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ABSTRACT

Residential Noise Exposure and Health: Evidence from Aviation Noise and Birth Outcomes*

Exploiting recent concentration of flight patterns under a new Federal Aviation Administration policy (called NextGen), we examine the impact of exposure to excessive noise levels on birth outcomes. Using birth records that include mothers' home addresses to measure airport proximity, we find the risk of low birth weight babies increases by 17 percent among mothers living near the airport in the direction of the runway. We utilize exogenous variation in noise exposure triggered by NextGen, which unintentionally increased noise in communities affected by the new flight patterns. Our finding informs policy-makers regarding the trade-off between flight optimization and human health.

JEL Classification: I10, I18, Q53, Q58, R11
Keywords: noise, airport runway, low birth weight, NextGen

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1 Introduction

Noise pollution, defined as "unwanted or excessive sound that can have deleterious effects on human health and environmental quality"[1] has been a subject of regulation under the Noise Control Act of 1972 in the United States.[2] However, despite being a significant public concern, noise pollution has not received adequate attention from policy-makers.[3] A study by Hammer, Swinburn and Neitzel (2014) estimates that, even in 2013, there were 104 million individuals at the risk of noise-induced hearing loss, and tens of millions *more* could suffer from noise-related health effects.

Adverse health effects of noise operate mainly through the activation of the central stress response system—the hypothalamic pituitary adrenal (HPA) axis. Noise-induced activation of the HPA axis can lead to disrupted sleep, increase in stress hormones, and elevated blood pressure and heart rate (Hoffmann, 2018). One important feature of this response of the HPA axis is that it does not require cognitive perception of the noise (Hoffmann, 2018), leading noise exposure to be referred to as a silent killer. Pregnant women are particularly vulnerable to noise because the increased HPA axis function during pregnancy can have negative effects on fetal health (Nieuwenhuijsen, Ristovska and Dadvand, 2017).

In 1997, the American Academy of Pediatrics Committee on Environmental Health (1997) issued a set of six recommendations. First among them was a call to pediatricians to "encourage research to determine health effects of noise exposure on pregnant women and their fetuses and infants" (p. 726). This call, more than two decades ago, resulted in only a sparse literature on noise and infant health in general and, to our knowledge, only one relatively recent study on exposure to aircraft noise and infant health. According to a 2017 World Health Organization (WHO) review of the 14 studies in the noise and infant health liter-

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[1] Source: https://www.britannica.com/science/noise-pollution (accessed on May 16, 2019).

[2] For more details, see https://www.epa.gov/laws-regulations/summary-noise-control-act (accessed on May 16, 2019).

[3] The U.S. Environmental Protection Agency (EPA), under the Noise Control Act of 1972, in principle has the authority to regulate noise emissions, but the EPA in reality has lost that authority since 1981, due to funding cuts (Hammer, Swinburn and Neitzel, 2014).

ature (Nieuwenhuijsen, Ristovska and Dadvand, 2017), only five were recent studies (post 2000) that examined the impact of traffic and total noise on infant health (Arroyo et al., 2016; Dadvand et al., 2014; Gehring et al., 2014; Hjortebjerg et al., 2016; Hystad et al., 2014), and only one (Matsui et al., 2003) specifically examined the impact of aircraft noise on infant health, despite the fact that aircraft noise, likely due to its intermittent nature, is more harmful than road traffic noise (Hoffmann, 2018). Our study aims to add to that literature and provides evidence of a potential causal effect of noise exposure on infant health. In the economics field, there is an extensive literature focusing on the causal effect of early-life exposure to pollution, which is summarized in Currie et al. (2014). However, that literature so far has not examined the causal effect of noise pollution, and our study aims to fill that gap.

In this study we focus on infant health at birth, and specifically low birth weight (LBW), defined as birth weight under 2,500 grams. Although in epidemiological studies an association between high-level noise exposure and LBW (but not other reproductive outcomes) has been found (Ristovska, Laszlo and Hansell, 2014), causal estimates of the effect of noise exposure on LBW are still lacking. Such estimates are essential not only for informing policy-making, but also for understanding the long-term impact of those policies, given the robust association found in the literature between birth weight and adulthood outcomes related to health, education and earnings (Currie and Rossin-Slater, 2015).

Identification of a causal effect of noise exposure on health requires exogenous variation in noise. While random assignment of noise exposure could produce that exogenous variation, in reality such random assignment of humans is rarely possible. However, a nationwide initiative undertaken by the U.S. Federal Aviation Administration (FAA)—the Next Generation Air Transportation System (known as NextGen)—aimed at improving air travel *unintentionally* produced significant, and arguably exogenous, variation in noise exposure, which we exploit to estimate a causal effect of noise exposure on health. One important feature of NextGen is the use of precision satellite monitoring (replacing radar-based surveillance), which produces satellite-designed optimum routes that reduce flight time and save fuel. In reality, however, usage of these optimum routes by more and more aircraft, combined with landing at *lower* altitudes (resulting from precision satellite monitoring), has exposed residents living in an area under the new routes to "a constant barrage of airplanes flying over their homes" (*CBS News*, 2015). These residents were caught off-guard, because the implementation of NextGen by the FAA was exempted by the U.S. Congress from normal environmental impact reviews and public hearings (*CBS News*, 2015).

Using unique birth data that contain information on mothers' exact home addresses, we are able to identify those living close to the airport and also in the direction of the runway, where there is a NextGen-induced, sharp increase in noise exposure. Given that our birth data are from New Jersey, our study focuses on births to mothers living near Newark Liberty International Airport (EWR), one of the busiest airports in the country. We examine the impact of exposure to noise levels in excess of 55 dB,[4] the threshold used for the protection of public health by the EPA (EPA, 1974) and the WHO (Berglund et al, 1999), on birth outcomes. Using birth data from 2004 to 2016, we find an increase of 1.24 percentage points (or 17 percent) in the risk of having LBW babies among mothers living close to the airport and in the direction of the runway. This effect increases to approximately 2 percentage points among births that occurred between 2011 and 2016 (i.e., the second half of our birth data period), when NextGen was being actively implemented at EWR. We also find the effect of residential noise exposure on LBW appears to be more salient among male babies than among female babies, which is consistent with the "fragile male" hypothesis (Eriksson et al., 2010).

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[4] Here, the noise level is measured, in decibel (dB) units, by the 24-hour equivalent continuous sound level (commonly written as Leq), which is the logarithmic average of sound energy over a 24-hour period (a.k.a., day-night average sound level, commonly written as DNL or Ldn). As a result, Leq itself does not represent any individual or "peak" event, but rather the sound energy averaged over a 24-hour period. We give a more detailed discussion on the measurement of noise in the data section. Here, we provide some examples for different noise levels: 70 dB—"passenger car at 65 mph at 25 ft (77 dB); freeway at 50 ft from pavement edge 10 a.m. (76 dB); living room music (76 dB); radio or TV-audio, vacuum cleaner (70 dB)"; 60 dB—"conversation in restaurant, office, background music, air conditioning unit at 100 feet"; 50 dB—"quiet suburb, conversation at home, large electrical transformers at 100 feet" (source: http://www.industrialnoisecontrol.com/comparative-noise-examples.htm, accessed on July 31, 2019).

The rest of the paper proceeds as follows. Section 2 reviews the literature. Section 3 describes the data. Section 4 describes our identification strategy (including a detailed description about NextGen), followed by Section 5 where we present the regression models. We discuss the findings in Section 6 and conclude the paper in Section 7.

2 Literature Review

Possible links between excessive noise exposure and adverse health outcomes have drawn the attention of researchers across a number of disciplines for decades. These studies vary by the source of noise (e.g., occupational, traffic, and aviation) and the type of health outcomes (e.g., general adult health, cognition, disease incidence, birth outcomes and infant health), but all are motivated by understanding the possible negative externalities of noise-generating activities.

2.1 Aircraft Noise and Birth Outcomes

Because we cannot do justice to the full literature and with our focus on the fetal health impact of aircraft noise (affected by the implementation of NextGen), our review of the literature focuses on recent studies that examine the impact of aircraft noise on birth outcomes, based mainly on the following three meta-analyses. One challenge in this literature is pointed out by Stansfeld (2015), who in his review of studies relating noise and air pollution to adult health outcomes discusses the difficulty inherent in separating out the effects of noises from the effects of air pollution given their substantial covariance. We give a detailed discussion on how our study deals with air pollution, a confounding factor, in the identification strategy section.

Morrell, Taylor and Lyle (1997), in an early meta-analysis, reviewed studies of aircraft noise and birth outcomes including premature birth, LBW and birth defects, and they report mixed results. Although one of the studies finds a significant impact on birth weight, they conclude that overall there is no strong evidence that aircraft noise significantly affects these birth outcomes. Notably none of those studies controlled for air pollution. Ristovska, Laszlo and Hansell (2014) also provide a systematic review of studies (conducted between 1973 and 2014) that includes road, aircraft and occupational noise.[5] They conclude that there is likely an effect of aircraft noise on infant health but more studies are needed. Nieuwenhuijsen, Ristovska and Dadvand (2017) provide the most recent meta-analysis on the association between environmental noise and adverse birth outcomes. After an examination of 12 papers that met their criteria for inclusion, the authors determined that there was weak evidence regarding an association between noise from aircraft and road traffic and the risk for low birth weight, small for gestational age or preterm birth. They included six studies that specifically focused on aircraft noise. Despite this meta-analysis being published in 2017, the most recent aircraft noise and infant health paper included in their review was published in 2003, using data up to 1997 (Matsui et al., 2003).

The literature reported in these meta-analyses that focuses specifically on aircraft noise finds varying effects of aircraft noise on infant health outcomes. Edmonds, Layde and Erickson (1979) and Rehm and Jansen (1978) report no effect, while Jones and Tauscher (1978), Knipschild, Meijer and Sallé (1981), Schell (1981) and Matsui et al. (2003) find adverse effects on various birth outcomes. These authors look at various noise exposure cutoffs near several airports around the world. These studies acknowledge the potential sorting by factors that also affect noise exposure and birth outcomes (i.e., the tendency for those who live closer to the noise source to be of lower socioeconomic status), and they control for this to varying degrees. However, their results are at best viewed as associations given that none of them have treatment groups that experience truly exogenous exposure to noise. Only one of these studies explicitly notes the confounding possibility of air pollution (Jones and Tauscher, 1978). They argue, however, that the traffic density throughout the sample area (from Los Angeles County) may contribute enough air pollution that the treatment area is

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[5] Notably for birth outcomes, they include exactly the same studies above suggesting that little has been done on this topic recently.

not different than the control area.

2.2 Possible Mechanisms

Our goal is to examine the impact of aviation noise exposure on birth outcomes. Possible mechanisms for such an effect include noise-induced hormonal activation, sleep disruption and stress from excessive noise that might interfere with healthy gestation. Adverse health effects of noise operate mainly through the activation of the HPA axis (Hoffmann, 2018; Morrell, Taylor and Lyle, 1997; Nieuwenhuijsen, Ristovska and Dadvand 2017), which is a human body's central stress response system. This noise-induced activation of the HPA axis triggers physiological responses, which in turn lead to, for example, disrupted sleep, increased heart rate, release of stress hormones, and elevated blood pressure (Hoffmann, 2018).

One important feature of this noise-induced activation of HPA axis is that the activation does not require cognitive perception of the noise, meaning that the aforementioned adverse outcomes can happen to a person whether or not the person feels annoyed by the noise (Hoffmann, 2018). Furthermore, physiological responses to noise will not be changed by subjective habituation (Babisch and Kamp, 2009). Pregnant women are particularly vulnerable to noise because of the increased HPA axis function during pregnancy and the resulting release of stress hormones that can have negative effects on fetal health (Nieuwenhuijsen, Ristovska and Dadvand, 2017).

3 Data

3.1 Birth Data

We obtained birth records on all live births that occurred in New Jersey between 2004 and 2016 from the NJDOH. One unique feature of our birth data is that it contains information on mothers' exact home addresses (geocoded by latitudes and longitudes). This information allows us to identify those who live in the direction of the airport's runway, by calculating the angle of each mother's home relative to the runway. The NJDOH data also provide information on birth weight (measured in grams), gestational length (measured in weeks), the sex of the baby, and the characteristics of the mother including her age, race and ethnicity, education, marital status, number of prenatal visits, and smoking status.[6] We focus on singleton births (96 percent of the birth records in our data), to avoid confounding factors in the determination of adverse birth outcomes that are related to carrying multiple fetuses.

3.2 Noise Data

We obtained the first-ever national transportation-focused noise data from the U.S. Department of Transportation (DOT), which were released in 2017.[7] At the time of our study, only the 2014 data are available, and in three categories: aviation noise, road (highway) noise, and the combination of aviation and road (highway) noise. In the DOT data, noise is measured at exact locations, based on which we merge the noise data into the birth data by each mother's home address.

