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July 26, 2022

SENT VIA EMAIL AND CERTIFIED MAIL

The Honorable Ro Khanna
Chair, Subcommittee on the Environment,
Committee on Oversight and Reform, U.S. House of Representatives
306 Cannon House Office Building
Washington, DC 20515

Dear Representative Khanna:

The County of Santa Clara, California ("County") writes to thank you for holding hearings on the dangers of leaded aviation gasoline ("avgas"), the primary fuel for piston-engine aircraft, and to urge you, the Congress, and the Administration to take swift action to end this public health and environmental justice crisis.

The severe and irreversible human health effects caused by lead exposure have been beyond dispute for decades. Leaded avgas is the number one source of airborne lead exposure in the Nation, and it is the last remaining leaded transportation fuel. While millions of Americans living near general aviation airports across the Nation are suffering daily exposure to this dangerous toxin, the harms of leaded avgas fall most heavily upon children in the communities surrounding general aviation airports with high piston-engine aircraft traffic. Reid-Hillview Airport ("RHV"), a County-operated general aviation airport in East San José, a historically marginalized, low-income community with 97% of residents identifying as people of color, embodies this trend. Like RHV in East San José, many of these general aviation airports are located in low-income communities of color, where lead exposures from avgas layer on top of a disproportionate burden from other toxic sources and compound the challenges facing these already vulnerable communities. The harms caused by leaded avgas extend far beyond these fence line communities, straining publicly operated hospitals and other safety net services, public education systems, and public safety infrastructure.

The County is committed to ending the threat of lead exposure to its residents. Since 2000, the County has played a leading role in successful and groundbreaking litigation against lead paint manufacturers to remedy harms from lead exposure. The County is equally determined to eliminate lead exposure from avgas. A peer-reviewed study completed in August 2021 ("RHV Study") demonstrated the connection between operations at RHV and childhood blood lead levels in the surrounding community, and found blood lead level increases on par with, or even exceeding, those found at the height of the Flint water crisis.[1] The County responded to this public health crisis by banning the sale of leaded avgas at County-operated airports effective January 1, 2022. In the past seven months, this policy has prevented the introduction of hundreds of pounds of lead into the environment with negligible effects on airport operations.

Strong federal leadership is essential to successfully ending the threat of lead exposure from avgas. Unfortunately, the primary federal agencies responsible for regulating leaded avgas have instead responded with inattention – and even resistance to local efforts. While the Environmental Protection Agency ("EPA") has spent decades regulating lead from other fuels, it has not yet even made the initial findings under the Clean Air Act that would allow it to issue standards for lead in avgas, despite repeated requests to do so since 2006. The Federal Aviation Administration ("FAA") has long sponsored initiatives such as the Piston Aviation Fuels Initiative, and its successor, the Eliminate Aviation Gasoline Lead Emissions Initiative, with the ostensible goal of developing a drop-in replacement for current leaded aviation fuels, though these initiatives have been more successful in obstructing new fuels from reaching the market than developing any of their own. The FAA's newly announced goal of eliminating the use of leaded avgas by the end of 2030 underscores the lack of urgency with which it views this issue. Despite the County's successful transition of its airport system away from the sale of leaded avgas, the FAA is investigating the County for allegedly violating its grant assurances and has signaled that it may seek to compel the County to continue selling leaded avgas.

The County respectfully requests that you take all available measures to expedite FAA's and EPA's efforts to promulgate regulations on lead emissions from avgas and to develop, test, and certify alternative unleaded avgas. The County further requests that you support, in the strongest possible terms, local governments taking necessary measures to protect communities from leaded avgas exposures, including by prohibiting the sale of leaded avgas.

I. Leaded Avgas is Causing Irreparable Harm to Children in Disadvantaged Communities

a. Lead Exposure from Avgas Causes Severe and Irreversible Human Health Impacts, Particularly in Children

The EPA and Centers for Disease Control and Prevention agree that there is *no* safe blood lead level in children.[2] Children are particularly vulnerable to lead exposure, both due to

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[1] Mountain Data Group, *Leaded Aviation Gasoline Exposure Risk at Reid-Hillview Airport in Santa Clara County, California* 1 (2021), available at https://news.sccgov.org/sites/g/files/exjcpb956/files/documents/RHV-Airborne-Lead-Study-Report.pdf.

behaviors that make them more susceptible to exposure and their greater sensitivity to lead toxicity. Even at the lowest detectable levels, exposure to lead can cause severe and often irreversible cognitive and intellectual impairment, harm academic performance, and increase children's risk for behavioral disorders and adult-onset physical health problems. In adults too, lead exposure can harm nervous, cardiovascular, immune, and reproductive systems, damage the kidneys, and cause anemia and increased blood pressure. As the federal government has long expressly recognized, there is no safe level of blood lead; indeed, the decline in cognitive ability due to marginal increases in blood lead is steepest at lower blood lead levels.

Since the early 1970s, the federal government has recognized airborne lead as contributing to an "epidemic" of "[e]xcessive lead exposures among children."[3] Leaded avgas is the largest single source of lead air pollution in the Nation, releasing one million pounds of lead into the environment each year.[4] Leaded avgas is used by around 170,000 piston-engine aircraft operating out of 20,000 airports across the United States.

b. Leaded Avgas Emissions from Operations Cause Significant Increases in Child Blood Lead Levels in the Surrounding Community

The RHV Study provides the most detailed analysis of the effects of general aviation operations on blood lead levels in local children. This peer-reviewed study by a leading expert in lead exposure examined over 300,000 blood lead test results collected by the California Department of Public Health ("CDPH") and documented a robust correlation between piston-engine aircraft activity at the airport and heightened blood lead levels in local children. Among its results, the study found that children residing within a half-mile of the airport have blood lead levels that are an average of 0.2 µg/dL higher than those of statistically similar children more distant from the airport. Children living downwind of the airport were at the greatest risk, with blood lead levels that were, on average, 0.4 µg/dL higher than their peers. These children were also 200% more likely than children residing upwind of RHV to have blood lead levels above 4.5 µg/dL – the action threshold used by CDPH when testing for elevated blood lead. Children commuting toward the airport to attend one of the 21 schools or childcare centers nearby also had increased blood lead. Measures of blood lead in local children also tracked changes in piston-engine aircraft activity in the airport. ***The study specifically found that blood lead levels of sampled children increase linearly with the quantity of aviation gasoline sold to fixed-base operators at RHV.*** An increase in piston-engine aircraft traffic from minimum to maximum levels caused blood lead levels to increase by 0.83 µg/dL in children living within a half-mile of

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[2] U.S. Envtl. Protection Agency, *Protect Your Children* (2022), available at https://www.epa.gov/lead/protect-your-children.

[3] U.S. Envtl. Protection Agency, *EPA's Position on the Health Effects of Airborne Lead* at VII-4 (Nov. 29, 1972), available at https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=9100EYMW.TXT.

[4] *See* Transp. Rsch. Bd. et al., *Options for Reducing Lead Emissions from Piston-Engine Aircraft* at 35 (National Academies of Sciences, 2021) [hereinafter "NAS Report"]; S. Zahran et. al., *The Effect of Leaded Aviation Gasoline on Blood Lead in Children,* 2(4) J. Assn. of Env't & Res. Economists 575, 579 (July 2017).

the airport; this difference in childhood blood lead levels between the period of lowest avgas sales and highest avgas sales is equivalent to about 50% of the estimated surge in child blood lead levels at the height of the Flint water crisis. The gravity of these increases constitutes an urgent public health crisis.

The conclusions of the RHV Study are consistent with the body of literature demonstrating the connection between lead exposure and general aviation operations. Studies of general aviation airports in Michigan to North Carolina found that children living in closer proximity to the airports had elevated blood lead levels.[5] Research conducted by the EPA further substantiates these findings.[6]

c. While Lead Emissions from Avgas Put Millions at Risk Nationwide, the Harms of Leaded Avgas Fall Hardest on Disadvantaged Communities Such as East San José

More than 16 million people live within a kilometer of a general aviation airport – a distance that puts them at heightened risk of lead exposures – and over 160,000 children attend school nearby.[7] However, just one percent of general aviation airports contribute 25 percent of total airport lead emissions.[8] These high emitting general aviation airports are disproportionately concentrated in minority communities. At least 60% of the 50 highest emitting airports are located in communities with larger racial minority populations than the national average.[9] And

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[5] *See* Marie Lynn Miranda et al., *A Geospatial Analysis of the Effects of Aviation Gasoline on Childhood Blood Lead Levels*, 119 Env't Health Perspectives 1513 (2011) (examining the relationship between proximity to airports in North Carolina where leaded aviation gas is used and blood lead levels in children and finding that "children living within 500 m, 1,000 m, or 1,500 m of an airport had average blood lead levels that were 4.4, 3.8, or 2.1% higher, respectively, than other children"); Zahran et al., *The Effect of Leaded Aviation Gasoline on Blood Lead in Children*, *supra* note 4, at 575–610 (examining the blood lead levels of children living within 2 kilometers of airports in Michigan and finding that "the odds that a child's [blood lead levels] will eclipse CDC thresholds for concern increases dose-responsively in proximity to airports, declines measurably in neighborhoods proximate to airports in the months following 9/11" (when there was less air traffic), and "increases dose-responsively in the flow of [piston-engine aircraft] traffic");

[6] See Advance Notice of Proposed Rulemaking on Lead Emissions From Piston-Engine Aircraft Using Leaded Aviation Gasoline, 75 Fed. Reg. 22,440 (Apr. 28, 2010) 22,442; Letter and Memorandum from Gina McCarthy, Assistant Administrator, EPA, to Deborah Behles & Helen Kang, Env't L. & Just. Clinic, & Marianna Engelman Lado et al., Earthjustice (July 18, 2012) (responding to Pet. for Rulemaking & Collateral Relief), at 7 ("For piston-engine aircraft using leaded avgas, our investigation to date indicates that the levels of lead in the air at and around general aviation airports increase with proximity to the airport.").

[7] U.S. Envtl. Protection Agency, *National Analysis of the Populations Residing Near or Attending School Near U.S. Airports 13 (2020), available at* https://nepis.epa.gov/Exe/ZyPDF.cgi/P100YG4A.PDF?Dockey=P100YG4A.PDF; NAS Report, *supra* note 4, at 11.

[8] NAS Report, *supra* note 4, at 41.

the harms of leaded avgas exposures often layer on top of an outsized share of exposures to other sources of toxins, such as lead-based paint hazards.[10]

RHV is emblematic of the environmental injustices posed by leaded avgas. RHV is one of the busiest and most lead-polluting airports in the Nation and also one of the most urban. In 2017, RHV ranked 24th nationally in general aviation operations and in the top 1.5% of landing facilities in the FAA's National Plan of Integrated Airport Systems in terms of annual lead emissions. Located only four miles from the heart of San José (the 10th largest city in the nation), there are 52,000 people living within 1.5 miles of the airport (including nearly 13,000 children) at a population density that is almost five times higher than the rest of the county.

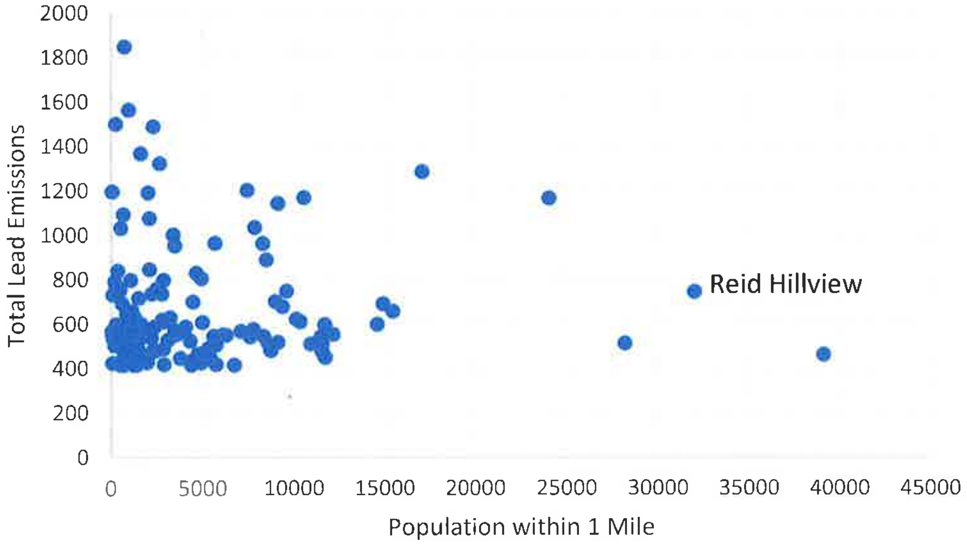

Figure 1: Annual lead emissions and population for top 150 airports by lead emissions in 2017

The community surrounding RHV is already one of the most vulnerable and historically marginalized in the county. It consists of primarily working-class, Latinx, and Asian families. This neighborhood has one of the highest percentages of nonwhite residents in the city (97%), and 79% of households speak a primary language other than English at home. Residents in East San José also have higher rates of mortality related to cancer, Alzheimer's disease, stroke, diabetes, and hypertension than in the rest of the county and are more likely to live in housing with lead hazards. These factors exacerbate the effects of lead exposure from avgas. More than one in four people in the four zip codes surrounding the airport live below 200% of the federal

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[9] Earthjustice et al., Petition for Rulemaking to EPA Seeking an Endangerment Finding for Leaded Avgas (Aug. 24, 2021, as updated Oct. 12, 2021), available at https://earthjustice.org/sites/default/files/files/2021.10.12_leadedavgaspetition.pdf.

[10] S. Zahran et. al., *The Effect of Leaded Aviation Gasoline on Blood Lead in Children*, *supra* note 4, at 576 (reporting that the percentage of homes presumed by their age to contain lead-based paint was almost twice as high in neighborhoods proximate to 448 airports in Michigan compared to neighborhoods more distant from the airports).

poverty line. Lead exposure inhibits residents of East San José seeking to rise out of this poverty. Accounting only for impacts of elevated blood lead on IQ, leaded avgas exposures translate to $11-24.9 million in lost lifetime earnings for the children residing within 1.5 miles of the airport.[11]

II. Lead Exposure from Avgas Imposes Significant Costs on Social Safety Net Systems and Public Services Systems

The costs of lead exposure extend far beyond the individuals living in adjacent communities. Lead exposure imposes significant costs on social safety net systems and public services systems, such as hospitals, schools, police, and airports, all while eroding the tax base that funds them. As many of these systems are administered by public agencies, the community at large ultimately bears much of these costs.

The most directly impacted public systems are public health systems, government-run hospitals, and other safety net services. State and local governments are at the frontline of public health protection, operating 19% of the nation's community hospitals,[12] and performing the bulk of public health activities nationwide. These public health and hospital systems expend resources to screen children for elevated blood lead levels, identify and prevent sources of exposure, and manage cases. In addition to direct treatment of lead-poisoned individuals, screening and treatment for the many secondary harms that lead poses – including harms to cardiovascular health, immune system and kidney function, reproductive system function, and cognition – consume staffing attention and resources.

Lead exposure also imposes costs on school systems, special education services, policing, and public safety infrastructure. In particular, behavioral and learning challenges resulting from lead exposures stress educational and childcare systems by necessitating increased investment in special education services and divert resources from other needs.[13] Behavioral effects of lead exposure also have consequences for crime levels, which in turn burden public safety systems.[14] For instance, empirical analysis suggests that the reduction in childhood lead exposure caused by the removal of lead from gasoline in the 1970s was the most significant driver of the drop in violent crime during the 1990s.[15]

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[11] RHV Study at 79.

[12] Am. Hosp. Ass'n., *Fast Facts on U.S. Hospitals* (2021), available at https://www.aha.org/statistics/fast-facts-us-hospitals.

[13] Elise Gould, *Childhood Lead Poisoning: Conservative Estimates of the Social and Economic Benefits of Lead Hazard Control*, 117 Env't Health Perspectives 1162, 1164-5 (July 2009).

[14] *Id.* at 1165.

[15] J. Wolpaw Reyes, *Environmental Policy as Social Policy? The Impact of Childhood Lead Exposure on Crime*, Nat'l. Bureau of Econ. Rsch. Working Paper No. 13097 (May 2007).

Lead exposure even compromises the operation of general aviation airports and the services those airports provide. In addition to hosting commercial and recreational flights and pilot trainings, many general aviation airports provide critical functions such as emergency medical transport and wildfire response. These services cannot be provided without putting workers and communities at undue risk while leaded fuel continues to be used. The use of leaded avgas jeopardizes the health and safety of airport workers and their families, as workers may be directly exposed to dispensed or spilled fuels and may take it home to their households on their clothes.[16] In addition to compromising the ability of airports to safely provide these services, these exposures result in healthcare costs, workers' compensation costs, and other benefits payouts.[17]

Public agencies operate many of the social services systems bearing the brunt of lead exposure. The additional costs lead exposure imposes on public services is compounded by the loss of revenue to support these services due to the reduction in lifetime earnings attributable to lead exposures.[18] Studies have conservatively estimated costs of $1 billion nationwide each year, accounting only for lost lifetime earnings due to IQ decreases resulting from leaded avgas exposures to young children.[19]

III. The County's Decision to Sell Only Unleaded Avgas has Substantially Reduced Lead Exposure with Negligible Effect on Airport Safety or Operations

Transitioning piston-engine aircraft to unleaded avgas wherever possible is essential to mitigating the risk from lead exposure. On August 17, 2021, the County Board of Supervisors directed County Administration to take all necessary actions to prevent lead contamination from operations at the two County-operated airports, RHV and San Martin Airport. Effective January 1, 2022, the County became the first airport system in the Nation to fully transition away from the sale of leaded avgas.

The County's tailored remedial measure has increased the market for and availability of unleaded avgas, which was not previously available from any airport in Santa Clara County. As of June 30, 2022, fuel sales at RHV are at about 90% of their level during the first six months of 2021, indicating significant adoption of unleaded avgas by aircraft operators. ***The County***

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[16] NAS Report, *supra* note 4, at 60, 63, 65-66.

[17] *See* Ronnie Levin, *The Attributable Annual Health Costs of U.S. Occupational Lead Poisoning*, 22 Int. J. Occupational Env't Health 107 (Apr. 2016).

[18] Gould, *Childhood Lead Poisoning*, *supra* note 13, at 1164.

[19] Zahran et. al., *The Effect of Leaded Aviation Gasoline on Blood Lead in Children, supra* note 4, at 604; Wolfe et. al., *Costs of IQ Loss from Leaded Aviation Gasoline Emissions*, 50(17) Env't. Sci. Tech. 9026 (2016); RHV Lead Study at 7.

estimates that the transition has eliminated over 400 pounds of lead emissions since January 1, 2022 that otherwise would have been released into the community around RHV.[20]

Increasing the availability of unleaded avgas at the County's airports will also reduce barriers to adoption. Making unleaded fuel the most convenient option for fueling at County Airports incentivizes adoption among the aviation community. Additionally, the County's collaboration with other airport operators seeking to make unleaded avgas available in the Bay Area has allowed manufacturers and transporters to better utilize economies of scale, reducing prices for unleaded avgas.

