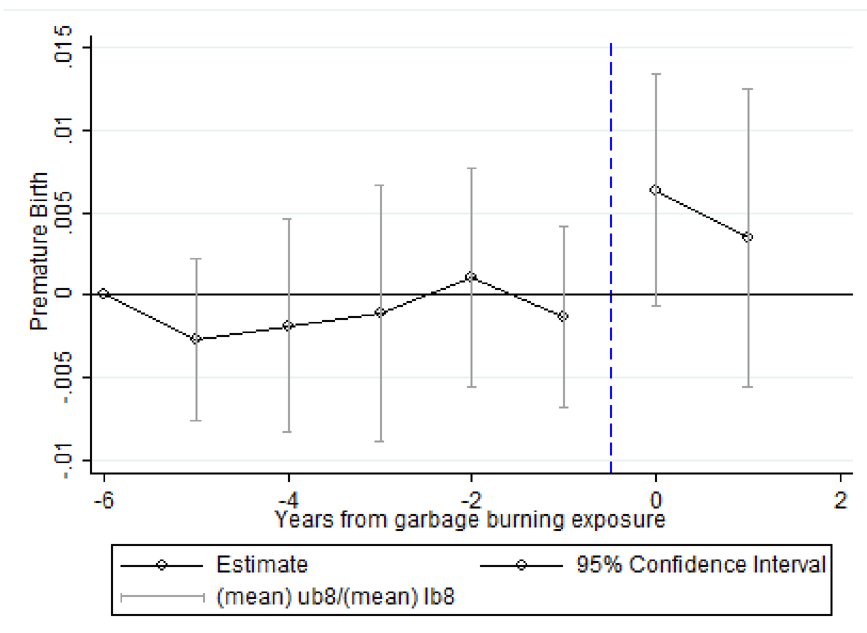
(b) Dynamic leads and lags with treatment intensity

- Notes: Each figure shows coefficients from a fully interacted generalized difference-in-difference specification that includes neighborhood and year fixed effects, and where the excluded time period is six or more years prior to the start of the crisis on July 17, 2015. Panel a shows results when treatment is defined as exposure to at least one burn, while Panel b shows results when treatment is defined as the number of fires to which one was exposed during pregnancy.

Figure 5: Likelihood of premature birth



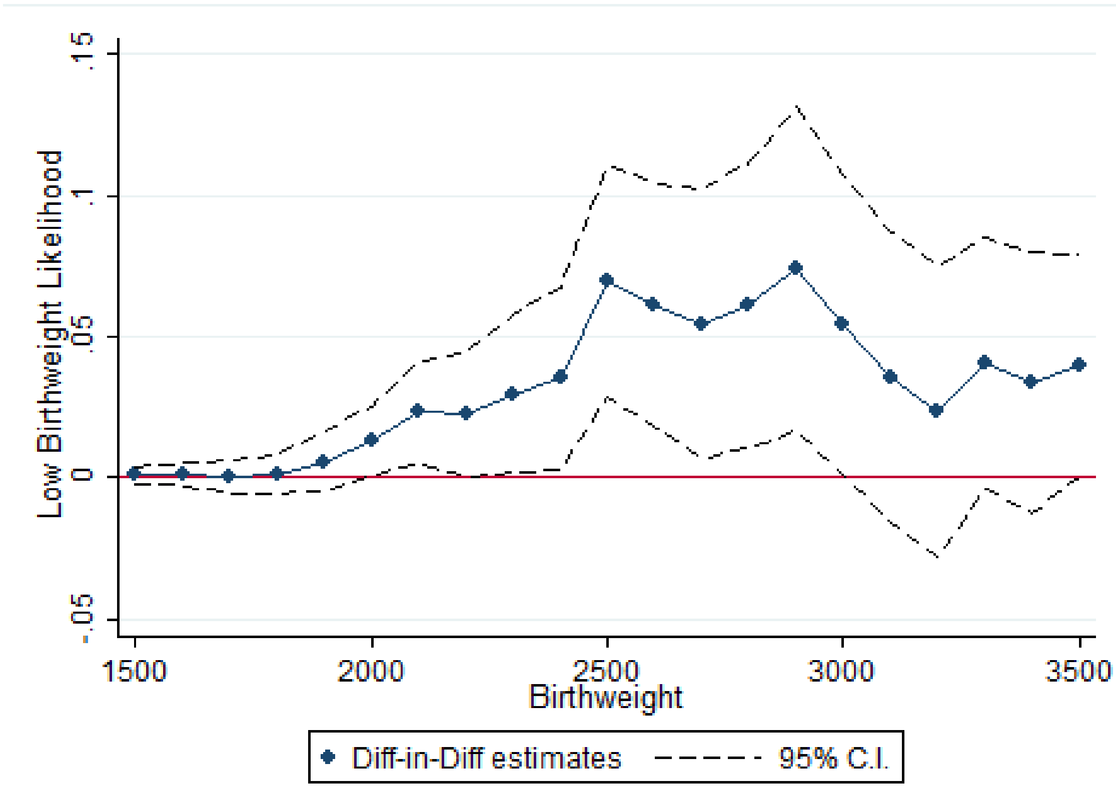
(a) Dynamic leads and lags with binary treatment