In the DOT data, noise is measured by the 24-hour equivalent continuous sound level (Leq), which is the logarithmic average of sound energy over a 24-hour period (a.k.a. day-night average sound level or DNL, or written as Ldn). Leq is expressed in decibels (dB), and often involves a correction method called "A-weighting," to make the measured sound level reflect the way the human ear hears sound. The Leq that uses the A-weighting is denoted by LAeq, and accordingly measured in units called dBA or dB(A). In the DOT data the A-weighting method was used, so strictly speaking, noise is measured by LAeq in dBA units. Since in practice the A-weighting correction method is commonly used, and for simplicity, throughout our paper we refer to noise as measured by Leq in dB units. Note that Leq (or DNL) uses logarithmic values to base 10, and log of 10 is equal to 1. So, an increase of 10

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[6] The exact wording of the question asked about maternal smoking in the NJDOH's birth records is this: "Did mother smoke cigarettes before or during pregnancy?" As a result, the variable on maternal smoking does not capture the smoking behaviors exclusively during pregnancy.

[7] For more details, see https://www.transportation.gov/highlights/national-transportation-noise-map (accessed on May 14, 2019).

dB indicates 10 times as much sound energy.[8]

Leq (or DNL) has been widely used as the best available method for measuring noise, and it has also been identified by the U.S. EPA as the main metric for analyzing airport noise exposure.[9] The calculation of Leq takes into account the time of a day: it adds a 10-dB penalty (when taking the logarithmic average) to a noise source (e.g., an airplane) during nighttime. A related measure, called day-evening-night level (or Lden), is a metric used by the European Union, which adds a 5-dB penalty (when taking the logarithmic average) to a noise source during the evening, in addition to the 10 dB penalty used by Leq.[10]

4 Identification Strategy

4.1 NextGen

To identify the causal effect of noise exposure on health, we exploit exogenous variation in noise exposure, resulting from the implementation of NextGen. Proposed by the FAA, NextGen is a nationwide initiative aimed at improving air travel, reducing airport delays and saving fuel. NextGen was started in 2007, fast-tracked by the Congress in 2012, and is expected to be completed in 2025.[11] One key component of NextGen is the transition from radar-based surveillance to precision satellite monitoring of all aircraft. In contrast to radars, satellites are able to pinpoint the exact location of each aircraft, therefore allowing for aircraft to fly closely together while being safely spaced. This allows more aircraft to use the same route. The use of satellite-based navigation, thanks to NextGen, has brought

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[8] For more details about decibels, see http://www.gracey.co.uk/basics/decibels-b1.htm (accessed on May 14, 2019).

[9] For details, see https://www.macnoise.com/faq/what-dnl-terms-aircraft-noise (accessed on May 14, 2019).

[10] Source: https://www.eea.europa.eu/help/glossary/eea-glossary/lden (accessed on May 14, 2019).

[11] For more details about NextGen and its implementation, see https://www.faa.gov/nextgen/faqs/ (accessed on May 16, 2019), for example: "NextGen is about halfway through a multi-year investment and implementation plan. For several years now, it has continually introduced new technologies to improve air travel. The FAA plans to continue implementing cutting-edge technologies, procedures, and policies that benefit passengers, the aviation industry, and the environment through 2025 and beyond."

about two important changes generating arguably exogenous variation in residential noise exposure.[12]

First, flight paths under NextGen have become satellite-designed optimum routes. These routes are more direct, with the purpose of reducing flight time and saving fuel. One important consequence of these optimum routes is that flight paths have become more concentrated. In reality, residents living in an area that is covered by the satellite-designed optimum routes have become the victims of an unexpected "air show" (*CBS News*, 2015).

Second, the use of precision satellite monitoring gives each aircraft an exact place in line for landing much earlier than before, which allows the aircraft to start a gradual descent as they approach the destination airport. While saving fuel, this gradual descent results in aircraft flying at a much lower altitude than before when approaching the airport, which significantly increases the noise exposure of residents who live underneath the flight path.[13]

The confluence of these two important changes results in a narrow band (i.e., a noise pollution corridor), within which residents are exposed to more frequent and much greater aviation noise after the implementation of NextGen. While individuals typically choose whether or not to live near an airport, we argue that conditional on those who already live close to an airport, the redistribution of aviation noise, due to NextGen, occurred in a way that is exogenous to the residents, who were caught off-guard. Indeed, as noted earlier, the implementation of NextGen by the FAA was exempted by the U.S. Congress from normal environmental impact reviews and public hearings, through the use of so-called "categorical exclusion."[14]

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[12] For details, see https://www.faa.gov/nextgen/what_is_nextgen/ (accessed on May 16, 2019).

[13] For a more specific example, see "Residents near BWI angry about increased jet traffic and noise, want FAA to act" (reported by *ABC* on May 24, 2017, https://youtu.be/XCvdheoHS9c?t=24).

[14] Specifically, a 2012 Congressional FAA Re-Authorization bill fast-tracked the rollout of NextGen by exempting it from normal environmental impact reviews and public hearings (*CBS News*, 2015). The U.S. Congressional Quiet Skies Caucus was founded in July 2015, in response to the need for addressing the issue of aviation noise. The caucus includes a group of lawmakers who represent districts that have been suffering from aircraft noise (https://nqsc.org/downloads/CAUCUS.pdf). Sponsored by the co-chair of the caucus, an amendment to directing the FAA to prioritize the work on addressing the aviation noise problem was passed by the U.S. House of Representatives on June 24, 2019 (https://www.washingtonpost.com/transportation/2019/06/25/house-passes-amendment-prioritize-efforts-combat-airplane-helicopter-noise/?noredirect=on&utm_term=.b814d6d71a39).

NextGen is a multi-component project, and it has been implemented in phases.[15] As a result, we cannot use the traditional difference-in-differences approach to evaluate the impact of NextGen. Our study uses arguably exogenous variation in noise exposure triggered by NextGen to define a treatment group and the associated control group (explained below). Based on this treatment-control designation, we examine a causal effect of noise exposure on health, which is lacking in the literature.

Our exploration of the exogenous variation in noise exposure is also guided by the recent DOT National Transportation Noise Map. Figure 1 shows the noise map for the region around EWR. As expected, there is a narrow band near the airport representing concentrated areas of high noise exposures. We further verify that the band indeed results from high levels of aviation noise (Figure 2), not from road noise (Figure 3). As previously discussed, the narrow band is likely to be imposed upon those who live close to the airport in a way that is exogenous to them, because the rollout of NextGen was exempted from normal environmental impact reviews and public hearings.

4.2 Defining the Treatment Group

Although the noise map released by the DOT allows us to pinpoint the locations with the highest noise exposure near the airport, the noise data used for the map (at the time of our study) are for the year 2014 only. As a result, the noise exposure pattern shown in Figures 1–3 may not be representative for the entire period of 2004–2016, the period of our New Jersey birth data. To overcome this data limitation, we utilize the information on the exact layout of EWR runways and mothers' home addresses, to identify those who live in the direction of the airport runway and therefore are likely to be exposed to greater aviation noise triggered by NextGen.

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[15] "NextGen is about halfway through a multi-year investment and implementation plan. For several years now, it has continually introduced new technologies to improve air travel. The FAA plans to continue implementing cutting-edge technologies, procedures, and policies that benefit passengers, the aviation industry, and the environment through 2025 and beyond" (source: https://www.faa.gov/nextgen/faqs/#q1, accessed on May 16, 2019). The implementation of NextGen started at EWR in 2006. For more details, see https://www.faa.gov/nextgen/snapshots/airport/?locationId=29 (accessed on May 16, 2019).

Figure 4 shows the three runways of EWR: 4L-22R, 4R-22L and 11-29. Runways 4L-22R and 4R-22L, running northeast-southwest, are equally frequently used. In contrast, the much shorter runway 11-29 runs east-west and is only occasionally used primarily under certain weather conditions (e.g., strong winds).[16] In our study we focus on runway 4L-22R.[17]

Specifically, we calculate the direction of the location of each mother's home relative to the runway. This calculation uses the latitudes and longitudes of two points—the mother's home address and the mid-point of runway 4L-22R. Throughout our study we use *azimuth* as the measure for that direction, which is an angle (ranging from 0 to 360 degrees) between the mid-point of runway 4L-22R (point A) and the mother's home address (point B) taking into account the curvature of the Earth. To calculate the azimuth of point B relative to point A, we project the vector $\overrightarrow{AB}$ onto a horizontal plane. On that horizontal plane, the reference vector is due North, which is used for point A and has an azimuth of 0 or 360 degrees; moving clockwise on a 360-degree circle, a point due East has an azimuth of 90 degrees, and accordingly, 180 degrees for due South and 270 degrees for due West. The azimuth of point B relative to point A is given by the angle between the projected vector $\overrightarrow{AB}$ and the reference vector on that horizontal plane.

Based on the azimuth calculated, we identify mothers who live 5 degrees off, in either direction, from the runway 4L-22R,[18] and also live within 5 miles of the mid-point of runway 4L-22R.[19] The identified group is shown in Figure 5 (Panels A and B), in a dragonfly-shaped zone, where θ (shown in Panel C) is equal to 10 degrees (i.e., 5 degrees off from the runway 4L-22R in either direction) and r (representing the radius, shown in Panel C) is equal to 5

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[16] For more details about the EWR runway usage, see https://www.spotterguide.net/planespotting/north-america/united-states-of-america/newark-liberty-ewr-kewr/ (accessed on May 16, 2019).

[17] Our empirical findings are expected to be the same if we focus on runway 4R-22L instead, given that these two runways are parallel and immediately next to each other.

[18] To do so, we also calculated the azimuth of the runway's end-point 22R relative to the end-point 4L, using the latitudes and longitudes of these two end-points. That azimuth is equal to 25.73 degrees, and it is compared with each mother's home azimuth relative to the mid-point of runway 4L-22R, to see if the two azimuths are different by 5 degrees.

[19] Throughout our study we use geodetic distance (a.k.a. geodesic distance) as the distance between two locations. Geodetic distance is the length of the shortest curve between two points on the Earth. The calculation of this distance uses the latitudes and longitudes of those two points.

miles.[20]

In our study we focus on mothers living within 5 miles of the airport. Among these mothers, those living within the dragonfly-shaped zone are the "treatment" group, and those living outside the zone, but within the 5-mile radius, are the "control" group. In the tables, we refer to this treatment group as mothers "living in the direction of the runway." Although this treatment and control designation is not precisely aligned with the "noise hot spots" shown in the DOT 2014 noise map, our designation of mothers living in the direction of the runway sufficiently covers residences with higher aviation noise exposure relative to the control group. In the absence of noise data from other years, we argue that this azimuth-based treatment-control designation is an effective way of extracting exogenous variation in residential noise exposure near the airport.[21] The source of the exogenous variation, as previously discussed, is the NextGen-induced concentration of flight paths and lower landing altitudes. These changes are likely to produce a narrow band (i.e., a noise pollution corridor) around the airport, largely following the layout of the runway and similar to the band shown in the DOT's 2014 noise map. Within this band, residents are exposed to much greater aviation noise.

Throughout our empirical analyses, we control for the distance between a mother's home and the mid-point of runway 4L-22R. To the extent that there is residential sorting based on the distance to the airport, but *not* based on the *runway layout*, and given the unexpected changes NextGen has brought to the public, we argue that, controlling for the distance between a mother's home and the airport runway, whether or not the mother lives inside the band is likely to be random.[22] The azimuth-based method of defining the treatment group

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[20] The associated arc length shown in Panel C of Figure 5 is equal to 0.873 miles.

[21] However, this azimuth-based treatment-control designation does not allow us to use house (i.e., mother's home address) fixed effects, because for each house there is only a single value of the azimuth (i.e., the angle ranging from 0 to 360 degrees) relative to the mid-point of runway 4L-22R. Similarly, we are also unable to use house fixed effects when using the DOT noise data, because for each house's location there is only a single value of the noise level (measured in 2014). The lack of variation in noise levels for each house precludes the use of house fixed effects.

[22] Support for this randomization is bolstered by articles in the popular press, reporting that residents living close to airports, including those living near EWR, were caught off-guard and exposed to more frequent and significantly greater aviation noise. Furthermore, it is reported that "sound-modeling data re-

in the direction of the runway allows us to approximate that band and also overcome the problem of using multiple years of birth records (to enhance statistical power) but with only one year of available noise data.

In Appendix Table A1, we further confirm the validity of this azimuth-based treatment zone, by showing that noise levels inside this zone, although not perfectly overlapped with the noise "hot spots" shown on the DOT's noise map, are indeed significantly higher than the noise levels in the area outside the zone but within 5 miles of the mid-point of the airport runway. The difference is about 14 to 17 dB, and the average noise level in the treatment group is approximately equal to 63 dB, well above the 55 dB threshold. In the results section, we provide further evidence showing the validity of using the dragonfly-shaped treatment zone by confirming that there are no statistically significant differences in observed maternal characteristics and behaviors between those living inside the zone and those living outside the zone but within 5 miles of the mid-point of the airport runway.