While these overwhelming public benefits stand alone, the County's action has also had a negligible effect on airport operations. Despite the unavailability of leaded avgas for sale at the airports, ***operations at both RHV increased about 4% in the first six months of 2022 relative to the same period in 2021.*** While not all operators are able to use the currently available unleaded avgas, leaded avgas remains readily available from multiple suppliers a short distance away, and the County maintains a protocol to ensure that aircraft can quickly access leaded fuel for emergency purposes if necessary. ***To date, there have been no known safety incidents at the County's airports related to the unavailability of leaded avgas***, and no requests to utilize the emergency protocol.

While these measures may be an incidental inconvenience for certain airport users, they are essential to prevent much more severe and even irreversible harms to young children living and going to school near the airport. Dr. Zahran's study evidences that RHV cannot be safely operated – that is, operated without exposing local children to unacceptable and unconscionable lead exposure risks – at previously prevailing levels of leaded fuel use. Eliminating leaded fuel sales and thereby lowering lead emissions from County airports mitigates the damaging health effects of leaded avgas exposures in these communities.

IV. Strong Federal Leadership is Necessary to Eliminate Lead Exposures from Avgas as Quickly as Possible

Congress has declared the safe operation of the national airport system the highest aviation priority.[21] The County respectfully requests that you, the Congress, and the Administration take all available measures to recognize and preserve local governments' authority to protect the public health, safety, and welfare in communities surrounding the airports they operate, including by prohibiting the sale of leaded avgas. The County further requests that you take all available measures to expedite EPA's efforts to promulgate regulations on lead emissions from avgas, and FAA's development, testing, and certification of alternative unleaded avgas.

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[20] U.S. Envtl. Protection Agency, *Lead Emissions from the Use of Leaded Aviation Gasoline in the United States: Technical Support Document*, EPA 420-R-08-20 (2008) at 2.

[21] 49 U.S.C. § 47101(a)(1); *see also, e.g.*, 49 U.S.C. § 40101(a)(1).

While the transition away from leaded avgas may take time, the FAA must support and empower local agencies in providing immediate relief to communities today. The County's successful transition of its airport system away from the sale of leaded avgas should be upheld as a national model for providing immediate relief to impacted communities. Instead, in a December 22, 2021 letter and subsequent correspondence, the FAA requested that the County suspend its ban on the sale of leaded fuel, initiated an investigation into whether the ban violates multiple grant assurances to the FAA, and signaled that it may take judicial action to try to compel the County to continue selling leaded avgas. This is consistent with the FAA's actions in a previous enforcement action against the City of Santa Monica where the FAA inserted language into the settlement agreement prohibiting the City from restricting the sale of leaded fuel.[22] ***Rather than deterring local agencies from taking immediate action to protect their communities, the FAA should affirm that promotion of unleaded avgas, including through restricting access to leaded avgas, is within the authority reserved to local agencies in their grant assurances.*** The FAA should also provide resources to local agencies seeking to promote the use of unleaded avgas through means such as installing additional fuel tanks or providing education for aircraft operators.

Developing alternative unleaded fuels is also crucial to transitioning the general aviation fleet away from leaded avgas. The FAA must prioritize the development and certification of new unleaded aviation fuels. In particular, ***the FAA must expedite completion of its review of the 100 octane unleaded avgas developed by General Aviation Modifications, Inc.***[23] Our understanding is that this fuel has passed all of its technical reviews and is only awaiting FAA headquarters approval for use in virtually the entire general aviation fleet.

Even when unleaded alternatives are widely available, aggressive regulation will also be essential to accomplish a rapid transition of the general aviation fleet away from leaded avgas. Toward this end, the EPA recently announced that it would open a long overdue rulemaking to issue a final endangerment finding for leaded avgas – the first step in regulating leaded avgas nationwide. While the County applauds this critical step, ***the EPA must promptly complete its endangerment finding and issue aggressive emission standards that spur investment and innovation in unleaded avgas technology and infrastructure and adoption of available unleaded products.*** While recent developments in the production of unleaded 100-octane drop-in replacement fuels usable by all aircraft have been promising, commercialization and FAA certification are slow and incentives to accelerate the transition are lacking. This provides little motivation for airports and pilots to make effective use of existing unleaded fuel options, or for

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[22] Settlement Agreement/Consent Decree, *City of Santa Monica v. USA*, January 30, 2017, available at https://www.faa.gov/airports/airport_compliance/santa_monica_settlement/media/Santa-Monica-settlement-stipulation-and-order-consent-decree-2017.

[23] Michael Coren, *Leaded Airplane Fuel Is Poisoning a new Generation of American Children*, QUARTZ (June 16, 2022) available at https://pulitzercenter.org/stories/leaded-airplane-fuel-poisoning-new-generation-american-children.

investors to fund research and development to accelerate advances in unleaded fuel technology.[24] Ultimately, the only way to keep general aviation airports safely open is through the promulgation of uniform national regulatory standards that correct the misaligned incentivize structure for fuel transitioning and quickly and completely eliminate use of leaded fuels.

Thanks again for your attention to this pressing issue. Please let us know if we can provide any further information in support of your efforts.

Sincerely,

Jeffrey V. Smith, County Executive
70 West Hedding Street, 11th Floor
San Jose, California 95110-1770

James R. Williams, County Counsel
70 West Hedding Street, East Wing, 9th Floor
San Jose, California 95110-1770

Attachment: Mountain Data Group, *Leaded Aviation Gasoline Exposure Risk at Reid-Hillview Airport in Santa Clara County*, California (Aug. 3, 2021)

c: Santa Clara County Board of Supervisors
Rep. Anna Eshoo, California Congressional District 18
Rep. Zoe Lofgren, California Congressional District 19
Rep. Jimmy Panetta, California Congressional District 20
Sen. Diane Feinstein, California
Sen. Alex Padilla, California

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[24] *See* NAS Report, *supra* note 4, at 83.

Leaded Aviation Gasoline Exposure Risk at Reid-Hillview Airport in Santa Clara County, California

mountain
data
group

Tuesday 3rd August, 2021

Preface

This report presents findings of a study sponsored by the County of Santa Clara and in cooperation with the California Department of Public Health (CDPH), Childhood Lead Poisoning Prevention Branch (CLPPB). The views and analysis presented here are those of the authors, and do not necessarily reflect the views of the County of Santa Clara or the CDPH. Pursuant to a Board request, this research was conducted by Mountain Data Group to assess statistical associations between the blood lead levels of sampled children and indicators of aviation gasoline exposure risk around Reid-Hillview Airport.

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List of Abbreviations

ACS	American Community Survey
BLLs	Blood Lead Levels
CAA	Clean Air Act
CDC	Centers for Disease Control and Prevention
CDPH	California Department of Public Health
CLPPB	Childhood Lead Poisoning Prevention Branch
E16	San Martin Airport
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FFE	Fuel Flowage Fee
FWC	Flint Water Crisis
LTO	Landing-Takeoff
NUQ	Moffett Federal Airfield
PAO	Palo Alto Airport
Pb	Lead
PEA	Piston Engine Aircraft
RHV	Reid-Hillview Airport
SES	Socioeconomic Status
SJC	Norman Y. Mineta San Jose International Airport
TEL	Tetraethyl-lead
TFMSC	Federal Aviation Administration Traffic Flow Management System Counts
TRI	Toxic Release Inventory

Executive Summary

Background

Lead (Pb) is a naturally occurring and ubiquitous metal, used in human industry since antiquity. Lead emissions persists in the lived environment. Lead ingested or inhaled resides in the human bloodstream for about sixty days, but can persist in human tissue, the brain, and the skeletal system for many decades after an exposure event. Lead has no known biological purpose in the human body.

As noted by Bellinger and Bellinger (2006), because "lead serves no useful purpose in the body, exposure to it – regardless of route – can lead to toxic effects." Children exposed to lead suffer substantial, long lasting, and possibly irreversible negative health, behavioral, and cognitive outcomes. Importantly, negative cognitive and behavioral effects in lead-exposed children are higher at lower blood lead levels (BLLs), with deleterious effects observable at BLLs in the range of 2 to 3 μg/dL (Miranda et al., 2007, 2009). On the question of safe exposure, the Centers for Disease Control and Prevention (CDC) states: "No safe blood lead level in children has been identified. Even low levels of lead in blood have been shown to affect IQ, ability to pay attention, and academic achievement."

Over the last four decades, the BLLs of children in the United States have declined significantly, coincident with a series of policies that expelled lead from paint, plumbing, food cans and automotive gasoline. Most effective was the phase-out of tetraethyl lead (TEL) from automotive gasoline induced by provisions of the Clean Air Act (CAA) of 1970. While TEL is no longer used as an additive in automotive gasoline, it remains a constituent in aviation gasoline used by an estimated 170,000 piston-engine aircraft (PEA) nationwide.

Consumption of lead-formulated aviation gasoline accounts for about half to two thirds of current lead emissions in the United States (Kessler, 2013). In a recently published consensus study on *Options for Reducing Lead Emissions by Piston-Engine Aircraft* by the National Academies of Sciences, Engineering, and Medicine, the authors note: “While the elimination of lead pollution has been a U.S. public policy goal for decades, the GA [General Aviation] sector continues to be a major source of lead emissions.” (2021, pg. 10-11).

Several studies have linked aviation gasoline use to elevated atmospheric lead levels in the vicinity of airports. The U.S. Environmental Protection Agency (EPA) estimates that four million persons reside, and about six hundred K-12th grade schools are located, within 500 meters of PEA servicing airports (EPA, 2020b). Zahran et al. (2017a) estimate that sixteen million persons – and about three million children – live within a kilometer of such airport facilities. The disposition of aviation gasoline around such airports may be a meaningful source of child lead exposure. To date, two studies have explicitly statistically linked aviation gasoline usage to blood lead levels of children residing in the vicinity of general aviation airports, showing the child BLLs increase in proximity to general aviation airports and increase dose-responsively with the volume of piston-engine aircraft traffic at general aviation airports.

Research Objective

The risk of aviation gasoline exposure for children varies considerably by airport, depending on 1) the volume of piston-engine aircraft traffic at the airport, 2) child residential proximity to the airport, and 3) child residential near angle to airport runways. Reid-Hillview Airport (RHV) is among a subset of airports identified by the EPA as having highest potential to exceed National Ambient Air Quality Standards for lead because of the combustion of leaded aviation gasoline. In this study, a team of data scientists from Mountain Data Group assessed whether the BLLs of sampled children around Reid-Hillview Airport are statistically associated with indicators of aviation-related lead exposure, net of other lead exposure pathways. To accomplish this objective, data were collected from various sources and analyzed using established statistical and econometric methods.

Materials and Methods

California Department of Public Health Data

Permission to analyze blood lead data was granted by agreement with the Childhood Lead Poisoning Prevention Branch (CLPPB) of the California Department of Public Health (CDPH). Restricting to children ≤ 18 years of age at the time of blood draw, residing < 1.5 miles of Reid-Hillview Airport, and sampled between January 1^{st}, 2011 and December 31^{st}, 2020, over 17,000 blood lead samples were obtained for statistical analysis.

The main outcome variable of analytic interest is *Blood Lead Level* (BLL) measured in micro-grams per deciliter of blood (μg/dL units). In extended analyses, BLLs are divided into a set of ordered categories moving in increments of 1.5 μg/dL from 0 to ≥ 4.5 μg/dL, the CDPH-defined threshold for service action. Also from CDPH data holdings, five control variables were obtained that are known to be correlated with child BLLs, including: child gender, child age, method of blood draw, sample detection limit, and sample order.

Main Indicators of Exposure Risk

Residential Distance

The Haversine distance from the residential address of a sampled child to Reid-Hillview Airport was calculated. Using distance information on each child as an indicator of exposure risk, we test whether BLLs increase measurably with proximity to Reid-Hillview Airport. Following previous research (Miranda et al., 2011; Zahran et al., 2017a), residential distance is analyzed both continuously and by division into categories of distance: $<$ 0.5 miles, 0.5 to 1 mile, and 1 to 1.5 miles from Reid-Hillview Airport. Over the period of January 1^{st}, 2011 to December 31^{st}, 2020, we observe a total of 1,065 records at $<$ 0.5 miles, 6,472 records at 0.5 to 1 mile, and 9,704 at 1 to 1.5 miles from Reid-Hillview Airport. Insofar as aviation gasoline exposure is a source of risk, and other things held equal, children in the nearest orbit to Reid-Hillview Airport should present with higher BLLs as compared to children in outer orbits.

Residential Near Angle

Airport proximity, by itself, is an imperfect indicator of aviation gasoline exposure risk. The fate and transport of lead emissions depend on the direction of prevailing winds. Insofar as aviation gasoline is an independent source of lead exposure, two children equidistant to the same airport face different risk of elevated blood lead depending on the child's residential near angle to the airport. In this study, each sampled child is assigned a near angle to Reid-Hillview Airport corresponding to the four cardinal directions of North, East, South and West. We observe 5,962 blood lead records residing North of Reid-Hillview Airport, 1,170 records East, 3,495 records South, and 6,614 records West of the airport. We also calculate the number of days that winds drift in the direction of a sampled child's residence from the date of blood draw. Because prevailing winds at Reid-Hillview Airport emanate from the West Northwest, children East of Reid-Hillview Airport should present with higher BLLs, other things held equal.

Piston-Engine Aircraft Traffic

The volume of PEA traffic varies meaningfully between airports and within an airport in time. Therefore, two children residing in the same household but sampled at different moments in a calendar year may present with different BLLs, depending on the coincidence of PEA traffic activity. To capture this channel of risk, we collected data on PEA departures and arrivals from Federal Aviation Administration Traffic Flow Management System Counts (TFMSC). Also, fuel flowage fee (FFE) data were obtained from personnel at the Roads and Airports Department of Santa Clara County. The FFE data track monthly quantities of aviation gasoline (100LL) sold to fixed-base operators at Reid-Hillview Airport from 2011 to 2019. Insofar as aviation gasoline exposure is a source of risk, then the BLLs of sampled children should correlate statistically with measured quantities of PEA traffic and aviation gasoline sales.

Control Variables

Lead-emitting industrial facilities are more common in the vicinity of airports (Zahran et al., 2017a). Children that are proximate to airports are therefore simultaneously proximate to other point source emitters of lead. Failing to account for this spatial coincidence can produce biased estimates of aviation gasoline exposure risk vis-à-vis child BLLs. The EPA's Toxic Release Inventory (TRI) system tracks the industrial management of over 650 listed chemicals that pose harm to humans and the environment. We collected records on all facilities in Santa Clara County with reported on-site releases of lead between 2011 to 2020, and calculated the Haversine distance of every sampled child to each of these TRI facilities operating in the year of blood draw.

Legacy use of lead-based paint remains an exposure risk to children. Exposure to lead-based paint is primarily a problem in older homes. By 1960, use of lead-based paint subsided by more than 90% from peak usage in the 1920s. Still, children in the United States may ingest paint chips or may be exposed to dust from deteriorating or haphazardly removed lead-based paint in homes built in the era before 1960. We collected American Community Survey data on the fraction of homes in a child's neighborhood built before 1960. In analyses that follow, each sampled child in our data is assigned a lead-based paint exposure risk according to the neighborhood of residence and year of blood draw, as captured by the percentage of homes built before 1960.

Studies show that children of low socioeconomic status are at greater risk of presenting with elevated BLLs (Campanella and Mielke, 2008; Zahran et al., 2010). Socioeconomic status proxies for household resources, knowledge about the dangers of, and protective actions taken against lead exposure (Zahran et al., 2017a). In addition to demographic information present in CDPH data, we measured the percentage of adults with a college degree, median home prices, and median household incomes to characterize the socioeconomic status of a child's residential neighborhood. These data were also collected from the American Community Survey.

Statistical Methods

To assess whether child BLLs (measured in units of μg/dL) are statistically associated with indicators of aviation gasoline exposure risk, net of other factors, we deploy a least squares estimator with census block fixed effects, and with bootstrapped standard errors to account for heteroeskedasticity and to relax distributional assumptions. To allow for non-linear associations, we use flexible specifications with categorical versions of continuous variables of interest, such as distance to the airport and PEA traffic. In extended analyses, we reconstitute our response variable in ordered categorical terms, defining mutually exclusive BLL categories ranging from 0 to exceedance of the CDPH-defined threshold of action of ≥ 4.5 μg/dL. The purpose here is to investigate threshold effects with respect to our main indicators of aviation gasoline exposure risk and to relax the assumption of precisely measured BLLs. Within this framework, we execute a series of Ordered Logit models estimating the odds that a sampled child's BLL exceeds a specified blood lead category as potentially resulting from exposure risk to lead-formulated aviation gasoline.

Main Results

Residential Distance Results

Evidence presented in Table 3 and Figure 9 indicates that children proximate to Reid-Hillview Airport present with systematically higher BLLs, net of other measured sources of lead exposure risk, child characteristics, and neighborhood conditions. This result is compatible with exposure risk to aviation gasoline, and consistent in direction and magnitude with previous studies (Miranda et al., 2011; Zahran et al., 2017a). As shown in Table 3, children within 0.5 miles of Reid-Hillview Airport have BLLs that are about $1/5^{th}$ of a μg/dL higher than statistically similar children more distant from Reid-Hillview Airport. This calculated difference is equivalent to about 50% of the estimated surge in child BLLs at the height of the Flint Water Crisis (FWC) of 0.35 to 0.45 μg/dL over baseline BLLs in Flint (Zahran et al., 2017c). These results are supported by analyses involving models with residential distance measured continuously and applying various transformations to both distance and child BLLs. As shown in Table 4, across all such models, child BLLs decrease statistically significantly with distance from Reid-Hillview Airport.

Residential Near Angle Results

Evidence presented in Table 5 and Figure 10 indicates that sampled children residing East and downwind of Reid-Hillview Airport have substantively higher BLLs. As compared to sampled children residing West (and predominately upwind) of Reid-Hillview Airport, sampled children residing East (and predominately downwind) of Reid-Hillview, present with BLLs that are 0.4 μg/dL higher, other things held equal. This estimated margin of difference of 0.4 μg/dL is approximately equal to the measured difference between children sampled at the peak of the FWC relative to children sampled before the FWC (Zahran et al., 2017c). These results are also supported by ancillary analyses involving the calculation of downwind days, showing that BLLs among sampled children increase significantly in the count of wind days drifting in the direction of a child's residence.

Piston-Engine Aircraft Results

Evidence presented in Table 6 and Figure 11 indicates that child BLLs increase significantly with exposure to piston-engine aircraft operations at Reid-Hillview Airport, net of all other factors. In going from the minimum to the maximum of child PEA traffic exposure, we find that child BLLs increase by 0.163 to 0.387 μg/dL, depending on the presence of control variables. This result holds with the division of PEA traffic into terciles, suggesting that child BLLs increase dose-responsively with PEA traffic. Moreover, as shown in Figure 13, the estimated positive association between child BLLs and PEA traffic is robust to the substitution of PEA traffic for the quantity of aviation gasoline sold at Reid-Hillview Airport, an independent indicator of lead exposure risk.