(b) Dynamic leads and lags with treatment intensity

- Notes: Each figure shows coefficients from a fully interacted generalized difference-in-difference specification that includes neighborhood and year fixed effects, and where the excluded time period is six or more years prior to the start of the crisis on July 17, 2015. Panel a shows results when treatment is defined as exposure to at least one burn, while Panel b shows results when treatment is defined as the number of fires to which one was exposed during pregnancy.

Figure 6: Likelihood of being born below numerous weight thresholds



- Notes: The above figure shows estimated difference-in-differences estimates of the effect of exposure to at least one waste burn during pregnancy on the probability birthweight is less than a given number of grams. Each point represents the coefficient of interest from a separate regression of the form used in Column (2) of Panel A in Table 3.

B Tables

Table 1: Sample statistics for key variables

	All neighborhoods	Treated neighborhoods	Treated neighborhoods	Control neighborhoods	Control neighborhoods
		Before Crisis	After Crisis	Before Crisis	After Crisis
	(1)	(2)	(3)	(4)	(5)
Controls:					
Maternal age	31.20	31.25	31.10	31.29	31.08
	(5.31)	(5.30)	(5.25)	(5.38)	(5.46)
Private insurance	0.438	0.445	0.441	0.447	0.428
Control/Potential Outcome:					
Baby gender	0.495	0.495	0.481	0.502	0.507
Outcomes:					
Birth weight (grams)	3218	3,231	3,147	3,257	3,216
	(472)	(457)	(523)	(438)	(480)
Likelihood of low birth weight	0.079	0.061	0.140	0.060	0.079
	(0.26)	(0.24)	(0.348)	(0.22)	(0.29)
Premature birth	0.094	0.082	0.143	0.079	0.066
	(0.29)	(0.28)	(0.35)	(0.27)	(0.25)
Gestational age (weeks)	38.25	38.34	37.96	38.33	38.30
	(1.37)	(1.26)	(1.71)	(1.27)	(1.25)
Ever exposed during pregnancy	0.161	0.001	0.748	0	0
Avg. number of exposures during pregnancy	0.55	0.001	2.58	0	0
Observations	6,531	3,527	1,403	1,191	410

Note: The sample contains all births at the American University of Beirut Medical Center (AUBMC) between 2010 and early 2017. Means and standard deviations (in parentheses) reported. Treatment neighborhoods defined as those exposed to at least one incident of trash burning after the garbage crisis started. Controls neighborhoods defined as those never exposed to any incident of trash burning after the garbage crisis started.In the above table, we uniformly define the "after crisis" period as anything after July, 2015 and the "before crisis" period as anything before that date. As a result, the above table represents a crude approximation of our difference-in-differences research design, allows treatment to vary over time for the different regions, in contrast to this table.

Table 2: Baseline covariates balance test

Outcome	(1)	(2)	(3)	(4)
Panel A: Log number of births				
Treatment: Ever exposed	0.016	0.026	0.000	-0.001
	(0.038)	(0.037)	(0.034)	(0.033)
Treatment: Number of exposures	-0.004	-0.003	-0.013	-0.012
	(0.007)	(0.007)	(0.010)	(0.011)
Panel B: Maternal age				
Treatment: Ever exposed	0.397	0.290	0.219	0.258
	(0.314)	(0.312)	(0.340)	(0.354)
Treatment: Number of exposures	0.127**	0.096*	0.087	0.088
	(0.057)	(0.058)	(0.067)	(0.073)
Panel C: Private insurance status				
Treatment: Ever exposed	-0.002	0.003	-0.023	-0.026
	(0.028)	(0.029)	(0.033)	(0.034)
Treatment: Number of exposures	0.002	0.002	0.001	0.002
	(0.004)	(0.004)	(0.005)	(0.006)
Panel D: Baby gender				
Treatment: Ever exposed	-0.035	-0.034	-0.041	-0.043
	(0.025)	(0.026)	(0.033)	(0.035)
Treatment: Number of exposures	-0.002	0.000	-0.001	-0.002
	(0.005)	(0.005)	(0.008)	(0.009)
Year Fixed Effects	Yes	Yes	Yes	Yes
Neighborhood Fixed Effects	Yes	Yes	Yes	Yes
Month Fixed Effects	Yes	Yes	Yes	Yes
District-by-year Fixed Effects	No	Yes	Yes	Yes
Neighborhood Linear Time Trends	No	No	Yes	No
Neighborhood Quadratic Time Trends	No	No	No	Yes
Observations	6,531	6,531	6,531	6,531