4.3 Air Pollution as a Confounder

Out of concern that air pollution could be driving our results, we focus on those living close to the airport. In a small area around the airport (within a 5-mile radius in our study), we present evidence that air pollution is likely to be evenly distributed while sharp changes in noise pollution exist. By focusing on those living close to the airport, we compare those who are likely to experience similar levels of air pollution but different levels of noise pollution.

A study by Wilson and Suh (1997) shows that fine particles (e.g., those smaller than 2.5 micrometers, a.k.a. $PM_{2.5}$) are evenly distributed over a large area, such as a city.[23] However, air pollutant monitors are often sparsely distributed, and in fact more than 80 percent of

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leased by the agency [the FAA] reveals that the gains and losses [from the implementation of NextGen] will not be spread evenly. Loud neighborhoods will, on average, be getting louder, while the biggest improvements will be in places that aren't that noisy to begin with" (source: https://www.cbsnews.com/news/complaints-over-noisy-new-flight-plans-11-01-2008/, accessed on August 8, 2019).

[23] "Because fine particles travel long distances and undergo extensive atmospheric mixing, they should be distributed evenly over urban or larger areas. Measurement of fine particles at one site, therefore, should give a good measurement of the concentration of fine particles across the entire city" (Wilson and Suh, 1997, p. 1244).

U.S. counties do not have a single $PM_{2.5}$ monitor in place (Fowlie, Rubin and Walker, 2019). As a result, a direct verification of the air pollutant distribution over a narrowly defined geographic area may not be possible. Nevertheless, as Fowlie, Rubin and Walker (2019) point out, "a growing suite of satellite observations of aerosol optical depth (AOD) makes it possible to estimate ground-level concentrations of $PM_{2.5}$ at fine spatial resolutions ($<$ 1km)" (p. 283). In their online Appendix Figure 1, Fowlie, Rubin and Walker (2019) plot satellite-based estimates of annual mean concentration of $PM_{2.5}$ for the entire continental United States for the year 2005. The $PM_{2.5}$ map they produced is consistent with Wilson and Suh (1997), showing that $PM_{2.5}$ in a small geographic area tends to be evenly distributed. This is in direct contrast to the DOT's noise map, which shows that noise levels can change sharply even within a narrowly defined area.

In addition, as Schlenker and Walker (2016) point out, most of the air pollution contributed by airports stems from aircraft idling. They show that "airport runway congestion, as measured by the total time planes spent taxiing between the gate and the runway, is a significant predictor of local pollution levels" (p. 769). As a result, given the layout of the terminal gates and the runways of EWR (shown in Figure 4), it is likely that air pollution from the airport spreads out in all directions, thus exposing the treatment and the control groups of our study, both near the runway 4L-22R, to similar levels of air pollution.

Furthermore, by controlling for the distance between a mother's home and the mid-point of runway 4L-22R in our analysis, to some degree we may also capture local air pollution levels that are affected by the airport. In our regression model (to be explained in the next section) we also add zip code-year-month-of-birth fixed effects. Assuming mothers living in the same zip code and giving birth in the same year and month are exposed to air pollution in a similar way during pregnancy, we use these fixed effects to control for fetal health effects of prenatal exposure to air pollution.

In addition, we examine two air pollutant monitors that are from the EPA's air quality monitoring network and located within 5 miles of the mid-point of the airport runway: one monitor is located within the area of the treatment group, and the other is located within the area of the control group. We check to see whether daily readings of air pollutant concentrations from these two monitors are indeed similar. Similar readings from these two monitors, located in areas exposed to significantly different levels of noise pollution, will support our strategy in isolating the effect of noise pollution from the effect of air pollution. The locations of these two monitors are shown in Figure 6. We discuss our findings in the results section.

5 Regression Models

Based on the identification strategy discussed above, we use the following regression models to estimate the health effect of residential noise exposure. The first regression model uses the DOT's 2014 noise data and includes births to mothers who live within 5 miles of the mid-point of the EWR's runway 4L-22R.

$$y_{i,jt} = \alpha_0 + \alpha_1 w_{1i,jt} + \alpha_2 w_{2i,jt} + \alpha_3 dist_{i,jt} + \mathbf{x}'_{i,jt}\alpha_4 + \delta_{jt} + \epsilon_{i,jt} \tag{1}$$

In this model, $y_{i,jt}$ denotes the birth outcome (e.g., low birth weight) of an infant born to mother i living in zip code j and giving birth in a year-month indexed by t, where the years are between 2004 and 2016. We use a comma between the subscripts i and jt to emphasize that our data are repeated cross-sections: there is no identifier for infant i's mother in the birth data, and therefore we are unable to use mother fixed effects since we cannot identify infants who were born to the same mother. In equation (1), $w_{1i,jt}$ denotes the noise level (in dB) measured in 2014 and at the home address of mother i living in zip code j and giving birth at time t. For this model we use two alternative measures of noise from the DOT data: 1) total aviation and road noise; and 2) aviation noise alone. The regressor $w_{2i,jt}$ is a binary indicator (1/0), which is equal to one (or zero) if $w_{1i,jt}$ is greater than or equal to (or less than) 55 dB; $dist_{i,jt}$ denotes the distance (in miles) between the mother's home address and the mid-point of EWR's runway 4L-22R; $\mathbf{x}_{i,jt}$ is a vector including individual level control variables: infant being female (1/0), mother's age, mother's race and ethnicity (1/0 dummy variables for white, black, and Hispanic), mother having completed a four-year college education or higher (1/0), mother being married (1/0), the number of prenatal visits, and maternal smoking (1/0).

In this regression model, we also include zip code-year-month fixed effects, denoted by δ_{jt}, which are fixed effects applied to each residential zip code-birth-year-month pair. To the extent that mothers living in the same zip code and giving birth in the same year and month are exposed to air pollution in a similar way during pregnancy, we argue that the use of zip code-year-month fixed effects serves as one way of controlling for fetal health effects of prenatal exposure to air pollution. Note that zip code-year-month fixed effects account for both zip code fixed effects and year-month fixed effects. Thus, zip code-year-month fixed effects also capture any time-invariant socio-economic and demographic characteristics of the mother's residential zip code, as well as any possible seasonality (i.e., year-month) effects that exist in birth outcomes. We estimate the regression model using ordinary least squares (OLS). Standard errors are clustered at the zip code level.[24]

The second regression model uses the azimuth-based treatment-control designation explained in the identification strategy section, and includes mothers who live within 5 miles of the mid-point of the EWR's runway 4L-22R.

$$y_{i,jt} = \beta_0 + \beta_1 d_{i,jt} + \beta_2 dist_{i,jt} + \mathbf{x}'_{i,jt}\beta_3 + \delta_{jt} + \epsilon_{i,jt} \tag{2}$$

In this model, we replace the 2014 transportation noise measures ($w_{1i,jt}$ and $w_{2i,jt}$) with a binary indicator denoted by $d_{i,jt}$. This indicator, as explained in the identification strategy section, is equal to one (indicating the treatment group) if the home address of mother i

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[24] In our estimation sample that includes mothers living with 5 miles of the mid-point of the EWR's runway 4L-22R and giving birth between 2004 and 2016, there are 47 clusters. The number of clusters increases to 100 in our alternative estimation sample that includes mothers living within 10 miles (detailed discussions provided in the results section) of the mid-point of runway 4L-22R and giving birth between 2004 and 2016.

living in zip code j and giving birth in a year-month indexed by t is within 5 degrees and within 5 miles of the mid-point of the EWR's runway 4L-22R; that indicator is equal to zero (indicating the control group) if the home address is outside 5 degrees, but within 5 miles of the mid-point of the EWR's runway 4L-22R.

To make a finer comparison, we define a third regression model by adding an interaction term between $d_{i,jt}$ (in equation 2) and $w_{2i,jt}$ (in equation 1), as well as expanding our estimation sample by including mothers who live between 5 and 10 miles of the mid-point of runway 4L-22R, among whom there are mothers living in the direction of the runway but actually farther away from the airport. The revised regression model is as follows.

$$y_{i,jt} = \gamma_0 + \gamma_1 w_{1i,jt} + \gamma_2 w_{2i,jt} + \gamma_3 d_{i,jt} + \gamma_4 d_{i,jt} \times w_{2i,jt} + \gamma_5 dist_{i,jt} + \mathbf{x}'_{i,jt}\gamma_6 + \delta_{jt} + \epsilon_{i,jt} \quad (3)$$

The definitions of variables in the above model follow equations (1) and (2).[25] A statistically significant coefficient γ_4 would indicate the presence of an effect on a resident who is exposed to noise levels that occur in the direction of the airport runway and also exceed 55 dB. Because this effect represents the effect of 55 dB whether living in the direction of the runway or not, γ_4 would also capture, to some degree, the effect of exposure to noise that comes from aircraft takeoffs and landings, which is more health-damaging because of the intermittent nature (Hoffmann, 2018). The use of 55-dB threshold alone (i.e., the "$w_{2i,jt}$" binary indicator) captures exposure to any type of noise that averages 55 dB, but not exclusively exposure to loud bursts from plane takeoffs and landings. Interacting that threshold with the indicator of living in the direction of the runway (i.e., "$d_{i,jt} \times w_{2i,jt}$") is one way of capturing residential exposure to intermittent loud noise generated specifically by aircraft.

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[25] Another reason for expanding the estimation sample to include mothers who live between 5 and 10 miles is this: Estimation of equation (3) is not feasible when we only include mothers living within 5 miles of the airport runway, because of a perfect collinearity problem. In the sample only including mothers living within 5 miles of the airport runway, there is no mother living in the direction of the runway and also exposed to noise levels that are lower than 55 dB, which makes "$d_{i,jt}$" and "$d_{i,jt} \times w_{2i,jt}$" in equation (3) become perfectly correlated with each other. Including mothers living within 10 miles of the airport runway solves this perfect collinearity problem.

6 Results

Table 1 reports the summary statistics, calculated based on our main estimation sample.[26] A significant proportion of mothers are exposed to noise levels exceeding the 55 dB threshold—11.6 percent in the case of aviation noise and 20.5 percent in the case of aviation and road noise, although the average noise exposure (around 47–50 dB) is below that threshold. Using the regression model described by equation (1), which includes the 2014 transportation noise data from the DOT, we examine the health effect of exposure to noise levels exceeding the 55 dB threshold, and the results are reported in Table 2. We examine the impact of aviation and road noise combined and aviation noise separately on the full sample of births (2004–2016 in Panel A) and then on the more recent portion of the sample that were most likely exposed to the concentrated flight patterns adopted under NextGen at EWR (2011–2016 in Panel B). We find that among mothers living within 5 miles of the airport, there appears to be an increased risk of having a LBW baby, by 1.47 percentage points (column 2 of Panel B), as a result of maternal exposure to aviation noise that is greater than or equal to 55 dB during the period of 2011–2016 when NextGen was being actively implemented at EWR.[27] It should be noted that exposure to more than 55 dB of aviation and road noise combined results in smaller, insignificant estimates. This is our first indication that the effect of aviation noise and road noise may affect birth outcomes differently.

Although the models in Table 2 control for distance from the runway and a continuous measure of noise exposure, one may still be concerned that residential sorting might occur in response to noise exposure. In Table 3 (columns 1 and 2) we provide evidence showing that there are no statistically significant differences in observed maternal characteristics between those whose noise exposures are greater than or equal to 55 dB and those whose noise exposures are below 55 dB. These results suggest that conditional on living close to

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[26] In the birth data we have regarding demographic characteristics, these two categories—white and Hispanic—are not mutually exclusive.

[27] For more detailed information regarding EWR's implementation of individual components of NextGen, see https://www.faa.gov/nextgen/snapshots/airport/?locationId=29 (accessed on May 16, 2019).

the airport, residential sorting is unlikely to occur based on the 55 dB cutoff. This suggests that mothers could be unknowingly (or randomly) assigned into a group exposed to noise levels higher than 55 dB, thus bolstering the interpretation of the finding reported in Table 2 as a causal effect. However, the noise data (from the DOT) were only available for the year 2014, and as a result, the validity of that causal interpretation also depends on an assumption that the noise exposure measured in 2014 is representative of noise exposure in other years. To relax this assumption and as discussed in the identification strategy section, we use an azimuth-based method to define treatment and control groups; the results of the associated "balancing test" are reported in column (3) of Table 3, where we confirm that, among those living near the airport, there is no residential sorting according to the airport's runway layout.