Extended Results

Blood Lead Threshold Results

Results on BLL threshold outcomes reported in Table 7 and Figure 14 are consistent with linear model results reported in Section 4. All indicators of aviation gasoline exposure risk – residential proximity to Reid-Hillview Airport, residing East and predominately downwind of Reid-Hillview Airport, and exposure to high PEA traffic – meaningfully increase the odds that a sampled child presents with a BLL $\geq$4.5 μg/dL relative to the combined odds of presenting with a lower category of blood lead. Specifically, we estimate that the probability of exceeding 4.5 μg/dL for sampled children in the nearest orbit is 20% and 27% higher than children in outer orbits of 0.5 to 1 mile and 1 to 1.5 miles, respectively. With respect to near angle, the probability of a sampled child residing East (predominantly downwind) of RHV presenting with a BLL $\geq$4.5 μg/dL is about 200% higher than sampled children West of Reid-Hillview Airport (and predominantly upwind). With respect to PEA traffic exposure, children exposed to maximum traffic have an estimated probability of superseding 4.5 μg/dL that is about 29% higher than children sampled in moments of minimum PEA traffic.

PEA Traffic Exposure × Residential Distance Results

The evidence presented in Table 8 and Figure 15 suggests that children residing within 0.5 miles of Reid-Hillview Airport are especially vulnerable to increases in PEA traffic. Children more distant from Reid-Hillview Airport (0.5 to 1.5 miles) experience a modest increase in BLLs of about $1/10^{th}$ of μg/dL from an increase in PEA traffic from the minimum to the maximum. By contrast, among sampled children at $<$ 0.5 miles of Reid-Hillview Airport, an increase from the minimum to maximum exposure to PEA traffic is associated with an estimated 0.83 μg/dL increase in BLLs – an effect that is substantively higher than the increase in BLLs caused by water system failures during the FWC. These results are supported by ancillary analyses presented in Figure 16 involving the statistical interaction between distance and aviation gasoline sales at Reid-Hillview Airport.

PEA Traffic Contraction Period Results

As the COVID-19 pandemic gripped the country, state and local governments enacted various restrictions on the behavior of households and firms to limit the spread of the disease. Corresponding with these efforts in Santa Clara County, PEA traffic declined over baseline levels by an estimated 35-45% at Reid-Hillview Airport over the months of February to July of 2020. As shown in Table 10 and Figure 17, children sampled in this PEA traffic contraction period presented with significantly lower BLLs – about 1/4th of a μg/dL lower – than children sampled outside this contraction window.

School Commuting Results

Knowing where school-aged children reside and assuming that such children attend the nearest grade-serving school, one can compute the distance a child commutes toward or away from Reid-Hillview Airport to attend school. Other things held equal, the evidence presented in Table 11 and Figure 19 indicates that commuting away from Reid-Hillview Airport to attend school is negatively correlated with child BLLs. Sampled children that commute toward Reid-Hillview Airport for school by 1 mile from their place of residence have predicted BLLs that are 0.65 μg/dL higher than sampled children commuting away from Reid-Hillview Airport for school by 1 mile.

Inclusion of All Airports Results

As indicated in Federal Aviation Administration (FAA) data, four other airports located in Santa Clara County service piston-engine aircraft, including Moffett Federal Airfield (NUQ), Palo Alto Airport (PAO), Norman Y. Mineta San Jose International Airport (SJC), and San Martin Airport (E16). Across an ensemble of tests, the results reported in Section 4 and Section 5 pertaining to Reid-Hillview Airport are statistically upheld with the inclusion of children proximate to other airports in Santa Clara County with non-zero piston-engine aircraft activity. Estimated coefficients are similar in direction and magnitude as RHV-specific analyses.

Reduction Scenario

To provide additional quantitative meaning to our results, we conservatively estimate the social benefits of a simulated reduction in PEA traffic from the 50^{th} (observed median) to the 1^{st} percentile (observed minimum). Social benefits are quantified with a standard syllogism in environmental health economics (PEA Traffic → Child BLLs → IQ → Lifetime Earnings) linking lead exposure source to child BLLs to IQ points and to the net present value of future earnings. Leveraging coefficients from our Distance × PEA Traffic test reported in Table 8 and visualized in Figure 15, we estimate a gain of \$11.0 to \$24.9 million in discounted net present value of earnings for the cohort of children ≤ 18 years of age residing within 1.5 miles of Reid-Hillview Airport from a simulated reduction in PEA traffic. Our social benefit estimate is not comprehensive since it reflect gains to a subset of the population (children ≤ 18 years of age), and only one benefit channel (lifetime earnings from expected gains in IQ).

Concluding Remarks

At the height of the Flint Water Crisis, child BLLs surged over pre-crisis levels by an estimated 0.35 to 0.45 μg/dL. Under periods of high piston-engine aircraft traffic, children proximate to Reid-Hillview Airport experience an increase in BLLs excess of what the children of Flint experienced during the FWC. Because negative cognitive and behavioral outcomes in lead-exposed children are higher at lower blood lead levels – the dose-response is non-linear – limiting exposure to lead-formulated aviation gasoline can deliver sizable and lasting social benefits. On the matter of aviation gasoline exposure risk to families and children proximate to general aviation airports, the National Academies of Sciences, Engineering, and Medicine maintains: "Because lead does not appear to exhibit a minimum concentration in blood below which there are no health effects, there is a compelling reason to reduce or eliminate aviation lead emissions." The ensemble of evidence compiled in this study supports the "compelling" need to limit aviation lead emissions to safeguard the welfare and life chances of at-risk children around Reid-Hillview.

1 Introduction and Background

Lead (Pb) is a naturally occurring and ubiquitous metal. Its physical properties of high malleability, ductility, low melting point, and resistance to corrosion invited widespread usage in human industry since antiquity (Flora et al., 2012). Lead persists in the lived environment because it is non-biodegradable. Lead enters the human body via inhalation or ingestion. The half-life of lead in the human bloodstream is about thirty days (Papanikolaou et al., 2005), but can persist in human tissue, the brain, and the skeletal system for many decades after an exposure event. Lead has no known biological purpose in the human body. The estimated pre-industrial concentration of lead in the human bloodstream is 0.016 μg/dL, more than 100-fold lower than the typical level observed in children in the United States today (Flegal and Smith, 1992).

1.1 Health and Human Capital Effects of Lead

While knowledge of the toxic effects of lead stretch back millennia, the evidence amassed by modern science indicates that the health and human capital costs of lead exposure in childhood are substantial, long lasting, and possibly irreversible. Numerous studies have linked elevated blood lead levels (BLLs) in children to cognitive and intellectual impairments, poor academic achievement, and higher risk of attention-deficit and hyperactivity disorders. Importantly, estimated marginal effects with respect to negative cognitive and behavioral outcomes in lead-exposed children are higher at lower BLLs (Nigg et al., 2010; Needleman and Gatsonis, 1990; Mielke and Zahran, 2012; Lanphear et al., 2005; Dietrich et al., 2001; Canfield et al., 2003).

Studies have also shown that lead exposure in childhood causes abnormal psychology and behavior in adolescence (Graff Zivin and Neidell, 2013). Curci and Masera (2018) find that childhood lead exposure results in higher incidents of juvenile delinquency in adolescence. Reyes (2015) links childhood lead exposure to “an unfolding series of adverse behavioral outcomes” that stretch into adolescence and early adulthood.

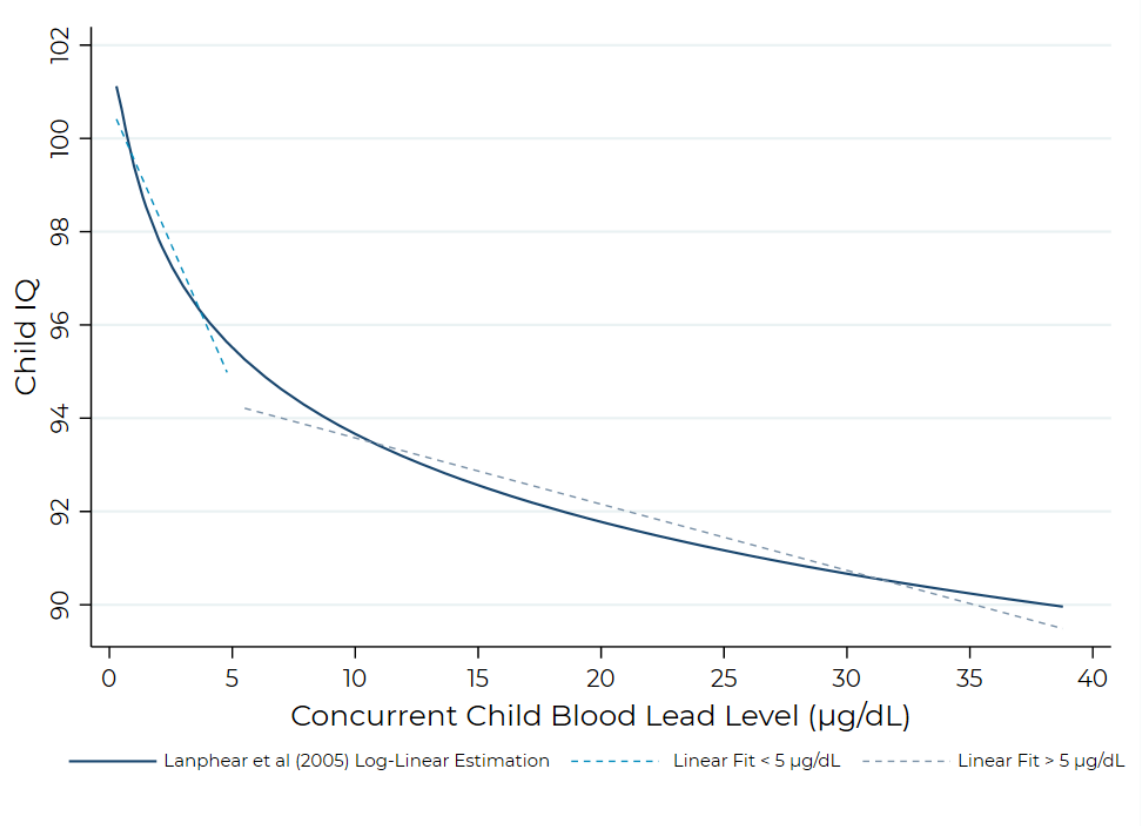
Childhood lead exposure has also been linked to adult-onset physical health problems, including hypertensive disorders, the malfunction of renal and cardiovascular systems, and all-cause and motor neuron disease mortality (Needleman and Gatsonis, 1990; Dietrich et al., 2001; Canfield et al., 2003; Lanphear et al., 2005; Nigg et al., 2010; Mielke and Zahran, 2012; Zahran et al., 2017b). Brain imaging studies find that adults exposed to lead as children present with volumetric loss in brain regions that govern judgment, decision-making and mood regulation (Cecil et al., 2008; Cecil, 2011), cognitive and socio-emotional traits that economists have linked to long-term life outcomes (Cunha et al., 2010; Almond and Currie, 2011; Doyle et al., 2013). In a recent study on the lasting consequences of child lead exposure, Reuben et al. (2017) find that adults in New Zealand exposed to lead in childhood had measurable reductions in IQ and occupational status in midlife, with these negative effects appearing to amplify over the life-course.

1.2 No Safe Blood Lead Level in Children

As noted by Bellinger and Bellinger (2006), because "lead serves no useful purpose in the body, exposure to it – regardless of route – can lead to toxic effects." Indeed, numerous studies (Needleman, 2004; Lanphear et al., 2005; Desrochers-Couture et al., 2018) find that the dose-response relationship between child cognitive ability and blood lead is non-linear, with the loss in ability proportionately steeper at lower BLLs (see Figure 1). In an analysis of about 5,000 children ages 6 to 16, for example, Lanphear et al. (2000) report that performance on Wide Range Achievement Tests in arithmetic, reading, verbal comprehension, and perceptual reasoning decline discernibly at the lowest measurable levels of blood lead. As compared to children with negligible BLLs of ≤ 1 μg/dL, average performance for children at 2 to 3 μg/dL was lower by 4% to 6% across cognitive tests, with observable differences persisting in the presence of statistical controls.

Despite scientific evidence of decelerating dose-response curves with measurable deleterious effects in children at very low BLLs (Lanphear et al., 2005), the current reference value of the U.S. Centers for Disease Control and Prevention (CDC) of 5 μg/dL is still rou-

Figure 1: Non-Linear IQ Response to Concurrent Child Blood Lead Level



Note: The data are from Lanphear et al. (2005) Figure 4, based on an international pooled analysis of low-level environmental lead exposure and children's intellectual function.

tinely and incorrectly used as a threshold for concern. The CDC is explicit on the statistical, not medical or epidemiological, meaning of this reference value. The threshold defines children with abnormally high BLLs – children that present with BLLs in the highest 2.5% of children tested.

Given the statistical nature of this threshold, the CDC reference value has undergone numerous revisions in time [1] as child BLLs have declined and evidence amassed for harm at lower BLLs: 1971: 40 μg/dL; 1975: 35 μg/dL; 1985: 25 μg/dL; 1991: 10 μg/dL; 2012: 5 μg/dL. According to Bellinger and Bellinger (2006), each revision has been followed by a series of studies to determine "whether the new level used to define *normal* provided children with an adequate margin of safety." The CDC summarizes the margin of safety question: "No safe blood lead level in children has been identified. Even low levels of lead in blood have been shown to affect IQ, ability to pay attention, and academic achievement."

1.3 Tetraethyl Lead (TEL) in Aviation Gasoline

It might be tempting to assume that lead exposure in the United States is a rear-view or legacy problem. BLLs in children of the United States have declined substantially over the last four decades, coincident with a series of regulatory actions that expelled lead from paint, plumbing, food cans and automotive gasoline. Most effective among these interventions was the phase-out of tetraethyl lead (TEL) from automotive gasoline induced by provisions of the Clean Air Act (CAA) of 1970.[2]

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[1] Recent research indicates "The 97.5th percentile BLL based on NHANES 2011 to 2014 results in children 1 to 5 years is 3.48 μg/dL, 30 percent lower than the current reference value of 5 μg/dL (Caldwell et al., 2017)

[2] Under the CAA, the removal of lead from gasoline launched in 1975. Over the next two decades, lead entering the environment from automobile emissions declined precipitously. Though the policy was enforced at the national level, the incentive structure for compliance, and the characteristics of the petroleum and automobile industries, produced significant variation in lead emissions across states between 1975 and 1990. Leveraging this between-state variation in phase-out efforts, Keyes and Zahran (2021) estimate that child BLLs decreased by about 40% for every g/gal reduction in TEL concentrations over this phase-out period.

While TEL is no longer used as an additive in automotive gasoline, it remains a constituent in aviation gasoline used by an estimated 170,000 piston-engine aircraft (PEA). These aircraft constitute about 70% of the U.S. air fleet. The rationale for continued use of TEL in aviation gasoline is aircraft safety. TEL is one of the best-known additives for mitigating the risk of *knocking* that can lead to sudden engine failure (Ells, 2006). The high intensity at which aircraft engines operate explains why TEL remains an additive in aviation gasoline even though it has been effectively banned from other transportation fuels. While Swift Fuels, LLC has produced an effective substitute to lead-formulated aviation gasoline covering an estimated two-thirds of aircraft in the general aviation fleet, more investment in airport infrastructure is necessary to enable transition.

Tens of millions of gallons of TEL-formulated gasoline are consumed by piston-engine aircraft (PEA) annually. The consequent emissions from this consumption accounts for about half to two thirds of current lead emissions in the United States (Kessler, 2013). In a recently published consensus study on *Options for Reducing Lead Emissions by Piston-Engine Aircraft* by the National Academies of Sciences, Engineering, and Medicine, the authors note: "While the elimination of lead pollution has been a U.S. public policy goal for decades, the GA [General Aviation] sector continues to be a major source of lead emissions" (2021, pg. 10-11).

1.4 Deposition of Lead from Aviation Gasoline

While the quantity of aviation gasoline consumed by PEA is historically low by comparison to the consumption of lead-formulated automotive gasoline, the emissions from piston-engine aircraft are highly spatially concentrated. Lead from aviation gasoline deposits near airports. The U.S. Environmental Protection Agency (EPA) estimates that around four million persons reside within 500 meters of PEA-servicing airports, including approximately six hundred K-12th grade schools (EPA, 2020b). Zahran et al. (2017a) estimate that sixteen million persons – and about three million children – live within a kilometer of such airport facilities. The disposition of aviation gasoline around such airports may be a meaningful source of child lead exposure.

Several studies have linked aviation gasoline use to elevated atmospheric lead levels in the vicinity of airports.[3] On the basis of such studies, various public interest organizations have petitioned the EPA to find endangerment from aviation gasoline emissions. While the EPA recognizes that there is no known safe level of lead exposure, it has cautioned that additional scientific research is needed "to differentiate aircraft lead emissions from other sources of ambient air lead" (EPA, 2010) that may cause elevated BLLs in nearby children.

1.5 Lead from Aviation Gasoline and Child BLLs

To date, only two studies have explicitly linked aviation gasoline usage to blood lead levels of children residing in the vicinity of general aviation airports. In a study involving over 125,000 BLL observations across six counties and 66 airports in North Carolina, Miranda et al. (2011) reported a striking correlation between child BLLs and airport proximity. "The estimated effect on blood lead levels exhibited a monotonically decreasing dose-response pattern" with children at 500 and 1,000 meters of an airport at greatest risk of elevated BLLs. Reported results statistically controlled for the age of housing stock, neighborhood socioeconomic conditions, and seasonality.

In a study involving over 1 million children and 448 airports in Michigan, Zahran et al. (2017a) found that child BLLs: 1) increased dose-responsively in proximity to airports, 2) declined measurably among children sampled in the months after the tragic events of 9-11, resulting from an exogenous reduction in PEA traffic, 3) increased dose-responsively in the flow of piston-engine aircraft traffic across a subset of airports, and 4) increased in the percent of prevailing wind days drifting in the direction of a child's residence.

With a standard syllogism linking BLLs to IQ and IQ to lifetime earnings, Zahran et al.

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[3] See recent findings from McCumber and Strevett (2017); Altuntas (2020); Matthews and Pandey (2020) along with previous research from Piazza (1999); Callahan (2010); Carr et al. (2011).

(2017a) estimate a 5-year cohort benefit from a hypothetical reduction in PEA traffic from the 50^{th} to the 10^{th} percentile at \$126 million for Michigan and \$4.9 billion nationwide. Using a Community Multi-Scale Air Quality model, Wolfe et al. (2016) arrive at a similar estimate, reporting a 1-year cohort cost of \$1.06 billion in economic damages from exposure to elevated atmospheric lead at general aviation airports nationwide. Calculations by Zahran et al. (2017a) and Wolfe et al. (2016) understate the gains available to society from reduced use of leaded aviation gasoline because the negative impacts of lead operate through many more channels than compromised cognitive abilities.