Note: Each cell represents a separate regression. Log number of births is based on collapsed neighborhood level data. Standard errors clustered at the neighborhood level are reported in parentheses. *** p <0.01 ** p <0.05 * p <0.1

Table 3: The effect of exposure to waste burning on infant birth outcomes (Binary treatment)

	(1)	(2)	(3)	(4)
Panel A: Low birth weight				
Treatment estimate	0.052**	0.069***	0.078***	0.084***
	(0.021)	(0.021)	(0.025)	(0.027)
Panel B: Birth weight				
Treatment estimate	-61.730**	-72.503***	-88.519***	-98.519***
	(28.190)	(27.529)	(32.934)	(34.545)
Panel C: Log birth weight				
Treatment estimate	-0.022**	-0.026***	-0.031***	-0.035***
	(0.010)	(0.010)	(0.011)	(0.012)
Panel D: Gestational age				
Treatment estimate	-0.247***	-0.262***	-0.223**	-0.225**
	(0.082)	(0.079)	(0.100)	(0.108)
Panel E: Premature birth				
Treatment estimate	0.042**	0.046**	0.038*	0.039*
	(0.020)	(0.020)	(0.021)	(0.023)
Year Fixed Effects	Yes	Yes	Yes	Yes
Neighborhood Fixed Effects	Yes	Yes	Yes	Yes
Month Fixed Effects	Yes	Yes	Yes	Yes
Baby Gender	No	Yes	Yes	Yes
Private Insurance	No	Yes	Yes	Yes
Maternal age	No	Yes	Yes	Yes
District-by-year Fixed Effects	No	Yes	Yes	Yes
Neighborhood Linear Time Trends	No	No	Yes	No
Neighborhood Quadratic Time Trends	No	No	No	Yes
Observations	6,531	6,531	6,531	6,531

Note: Each cell represents a separate regression. Treatment is defined as a binary variable indicating a birth within 9 months of exposure to at least one incidence of waste burning. Standard errors clustered at the neighborhood level and reported in parentheses. *** p <0.01 ** p <0.05 * p <0.1

Table 4: The effect of exposure intensity on infant birth outcomes (Linear specification)

	(1)	(2)	(3)	(4)
Panel A: Low birth weight				
Treatment intensity estimate	0.006**	0.010***	0.008**	0.009*
	(0.003)	(0.004)	(0.004)	(0.004)
Panel B: Birth weight				
Treatment intensity estimate	-9.551*	-14.036***	-16.934***	-18.501***
	(4.952)	(4.737)	(5.820)	(6.690)
Panel C: Log birth weight				
Treatment intensity estimate	-0.003*	-0.005***	-0.006***	-0.006***
	(0.002)	(0.002)	(0.002)	(0.002)
Panel D: Gestational age				
Treatment intensity estimate	-0.046**	-0.050***	-0.043*	-0.041*
	(0.019)	(0.018)	(0.022)	(0.024)
Panel E: Premature birth				
Treatment intensity estimate	0.006*	0.006*	0.004	0.004
	(0.004)	(0.004)	(0.004)	(0.004)
Year Fixed Effects	Yes	Yes	Yes	Yes
Neighborhood Fixed Effects	Yes	Yes	Yes	Yes
Month Fixed Effects	Yes	Yes	Yes	Yes
Baby Gender	No	Yes	Yes	Yes
Private Insurance	No	Yes	Yes	Yes
Maternal age	No	Yes	Yes	Yes
District-by-year Fixed Effects	No	Yes	Yes	Yes
Neighborhood Linear Time Trends	No	No	Yes	No
Neighborhood Quadratic Time Trends	No	No	No	Yes
Observations	6,531	6,531	6,531	6,531

Note: Each cell represents a separate regression. Treatment intensity is a continuous variable indicating the number of waste burns to which a mother was exposed to waste burning within 9 months of giving birth. Standard errors clustered at the neighborhood level are reported in parentheses. *** p <0.01 ** p <0.05 * p <0.1

Table 5: The effect of exposure intensity on infant birth outcomes (Non-linear specification)