Next we estimate the health effects of residential noise exposure based on location relative to the runway path as specified in equation (2). These results are reported in Table 4. Among all births that occurred between 2004 and 2016, we find that there is an increased risk of having LBW babies, by about 0.7 percentage points[28] (column 2 of Panel A), for mothers living in the direction of the runway, who are likely to be exposed to higher aviation noise levels (a higher probability of exposure $>$ 55 dB) compared with those who live equally close to the airport but are not along the runway and flight path.[29] Consistent with the "balancing results" (reported in Table 3), in Table 4 we find that the estimates of the LBW effect of residential noise exposure are similar in magnitude (columns 1 vs. 2), whether or not we control for maternal characteristics. Those estimates are also larger for births that occurred between 2011 and 2016 (Panel B), when NextGen was being actively implemented at EWR, than for births that occurred between 2004 and 2010 (Panel C), when NextGen was only

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[28] Note that this estimate (0.7 percentage points) is smaller than the estimate (1.47 percentage points) reported in Table 2 (column 2 of Panel B). Although both are of similar magnitude, they are not directly comparable. The former does not distinguish among different categories of noise (e.g., aviation noise vs. road noise), while the latter is only for aviation noise.

[29] In Appendix Table A1 we show that noise levels in the treatment group are significantly higher than those in the control group: the difference is about 14 to 17 dB, and the average noise level in the treatment group is approximately equal to 63 dB, well above the 55 dB threshold used by the EPA (EPA, 1974) and the WHO (Berglund et al., 1999).

beginning at EWR.[30]

We conduct a test of the validity of the azimuth-based method, and the results are reported in column (3) of Table 4. Specifically, we estimate the effect of living in the direction of the runway but only for births to mothers living more than 20 miles away from the airport. In this case there should be little runway-induced variation in residential noise exposure, given the long distance between a home and the airport runway. If our azimuth-based method indeed captures runway-induced variation in residential noise exposure, then conditional on living far away from the airport, we would expect to find the coefficient on the indicator for "living in the direction of the runway" to be statistically insignificant. Results reported in column (3) of Table 4 confirmed our expectation.

In Table 5 we conduct two robustness checks. The first uses an estimation sample that includes only residents of three New Jersey counties—Essex, Union and Hudson—and no longer restricts the sample to be within 5 miles of the runway. Figure 5 shows that EWR is located in both Essex and Union Counties, with its runways (4L-22R and 4R-22L, shown in Figure 4) crossing the borderline of these two counties; Hudson County is immediately across from EWR, on the east side of Newark Bay. The estimation results based on residents of these three counties are reported in column (1) of Table 5, and the estimates are very similar to, only slightly smaller than those reported in column (2) of Table 4. This pattern is reasonable, given that in the three-county estimation sample there are some mothers living more than 5 miles away from the airport runway, who are possibly exposed to less aviation noise. If this is true, then including them in the estimation sample should make the estimate of the effect of residential noise exposure smaller.

In the second robustness check we use an estimation sample that includes only two New Jersey cities—Elizabeth and Newark, both of which are immediately next to the airport

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[30] In Appendix Table A2 we report the full set of coefficient estimates (and the associated standard errors) for one of the results reported in Table 4 (Panel A and column 2), where we show all coefficient estimates are reasonable. For example, female babies are more likely to be LBW than male babies; mothers with higher levels of education are at a lower risk of having LBW babies; and maternal smoking is associated with an increased risk of having LBW babies.

(shown in Figure 5) and presumably heavily affected by the aviation noise. Results of this robustness check are reported in column (2) of Table 5: the estimates are extremely close to those reported in column (2) of Table 4, suggesting that the health effects detected in column (2) of Table 4 are driven mainly by aviation noise affecting those who live near the airport and in the direction of the runway. We also emphasize that the robustness of the estimates reported in column (2) of Table 4, in comparison with those reported in Table 5, is remarkable, in light of the sample size difference: in the first robustness check, the sample size used in column (1) of Table 5 is almost three times as large as the sample size in column (2) of Table 4; in the second robustness check, the sample size used in column (2) of Table 5 is about 30 percent smaller than the sample size used in column (2) of Table 4.

Next, in Table 6 we conduct a further robustness check by dropping individuals who live within 2 miles of the mid-point of runway 4L-22R.[31] We do so to evaluate the validity of the criteria for inclusion in the treatment zone (shown in Figure 5). As previously discussed, in Appendix Table A1 we show that there is a statistically significant difference in the noise level between the treatment and control groups (by about 14 to 17 dB, with the average noise level in the treatment group being approximately equal to 63 dB). It is possible that individuals living next to the airport but not in the direction of runway 4L-22R (i.e., just outside the dragonfly-shaped zone) may actually experience high levels of aviation noise but are incorrectly excluded from the treatment group used by our estimation based on equation (2). In this case, we would under-estimate the effect of residential noise exposure. In Table 6 we drop those living close to the runway (specifically, within 2 miles of the mid-point of runway 4L-22R) from the estimation sample, a group that is most likely to have an incorrect treatment-control group designation. These results, shown in Table 6, are very similar to previous results.[32]

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[31] In our data the minimal distance between a mother's home and the mid-point of runway 4L-22R is 1.09 miles. Using a radius greater than that minimal distance is necessary, to ensure we obtain a substantially different sample for this robustness check.

[32] While the under-estimation is conceivable, estimates reported in Table 6 are actually very similar to those reported in Table 4 and Table 5. One explanation is that the observations we dropped could include: (i) those who were actually affected by aviation noise but incorrectly included in the control group (because

Table 7 reports the estimation results based on the regression model described by equation (3), aimed at capturing residential exposure to intermittent loud noise generated specifically by aircraft. We find that among those living within 10 miles of the airport runway, it is the combination of living within 5 degrees of the runway and being exposed to noise levels (measured in 2014) of at least 55 dB that appears to increase the LBW likelihood by 1.24 percentage points (column 1 of Panel A), or 17 percent when compared with the LBW rate among singleton births (7.3%) reported in Table 1. As we explained in the regression models section, this effect, to some degree, represents the impact of residential exposure to intermittent loud noise coming from aircraft takeoffs and landings. This effect increases to 2.187 percentage points in the sample of singleton births that occurred between 2011 and 2016 (column 1 of Panel B), when NextGen was being implemented at EWR.

In contrast, among those living within 10 miles of the runway, living in the direction of the runway but being exposed to noise levels (measured in 2014) that are lower than 55 dB is associated with a lower risk of LBW. This could be explained by the distance between a home and the runway being long enough (e.g., longer than 5 miles) to effectively reduce residential exposure to aviation noise, therefore reducing the risk of LBW. We further confirm the robustness of the estimates reported in Table 7 by dropping those living within 2 miles of the runway (Table 8). This robustness check suggests that the adverse health effects reported in Table 7 are not driven by those living immediately next to the runway, but driven by those living relatively close to, and more importantly, in the direction of the runway, who are likely to experience high levels of aviation noise. As expected, in both

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of the use of that dragonfly-shaped zone); and (ii) those who were affected by the noise and also correctly included in the treatment group (i.e., inside the dragonfly-shaped zone). Dropping observations of case (i) should mitigate the under-estimation problem, but simultaneously dropping observations of case (ii) will exacerbate that under-estimation problem. Results in Table 6 suggest that aviation noise in the area that is 2 miles of the mid-point of runway 4L-22R could be evenly distributed. If this is indeed the case, then the use of that dragonfly-shaped zone will be ineffective in distinguishing between a treatment group and a control group. Despite this potential limitation in the use of that dragonfly-shaped zone, the robustness in the estimates shown in Table 6 (in comparison with those reported in Table 4 and Table 5) suggests that the “living in the direction of the runway (1/0)” indicator, constructed based on the dragonfly-shaped zone, is still valid in the sense of capturing excessive variation in noise that comes from the direction of, not the proximity to, the airport runway.

Tables 7 and 8 we also find the effect of residential noise exposure on LBW appears to be more salient among male babies than among female babies. This finding is consistent with the "fragile male" hypothesis that male fetuses are more vulnerable than female fetuses to adverse environment shocks *in utero* (Eriksson et al., 2010).

In Table 9 we examine the effects of residential noise exposure on other birth outcomes. Similar to the results reported in Tables 7 and 8, we find the estimates to be robust when individuals living within 2 miles of the airport runway are excluded from the estimation sample. Results in Table 9 suggest an increased risk of having preterm babies (by about 1.6 percentage points, column 1) and shortened gestational length (by about 0.15 weeks, column 2) for those living in the direction of the runway and exposed to noise levels (measured in 2014) of at least 55 dB. In Table 9 we do not find any adverse effect of residential noise exposure on the continuous measure of birth weight, on average (column 3). One explanation is the potential presence of an effect of noise on fetal macrosomia (birth weight $> 4{,}000$ grams, column 4), which in combination with the effect of noise on LBW could make the effect of noise on birth weight, on average, become zero.

Lastly, in Figure 7 we examine the daily air pollution variation for two monitors, both located in the region covered by our estimation sample but exposed to significantly different noise levels: one monitor is located in the treatment group area, and the other is located in the control group area. We examine three specific air pollutants, which are available from the EPA's air quality monitoring network—carbon monoxide (CO), nitrogen dioxide (NO_2), and particulate matter that is smaller than 2.5 micrometers ($PM_{2.5}$). According to Schlenker and Walker (2016), aircraft's high power operations, such as takeoff, produce more NO_2 emissions, while low power operations, such as taxiing, produce more CO emissions. Their study finds that it is CO, not NO_2, that affects the health of residents living within 10 km (i.e., 6.2 miles) of the airports in California, with one caveat: "One potential omitted variable that we unfortunately cannot measure well is particulate matter, a pollutant which may emerge from combustion emissions and has been shown in the past to increase infant mortality due to respiratory causes" (p. 800). In Panel A of Figure 7 we plot the daily variation, measured in 2014 (the same year of the noise data) for each of the three air pollutants—CO, NO_2 and $PM_{2.5}$—by each monitor. Overall, we do not find any noticeable difference in the daily variation of each of the three air pollutants between the two monitors, except that CO levels measured at the monitor located in the treatment group were higher than those measured at the monitor located in the control group during the summer (July, August and September) of 2014. However, this pattern seems to be transitory and specifically for the summer of 2014: we do not find this pattern in Panel B of Figure 7, where we plot the daily variation of each of the three air pollutants measured in 2015. Overall, results in Figure 7 suggest that air pollutant concentrations, although likely to vary significantly *at* airport runways (due to plane takeoffs and landings), could be evenly distributed within a small area relatively close to the runways. The even distribution of air pollutant concentrations in a small area with sharply different noise levels allows us to disentangle the effect of noise from the effect of air pollution.

7 Conclusion

Using unique birth data that contain information on mothers' exact home addresses, our study finds that among all births that occurred between 2004 and 2016, there is an increase of 1.24 percentage points (or 17 percent) in the likelihood of having a LBW baby among mothers living close to the airport, in the direction of the runway, and exposed to noise levels over the 55 dB threshold recommended by the EPA and the WHO. This effect increases to approximately 2 percentage points among births that occurred between 2011 and 2016, when NextGen was being actively implemented at the airport.

To identify this causal effect of noise exposure on health, we utilize the arguably exogenous variation in residential noise exposure triggered by the NextGen. Our study has an important implication regarding its *unintended* consequence in the case of fetal health, which can have far-reaching impact on adult health. Attention to this unintended consequence is especially important in light of the many efficiency benefits attributed to NextGen.[33] In this sense, our results are aligned with a recent study by Zafari et al. (2018), who explicitly model the trade-off between NextGen's flight path optimization and potential adverse health impacts from noise, and they find that benefits in terms of increased fuel efficiency and reduced flight time may be offset by unintended adverse effects on health in terms of reduced quality-adjusted life years. Our study broadens the scope of that finding by taking compromised fetal health into account.

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[33] For example: "The FAA estimates that NextGen's implemented improvements have accrued $4.7 billion worth of benefits from 2010–2017, which consists of $2.6 billion in decreased passenger travel time, $1.8 billion in lower aircraft operating expenses, and $300 million in safety benefits" (source: https://www.faa.gov/nextgen/faqs/, accessed on May 16, 2019). Schlenker and Walker (2016), in the examination of daily pollution exposure caused by idiosyncratic air traffic congestion that results in excessive aircraft idling and taxiing time for individuals living within 10 km (i.e., 6.2 miles) of the airports, find that increased exposure in daily air pollution levels increases hospitalization for respiratory and heart-related conditions. Their results suggest that policies that improve airport efficiency for companies and passengers can have positive health externalities to nearby residents.