1.6 Studying Exposure Risk at Reid-Hillview Airport

The risk of aviation gasoline exposure for children varies considerably by airport, depending on the volume of PEA traffic, as well as neighborhood proximity and near angle to airport runways. Reid-Hillview (RHV) is among seventeen airports identified by the U.S. EPA with the highest potential of approaching or exceeding National Ambient Air Quality Standards for lead due to the local combustion of leaded aviation gasoline.

In this study, data scientists at Mountain Data Group assess whether child exposure to lead from aviation-related sources in Santa Clara County is statistically associated with the BLLs of sampled children, independent of other lead exposure pathways. Specifically, statistical relationships between the BLLs of sampled children and the following indicators of aviation gasoline exposure risk are assessed: 1) child residential proximity to Reid-Hillview Airport, 2) variation in piston aircraft operations at Reid-Hillview Airport, and 3) child residential near angle to Reid-Hillview Airport.

Materials and methods to conduct statistical assessments are detailed below. Section 2 describes the data sources leveraged in this study, as well as the various measurement decisions made to estimate exposure risk to lead-formulated aviation gasoline. Section 3 describes the logic of statistical strategies used to assess whether indicators of aviation gasoline exposure risk are independently correlated with the BLLs of sampled children.

Section 4 presents main statistical results, and Section 5 presents statistical findings from various extension and robustness tests. Section 6 considers results in the context of a simulation involving a reduction in piston-engine aircraft operations at Reid-Hillview Airport and Section 7 concludes the study with a recapitulation of key results.

2 Data and Measurement

2.1 Childhood Lead Poisoning Prevention Data

Permission to analyze blood lead was granted by agreement with the Childhood Lead Poisoning Prevention Branch (CLPPB) of the California Department of Public Health (CDPH). All blood lead results from sampled children in California are reported to CDPH. In California, children in publicly supported programs (such as Medi-Cal and WIC) are mandated to be tested at 1 and 2 years with catch-up testing up to 6 years of age. Children not in publicly supported programs are mandated to be asked by a health care provider: "Does your child live in, or spend a lot of time in, a place built before 1978 that has peeling or chipped paint or that has been recently renovated?" to determine whether the child should be tested. Providers also test for lead poisoning if a change in circumstance has placed a child at risk of lead exposure. Laboratories and health providers submit HL7 formatted blood lead test information to WEBCOLLECT – a web-based data management platform that centralizes blood lead data on children statewide.

HL7 submitted data pass through successive quality checks, and deposit in the Response and Surveillance System for Childhood Lead Exposures (RASSCLE II) database. Tables in the RASSCLE II database contain demographic and clinical information on a sampled person, including residential address, date of birth, sex/gender, clinical information on the date and method of blood draw, and the laboratory performing analysis on blood samples. Some children are sampled repeatedly in the first few years of life.

The RASSCLE II database was queried for records with: 1) an indication of residence in Santa Clara County, 2) a date of blood draw occurring within the last 10 years, 3) a date of birth for the sampled person, and 4) a reported blood lead value. Candidate records extracted from RASSCLE II were interrogated for anomalies and completeness. Unprocessed HL7 records not appearing in RASSCLE II were also examined for inclusion.

RASSCLE II and HL7 Records with indication of a residential address were independently geo-coded. Address records were matched to latitude and longitude coordinates. This process enabled the assignment of a unique geographic identifier (FIPS), defined by the U.S. Census Bureau. Between processed RASSCLE II and unprocessed HL7 files, and restricting to children $\leq$ 18 years of age at the time of blood draw, residing $<$ 1.5 miles of Reid-Hillview Airport, and observed from January 1^{st}, 2011 to December 31^{st}, 2020, we arrived at 17,241 blood lead sample observations amenable to statistical analysis.

2.1.1 Child Blood Lead Data

The main response or outcome variable of analytic interest is *Blood Lead Level* (BLL) measured in micro-grams per deciliter of blood (μg/dL units). Restricting to children $\leq$ 18 years of age at the moment of blood sample, residing $<$ 1.5 miles of Reid-Hillview, and observed from January 1^{st}, 2011 to December 31^{st}, 2020, the unconditional mean BLL of sampled children was 1.83 μg/dL. About 1.7% of sampled children present with BLLs in excess of 4.5μg/dL, the CLPPB-defined threshold for action.

Five control variables from RASSCLE II/HL7 known to be correlated with child BLLs were collected from CDPH data, including: child gender, child age, method of blood draw, sample detection limit, and sample order. *Gender* is measured as $1\ =$ female; child *age* is measured in years (ranging from 0 to 18); the *method of blood draw* $=\ 1$ if capillary, and $0\ =$ otherwise; sample *detection limit* is measured as $1\ =$ if the reported BLL is at or below the limit of quantification, and $0\ =$ otherwise; and *sample order* which codes the count of blood samples (0=singleton observation, 1,...,n = repeated n times).

2.2 Aviation Gasoline Exposure Risk Data

2.2.1 Residential Distance

Following others (Miranda et al., 2011; Zahran et al., 2017a), we calculate the distance from the residential address of a sampled child to Reid-Hillview Airport. Using distance information on each child as an indicator of exposure risk, we test whether the BLLs of sampled children increase measurably with proximity to Reid-Hillview Airport.

Over the Landing-Takeoff (LTO) cycle, studies find that the bulk of aircraft emissions are released during departure phases of run-up, takeoff, and climb-out (Song and Shon, 2012; Feinberg et al., 2016; Mazaheri et al., 2011). According to Carr et al. (2011), total fuel consumed by piston aircraft in departure phases of the LTO cycle is estimated at 82% for twin-engine aircraft and 85% for single-engine aircraft. About 80% of lead emissions are released during departure phases of the LTO cycle (Carr et al., 2011).

Given that the bulk of lead emissions are released during departure phases of the LTO cycle, we capture child proximity by calculating the Haversine distance[4] from the child's residence at the date of blood draw to the northwest tip of Reid-Hillview Airport (longitude and latitude point coordinates -121.8230194, 37.3362252). In addition to measuring distance continuously, residential distance is also divided into three even categories: $<$ 0.5 miles, 0.5 to 1 mile, and 1 to 1.5 miles from Reid-Hillview Airport [5].

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[4] The haversine of the central angle, which is d over the r, is calculated by: $\left(\frac{d}{r}\right)$ = $haversine(\Phi_2 - \Phi_1) + cos(\Phi_1)cos(\Phi_2)haversine(\lambda_2 - \lambda_1)$, where r is the radius of earth(6,371 km), d is the distance between a child's residence and Reid-Hillview Airport, ϕ_1, ϕ_2 is latitude and λ_1, λ_2 is longitude of the child's residence and Reid-Hillview, respectively. We solve for d by the inverse sine function, getting: $d = rhav^{-1}(h) = 2rsin^{-1}(\sqrt{h})$.

[5] Our inner orbit of exposure risk at $<$ 0.5 miles conforms to previous research. Recall, Miranda et al. (2011) find that children at 500m to 1km from a general aviation airport in North Carolina are at highest at-risk of presenting with elevated BLLs. Zahran et al. (2017a) find that sampled children within 1km of 448 airports in Michigan are at greatest risk. The EPA (U.S. Environmental Protection Agency, 2020) maintains that children within 500m of PEA-servicing airports are at highest risk of exposure to aviation-related atmospheric lead. Our inner distance of $<$ 0.5 miles sits between the consensus range of exposure risk at 500m to 1km.

Figure 2 shows the spatial distribution of blood lead samples by distance categories. Over the period of January 1^{st}, 2011 to December 31^{st}, 2020, we observe a total of 1,065 records at $<$ 0.5 miles, 6,472 records at 0.5 to 1 mile, and 9,704 at 1 to 1.5 miles from Reid-Hillview Airport. Insofar as aviation gasoline exposure is a source of risk, sampled children in the nearest orbit to Reid-Hillview Airport should present with higher BLLs as compared to sampled children in outer orbits.

2.2.2 Residential Near Angle

Airport proximity, by itself, is an imperfect measure of aviation gasoline exposure risk. The fate and transport of lead emissions depend on the direction of prevailing winds that vary in and across airport facilities. Insofar as aviation gasoline is an independent source of lead exposure, two children equidistant to the same airport face different risk of elevated blood lead depending on the child's residential near angle to the airport.

A near angle group was assigned to each address by calculating the compass bearing (degrees) between a child's residential location and Reid-Hillview Airport.[6] We define near angle groups by the four cardinal directions: North (N), East (E), South (S) and West (W). For a BLL sample from child i in time t, with range of possible compass bearings $b_{it} \in [0,\ 360)$, we assign near angle group a_{it} as:

$$a_{it} = \begin{cases} E, & \text{if } b_{it} \in [45^\circ, 135^\circ)\,, \\ S, & \text{if } b_{it} \in [135^\circ, 225^\circ)\,, \\ W, & \text{if } b_{it} \in [225^\circ, 315^\circ)\,, \\ N, & \text{otherwise.} \end{cases} \tag{1}$$

Figure 3 shows the spatial distribution of BLL samples over our observation period by near angle groups. We observe 5,962 records residing North of Reid-Hillview Airport, 1,170 records East, 3,495 records South, and 6,614 records West of the airport. As

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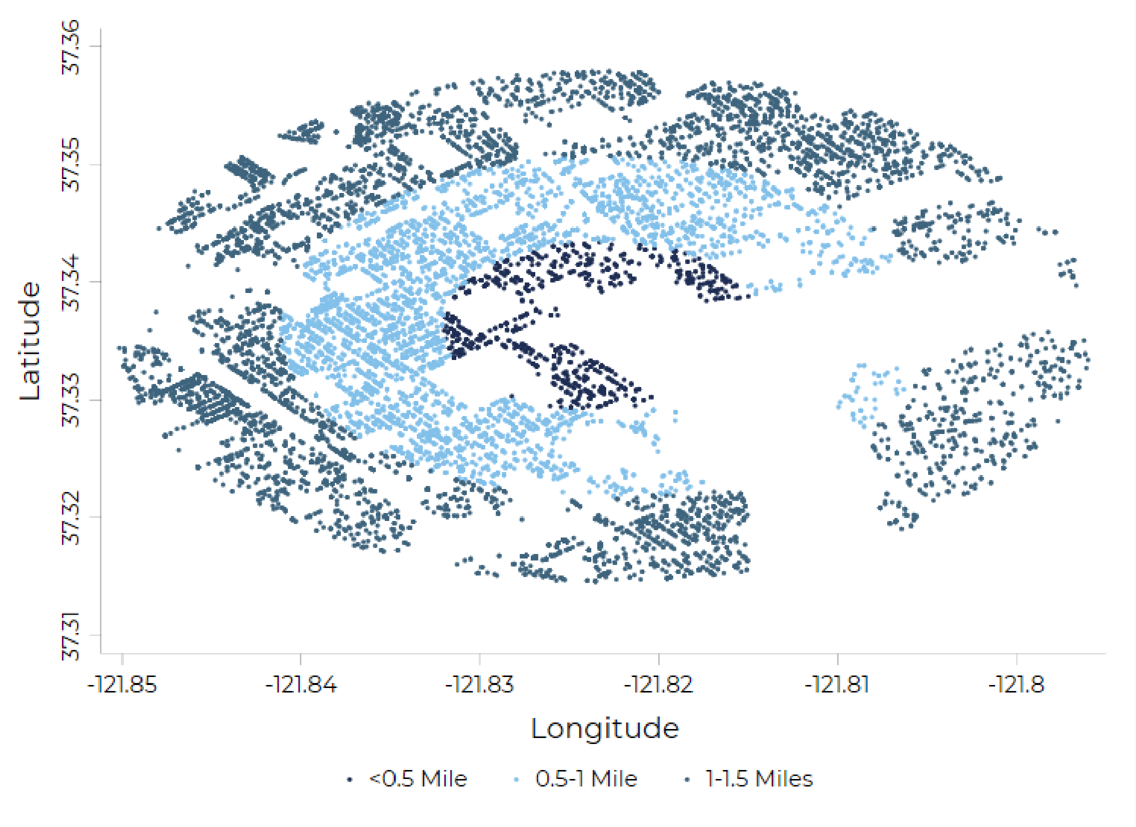
[6] See Appendix Figure A.1 for example calculations.

Figure 2: BLL Samples by Distance Categories to Reid-Hillview Airport



Note: Distance is calculated as the Haversine distance to North tip of runway at Reid-Hillview Airport, (-121.823, 37.336). BLL samples are restricted to children $\leq$ 18 years of age at the time of blood draw, residing $<$ 1.5 miles of Reid-Hillview Airport, and observed from 1/1/2011 to 12/31/2020. Over the observation period, we observe a total of 1,065 records at $<$ 0.5 miles, 6,472 records at 0.5 to 1 mile, and 9,704 at 1 to 1.5 miles from Reid-Hillview Airport. On recommendation of scientific staff from (CLPPB), three sample locations have been suppressed to protect the anonymity of sampled children.

shown in Appendix Figure A.2, prevailing winds at Reid-Hillview Airport emanate from the West and Northwest. Insofar as aviation gasoline exposure is a source of risk, children East of Reid-Hillview Airport should present with higher BLLs.

In addition to residential near angle, we collected prevailing wind direction data from ©Dark Sky. Daily weather data include average daily wind bearing (degrees) and were collected at Reid-Hillveiw Airport from 2011 to 2020. Prevailing wind bearing was assigned a near angle group as in Equation 1. For a given day, an address is defined as downwind if the assigned near angle groups of the wind and address are equal. Because the half-life of lead in the bloodstream is estimated at around 30 days (Lidsky and Schneider, 2003), we calculate the number of days in the last 60 (from date of blood draw) that a child is downwind from Reid-Hillview Airport. This measurement decision assumes that children have continuity of residence for 60 days.

2.2.3 Piston-Engine Aircraft Traffic and Aviation Gasoline Sales

The volume of PEA traffic varies meaningfully between airports and within an airport in time. Therefore, two children residing in the same household but sampled at different moments in a calendar year may present with different BLLs, depending on the coincidence of PEA traffic. To capture this channel of risk, we collected data on PEA departures and arrivals from Federal Aviation Administration Traffic Flow Management System Counts (TFMSC) .

Daily piston-engine aircraft data were available for Reid-Hillview Airport and all other operational PEA-servicing airports in Santa Clara County, including Palo Alto Airport (PAO), Moffett Federal Airfield (NUQ), San Martin Airport (E16), and Norman Y. Mineta San Jose International Airport (SJC).[7] Because the half-life for lead in blood is about 30 days (Lidsky and Schneider, 2003), we back calculated a rolling average of PEA operations over

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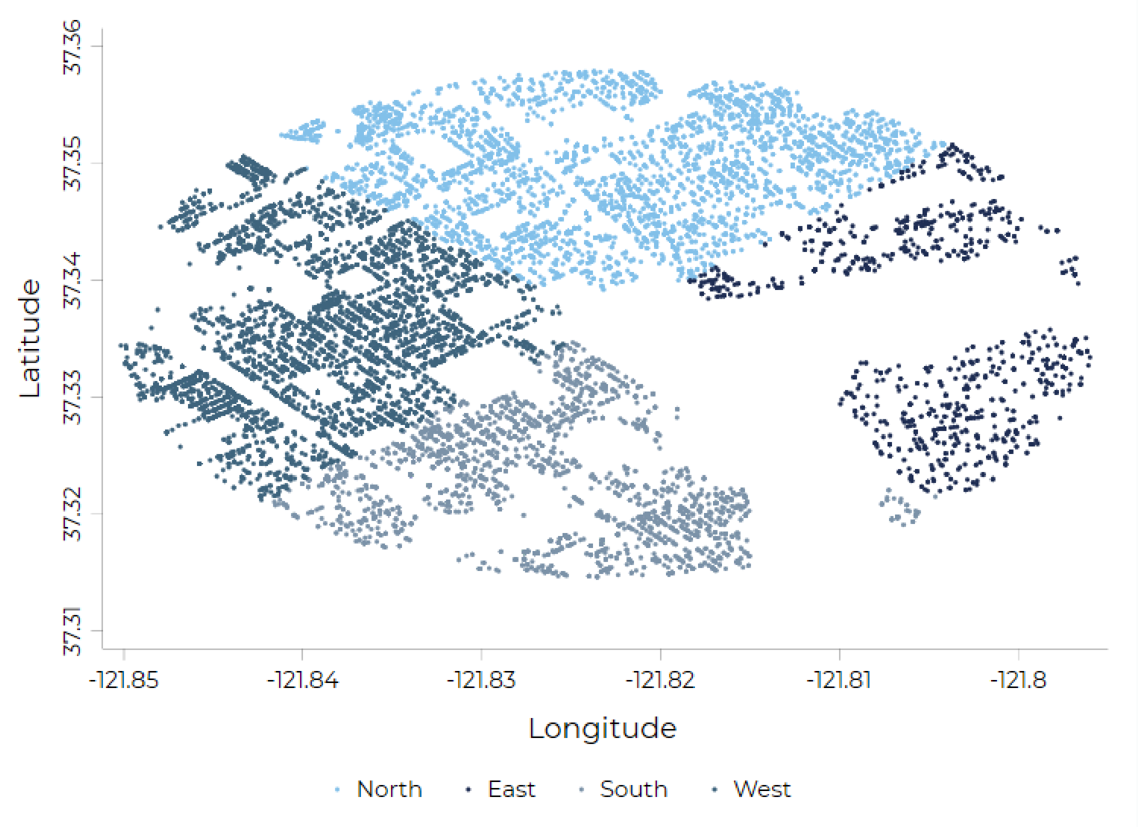
[7] General aviation count data was also available for RHV, SJC, and PAO in the TFMSC system, but departure and arrival information was not distinguishable by physical class (i.e., piston, turbine, or jet).