Outcome	(1) Low BW	(2) Birth weight	(3) ln(BW)	(4) Gestational age	(5) Premature
One exposure	0.051*	-47.218	-0.015	-0.127	0.046*
	(0.031)	(36.263)	(0.012)	(0.110)	(0.025)
Medium exposure (2-3 exposures)	0.066**	-62.935*	-0.024*	-0.284**	0.047*
	(0.026)	(36.002)	(0.013)	(0.110)	(0.027)
High exposure (4+ exposures)	0.102***	-124.536***	-0.044***	-0.416***	0.045
	(0.027)	(32.553)	(0.011)	(0.110)	(0.028)
Individual Controls	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes
Neighborhood Fixed Effects	Yes	Yes	Yes	Yes	Yes
Month Fixed Effects	Yes	Yes	Yes	Yes	Yes
District-by-year Fixed Effects	Yes	Yes	Yes	Yes	Yes
Observations	6,531	6,531	6,531	6,531	6,531

Note: Each column represents a separate regression. Treatment is defined using bins for exposure intensity. Standard errors clustered at the neighborhood level are reported in parentheses. *** p <0.01 ** p <0.05 * p <0.1

Table 6: Heterogeneous treatment effects by trimester

Outcome	(1) Low BW	(2) Birth weight	(3) ln(BW)	(4) Gestational age	(5) Premature
First Trimester	0.032	-49.757	-0.019*	-0.203*	0.027
	(0.025)	(34.658)	(0.011)	(0.121)	(0.019)
Second Trimester	0.028	-55.564*	-0.019*	-0.166*	0.029*
	(0.024)	(32.796)	(0.011)	(0.089)	(0.017)
Third Trimester	0.032	-5.903	-0.003	-0.041	0.013
	(0.019)	(27.854)	(0.010)	(0.111)	(0.021)
Individual Controls	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes
Neighborhood Fixed Effects	Yes	Yes	Yes	Yes	Yes
Month Fixed Effects	Yes	Yes	Yes	Yes	Yes
District-by-year Fixed Effects	Yes	Yes	Yes	Yes	Yes
Observations	6,531	6,531	6,531	6,531	6,531

Note: Each column represents a separate regression. Treatment is defined separately for each trimester and measures whether the mother was exposed to at least one waste burn during that trimester. Standard errors clustered at the neighborhood level are reported in parentheses. *** p <0.01 ** p <0.05 * p <0.1

Table 7: Robustness: Sample of mothers giving birth within nine months of the start of the crisis

	(1)	(2)	(3)	(4)	(5)
Outcome	Low BW	Birth weight	ln(BW)	Gestational age	Premature
Panel A: Binary Treatment	0.102***	-106.383***	-0.038***	-0.389***	0.063**
	(0.027)	(38.404)	(0.013)	(0.121)	(0.026)
Panel B: Treatment Intensity	0.016***	-22.021**	-0.008**	-0.098***	0.010**
	(0.006)	(9.097)	(0.003)	(0.031)	(0.005)
Individuals Controls	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes
Neighborhood Fixed Effects	Yes	Yes	Yes	Yes	Yes
Month Fixed Effects	Yes	Yes	Yes	Yes	Yes
District-by-year Fixed Effects	Yes	Yes	Yes	Yes	Yes
Observations	5,581	5,581	5,581	5,581	5,581