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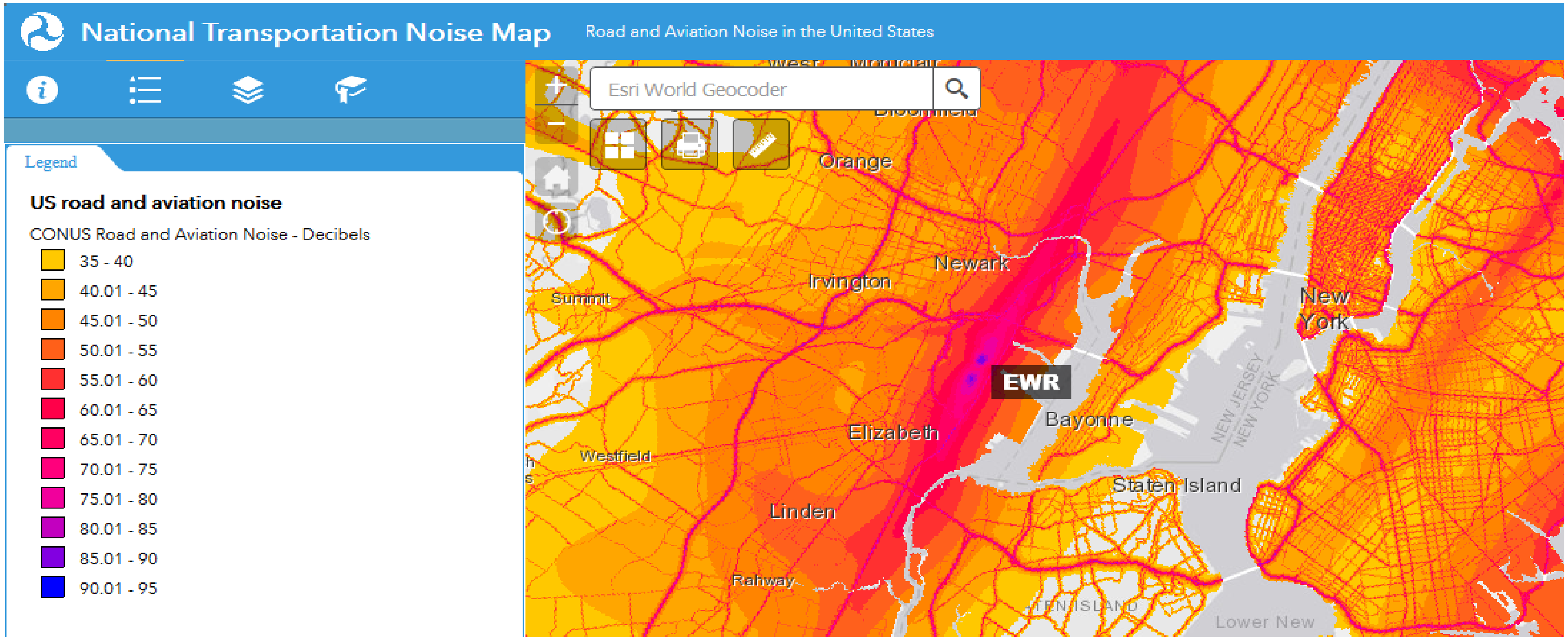

Figure 1: Aviation and Road Noise near the Newark Liberty International Airport (EWR)

Notes: This figure is extracted from the National Transportation Noise Map available at https://www.transportation.gov/highlights/national-transportation-noise-map.

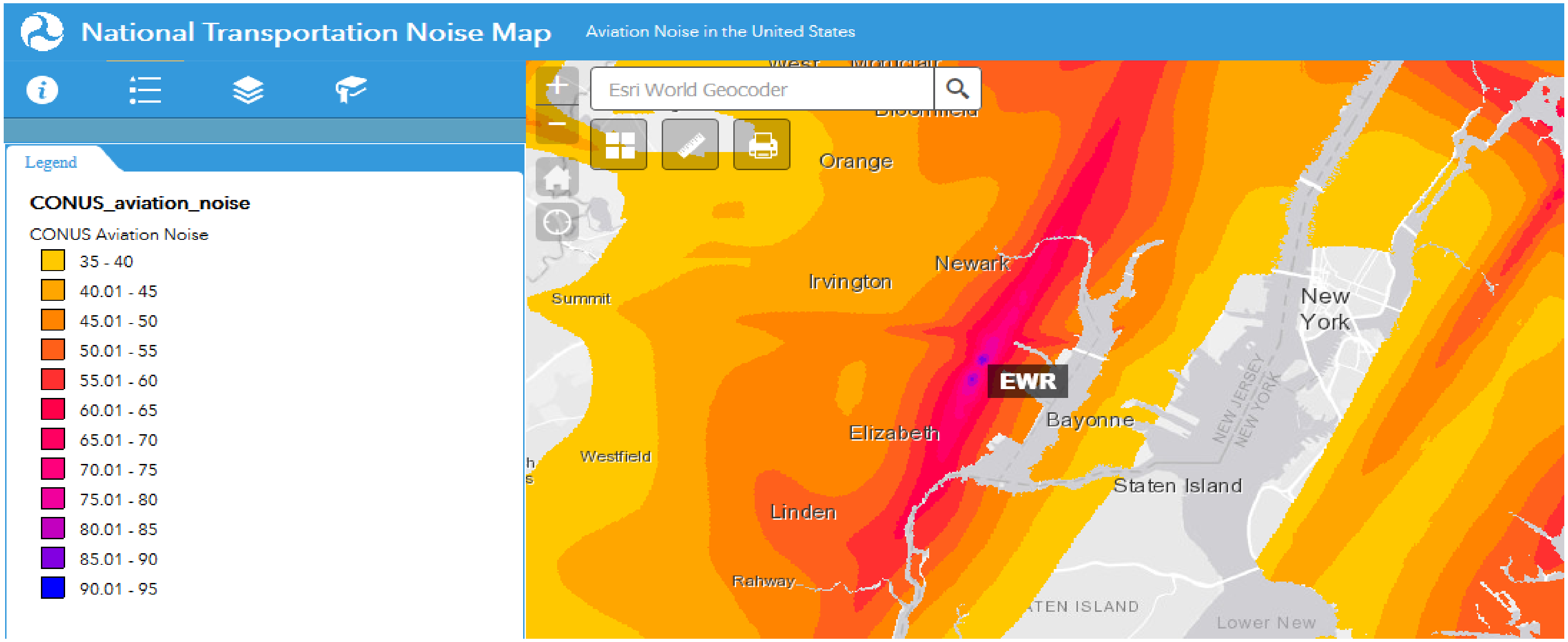

Figure 2: Aviation Noise near the Newark Liberty International Airport (EWR)

Notes: This figure is extracted from the National Transportation Noise Map available at https://www.transportation.gov/highlights/national-transportation-noise-map.

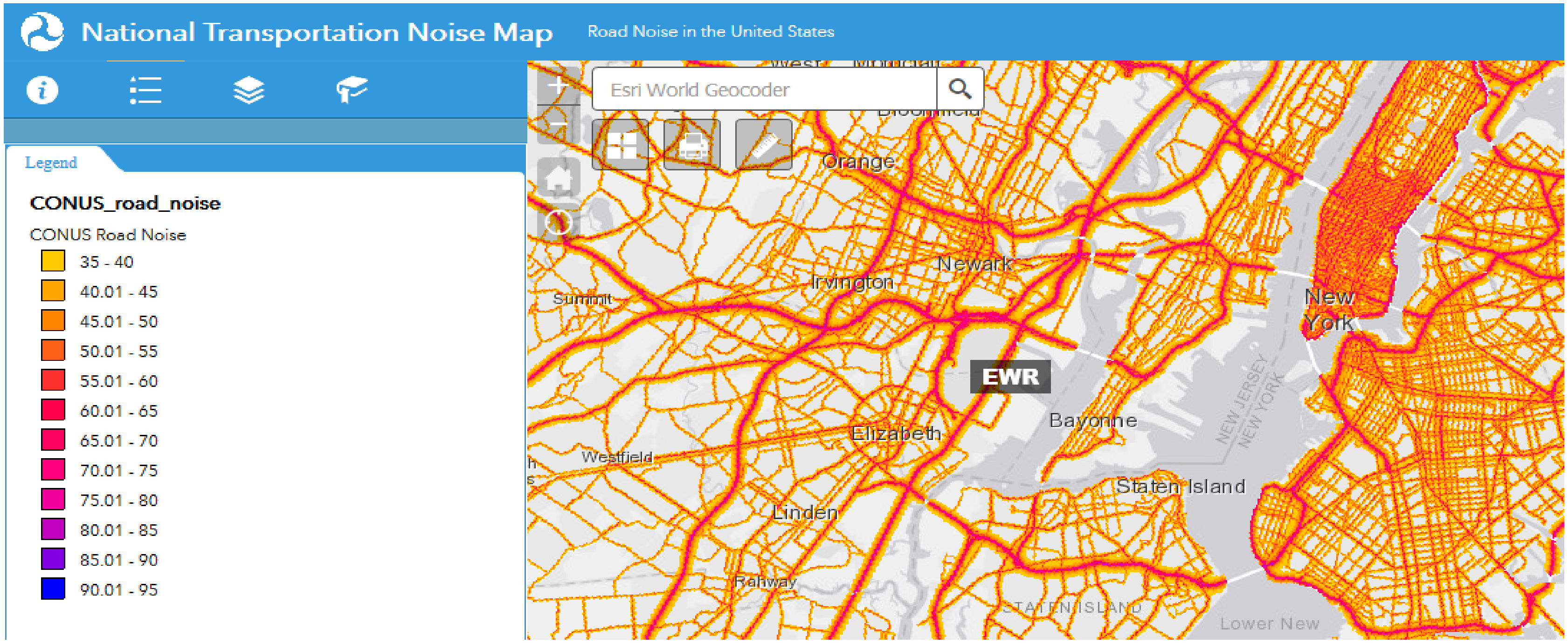

Figure 3: Road Noise near the Newark Liberty International Airport (EWR)

Notes: This figure is extracted from the National Transportation Noise Map available at https://www.transportation.gov/highlights/national-transportation-noise-map.

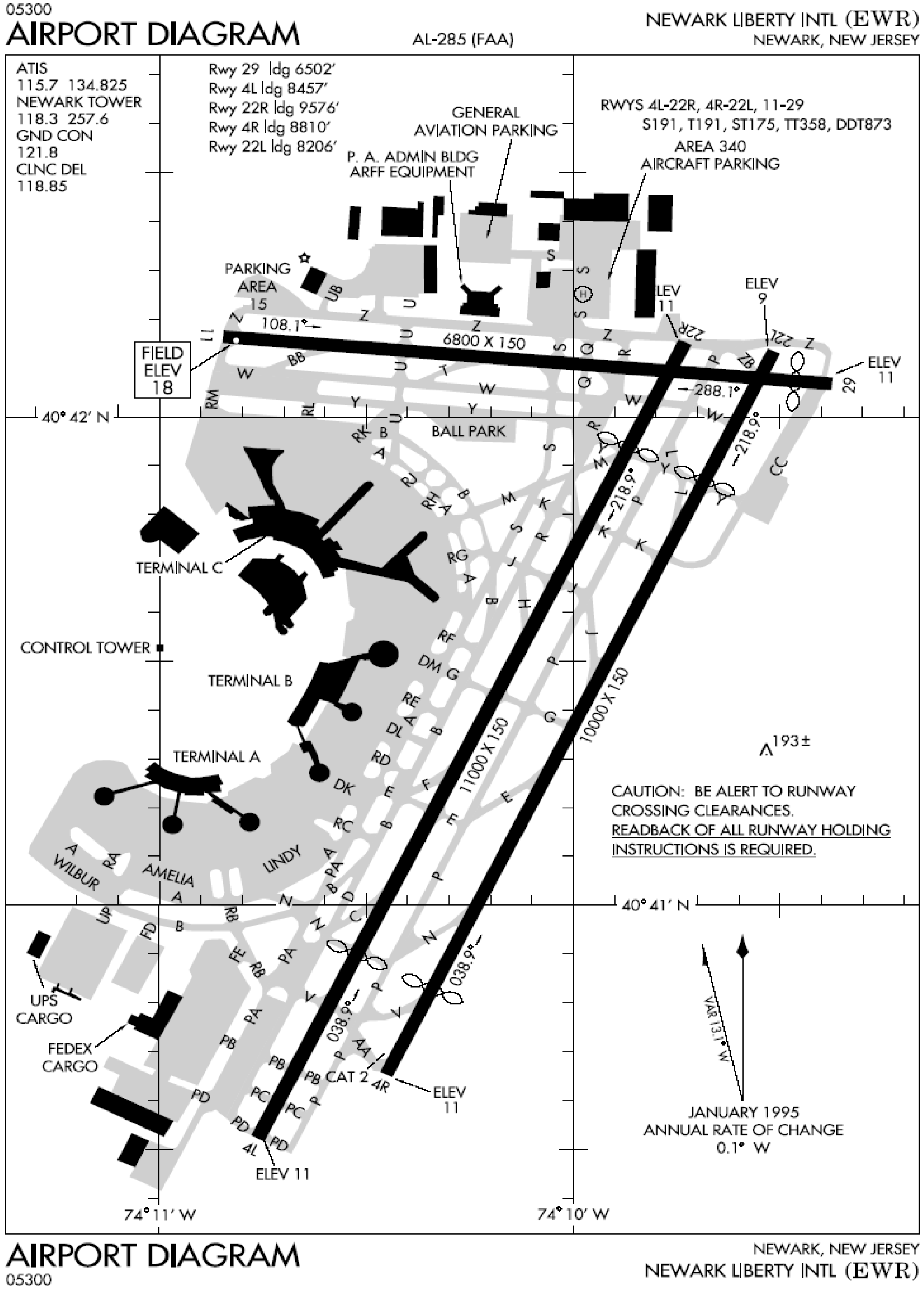

Figure 4: Diagram of the Newark Liberty International Airport (EWR)

Notes: This diagram is obtained from http://www.nycaviation.com/spotting-guides/ewr/ewr-general-information.