Figure 3: BLL Samples by Residential Near Angle to Reid-Hillview Airport

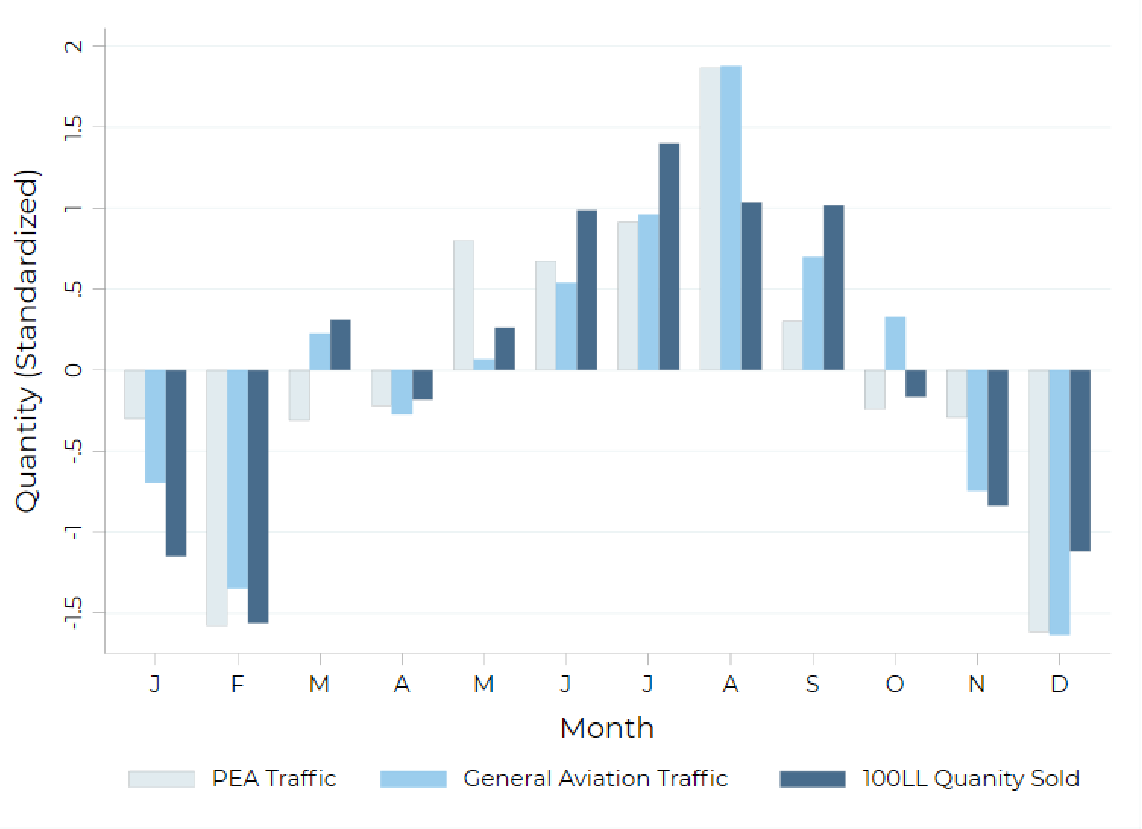


Note: Near angle groups assigned using Equation 1 and relative to Reid-Hillview Airport. BLL samples are restricted to children ≤ 18 years of age at the time of blood draw, residing < 1.5 miles of Reid-Hillview, and observed from 1/1/2011 to 12/31/2020. Over the observation period, We observe 5,962 records residing North of Reid-Hillview, 1,170 records East, 3,495 records South, and 6,614 records West of Reid-Hillview Airport. On recommendation of scientific staff from (CLPPB), three sample locations have been suppressed to protect the anonymity of sampled children.

60 days from the date of a child's blood draw. With the date of blood draw linked to the quantity of PEA traffic, one can test whether child BLLs are dose-responsive with the volume of PEA traffic. Our measurement of PEA traffic exposure assumes that children have continuity of residence for 60 days.

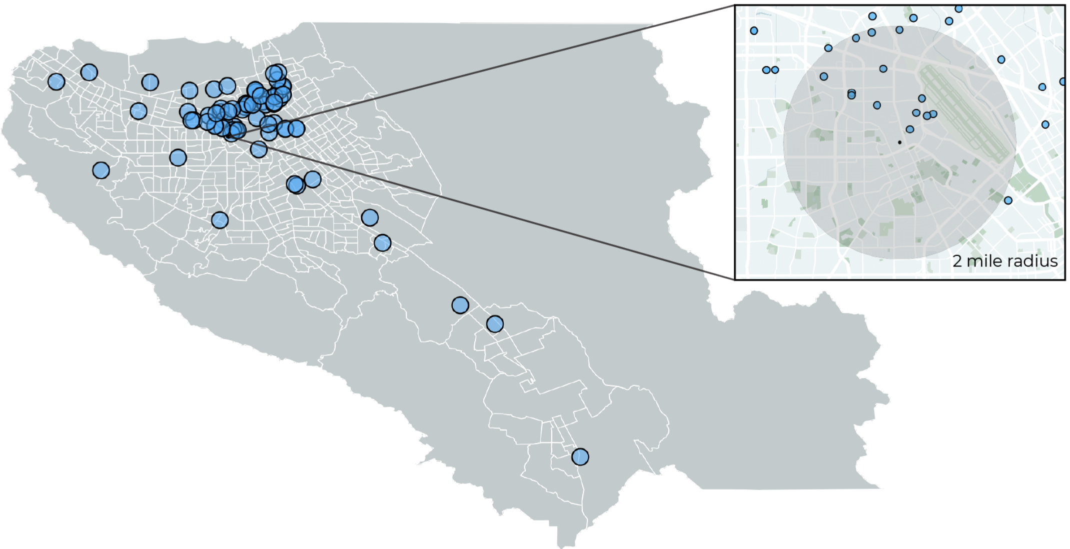
Also, fuel flowage fee (FFE) data were obtained from personnel at the Roads and Airports Department of Santa Clara County. The FFE data track monthly quantities of aviation gasoline (100LL) sold to fixed-base operators at Reid-Hillview Airport from 2011 to 2019. Each child is matched to the two-month rolling average of quantities of 100LL sold from date of blood draw. As with PEA traffic, we test whether child BLLs are dose-responsive with aviation gasoline sales at Reid-Hillview Airport. Figure 4 shows high statistical agreement between quantities of 100LL sold and Federal Aviation Administration (FAA) traffic data by month at Reid-Hillview Airport.

Figure 4: Monthly Variation in Quantity of FAA Traffic & 100LL Sold at Reid-Hillview Airport



Note: Because aircraft traffic and gallons of 100LL sold are measured differently, we use standardization by z-score to resolve unit incommensurability. The z-score is calculated by taking the observed value for a given month minus the series mean over the series standard deviation. Data from 1/1/2011-12/31/2020 for general aviation traffic and piston-engine aircraft traffic (arrivals and departures). Gallons of 100LL sold to fixed-base operators at Reid-Hillview Airport are from 1/2011 till 12/2019.

Figure 5: Location of Unique Lead-Emitting TRI Facilities in Santa Clara County from 2011 to 2020.



Note: We display the complete inventory of lead-emitting TRI facilities over the observation period, 1/1/2011-12/31/2020. The count of facilities varies by year, as firms enter and exit the TRI system on the basis of reported on-site lead releases. Two mile radius drawn from hypothetical residential address for sampled child. Data collected from U.S. Environmental Protection Agency's Toxic Release Inventory (TRI) system.

2.3 Control Data

2.3.1 Toxic Release Inventory Facilities

Lead-emitting industrial facilities are more common in the vicinity of airports (Zahran et al., 2017a). Children that are proximate to airports are therefore simultaneously proximate to other point source emitters of lead. Failing to account for this spatial coincidence can produce biased estimates of aviation gasoline exposure risk vis-à-vis BLLs in children. The U.S. EPA's Toxic Release Inventory (TRI) system tracks the industrial management of over 650 listed chemicals that pose harm to humans and the environment.

Under Section 313 of the Emergency Planning and Community Right to Know Act, firms that release, transfer, or dispose of listed chemicals are required to submit annual reports to the EPA. Firms that exceed thresholds for listed chemicals must report to the EPA under the TRI system, detailing quantities of toxins used. Default thresholds for both private and federal facilities are 25,000lbs for manufacturing and processing activities, and 10,000lbs for toxic chemicals otherwise used. In 2001, the EPA determined that lower reporting thresholds for lead and lead compounds were warranted because lead persists in the environment, posing substantial health risk to human populations. The reporting threshold for lead was lowered to 100lbs across all uses of the toxicant (Zahran et al., 2014).

We collected records on all facilities in Santa Clara County with reported on-site releases of lead between 2011 to 2020. Following Zahran et al. (2017a), with the location of each facility and the year of reported release event, we counted the number of lead-emitting TRI facilities ≤ 2 miles of a child's residence in the corresponding year of blood draw. All results pertaining to the assessment of statistical relationships of child BLLs and indicators of aviation gasoline exposure risk control for the presence of this alternative source of lead exposure. Figure 5 illustrates the measurement logic, showing the distribution of unique TRI facilities countywide and zooming to the hypothetical residential location of a sampled child.

2.3.2 Lead-Based Paint Risk

Legacy use of lead-based paint remains an exposure risk to children. Exposure to lead-based paint is primarily a problem in older homes. Figure 6 traces lead use in the United States over the 20^{th} century by two major sources, namely lead in paint and lead in automotive gasoline. By 1960, the use of lead-based paint subsided over 90% from peak usage in the 1920s. Nonetheless, children in the United States may consume lead directly or may be exposed to leaded dust associated with deteriorating or haphazardly removed lead-based paint in homes from this era (Rabito et al., 2007; Farfel et al., 2003, 2005).

Moreover, in Michigan, Zahran et al. (2017a) report that the percentage of homes built in the era of widespread lead-based paint usage were almost twice as high in neighborhoods proximate to airports as compared to neighborhoods more distant from airports. In other words, children most at-risk to aviation gasoline exposure simultaneously face higher lead-based paint exposure risk.

To account for this potential confounding factor, we collected American Community Survey (ACS) data from the U.S. Census Bureau on the fraction of homes in a neighborhood (census tract) built before 1960. In analyses that follow, each child in our analytic set is assigned a lead-based paint exposure risk according to the neighborhood of residence and year of blood draw, as captured by the percentage of homes built before 1960.[8] Figure 7 shows the spatial distribution of the percentage of housing stock built before 1960 at the census tract scale in Santa Clara County as of 2019.

2.3.3 Neighborhood Socioeconomic Status

Studies show that children of low socioeconomic status are at greater risk of presenting with elevated BLLs (Campanella and Mielke, 2008; Zahran et al., 2010). Socioeconomic status proxies for resource access, knowledge about the dangers of, and protective actions taken against lead exposure (Zahran et al., 2017a).

In addition to the use of socio-demographic information present in RASSCLE II/HL7 data (described in Section 2.1.1), we measured the percentage of adults with a college degree, median home prices, and median household incomes to characterize the socioe-

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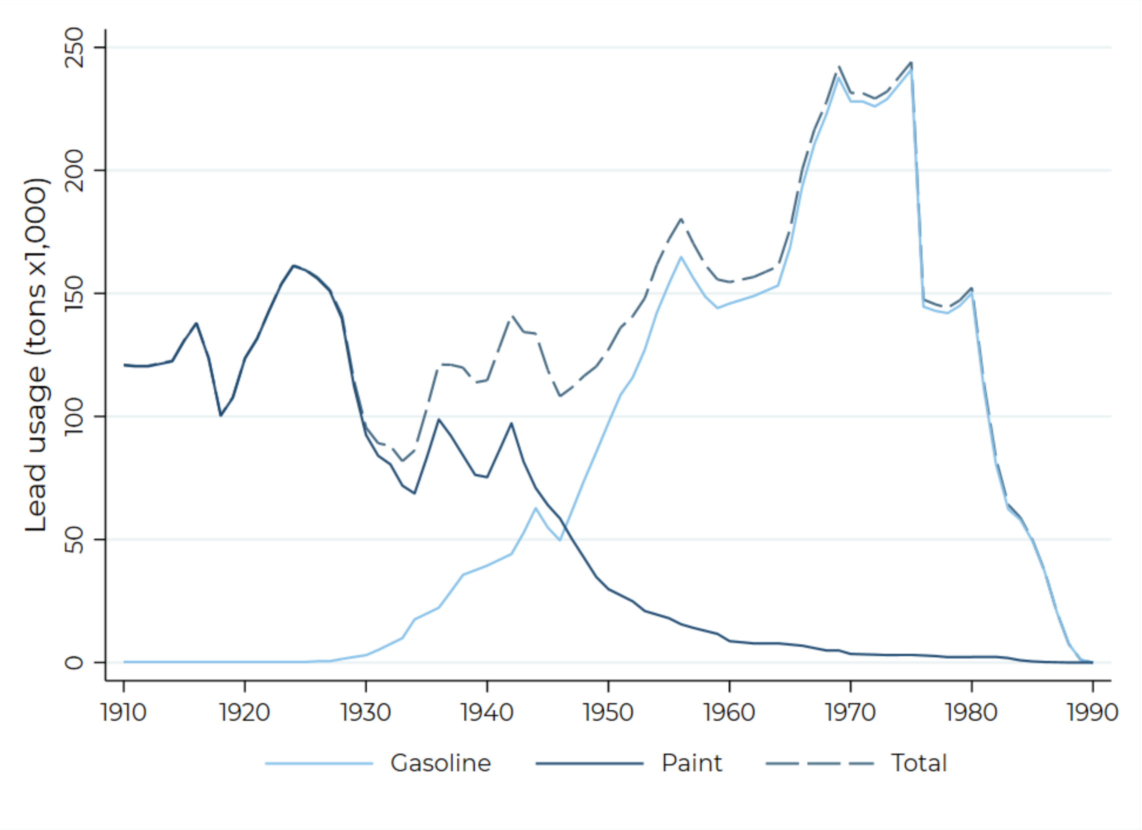
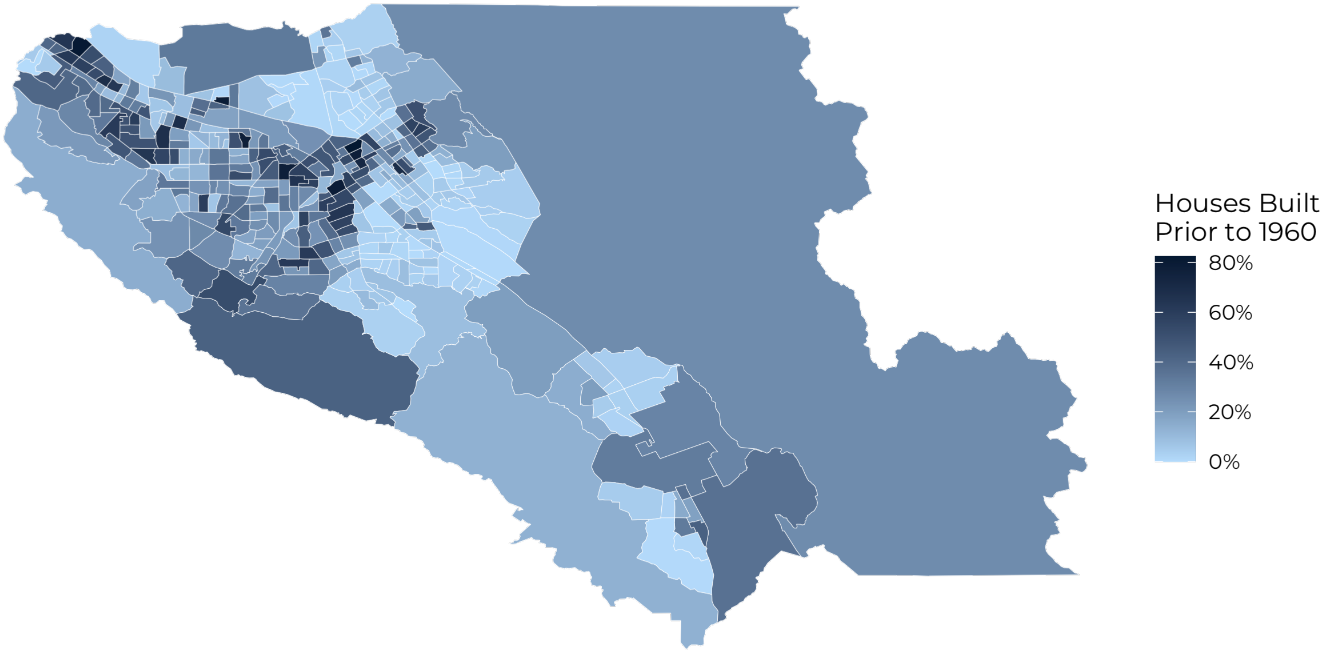
[8] This measurement strategy capitalizes on the fact that the age of homes within a neighborhood (or census tract) are more alike than the age of homes across neighborhoods. We also considered a more involved strategy of linking RASSCLE II/HL7 residential information on a sampled child to the same residential address in Santa Clara County Assessor files, where the age of a home is typically indicated. This effort produced intolerably high listwise deletion from imperfect matching across files.

Figure 6: Lead Use (in tons × 1,000) in the United States over 20^{th} Century by Major Source



Note: Estimates of the legacy use of lead-based paint and lead in automotive gasoline in tonnages are from Laidlaw and Filippelli (2008).

Figure 7: Lead-Based Paint Exposure Risk by Neighborhood in Santa Clara County

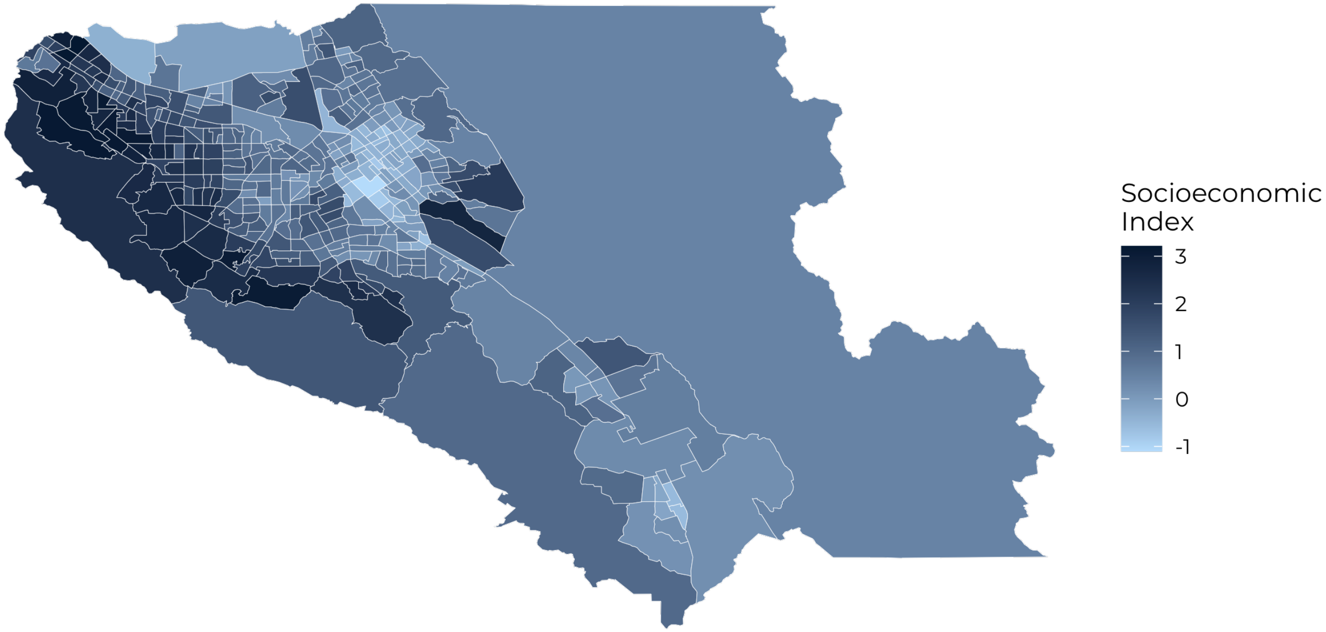


Note: The data displaying the percentage of housing stock in a census tract built prior to 1960 are from the U.S. Census Bureau ACS for the observation year of 2019.

conomic status of a child's neighborhood (i.e., census tract). These data were collected from the American Community Survey. Given the very high correlation across these variables, we distilled the data to a single Socioeconomic Index value for each neighborhood in Santa Clara County by year and matched to each child's residential location and year of blood draw. The index was computed by averaging standardized scores across indicators of neighborhood socioeconomic status. Figure 8 shows the spatial distribution of the neighborhood socioeconomic status index across Santa Clara County as of 2019.