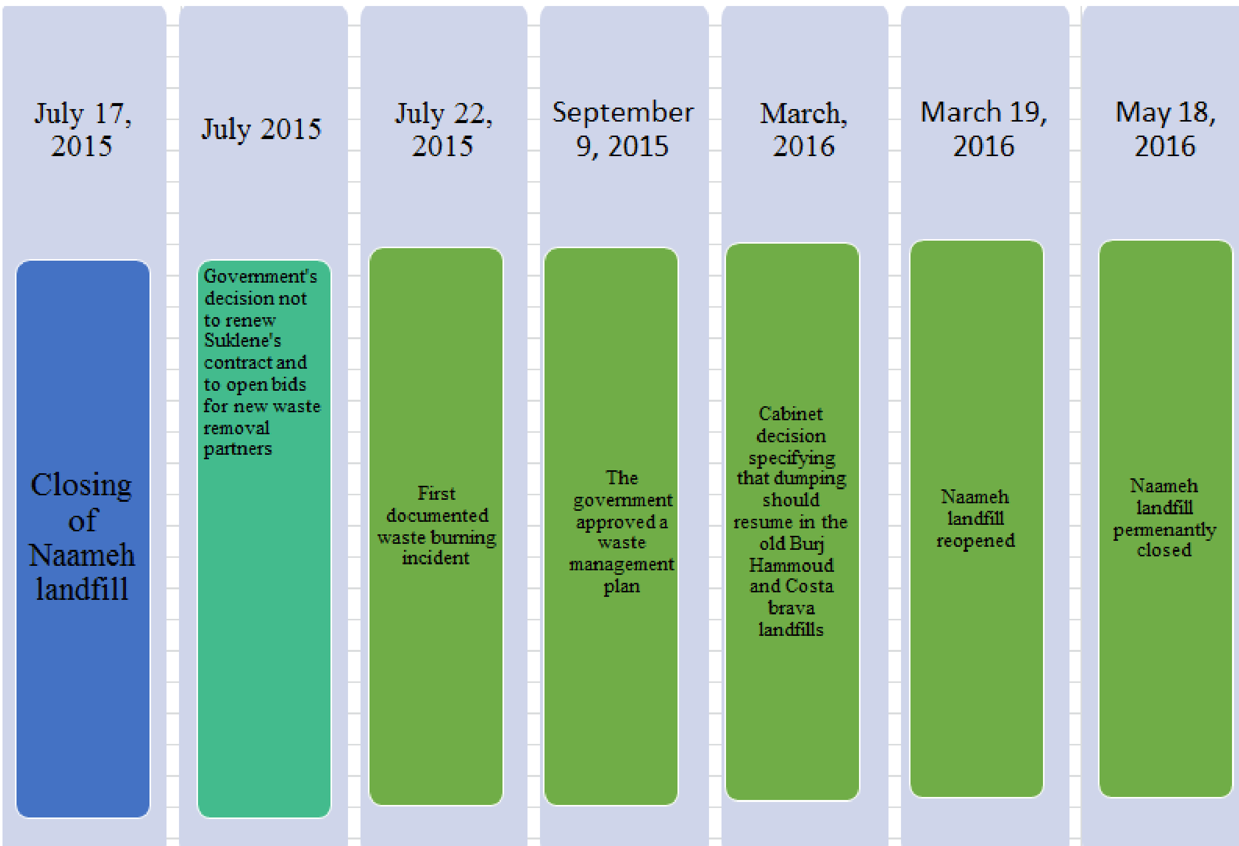
Note: Each cell represents a separate regression in which treatment is defined as exposure to at least one waste burn during pregnancy. All regressions condition on the sample of mothers who gave birth within nine months of the start of the crisis in July 2015. Standard errors clustered at the neighborhood level are reported in parentheses. *** p <0.01 ** p <0.05 * p <0.1

C Appendix Figures

Figure A1: Map of Lebanon

- Notes: The garbage crisis and the abrupt closure of the Naameh landfill mainly affected garbage management in the governorates of Mount Lebanon and Beirut. The governorates of Beirut and Mount Lebanon are home to more than half of the Lebanese population—more than 2 million individuals—and contain seven districts: Beirut, Jbail, Kesrouan, El Metn, Baabda, Aley and Chouf.

Figure A2: Timeline of events surrounding the Lebanese garbage crisis



D Appendix Tables

Table A1: Pollutants and health hazards from open-air waste burning

Pollutant	Global Emissions of Pollutant Due to Open Burning (Kg/year)	Percent of Total Global Emissions of Pollutant Due to Open Burning	Potential Serious Health Impacts
Carbon Dioxide (CO2)	1.4 Trillion	5%	• Cardiorespiratory failure • Climate change associated risks
Methane (CH4)	3.6 Billion	1%	•Respiratory arrest • Climate change associated risks
Carbon Monoxide (CO)	37 Billion	7%	• Ataxia • Seizures
Coarse Particulates (PM10)	12 Billion	24%	• Lung cancer • Respiratory disease • Heart failure • Birth outcomes
Fine Particulates (PM2.5)	10 Billion	19%	• Lung cancer • Respiratory disease • Heart failure • Birth outcomes
Black Carbon (BC)	632 Million	11%	• Lung cancer • Respiratory disease • Heart failure • Birth outcomes
Organic Carbon (OC)	5.1 Billion	43%	• Lung cancer • Respiratory disease • Heart failure • Birth outcomes
Polycyclic Aromatic Hydrocarbons (PAH)	334 Million	39%	• Skin, bladder and lung cancer • Poor cognitive development
Benzene	875 Million	25%	• Chromosomal mutations • Acute myeloid leukemia
Hydrochloric Acid (HCL)	3.5 Billion	39-58%	• Respiratory issues • Glaucoma and cataracts

- *Source:* Wiedinmyer, Yokelson, and Gullett (2014)