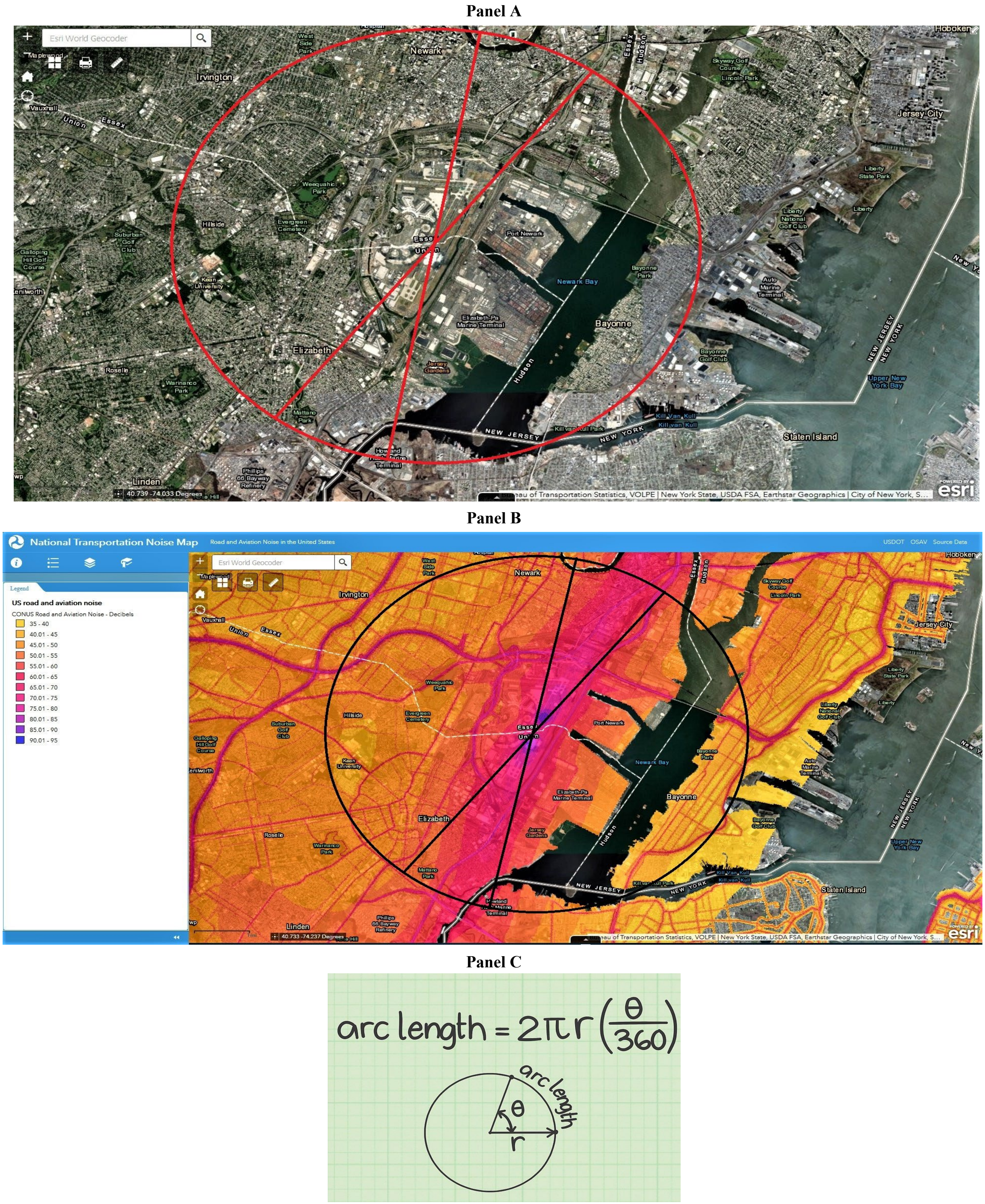

Figure 5: Illustration of the Research Design

Notes: Panels A and B are based on the National Transportation Noise Map available at https://www.transportation.gov/highlights/national-transportation-noise-map. The center of the circle (which is also the intersection) is the Newark Liberty International Airport. Panel C is from https://www.wikihow.com/Find-Arc-Length.

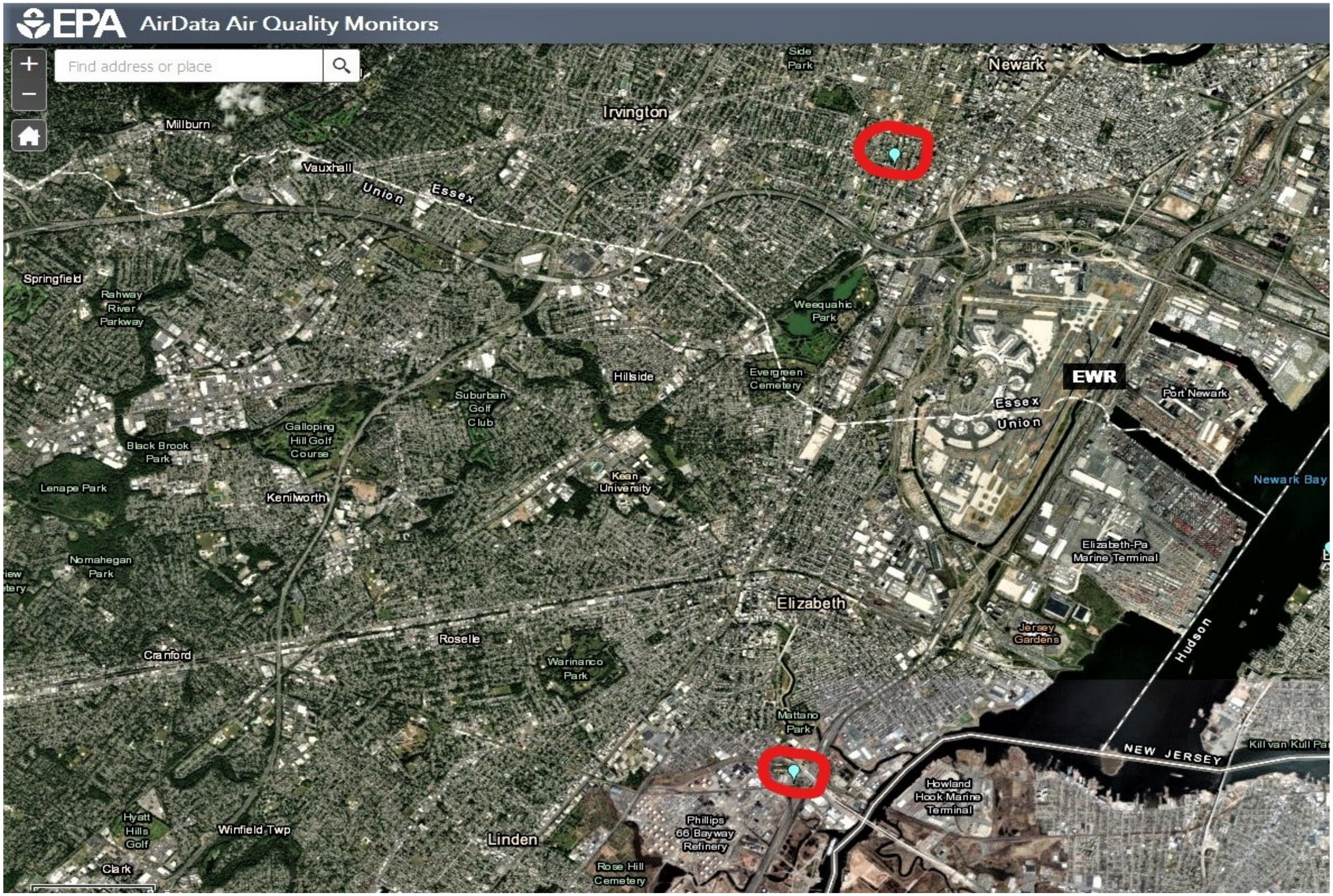

Figure 6: Air Pollutant Monitors near the Newark Liberty International Airport (EWR)

Notes: Circled (in red) are the two air pollutant monitors that have readings on carbon monoxide (CO), nitrogen dioxide (NO2) and fine particulate matter (PM2.5), with the data provided by the EPA's AQS Data Mart available at https://www.epa.gov/outdoor-air-quality-data/interactive-map-air-quality-monitors. The circled monitor near the bottom of the figure is located in the "treated" area, that is, the area within 5 miles and also within 5 degrees of the mid-point of EWR runway 4L-22R. The circled monitor near the top of the figure is located in the "control" area, that is, the area within 5 miles but outside 5 degrees of the mid-point of EWR runway 4L-22R.

Figure 7: Carbon Monoxide (CO), Nitrogen Dioxide (NO2) and Fine Particulate Matter (PM2.5) near the Newark Liberty International Airport (EWR)

Notes: Data are from the EPA's AQS Data Mart available at https://www.epa.gov/outdoor-air-quality-data/interactive-map-air-quality-monitors. Depicted are the CO readings averaged over every 1-hour period each day, NO2 readings averaged over every 1-hour period each day, and PM2.5 readings averaged over every 24-hour period each day. Panel A shows the air pollutant monitors' daily readings throughout the entire year of 2014. Panel B shows the air pollutants' daily readings throughout the entire year of 2015. The "treated" area is the one located within 5miles and also within 5 degrees of the mid-point of EWR runway 4L-22R. The "control" area is the one located within 5 miles but outside 5 degrees of the mid-point of EWR runway 4L-22R.

Table 1: Summary Statistics

Variables	Mean	Std. dev.	No. of obs.
Aviation and road noise (measured in dB)	49.947	6.546	107,401
Aviation noise (measured in dB)	47.153	6.177	107,410
Aviation and road noise (measured in dB) ≥ 55 (1/0)	0.205	0.404	107,401
Aviation noise (measured in dB) ≥ 55 (1/0)	0.116	0.321	107,410
Living in the direction of the runway (1/0)	0.051	0.220	107,495
Distance between mother's home and the mid-point of EWR runway 4L-22R (measured in miles)	3.554	0.874	107,495
Birth weight (measured in grams), among single births	3253.037	540.575	107,495
Low birth weight (1/0): birth weight < 2,500 grams, among singleton births	0.073	0.259	107,495
Fetal macrosomia (1/0): birth weight > 4,000 grams, among single births	0.066	0.248	107,495
Gestational length (measured in weeks), among singleton births	38.592	1.839	107,495
Preterm (1/0): gestational length < 37 weeks, among singleton births	0.090	0.286	107,495
Female baby (1/0)	0.491	0.500	107,495
Mother's age	28.278	6.179	107,495
Mother being White (1/0)	0.450	0.498	107,495
Mother being Black (1/0)	0.456	0.498	107,495
Mother being Hispanic (1/0)	0.395	0.489	107,495
Mother having completed a four-year college or higher (1/0)	0.192	0.394	107,495
Mother being married (1/0)	0.401	0.490	107,495
Number of prenatal visits	9.095	3.541	107,495
Mother smoked cigarettes before or during her pregnancy (1/0)	0.061	0.240	107,495

Notes: Summary statistics are based on the estimation sample of Table 4 (Panel A). The estimation sample includes live and singleton births of mothers who live within 5 miles of the mid-point of EWR runway 4L-22R. “Living in the direction of the runway” is a dummy variable, which is equal to one for mothers living within 5 degrees of the mid-point of EWR runway 4L-22R and equal to zero otherwise. The data on noise are from the U.S. Department of Transportation. The variables on noise are measured in decibels (dB) for each mother’s residential address and for year 2014.