In the next section we detail the logic of statistical strategies used to assess whether indicators of aviation gasoline exposure risk are independently correlated with the BLLs of sampled children. Accompanying the description of each statistical strategy is a stated expectation on the behavior of estimated coefficients corresponding to each indicator of aviation gasoline exposure, net of other factors.

Figure 8: Socioeconomic Status Index by Neighborhood in Santa Clara County



Notes: The neighborhood socioeconomic index was calculated by taking the average of standardized scores across the three variables of the percentage of adults with a college degree, median home prices, and median household incomes. Displayed data are from the U.S. Census Bureau American Community Survey for the observation year of 2019. Darker colors reflect higher socioeconomic status.

3 Empirical Methods

3.1 Main Effects

To assess whether the BLLs of sampled children are statistically associated with indicators of aviation gasoline exposure risk we deploy a linear least squares estimator with census block fixed effects, accounting for heteroeskedasticity and relaxing distributional assumptions with bootstrapped standard errors.

The outcome of interest is child BLL, measured as a continuous variable in μg/dL. For sampled child i in neighborhood block j at time t, we estimate the responsiveness of child blood lead Y_{ijt} to indicators of aviation gasoline exposure risk with the following linear model:

$$\begin{aligned}Y_{ijt} = {} & \beta_0 + \beta_1 D_{it}^n + \beta_2 D_{it}^f + \beta_3 T_{it} + \beta_4 W_{it}^e + \beta_5 W_{it}^s + \beta_6 W_{it}^w \\ & + \Gamma_1 G_i + \Gamma_2 A_{it} + \Gamma_3 C_{it} + \Gamma_4 S_i + \Gamma_5 Z_{it} + \Gamma_6 L_{it} \\ & + \lambda_1 F_{it} + \lambda_2 H_{jt} + \lambda_3 I_{jt} + \lambda_4 Q_{it} + \gamma_j + \varepsilon_{ijt} \qquad (2)\end{aligned}$$

Knowing that relationships of interest are possibly non-linear, we use a flexible specification where distance D is measured as a series of dichotomous variables, where $D_{it}^n = 1$ if child i in time t resides 0.5-1 miles from Reid-Hillview Airport, $0 =$ otherwise, and $D_{it}^f = 1$ if child i in time t resides 1-1.5 miles from Reid-Hillview Airport, and 0 otherwise. Children most proximate to Reid-Hillview Airport (< 0.5 miles) constitute the reference distance. The flow of lead emitted from the aircraft traffic T_{it} is the count of PEA operations (measured in percentile terms) in the last 60 days relative to the draw date t of child i. Insofar as lead emitted from PEA traffic is not distributed uniformly over the distance gradient, but is a function of the prevailing wind direction, we include a series of dummy variables W for the location of child i in time t relative to the airport, with North being the reference direction, and: $W_{it}^e = 1$ if a child resides East of RHV, $0 =$ otherwise, $W_{it}^s = 1$ if a child resides South of RHV, $0 =$ otherwise, and $W_{it}^w = 1$ if a child resides West of RHV, $0 =$ otherwise.

A series of variables are included to control for the timing, method, quantification limit, and order of blood draw, where C_{it} is whether or not the method of blood draw is capillary, L_{it} is whether the measured BLL is at or below the limit of test detection, Z_{it} is the year and quarter of the blood draw, and S_i is the order of sample for children sampled repeatedly.[9] Child demographic characteristics include the child's age A_{it} measured in years, and an indicator for whether the child is female G_i.

A suite of controls are included to account for confounding sources of lead exposure and neighborhood socioeconomic status corresponding to the residential location of a sampled child and date of blood draw. F_{it} is the count of nearby lead-emitting toxic release inventory facilities ≤ 2 miles of a child's residence, and H_{jt} is the percent of homes built ≤ 1960 in child's neighborhood of residence, proxying for lead-based paint exposure risk. Because atmospheric concentrations of lead fluctuate seasonally – in part because of the re-suspension of lead-contaminated surface soils by turbulence (Laidlaw et al., 2012; Zahran et al., 2013) – our statistical models proxy for this phenomenon with a series of dummy variables corresponding to the season of blood draw, Q_{it}, with winter as our reference season. Also included is I_{jt}, estimating the socioeconomic status of a neighborhood by an quantitative index that incorporates measures of educational attainment, median household income, and property values (proxying for household wealth).

Importantly, γ_j is the neighborhood or census block fixed effect. Inclusion of γ accounts for non-time varying unobservable factors which may influence BLLs that are common to sampled children within a given neighborhood but varying across neighborhoods. Fixed effects absorb omitted variables by estimating a distinct mean BLL value (or intercept) for each neighborhood. Finally, ε_{ijt} is the random error term associated to the observed Y_{ijt}.

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[9] For a singleton observation (non-repeated child) i, $S_i = 0$. Otherwise, $S_i = 1, ..., n$ for child i repeated n times over the observation period, January 1st, 2011 to December 31st, 2020. The date of birth, child sex, child name, and date of blood draw were used to identify sample order for each child. The majority of children (53.8%) appearing in CDPH data were sampled only once.

3.2 Parameter Direction Expectations

3.2.1 Residential Distance

Insofar as aviation gasoline exposure is a source of risk, sampled children in the nearest orbit to Reid-Hillview Airport should present with higher BLLs as compared to children in outer orbits. Therefore, other things held equal, we expect β_1 and β_2 in Equation 2 corresponding to D^n_{it} and D^f_{it} to be negative, reflecting lower exposure risk for children residing at 0.5-1 mile and 1-1.5 miles, respectively, relative to children at < 0.5 miles from Reid-Hillview Airport. In addition to treating residential distance to Reid-Hillview Airport categorically, we estimate a series of linear models with residential distance measured continuously, applying various linear transformations to Equation 2. The expectation here is estimated coefficients should be negative, indicating that BLLs of sampled children decline with distance from Reid-Hillview Airport, other things held equal.

3.2.2 Residential Near Angle

The atmospheric transport of lead emissions from aviation gasoline used by piston-engine aircraft depend on the direction of prevailing winds that vary in and across airport facilities. As shown Appendix Figure A.2, prevailing winds at Reid-Hillview Airport emanate predominately from the West and Northwest. Insofar as exposure to aviation gasoline is a source of risk, then sampled children residing East of Reid-Hillview Airport should present with higher BLLs. Therefore, other things held equal, we expect β_4 corresponding to W^e_{it} to be positive, indicating that sampled children residing east of Reid-Hillview Airport (and predominantly downwind) have higher BLLs than other children (not residing predominantly downwind of RHV).

We also execute a version of Equation 2 that substitutes our indicator variables for residential near angle with a continuous measure of downwind risk (DW_{it}) that captures the number of days in the last 60 (from date of blood draw) where prevailing winds drift in the residential direction of a child. In this model, β_4 is expected to be positive, indicating that other things held equal, child BLLs increase with days of downwind drift. A graphical summary of results from this additional exercise is presented in Appendix Figure A.3.

3.2.3 Piston-Engine Aircraft Traffic Exposure

Following Zahran et al. (2017a), the inclusion of daily PEA traffic (T) shown in Equation 2 and detailed in Section 2.2.3 is meant to capture variation in the flow of atmospheric lead emissions attributable to aviation gasoline at Reid-Hillview Airport that may impact the BLLs of sampled children nearby. Other things held equal, then, we expect β_3 corresponding to T_{it} to be positive, indicating that BLLs increase with measured PEA operations at Reid-Hillview Airport.

We extend this test by converting our continuous PEA operations variable into a series of indicators corresponding to PEA traffic terciles at each airport. Denoting medium (m) and high (h) terciles of PEA traffic at Reid-Hillview Airport and letting the first tercile be the reference group, we modify Equation 2 by replacing the continuous variable T_{it} with dummy variables T_{it}^{m} and T_{it}^{h} for medium and high traffic terciles respectively. We expect β_{3a} and β_{3b}, corresponding to T_{it}^{m} and T_{it}^{h}, to be positive, indicating that BLLs are higher for children exposed to medium and high levels of PEA traffic in the last 60 days from draw date relative to children exposed to low levels of PEA traffic.

We also estimate a version of Equation 2 where measured PEA traffic is substituted for the monthly quantities of aviation gasoline (AG_{it}) sold to fixed-base operators at Reid-Hillview Airport. In this external validation exercise, we similarly expect β_3 to be positive, indicating that child BLLs increase with monthly quantities of aviation gasoline sold at Reid-Hillview Airport.

4 Main Results

4.1 Descriptive Statistics

Appendix Table A.1 reports descriptive statistics on our study population. The average age of sampled children is 2.82 years, with 51.2% identified as male and 48.8% identified as female. Table 1 shows descriptive statistics on child BLLs by residential distance, residential near angle, and terciles of piston-engine aircraft traffic at Reid-Hillview Airport over the entire observation period of January 1^{st} 2011 to December 31^{st} 2020. Across all conditions, mean BLLs behave as expected. Sampled children proximate to Reid-Hillview Airport ($<$ 0.5 miles) present with higher mean BLLs than more distant children. Combining children in the outer orbits, we find that mean BLLs of near vs far children are modestly different (1.93 vs 1.83 μg/dL), but statistically discernible from chance (one-tailed t = 1.92, p = 0.027).[10]

Column 2 of Table 2, shows mean BLLs of children at the four cardinal directions from Reid-Hillview Airport. Combining blood lead samples of children not east of Reid-Hillview Airport, we find that mean BLLs of children East vs not East of Reid-Hillview Airport are modestly different (1.94 vs 1.82 μg/dL) and statistically significant (one-tailed t = 2.59, p = 0.005). Finally, Column 3 shows mean BLLs by low, medium, and high PEA traffic terciles. Indicative of an aviation gasoline exposure effect, we find that mean BLLs graduate upward across PEA traffic terciles, increasing from 1.72 to 1.81 to 1.96 μg/dL, respectively.

While results in Table 2 are consistent with expectations, they do not control for the demographic characteristics of sampled children, blood testing method, timing and order of blood draw, alternative sources of lead, or neighborhood conditions, both observable and unobservable. In the next section we present regression results that account for

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[10] As shown in Table 1, sampled children in outer orbits (of 0.5 to 1.5 miles from Reid-Hillview Airport) have different demographic and neighborhood characteristics that are likely to attenuate observed differences in unconditional means by residential distance categories.

these factors. We begin with the question of residential distance, then move to results on residential near angle and downwind effects, and then complete our main effects investigation with results on piston-engine aircraft traffic and aviation gasoline sales.

4.2 Residential Distance

Before estimating regression coefficients pertaining to residential distance we compare sampled children in the inner orbit of proximity to Reid-Hillview Airport (< 0.5 miles) against children in outer orbits (0.5-1.5 miles) with respect to aviation gasoline exposure variables, and observable demographic and neighborhood characteristics. Table 1 shows means by distance categories on variables of interest, with computed p-values pertaining to one-tailed t-tests. The purpose here is to assess comparability of children by airport proximity. Sampled children are statistically similar with respect gender, residential near angle, age, PEA traffic exposure, sample order, and year or timing of blood draw, where $p > 0.05$.

We do observe statistically significant differences with respect to the proportion of children sampled by capillary method (0.24 vs 0.26, $p = 0.024$), the percentage of neighborhood homes built prior to 1960 (23.8 vs 27.94, $p < 0.001$), the count of lead-emitting TRI facilities within 2 miles of a child's residence (2.38 vs 2.51, $p < 0.001$), and neighborhood socioeconomic status (-0.21 vs -0.25, $p = 0.006$). On variables where statistically significant differences are observed, all function to inflate the BLLs of sampled children in outer orbits as opposed to sampled children most proximate to Reid-Hillview Airport. Therefore, whatever differences in estimated BLLs that may obtain between sampled children by residential distance in regression analyses that follow, we may regard these differences as possibly attenuated.

Table 3 reports regression coefficients on residential distance to Reid-Hillview Airport. Recall, our response variable of child BLL is measured in μg/dL units. Distance is measured categorically with our reference group being children residing within 0.5 miles of

Table 1: Comparison of Variable Means by Residential Distance, (t-Test)

	Home <0.5 Miles	Home 0.5-1.5 Miles	p value
PEA Traffic Exposure	0.50	0.51	0.239
Residence East of RHV	0.06	0.07	0.098
Age (years)	2.71	2.82	0.057
Female	0.48	0.49	0.373
Capillary Blood Draw	0.24	0.26	0.024
Sample Order	0.83	0.82	0.369
Tri Facilities $<$ 2 miles	2.38	2.51	<0.001
Neighborhood % Stock $<$ 1960	23.80	27.94	<0.001
Neighborhood SES	-0.21	-0.25	0.006
Year of Sample	2015.4	2015.5	0.094

Note: p values correspond to one-tailed t-tests with equal variances assumed across variables.

Table 2: Cross-tabulations of BLLs by Distance, Near Angle, and PEA Traffic at RHV

Distance	Blood Lead Level (μg/dL)	Near Angle	Blood Lead Level (μg/dL)	Operations	Blood Lead Level (μg/dL)
0-0.5 Miles	1.93	North	1.83	Low	1.72
	(1.93)		(1.27)		(1.91)
0.5-1 Miles	1.85	East	1.94	Medium	1.81
	(2.01)		(1.49)		(1.37)
1-1.5 Miles	1.81	South	1.77	High	1.96
	(1.41)		(2.24)		(1.63)
		West	1.82		
			(1.59)		
Total	1.83	Total	1.82	Total	1.83
	(1.69)		(1.66)		(1.66)

Notes: Mean blood lead values are in μg/dL; Standard deviations in parentheses; The unconditional sample mean is shown as Total; Near angle groups are assigned using Equation 1 and calculated from residential address relative to Reid-Hillview Airport; Airport operations are calculated as PEA traffic terciles;

Reid-Hillview Airport. Reported coefficients therefore have the interpretation of an estimated difference in mean BLLs (in μg/dL units) for children at 0.5 to 1 mile and 1 to 1.5 miles, respectively, vis-à-vis children most proximate to Reid-Hillview Airport.

Coefficients are reported from seven different models that graduate in their saturation of control variables. Coefficients pertaining to both outer distances behave relatively consistently across models of varying saturation. Focusing our interpretation on model (7) including all possible control variables, we find that sampled children at 0.5 to 1 mile present with BLLs that are 0.179 μg/dL lower on average than sampled children nearest to Reid-Hillview Airport ($<$ 0.5 miles). This observed difference is statistically distinguishable from chance. Other things held equal, we also find that blood lead samples of children at 1 to 1.5 miles are, on average, 0.202 μg/dL lower than statistically similar children proximate to Reid-Hillview Airport. Even though coefficients appear to decrease with distanced categories, the estimated difference in BLLs of sampled children at 0.5 to 1 mile vs 1 to 1.5 miles is not statistically significant.

Figure 9 displays predicted BLLs by categories of distance to Reid-Hillview Airport. Predicted values are from model (7) in Table 3 where all other model variables are fixed at their sample means. Under this prediction scenario, we find that sampled children most proximate to Reid-Hillview Airport ($<$ 0.5 miles) present with BLLs that are 9.8% and 11.2% higher than sampled children at 0.5 to 1 mile and 1 to 1.5 miles, respectively.

Next, Table 4 reports results involving the estimation of a series of linear models with residential distance measured continuously and applying various transformations to both distance and child BLLs. All things held equal, we find that no matter the measurement or transformation – distance measured linearly, log or square root transformed and child BLLs measured linearly or log transformed – child BLLs decrease statistically significantly with residential distance from Reid-Hillview Airport.

Table 3: Residential Distance to Reid-Hillview Airport and Child BLLs

BLL (μg/dL)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Distance (Reference < 0.5 miles)							
0.5 to 1 miles	-0.148*	-0.152**	-0.143*	-0.149*	-0.175**	-0.179**	-0.179**
	(0.078)	(0.077)	(0.078)	(0.078)	(0.074)	(0.074)	(0.074)
1 to 1.5 miles	-0.162**	-0.167**	-0.163**	-0.165**	-0.182**	-0.192**	-0.202***
	(0.079)	(0.080)	(0.079)	(0.079)	(0.075)	(0.075)	(0.075)
Constant	1.977***	1.797***	1.789***	1.703***	2.043***	1.988***	2.131***
	(0.075)	(0.076)	(0.080)	(0.086)	(0.097)	(0.094)	(0.308)
Observations	17,241	17,162	17,162	17,162	17,162	17,162	17,162
Block FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Distance	Yes	Yes	Yes	Yes	Yes	Yes	Yes
PEA Traffic	No	Yes	Yes	Yes	Yes	Yes	Yes
Near Angle FE	No	No	Yes	Yes	Yes	Yes	Yes
Demography	No	No	No	Yes	Yes	Yes	Yes
Draw Controls	No	No	No	No	Yes	Yes	Yes
Other Exposures	No	No	No	No	No	Yes	Yes
SES	No	No	No	No	No	No	Yes
Timing Controls	No	No	No	No	No	No	Yes