Table 2: Effects of Noise Exposure on Low Birth Weight

Outcome variable: low birth weight (birth weight < 2,500 grams)		
Noise variable used in the regression model is:	Aviation and road noise (1)	Aviation noise (2)
Panel A: Births ocurred between 2004 and 2016		
Noise (measured in dB) ≥ 55 (1/0)	-0.00330	0.00882
	(0.00289)	(0.00582)
Noise (measured in dB, a continuous variable)	-0.00001	-0.00053
	(0.00018)	(0.00033)
Distance between mother's home and the mid-point of EWR runway 4L-22R (measured in miles)	-0.00214 (0.00170)	-0.00283 (0.00177)
Number of observations	107,401	107,410
Panel B: Births occurred between 2011 and 2016		
Noise (measured in dB) ≥ 55 (1/0)	-0.00054	0.01470**
	(0.00388)	(0.00681)
Noise (measured in dB, a continuous variable)	0.00025	-0.00078
	(0.00041)	(0.00074)
Distance between mother's home and the mid-point of EWR runway 4L-22R (measured in miles)	-0.00026 (0.00269)	-0.00146 (0.00306)
Number of observations	48,261	48,269
Control variables used in Panels A and B		
Individual level demographic variables	Yes	Yes
Zip code-year-month fixed effects	Yes	Yes

Notes: The estimation sample includes live and singleton births of mothers who live within 5 miles of the mid-point of EWR runway 4L-22R. The estimation is based on the regression model described by equation (1) in the text. The data on noise are from the U.S. Department of Transportation. The variables on noise are measured in decibels (dB) for each mother’s residential address and for year 2014. Individual level demographic variables controlled for are infant being female (1/0), mother’s age, mother’s race and ethnicity (1/0 dummy variables for White, Black, and Hispanic), mother having completed a four-year college education or higher (1/0), mother being married (1/0), the number of prenatal visits, and maternal smoking (1/0). The zip code-year-month fixed effects are the fixed effects applied to each mother’s residential zip code-year-month of birth pair. Standard errors (reported in parentheses) are clustered at the mother’s residential zip code level. * *p* -value < 0.1; ** *p* -value < 0.05; *** *p* -value < 0.01.

Table 3: Comparisons of Maternal Demographic Characteristics and Health Behaviors

Birth years included in the estimation sample:	2004–2016		2004–2016
	Coefficient on "noise (measured in dB) ≥ 55" (which is a dummy variable)		Coefficient on "living in the direction of the runway" (which is a dummy variable)
Noise variable used in the regression model is:	Aviation and road noise	Aviation noise	
	(1)	(2)	(3)
(a) Mother's age	-0.03582	-0.54781	0.17253
	(0.25033)	(0.79719)	(0.13744)
(b) Mother being While (1/0)	0.00010	0.02277	0.00078
	(0.02206)	(0.04184)	(0.03027)
(c) Mother being Black (1/0)	0.01753	0.05447	-0.02101
	(0.02645)	(0.09129)	(0.04202)
(d) Mother being Hispanic (1/0)	-0.00776	0.01855	0.01383
	(0.02166)	(0.04838)	(0.06241)
(e) Mother having completed a four-year college or higher (1/0)	-0.01010	-0.09601	0.00987
	(0.01316)	(0.06842)	(0.00843)
(f) Mother being married (1/0)	-0.00812	-0.06771	0.01728
	(0.02419)	(0.09603)	(0.01397)
(g) Number of prenatal visits	-0.05408	-0.24355	0.03350
	(0.09015)	(0.25039)	(0.04121)
(h) Maternal smoking (1/0)	-0.00323	0.01811	0.00229
	(0.00449)	(0.01658)	(0.01084)
Control variables			
Aviation and road noise (measured in dB, a continuous variable)	Yes	No	No
Aviation noise (measured in dB, a continuous variable)	No	Yes	No
Distance between mother's home and the mid-point of EWR runway 4L-22R (measured in miles)	Yes	Yes	Yes
Zip code-year-month fixed effects	Yes	Yes	Yes
Number of observations	107,401	107,410	107,495

Notes: The estimation sample includes live and singleton births of mothers who live within 5 miles of the mid-point of EWR runway 4L-22R. “Living in the direction of the runway” is dummy variable, which is equal to one for mothers living within 5 degrees of the mid-point of EWR runway 4L-22R and equal to zero otherwise. The data on noise are from the U.S. Department of Transportation. The variables on noise are measured in decibels (dB) for each mother’s residential address and for year 2014. Each column of (1) and (2) is an ordinary least squares (OLS) regression of each of the mother’s demographic characteristics and health behaviors (listed in the table, from a to h) on an intercept, the “noise (measured in dB) ≥ 55” dummy variable, and the control variables (listed at the end of the table). Column (3) is an OLS regression of each of the mother’s demographic characteristics and health behaviors (listed in the table, from a to h) on an intercept, the “living in the direction of the runway” dummy variable, and the control variables (listed at the end of the table). The zip code-year-month fixed effects are the fixed effects applied to each mother’s residential zip code-year-month of birth pair. Standard errors (reported in parentheses) are clustered at the mother’s residential zip code level. * *p* -value < 0.1; ** *p* -value < 0.05; *** *p* -value < 0.01.

Table 4: Effects of Living in the Direction of the Runway on Low Birth Weight

Outcome variable: low birth weight (birth weight < 2,500 grams)			
The distance between mother's home and the mid-point of EWR runway 4L-22R in the estimation sample is:	Within 5 miles	Within 5 miles	Outside 20 miles
	(1)	(2)	(3)
Panel A: Births ocurred between 2004 and 2016			
Living in the direction of the runway (1/0)	0.00645***	0.00702***	-0.00269
	(0.00096)	(0.00146)	(0.00370)
Distance between mother's home and the mid-point of EWR runway 4L-22R (measured in miles)	-0.00068	-0.00260*	0.00005
	(0.00406)	(0.00150)	(0.00028)
Number of observations	107,495	107,495	595,531
Panel B: Births occurred between 2011 and 2016			
Living in the direction of the runway (1/0)	0.00824***	0.00915***	-0.00039
	(0.00165)	(0.00271)	(0.00449)
Distance between mother's home and the mid-point of EWR runway 4L-22R (measured in miles)	0.00122	-0.00101	-0.00016
	(0.00491)	(0.00263)	(0.00042)
Number of observations	48,351	48,351	259,191
Panel C: Births occurred between 2004 and 2010			
Living in the direction the runway (1/0)	0.00497***	0.00527***	-0.00433
	(0.00161)	(0.00076)	(0.00410)
Distance between mother's home and the mid-point of EWR runway 4L-22R (measured in miles)	-0.00240	-0.00401	0.00023
	(0.00468)	(0.00295)	(0.00033)
Number of observations	59,144	59,144	336,340
Control variables used in Panels A and B			
Individual level demographic variables	No	Yes	Yes
Zip code-year-month fixed effects	Yes	Yes	Yes

Notes: The estimation sample includes live and singleton births. The estimation is based on the regression model described by equation (2) in the text. "Living in the direction of the runway" is a dummy variable, which is equal to one for mothers living within 5 degrees of the mid-point of EWR runway 4L-22R and equal to zero otherwise. Individual level demographic variables controlled for are infant being female (1/0), mother's age, mother's race and ethnicity (1/0 dummy variables for White, Black, and Hispanic), mother having completed a four-year college education or higher (1/0), mother being married (1/0), the number of prenatal visits, and maternal smoking (1/0). The zip code-year-month fixed effects are the fixed effects applied to each mother's residential zip code-year-month of birth pair. Standard errors (reported in parentheses) are clustered at the mother's residential zip code level. * *p* -value < 0.1; ** *p* -value < 0.05; *** *p* -value < 0.01.

Table 5: Effects of Living in the Direction of the Runway on Low Birth Weight (Robustness Checks)

Outcome variable: low birth weight (birth weight < 2,500 grams)		
Estimation sample includes mothers living in:	Essex, Union and Hudson (i.e., three NJ counties) (1)	Elizabeth and Newark (i.e., two NJ cities) (2)
Panel A: Births ocurred between 2004 and 2016		
Living in the direction of the runway (1/0)	0.00623***	0.00714***
	(0.00161)	(0.00150)
Distance between mother's home and the mid-point of EWR runway 4L-22R (measured in miles)	-0.00066	-0.00260*
	(0.00070)	(0.00147)
Number of observations	303,441	74,694
Panel B: Births occurred between 2011 and 2016		
Living in the direction of the runway (1/0)	0.00876***	0.00960***
	(0.00274)	(0.00268)
Distance between mother's home and the mid-point of EWR runway 4L-22R (measured in miles)	-0.00050	-0.00212
	(0.00088)	(0.00130)
Number of observations	137,539	33,427
Panel C: Births occurred between 2004 and 2010		
Living in the direction of the runway (1/0)	0.00408***	0.00520***
	(0.00081)	(0.00094)
Distance between mother's home and the mid-point of EWR runway 4L-22R (measured in miles)	-0.00081	-0.00326
	(0.00121)	(0.00339)
Number of observations	165,902	41,267
Control variables used in Panels A and B		
Individual level demographic variables	Yes	Yes
Zip code-year-month fixed effects	Yes	Yes

Notes: The estimation sample includes live and singleton births. The estimation is based on the regression model described by equation (2) in the text. "Living in the direction of the runway" is a dummy variable, which is equal to one for mothers living within 5 degrees of the mid-point of EWR runway 4L-22R and equal to zero otherwise. Individual level demographic variables controlled for are infant being female (1/0), mother's age, mother's race and ethnicity (1/0 dummy variables for White, Black, and Hispanic), mother having completed a four-year college education or higher (1/0), mother being married (1/0), the number of prenatal visits, and maternal smoking (1/0). The zip code-year-month fixed effects are the fixed effects applied to each mother's residential zip code-year-month of birth pair. Standard errors (reported in parentheses) are clustered at the mother's residential zip code level. * *p* -value < 0.1; ** *p* -value < 0.05; *** *p* -value < 0.01.

Table 6: Effects of Living in the Direction of the Runway on Low Birth Weight

Outcome variable: low birth weight (birth weight < 2,500 grams)			
Estimation sample includes mothers	whose homes are between 2 and 5 miles of the mid-point of EWR runway 4L-22R	who live in Essex, Union and Hudson (i.e., three NJ counties) and whose homes are at least 2 miles away from the mid-point of EWR runway 4L-22R	who live in Elizabeth and Newark (i.e., two NJ cities) and whose homes are at least 2 miles away from the mid-point of EWR runway 4L-22R
	(1)	(2)	(3)
Panel A: Births ocurred between 2004 and 2016			
Living in the direction of the runway (1/0)	0.00672***	0.00597***	0.00684***
	(0.00147)	(0.00164)	(0.00151)
Distance between mother's home and the mid-point of EWR runway 4L-22R (measured in miles)	-0.00242	-0.00061	-0.00242
	(0.00154)	(0.00071)	(0.00156)
Number of observations	105,170	301,116	72,370
Panel B: Births occurred between 2011 and 2016			
Living in the direction of the runway (1/0)	0.00847***	0.00820***	0.00898***
	(0.00272)	(0.00281)	(0.00270)
Distance between mother's home and the mid-point of EWR runway 4L-22R (measured in miles)	-0.00055	-0.00045	-0.00190
	(0.00276)	(0.00089)	(0.00138)
Number of observations	47,387	136,575	32,464
Panel C: Births occurred between 2004 and 2010			
Living in the direction the runway (1/0)	0.00527***	0.00407***	0.00515***
	(0.00080)	(0.00082)	(0.00101)
Distance between mother's home and the mid-point of EWR runway 4L-22R (measured in miles)	-0.00410	-0.00077	-0.00315
	(0.00313)	(0.00122)	(0.00365)
Number of observations	57,783	164,541	39,906
Control variables used in Panels A and B			
Individual level demographic variables	Yes	Yes	Yes
Zip code-year-month fixed effects	Yes	Yes	Yes

Notes: The estimation sample includes live and singleton births. The estimation is based on the regression model described by equation (2) in the text. “Living in the direction of the runway” is a dummy variable, which is equal to one for mothers living within 5 degrees of the mid-point of EWR runway 4L-22R and equal to zero otherwise. Individual level demographic variables controlled for are infant being female (1/0), mother’s age, mother’s race and ethnicity (1/0 dummy variables for White, Black, and Hispanic), mother having completed a four-year college education or higher (1/0), mother being married (1/0), the number of prenatal visits, and maternal smoking (1/0). The zip code-year-month fixed effects are the fixed effects applied to each mother’s residential zip code-year-month of birth pair. Standard errors (reported in parentheses) are clustered at the mother’s residential zip code level. * p -value < 0.1; ** p -value < 0.05; *** p -value < 0.01.

Table 7: Effects of Living in the Direction of the Runway on Low Birth Weight, Controlling for Aviation and Road Noise

Outcome variable: low birth weight (birth weight < 2,500 grams)

The distance between mother's home and the mid-point of EWR runway 4L-22R in the estimation sample is within 10 miles.