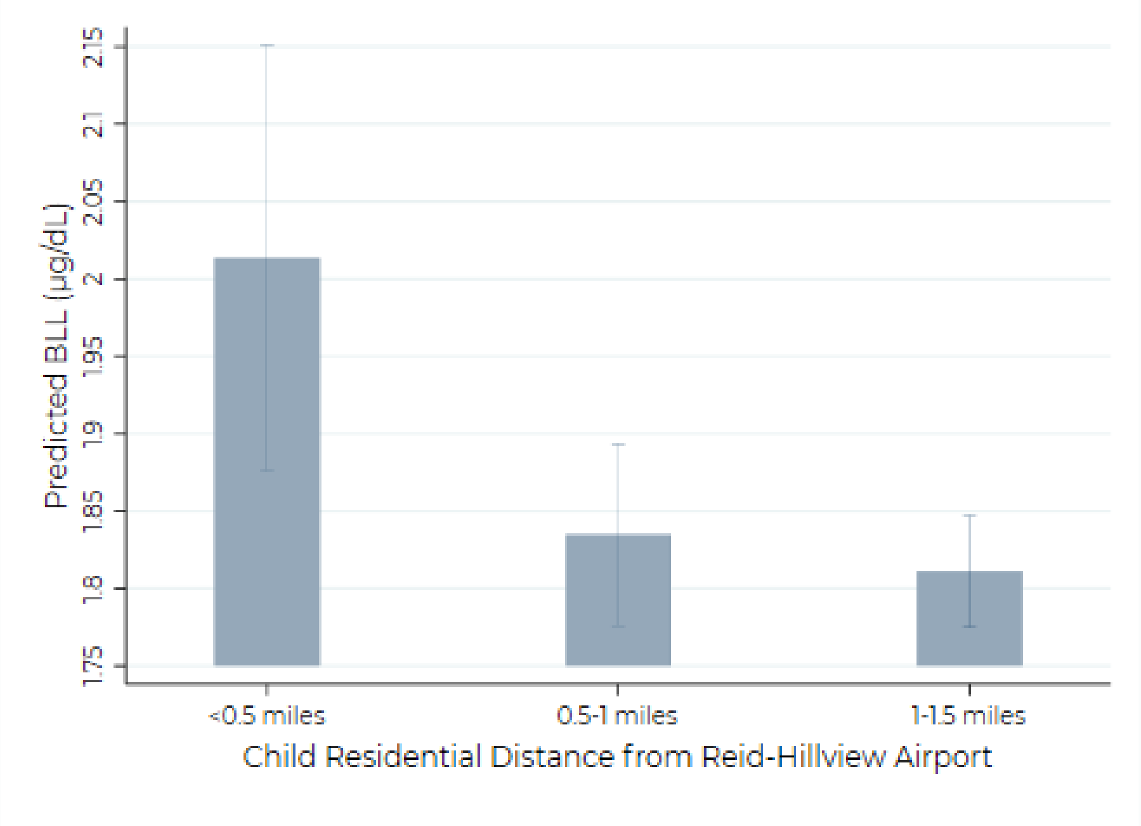
Notes: Bootstrapped standard errors in parentheses $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$; All models limited to children $\leq$ 18 years of age at the time of blood draw, residing < 1.5 miles RHV, and observed from January 1st, 2011 to December 31st, 2020; Dependent variable is child BLL (μg/dL); Distance groups are assigned using the distance (miles) between RHV and the child's place of residence; Demography includes child's age (years) and sex (1=female, 0=otherwise); Draw controls includes: draw method (1=capillary, 0=otherwise), limit of quantification (1=BLL $\leq$ limit of quantification, 0=otherwise), and repeated sample (0=singleton observation, $1,\ldots,n$=repeated n times); Other exposures includes: count of TRI facilities $\leq$ 2 miles from residential address, and percent of neighborhood housing stock built $\leq$ 1960; SES is the neighborhood socioeconomic status index; Timing controls include a set of indicators for season and year-quarter of the date of draw;

Table 4: Functions of Residential Distance to Reid-Hillview and Child BLLs

	(1) BLL	(2) BLL	(3) BLL	(4) Log BLL	(5) Log BLL	(6) Log BLL
Linear Distance	-0.102**			-0.040***		
	(0.047)			(0.012)		
Sqrt Distance		-0.197**			-0.077***	
		(0.086)			(0.022)	
Log Distance			-0.090**			-0.034***
			(0.037)			(0.010)
Constant	2.057***	2.144***	1.940***	0.845***	0.879***	0.800***
	(0.325)	(0.327)	(0.329)	(0.101)	(0.101)	(0.102)
Observations	17,162	17,162	17,162	17,162	17,162	17,162
Fully Saturated	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Bootstrapped standard errors in parentheses *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; All models limited to children $\leq$ 18 years of age at the time of blood draw, residing < 1.5 miles RHV, and observed from January 1st, 2011 to December 31st, 2020; Dependent variable in Models (1) to (3) is child BLL (μg/dL); Dependent variable in Models (4) to (6) is the natural log of child BLL (μg/dL); Distances are assigned using the distance (miles) between RHV and the child's place of residence; Full saturation of controls includes: child's age (years) and sex (1=female, 0=otherwise), draw method (1=capillary, 0=otherwise), limit of quantification (1=BLL $\leq$ limit of quantification, 0=otherwise), and repeated sample (0=singleton observation, 1,...,n=repeated n times), count of TRI facilities $\leq$ 2 miles from residential address, and percent of neighborhood housing stock built $\leq$ 1960, neighborhood socioeconomic status index, and a set of indicators for season and year-quarter of the date of draw;

Figure 9: Residential Distance to Reid-Hillview Airport and Predicted Child BLLs



Note: Predictions are from model (7) in Table 3, with all other model variables fixed at their sample means.

4.2.1 Results Summary, Section 4.2

The evidence presented in Table 3 and Figure 9 indicates that children proximate to Reid-Hillview Airport present with systematically higher BLLs, net of other measured sources of lead exposure risk, child demographic characteristics, and observed and unobserved neighborhood conditions. This result is compatible with exposure risk to aviation gasoline, and consistent in both direction and magnitude with previous studies (Miranda et al., 2011; Zahran et al., 2017a).

To contextualize the meaning of estimated conditional mean differences in BLLs by categories of distance, we compare our results to the estimated increase in BLLs of children in Flint during the much publicized Flint Water Crisis (FWC). At the height of the FWC, child BLLs surged by an estimated 0.35 to 0.45 μg/dL over baseline levels (Zahran et al., 2017c) [11]. As shown in Table 3, children within 0.5 miles of RHV have BLLs that are about $1/5^{th}$ μg/dL higher than statistically similar children more distant from Reid-Hillview Airport. This difference is equivalent to about 50% of the estimated increase in BLLs of sampled children at the height of the FWC.

4.3 Residential Near Angle

Regression results of residential near angle relative to Reid-Hillview Airport are presented in Table 5. Again, the response variable is child BLL and is measured in μg/dL units. As detailed in Section 2.2.2, the near angle groups are mutually exclusive and correspond to the four cardinal directions. Parameter estimates have the interpretation of an estimated difference in mean BLLs (in μg/dL units) for sampled children in their respective near angle group, relative to sampled children North of Reid-Hillview Airport.

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[11] With over 21,000 time-stamped blood lead samples from children in Genesee County drawn from January 01, 2013 to July 19, 2016, Zahran et al. (2017c) pursued a series of quasi-experimental tests to identify the causal effects of water-lead exposure, finding that the switch in water source in Flint caused child BLLs to increase by about 0.35 to 0.45 μg/dL from a pre-crisis baseline of about 2.3 μg/dL

As in the analysis of residential distance above, Table 5 presents a series of models with increasing degrees of saturation in terms of included control variables. Coefficient estimates across all models behave as expected, with sampled children residing East of Reid-Hillview Airport having higher BLLs relative to their counterparts North of Reid-Hillview Airport, all else equal. The estimated difference in mean BLLs for sampled children to the South and West of Reid-Hillview Airport relative to children North of the airport are near zero and indistinguishable from chance. Focusing on saturated model (7), we find that mean BLLs among sampled children in the East near angle group have an estimated mean BLL that is 0.4 μg/dL higher than those to the North of Reid-Hillview Airport, all else equal.

Using the estimates from Table 5 and fixing control variables at their means, Figure 10 illustrates the difference in predicted mean BLL across near angle groups. Other things held equal, children predominantly downwind of Reid-Hillview Airport (East) present with BLLs that are 25.5% higher than sampled children living North of Reid-Hillview Airport. Estimated mean BLL values for children in the North, South, and West near angle groups are not statistically different from one another. Consistent with these results, analyses involving the calculation of downwind days show that BLLs increase significantly with the count of wind days drifting in the residential direction of a child from the date of blood draw (see Appendix Figure A.3) An increase from the minimum to maximum number of downwind days is associated with an increase in BLLs of about $1/4^{th}$ μg/dL.

4.3.1 Results Summary, Section 4.3

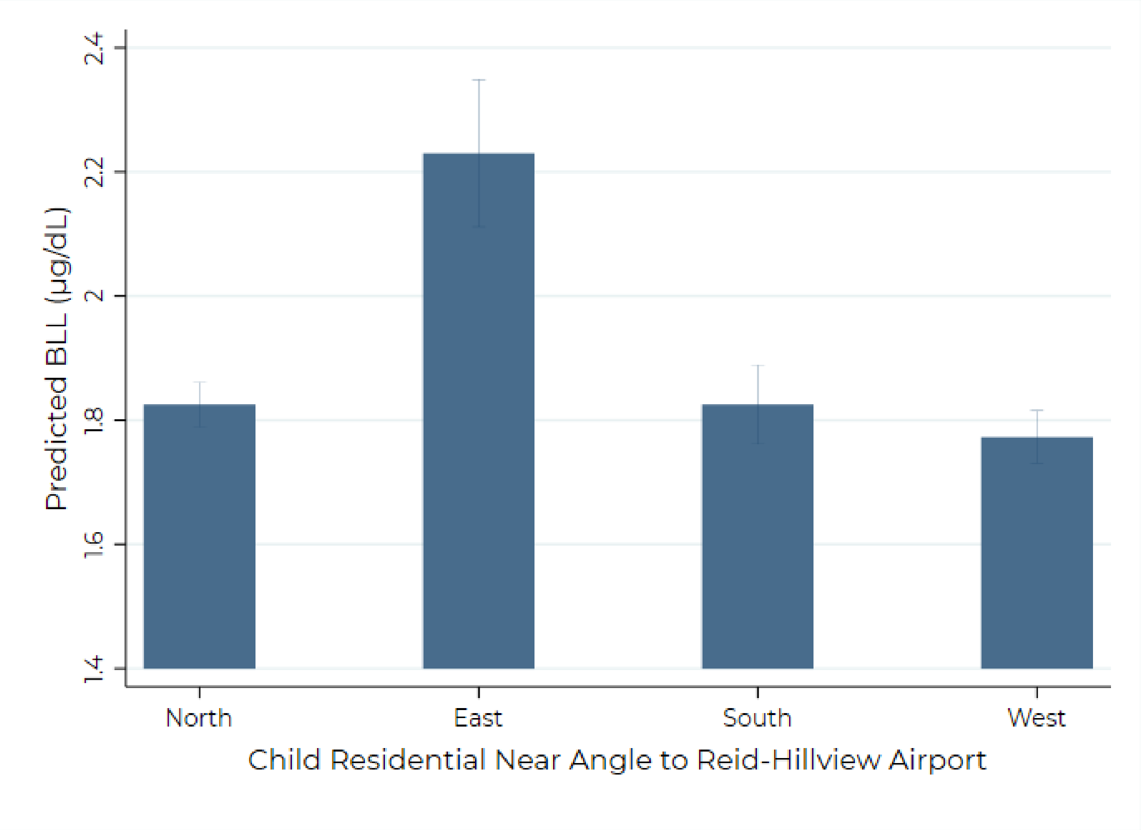
Overall, the findings presented in Table 5 and Figure 10 support the hypothesis that residing predominantly downwind of Reid-Hillview Airport is associated with substantively and statistically significantly higher BLLs. Returning to our comparison with the FWC, the margin of difference (~0.4 μg/dL) in average BLLs of sampled children East (and predominantly downwind) of Reid-Hillview Airport compared to children West (pre-

Table 5: Residential Near Angle to Reid-Hillview Airport and Child BLLs

BLL (μg/dL)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Near Angle (Reference North)							
East	0.130***	0.131**	0.144***	0.139***	0.265***	0.272***	0.405***
	(0.049)	(0.051)	(0.047)	(0.047)	(0.045)	(0.045)	(0.060)
South	-0.022	-0.018	-0.014	-0.013	0.027	0.009	0.000
	(0.036)	(0.038)	(0.036)	(0.035)	(0.036)	(0.035)	(0.037)
West	-0.022	-0.017	-0.017	-0.013	-0.028	-0.047	-0.052*
	(0.029)	(0.028)	(0.030)	(0.030)	(0.028)	(0.031)	(0.031)
Constant	1.821***	1.965***	1.794***	1.715***	2.036***	1.983***	2.131***
	(0.039)	(0.088)	(0.083)	(0.087)	(0.094)	(0.092)	(0.318)
Observations	17,241	17,241	17,162	17,162	17,162	17,162	17,162
Block FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Distance	No	Yes	Yes	Yes	Yes	Yes	Yes
PEA Traffic	No	No	Yes	Yes	Yes	Yes	Yes
Near Angle FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Demography	No	No	No	Yes	Yes	Yes	Yes
Draw Controls	No	No	No	No	Yes	Yes	Yes
Other Exposures	No	No	No	No	No	Yes	Yes
SES	No	No	No	No	No	No	Yes
Timing Controls	No	No	No	No	No	No	Yes

Notes: Bootstrapped standard errors in parentheses *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; All models limited to children $\leq$ 18 years of age at the time of blood draw, residing < 1.5 miles RHV, and observed from January 1st, 2011 to December 31st, 2020; Dependent variable is child BLL (μg/dL); Near angle groups are defined in Section 2.2.2 and assigned using the angle between RHV and child's place of residence; Demography includes child's age (years) and sex (1=female, 0=otherwise); Draw controls includes: draw method (1=capillary, 0=otherwise), limit of quantification (1=BLL $\leq$ limit of quantification, 0=otherwise), and repeated sample (0=singleton observation, $1,...,n$=repeated n times); Other exposures includes: count of TRI facilities $\leq$ 2 miles from residential address, and percent of neighborhood housing stock built $\leq$ 1960; SES is the neighborhood socioeconomic status index; Timing controls include a set of indicators for season and year-quarter of the date of draw;

Figure 10: Residential Near Angle to Reid-Hillview Airport and Predicted Child BLLs



Note: Predictions are from model (7) in Table 5, with all other model variables fixed at their sample means.

dominantly upwind) of Reid-Hillview Airport is approximately equal to the margin of difference between children sampled at the peak of the FWC relative to children sampled before the crisis. These results are also supported by ancillary analyses involving the calculation of downwind days, showing that BLLs increase significantly with the count of downwind days from the date of blood draw (see Appendix Figure A.3).

4.4 PEA Traffic Exposure

Table 6 reports regression coefficients on piston-engine aircraft traffic to Reid-Hillview Airport. Recall, because the half-life for lead in blood is about 30 days (Lidsky and Schneider, 2003), we measure PEA traffic exposure as a rolling average of PEA operations over 60 days from the date of a child's blood draw. This quantity is converted to a percentile ranging from 0 to 1. Reported coefficients therefore have the interpretation of the estimated change in child BLLs (in μg/dL units) associated with an increase in PEA traffic exposure from the observed minimum to the maximum.

As before, we present coefficients from seven different models that increase successively in the saturation of control variables. Across models (1) through (7), we find that an increase in piston-engine aircraft exposure from the min to the max is associated with a 0.163 to 0.387 μg/dL increase in child BLLs, depending on the presence of control variables. For reference, a change in PEA traffic exposure from the min to max is equivalent to a 2.5× increase in the daily volume of PEA traffic. All estimated coefficients are distinguishable from chance occurrence, with $p < 0.01$.

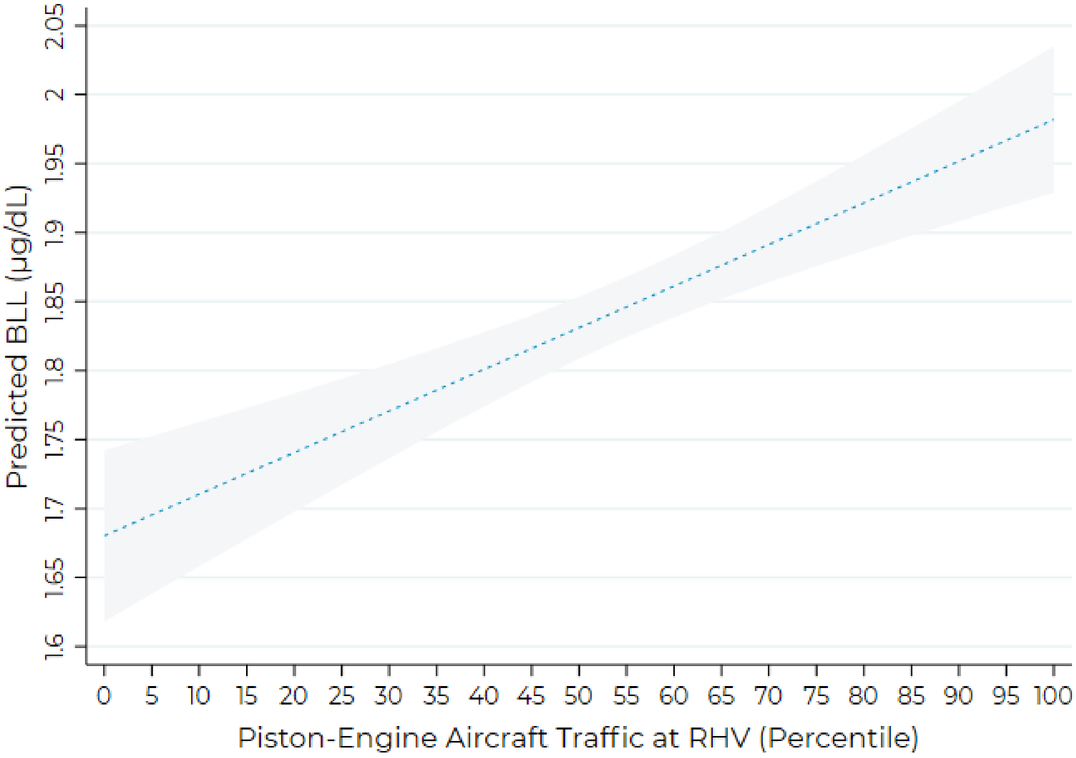
Figure 11 shows predicted BLLs over the observed range of child PEA traffic exposure at Reid-Hillview Airport. Predicted values are from model (6) in Table 6 where, again, all other model variables are fixed at their sample means. Under this prediction scenario, we find that child BLLs increase measurably with the volume of PEA traffic exposure, other factors held equal. In going from the minimum to the maximum of child PEA traffic exposure, we find that child BLLs increase by about 0.3 μg/dL.