	Full sample (1)	Male sample (2)	Female sample (3)
Panel A: Births ocurred between 2004 and 2016			
Living in the direction of the runway (1/0) × Aviation and road noise (measured in dB) ≥ 55 (1/0)	0.01240***	0.01515*	0.00876
	(0.00439)	(0.00899)	(0.00537)
Living in the direction of the runway (1/0)	-0.00716*	-0.00815	-0.00399
	(0.00380)	(0.00661)	(0.00260)
Aviation and road noise (measured in dB) ≥ 55 (1/0)	-0.00323	-0.00460	-0.00255
	(0.00244)	(0.00377)	(0.00404)
Aviation and road noise (measured in dB, a continuous variable)	0.00002	0.00016	-0.00018
	(0.00015)	(0.00017)	(0.00022)
Distance between mother's home and the mid-point of EWR runway 4L-22R (measured in miles)	-0.00081	-0.00202	-0.00001
	(0.00096)	(0.00146)	(0.00138)
Number of observations	261,232	133,254	127,978
Panel B: Births occurred between 2011 and 2016			
Living in the direction of the runway (1/0) × Aviation and road noise (measured in dB) ≥ 55 (1/0)	0.02187***	0.02619**	0.02357***
	(0.00703)	(0.01134)	(0.00494)
Living in the direction of the runway (1/0)	-0.01505**	-0.01520	-0.01919***
	(0.00583)	(0.00976)	(0.00381)
Aviation and road noise (measured in dB) ≥ 55 (1/0)	-0.00523	-0.00548	-0.00535
	(0.00323)	(0.00453)	(0.00534)
Aviation and road noise (measured in dB, a continuous variable)	0.00021	0.00043	-0.00003
	(0.00021)	(0.00026)	(0.00028)
Distance between mother's home and the mid-point of EWR runway 4L-22R (measured in miles)	-0.00049	-0.00057	-0.00119
	(0.00123)	(0.00192)	(0.00177)
Number of observations	118,450	60,250	58,200
Control variables used in Panels A and B			
Individual level demographic variables	Yes	Yes	Yes
Zip code-year-month fixed effects	Yes	Yes	Yes

Notes: The estimation sample includes live and singleton births. The estimation is based on the regression model described by equation (3) in the text. “Living in the direction of the runway” is dummy variable, which is equal to one for mothers living within 5 degrees of the mid-point of EWR runway 4L-22R and equal to zero otherwise. The data on noise are from the U.S. Department of Transportation. The variables on noise are measured in decibels (dB) for each mother’s residential address and for year 2014. Individual level demographic variables controlled for are infant being female (1/0) except columns (2) and (3), mother’s age, mother’s race and ethnicity (1/0 dummy variables for White, Black, and Hispanic), mother having completed a four-year college education or higher (1/0), mother being married (1/0), the number of prenatal visits, and maternal smoking (1/0). The zip code-year-month fixed effects are the fixed effects applied to each mother’s residential zip code-year-month of birth pair. Standard errors (reported in parentheses) are clustered at the mother’s residential zip code level. * p -value < 0.1; ** p -value < 0.05; *** p -value < 0.01.

Table 8: Effects of Living in the Direction of the Runway on Low Birth Weight, Controlling for Aviation and Road Noise

Outcome variable: low birth weight (birth weight < 2,500 grams)

The distance between mother's home and the mid-point of EWR runway 4L-22R in the estimation sample is between 2 and 10 miles.

	Full sample (1)	Male sample (2)	Female sample (3)
Panel A: Births ocurred between 2004 and 2016			
Living in the direction of the runway (1/0) × Aviation and road noise (measured in dB) ≥ 55 (1/0)	0.01204***	0.01436	0.00885
	(0.00444)	(0.00904)	(0.00540)
Living in the direction of the runway (1/0)	-0.00707*	-0.00794	-0.00400
	(0.00380)	(0.00663)	(0.00260)
Aviation and road noise (measured in dB) ≥ 55 (1/0)	-0.00296	-0.00375	-0.00284
	(0.00244)	(0.00369)	(0.00412)
Aviation and road noise (measured in dB, a continuous variable)	0.00001	0.00014	-0.00018
	(0.00015)	(0.00017)	(0.00022)
Distance between mother's home and the mid-point of EWR runway 4L-22R (measured in miles)	-0.00074	-0.00177	-0.00009
	(0.00097)	(0.00148)	(0.00140)
Number of observations	258,907	132,080	126,827
Panel B: Births occurred between 2011 and 2016			
Living in the direction of the runway (1/0) × Aviation and road noise (measured in dB) ≥ 55 (1/0)	0.02136***	0.02497**	0.02377***
	(0.00708)	(0.01143)	(0.00493)
Living in the direction of the runway (1/0)	-0.01506**	-0.01502	-0.01930***
	(0.00582)	(0.00976)	(0.00380)
Aviation and road noise (measured in dB) ≥ 55 (1/0)	-0.00529	-0.00487	-0.00594
	(0.00330)	(0.00459)	(0.00552)
Aviation and road noise (measured in dB, a continuous variable)	0.00021	0.00041	-0.00002
	(0.00021)	(0.00026)	(0.00028)
Distance between mother's home and the mid-point of EWR runway 4L-22R (measured in miles)	-0.00041	-0.00028	-0.00126
	(0.00125)	(0.00193)	(0.00179)
Number of observations	117,486	59,758	57,728
Control variables used in Panels A and B			
Individual level demographic variables	Yes	Yes	Yes
Zip code-year-month fixed effects	Yes	Yes	Yes

Notes: The estimation sample includes live and singleton births. The estimation is based on the regression model described by equation (3) in the text. "Living in the direction of the runway" is dummy variable, which is equal to one for mothers living within 5 degrees of the mid-point of EWR runway 4L-22R and equal to zero otherwise. The data on noise are from the U.S. Department of Transportation. The variables on noise are measured in decibels (dB) for each mother's residential address and for year 2014. Individual level demographic variables controlled for are infant being female (1/0) except columns (2) and (3), mother's age, mother's race and ethnicity (1/0 dummy variables for White, Black, and Hispanic), mother having completed a four-year college education or higher (1/0), mother being married (1/0), the number of prenatal visits, and maternal smoking (1/0). The zip code-year-month fixed effects are the fixed effects applied to each mother's residential zip code-year-month of birth pair. Standard errors (reported in parentheses) are clustered at the mother's residential zip code level. * p-value < 0.1; ** p-value < 0.05; *** p-value < 0.01.

Table 9: Effects of Living in the Direction of the Runway on Other Birth Outcomes, Controlling for Aviation and Road Noise

Estimation sample includes births that occurred between 2011 and 2016.

Outcome variables:	Preterm (1/0): gestational length < 37 weeks	Gestational Length (in weeks)	Birth weight (in grams)	Fetal macrosomia (1/0): birth weight > 4,000 grams
	(1)	(2)	(3)	(4)
Panel A: The distance between mother's home and the mid-point of EWR runway 4L-22R in the estimation sample is within 10 miles.				
Living in the direction of the runway (1/0) × Aviation and road noise (measured in dB) ≥ 55 (1/0)	0.01673**	-0.15135***	0.98452	0.00014
	(0.00785)	(0.03145)	(12.98653)	(0.00719)
Living in the direction of the runway (1/0)	-0.00539*	0.05868**	6.46302	0.00402
	(0.00320)	(0.02799)	(12.20876)	(0.00537)
Aviation and road noise (measured in dB) ≥ 55 (1/0)	0.00138	0.01044	11.98204*	0.00386
	(0.00333)	(0.01810)	(6.30469)	(0.00258)
Aviation and road noise (measured in dB, a continuous variable)	-0.00010	-0.00029	-0.83296	-0.00008
	(0.00022)	(0.00155)	(0.51291)	(0.00021)
Distance between mother's home and the mid-point of EWR runway 4L-22R (measured in miles)	-0.00014	0.00838	2.98148	0.00061
	(0.00144)	(0.01168)	(3.04323)	(0.00127)
Number of observations	118,450	118,450	118,450	118,450
Panel B: The distance between mother's home and the mid-point of EWR runway 4L-22R in the estimation sample is between 2 and 10 miles.				
Living in the direction of the runway (1/0) × Aviation and road noise (measured in dB) ≥ 55 (1/0)	0.01619**	-0.14813***	1.37894	0.00023
	(0.00789)	(0.03179)	(12.98294)	(0.00723)
Living in the direction of the runway (1/0)	-0.00537*	0.05827**	6.50482	0.00404
	(0.00320)	(0.02800)	(12.18451)	(0.00536)
Aviation and road noise (measured in dB) ≥ 55 (1/0)	0.00162	0.01004	12.57803*	0.00417*
	(0.00341)	(0.01852)	(6.37760)	(0.00250)
Aviation and road noise (measured in dB, a continuous variable)	-0.00011	-0.00027	-0.82471	-0.00008
	(0.00022)	(0.00155)	(0.51506)	(0.00021)
Distance between mother's home and the mid-point of EWR runway 4L-22R (measured in miles)	-0.00015	0.00668	2.96331	0.00057
	(0.00147)	(0.01189)	(3.08857)	(0.00129)
Number of observations	117,486	117,486	117,486	117,486
Control variables used in Panels A and B				
Individual level demographic variables	Yes	Yes	Yes	Yes
Zip code-year-month fixed effects	Yes	Yes	Yes	Yes

Notes: The estimation sample includes live and singleton births. The estimation is based on the regression model described by equation (3) in the text. “Living in the direction of the runway” is dummy variable, which is equal to one for mothers living within 5 degrees of the mid-point of EWR runway 4L-22R and equal to zero otherwise. The data on noise are from the U.S. Department of Transportation. The variables on noise are measured in decibels (dB) for each mother’s residential address and for year 2014. Individual level demographic variables controlled for are infant being female (1/0) except columns (2) and (3), mother’s age, mother’s race and ethnicity (1/0 dummy variables for White, Black, and Hispanic), mother having completed a four-year college education or higher (1/0), mother being married (1/0), the number of prenatal visits, and maternal smoking (1/0). The zip code-year-month fixed effects are the fixed effects applied to each mother’s residential zip code-year-month of birth pair. Standard errors (reported in parentheses) are clustered at the mother’s residential zip code level. * p-value < 0.1; ** p-value < 0.05; *** p-value < 0.01.

Appendix Table A1: Difference in the Noise Level between Those Living near the Airport and also in the Direction of the Airport Runway and Those Living near the Airport but Not in the Direction of the Airport Runway

Outcome variable:	Aviation and road noise (1)	Aviation noise (2)
Living in the direction of the runway (1/0)	14.18558***	17.03129***
	(1.21443)	(1.42064)
Intercept	49.22098***	46.27709***
	(0.85616)	(1.08566)
Number of observations	108,939	108,948

Notes: The estimation sample includes live and singleton births (2004–2016) of mothers who live within 5 miles of the mid-point of EWR runway 4L-22R. The data on noise are from the U.S. Department of Transportation. The variables on noise are measured in decibels (dB) for each mother's residential address and for year 2014. "Living in the direction of the runway" is a dummy variable, which is equal to one for mothers living within 5 degrees of the mid-point of EWR runway 4L-22R and equal to zero otherwise. Each column is an OLS regression of the noise variable on the "living in the direction of the runway" variable and an intercept term. Standard errors (reported in parentheses) are clustered at the mother's residential zip code level. * p -value < 0.1; ** p -value < 0.05; *** p -value < 0.01.

Appendix Table A2: Effects of Living in the Direction of the Runway on Low Birth Weight

Outcome variable: low birth weight (birth weight < 2,500 grams)	
The distance between mother's home and the mid-point of EWR runway 4L-22R in the estimation sample is:	Within 5 miles
Births ocurred between 2004 and 2016	
Living in the direction of the runway (1/0)	0.00702***
	(0.00146)
Distance between mother's home and the mid-point of EWR runway 4L-22R	-0.00260*
(measured in miles)	(0.00150)
Female baby (1/0)	0.01165***
	(0.00189)
Mother's age	0.00146***
	(0.00025)
Mother being White (1/0)	-0.01676***
	(0.00373)
Mother being Black (1/0)	0.00503**
	(0.00222)
Mother being Hispanic (1/0)	-0.01019***
	(0.00252)
Mother having completed a four-year college or higher (1/0)	-0.00541**
	(0.00255)
Mother being married (1/0)	-0.01145***
	(0.00165)
Number of prenatal visits	-0.00941***
	(0.00047)
Mother smoked cigarettes before or during her pregnancy (1/0)	0.04789***
	(0.00309)
Zip code-year-month fixed effects	Yes
Number of observations	107,495

Notes: The estimation sample includes live and singleton births. The estimation is based on the regression model described by equation (2) in the text. "Living in the direction of the runway" is a dummy variable, which is equal to one for mothers living within 5 degrees of the mid-point of EWR runway 4L-22R and equal to zero otherwise. The zip code-year-month fixed effects are the fixed effects applied to each mother's residential zip code-year-month of birth pair. Standard errors (reported in parentheses) are clustered at the mother's residential zip code level. * *p* -value < 0.1; ** *p* -value < 0.05; *** *p* -value < 0.01.