Table 6: Piston-Engine Aircraft Traffic to Reid-Hillview Airport and Child BLLs

BLL (μg/dL)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
PEA Traffic	0.370***	0.371***	0.374***	0.387***	0.296***	0.302***	0.163***
	(0.054)	(0.054)	(0.053)	(0.054)	(0.056)	(0.054)	(0.058)
Constant	1.640***	1.798***	1.794***	1.715***	2.036***	1.983***	2.131***
	(0.047)	(0.080)	(0.083)	(0.087)	(0.094)	(0.092)	(0.318)
Observations	17,162	17,162	17,162	17,162	17,162	17,162	17,162
Block FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Distance	No	Yes	Yes	Yes	Yes	Yes	Yes
PEA Traffic	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Near Angle FE	No	No	Yes	Yes	Yes	Yes	Yes
Demography	No	No	No	Yes	Yes	Yes	Yes
Draw Controls	No	No	No	No	Yes	Yes	Yes
Other Exposures	No	No	No	No	No	Yes	Yes
SES	No	No	No	No	No	No	Yes
Timing Controls	No	No	No	No	No	No	Yes

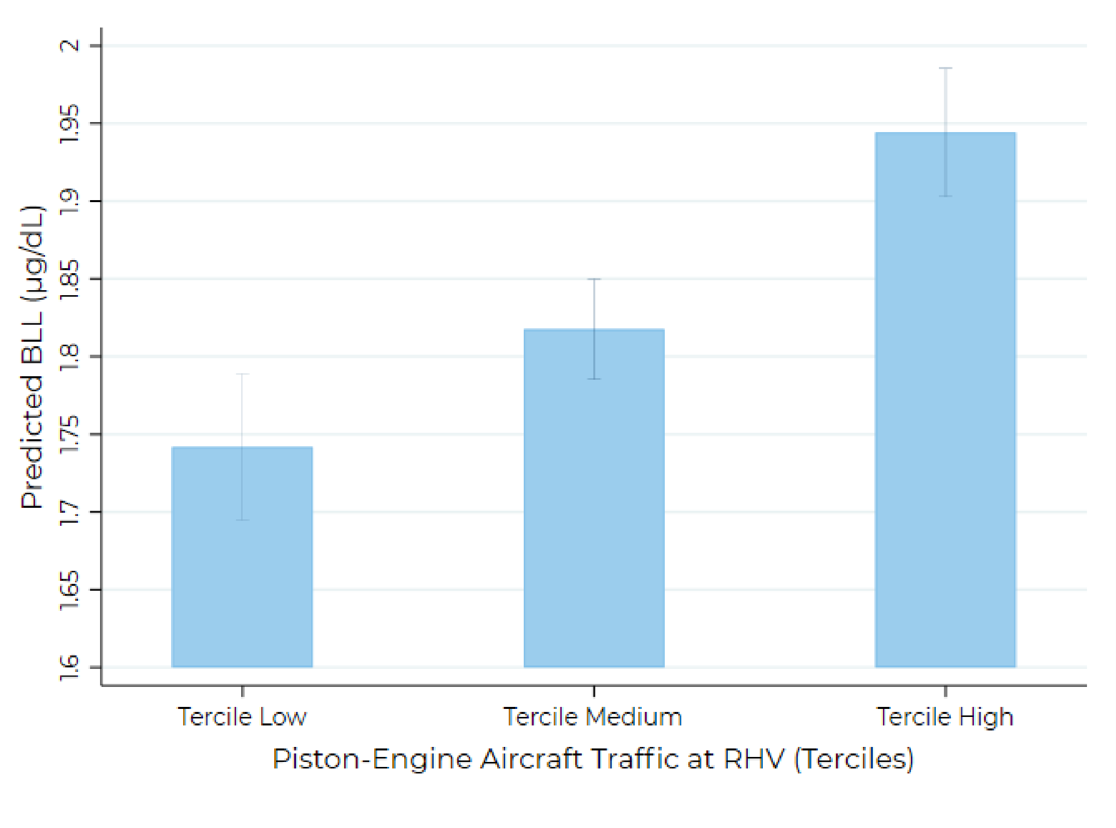
Notes: Bootstrapped standard errors in parentheses *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; All models limited to children $\leq$ 18 years of age at the time of blood draw, residing $<$ 1.5 miles RHV, and observed from January 1st, 2011 to December 31st, 2020; Dependent variable is child BLL (μg/dL); PEA traffic is average daily PEA operations at RHV, calculated over 60 days from child's date of draw and converted to percentiles; Demography includes child's age (years) and sex (1=female, 0=otherwise); Draw controls includes: draw method (1=capillary, 0=otherwise), limit of quantification (1=BLL $\leq$ limit of quantification, 0=otherwise), and repeated sample (0=singleton observation, 1,...,n=repeated n times); Other exposures includes: count of TRI facilities $\leq$ 2 miles from residential address, and percent of neighborhood housing stock built $\leq$ 1960; SES is the neighborhood socioeconomic status index; Timing controls include a set of indicators for season and year-quarter of the date of draw;

Figure 11: Piston-Engine Aircraft Traffic at Reid-Hillview Airport and Child BLLs



Note: Predictions are from model (6) in Table 6, with all other model variables fixed at their sample means.

Figure 12: Piston-Engine Aircraft Traffic Terciles at Reid-Hillview and Child BLLs



Note: Predictions are from model (6) in Table 6, with all other model variables fixed at their sample means.

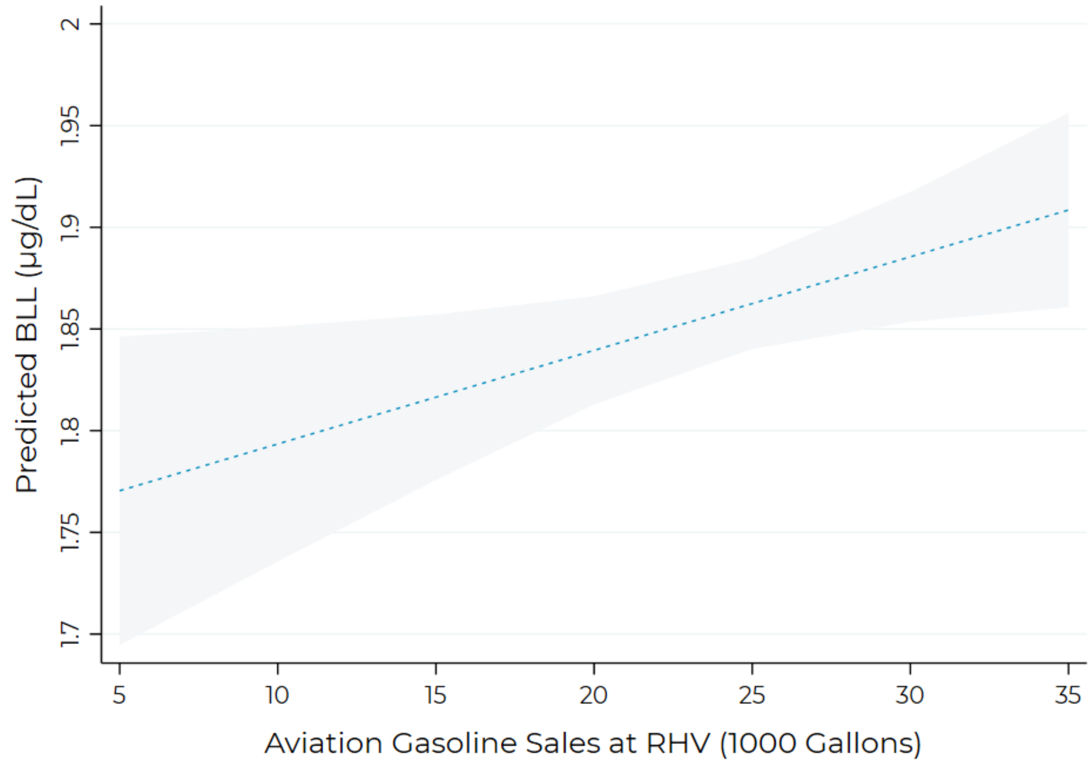
Figure 12 provides evidence of the dose-responsiveness of results reported in Table 6 and Figure 11, showing predicted child BLLs at terciles of low, medium and high PEA traffic exposure. Terciles are derived by dividing the distribution of PEA traffic exposure into three equal-sized groupings in terms of the count of blood samples observed. Other things held equal, we find that child BLLs graduate upward with PEA traffic exposure terciles, increasing from 1.74 to 1.82 to 1.94 μg/dL, respectively.

Substituting PEA traffic exposure for aviation gasoline sales (in 1,000s of gallons) and recapitulating model (7) in Table 6, Figure 13 shows predicted BLLs over the observed range of aviation gasoline sold at Reid-Hillview Airport. Predicted values are derived with all other model variables fixed at their sample means. As with PEA traffic, we find that the BLLs of sampled children increase linearly with the quantity of aviation gasoline sold to fixed-base operators at Reid-Hillview Airport, other factors held equal. A change in the quantity of aviation gasoline sold from the observed minimum to the maximum is associated with an increase in child BLLs by about 0.18 μg/dL.

4.4.1 Results Summary, Section 4.4

On balance, the evidence presented in Table 6, Figure 11 indicates that the BLLs of sampled children increase with exposure to piston-engine aircraft operations at Reid-Hillview Airport, net of all other factors. This result holds with the division of PEA traffic into terciles, suggesting that child BLLs increase dose-responsively with PEA traffic. Moreover, as evidenced in Figure 13, the estimated positive association between child BLLs and PEA traffic is robust to the substitution of PEA traffic for the quantity of aviation gasoline sold at Reid-Hillview Airport, an analogous and independent indicator of lead exposure. The size of the estimated increase in child BLLs in going from the minimum to maximum PEA traffic exposure is on par with the increase in child BLLs caused by failures in the water system during the FWC.

Figure 13: Aviation Gasoline Sales at Reid-Hillview Airport and Child BLLs



Note: Predictions are from model (6) in Table 6, with all other model variables fixed at their sample means.

4.5 Robustness

In Table A.9, Table A.10, Table A.11, Table A.12, and Table A.13 of our appendices, we report results from various robustness tests involving successively restricting observations to highest-confidence geo-coded residences, highly sampled neighborhoods ($\geq$ 100 blood lead samples), introducing a new variable that accounts for possible variation in BLL measurement precision across laboratories, the inclusion of clustering of standard errors by sample order, the restriction of observations to children $\leq$ 6 years of age, and the introduction of a series of single imputation operations for test results at or below the limit of quantification. Across all robustness tests rendered, results pertaining to our main indicators of aviation gasoline exposure risk behave similarly.

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5 Extended Results

While results reported in Section 4 on child residential distance, residential near angle, and exposure to piston-engine aircraft traffic all support the supposition that child BLLs are statistically associated with the risk of exposure to aviation gasoline, in this section we report results from various exercises involving the reconstitution of child BLLs in ordered categorical terms to analyze threshold effects, tests involving the statistical interaction of residential distance and piston-engine aircraft traffic, a natural experiment exploiting an observed contraction in PEA aircraft at Reid-Hillview Airport following social distancing measures enacted countywide, a test of school-aged children that exploits relative distances to Reid-Hillview Airport from a child's place of residence and nearest assigned school, and from a battery of tests involving the inclusion of sampled children proximate to other airports in Santa Clara County.

5.1 Blood Lead Thresholds

We begin with the analysis of threshold effects. We reconstitute our response variable in ordered categorical terms, defining mutually exclusive BLL categories ranging from 0 to the exceedance of the CDPH-defined threshold of 4.5 μg/dL. The purpose here is to investigate threshold effects with respect to our main operations of aviation gasoline exposure risk and to relax the assumption of precisely measured BLLs, given uncertain laboratory test precision.

Under the premise that a given blood lead concentration is an imperfectly observed variable, we execute an ordered logistic regression, modeling BLL as a set of ordinal categories. Moving in increments of 1.5 μg/dL we convert the continuous measure of blood lead concentration Y_{it} to a categorical variable B_{it}, with cutpoints defined as:

$$B_{it} = \begin{cases} 1, & \text{if } Y_{it} \ < \ 1.5, \\ 2, & \text{if } 1.5 \ \leq \ Y_{it} \ < \ 3, \\ 3, & \text{if } 3 \ \leq \ Y_{it} \ < \ 4.5, \\ 4, & \text{if } Y_{it} \ \geq \ 4.5, \end{cases}$$

where Y_{it} is in units of μg/dL.[12] Within this framework, one can estimate the proportional odds a given blood lead concentration is in exceedance of a specified blood lead category. For child i with corresponding BLL observation in time t, B_{it} takes on the ordinal values $k = 1, ..., 4$, then we define the cumulative response probabilities as:

$$b_{itk} = \text{Prob}(B_{it} \leq k | \mathbf{X}_{it}), \qquad k = 1, ..., 4 \tag{3}$$

where $\mathbf{X}_{it}$ is a vector of explanatory values related to child i in time t. Using Equation 3, we can represent a generalized logistic model as:

$$\begin{aligned} \text{logit}\,(b_{itk}) &= \ln\left(\frac{b_{itk}}{1 - b_{itk}}\right) \\ &= \theta_k + \mathbf{X}_{it}^{'}\beta \end{aligned} \tag{4}$$

where $\theta_1 \leq \theta_2 ... \leq \theta_k$. Taking the generalized model in Equation 4 and the suite of covariates defined in Equation 2, the fully specified model used to estimate the log-odds of sampled child i in neighborhood block j at time t being in BLL category B_{it} becomes:

$$\begin{aligned} \text{logit}\,(b_{ijtk}) = \ & \theta_k + \ \beta_1 D_{it}^{n} + \ \beta_2 D_{it}^{f} + \ \beta_3 T_{it} + \ \beta_4 W_{it}^{e} + \ \beta_5 W_{it}^{s} + \ \beta_6 W_{it}^{w} \\ & + \ \Gamma_1 G_i + \ \Gamma_2 A_{it} + \ \Gamma_3 C_{it} + \ \Gamma_4 S_i + \ \Gamma_5 Z_{it} + \ \Gamma_6 L_{it} \\ & + \ \lambda_1 F_{it} + \ \lambda_2 H_{jt} + \ \lambda_3 I_{jt} + \ \lambda_4 Q_{it} + \ \gamma_j, \qquad k = 1, ..., 4 \end{aligned} \tag{5}$$

---

[12] For sampled children within 1.5 miles of Reid-Hillview, we observe 7,341 records at $<$ 1.5 μg/dL, 7,980 records at 1.5 to <3 μg/dL, 1,633 records at 3 to $<$ 4.5 μg/dL, and 287 records at $\geq$ 4.5 μg/d.

Our expectation is that the exponentiated log-odds corresponding to D_{it}^{n} and D_{it}^{f} will be < 1.0 reflecting lower risk of exceeding the threshold of 4.5 μg/dL among children in outer orbits of Reid-Hillview Airport relative to children nearest to Reid-Hillview Airport. We also expect that exponentiated log-odds corresponding W_{it}^{e} to be > 1.0, reflecting higher odds of maximum categorical blood lead for sampled children East of Reid-Hillview Airport relative to children North of Reid-Hillview Airport. Similarly, we expect the exponentiated coefficient on T_{it} to be > 1.0, indicating that the risk of exceeding the CDPH-defined threshold of 4.5 μg/dL increases with exposure to piston-engine aircraft traffic.

Table 7 reports odds ratios and 95% intervals of confidence in square brackets for our main indicators of aviation gasoline exposure risk. Given the ordered categorical measurement of our response variable, reported odds ratios have the interpretation of the expected change in the odds of a child's blood lead sample exceeding 4.5 μg/dL relative to the combined odds of appearing in lower BLL categories. Focusing on saturated model (3), as compared to children $<$ 0.5 miles of Reid-Hillview Airport, sampled children residing 0.5 to 1 mile from Reid-Hillview Airport have 0.858× lower odds of superseding 4.5 μg/dL relative to the combined odds of lower BLL categories. For children at 1 to 1.5 miles, the probability of a blood lead sample exceeding 4.5 μg/dL is 22.1% lower than statistically similar children at $<$ 0.5 miles. With respect to residential near angle, children residing East of Reid-Hillview Airport are 2.37× (95% Confidence Intervals: 1.98, 2.85) more likely to present with BLLs ≥4.5 μg/dL than children residing North of Reid-Hillview Airport, all else held equal. On the question of PEA traffic exposure, we find that an increase from minimum to maximum exposure increases the odds of eclipsing 4.5 μg/dL relative to the combined odds of presenting with a lower BLL category by a multiplicative factor of 1.30 (95% CI: 1.12, 1.50).

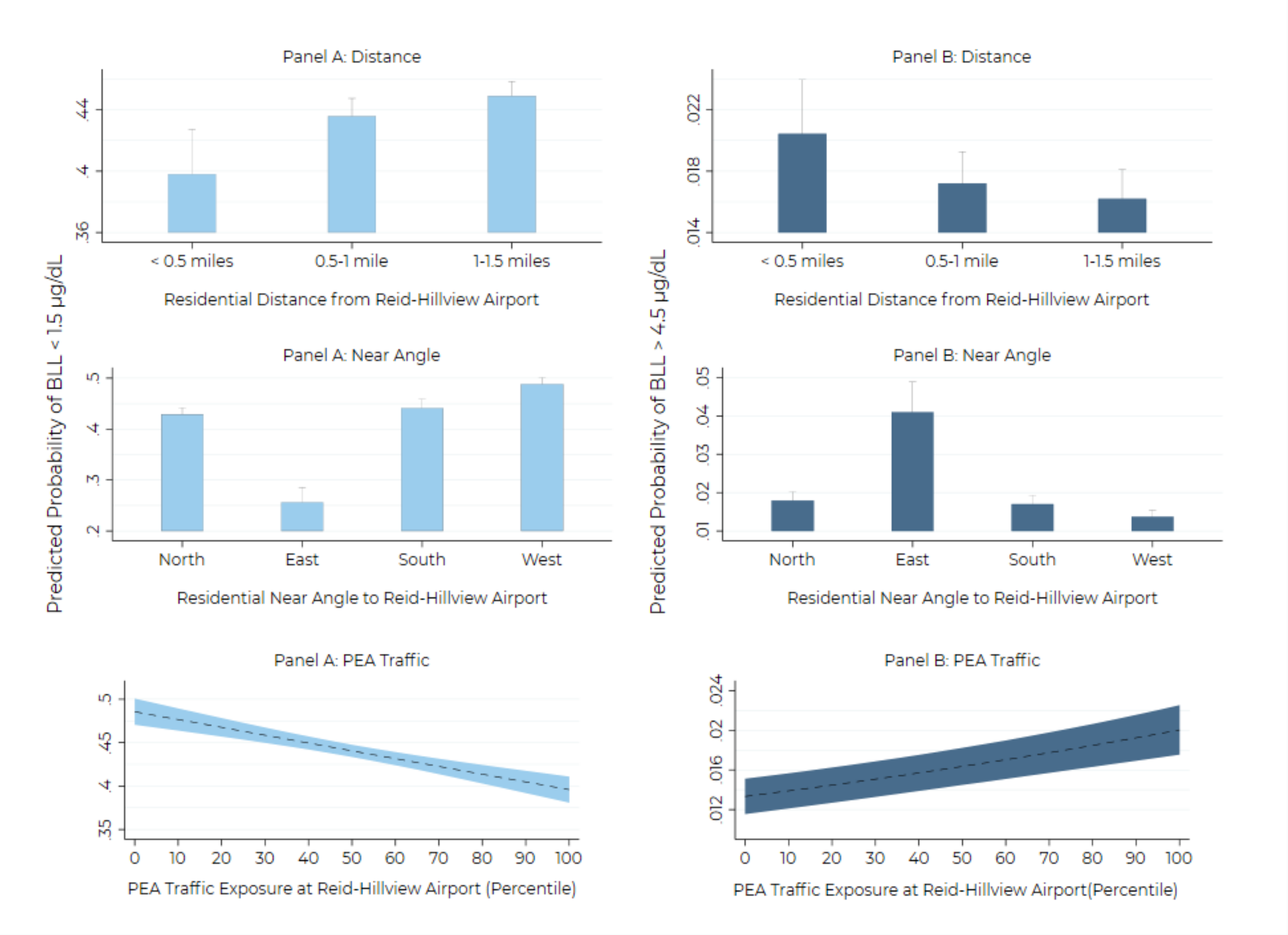
Figure 14 shows predicted probabilities of a sampled child appearing in the minimum (<1.5 μg/dL) and maximum (≥4.5 μg/dL) specified categories of blood lead. Predicted probabilities are from model (3) in Table 7 where all other model variables are set to their

Table 7: Distance, Near Angle, PEA Traffic and Child BLL Categories, Proportional Odds

BLL Category	(1)	(2)	(3)
Distance RHV (Reference < 0.5 miles)			
0.5 to 1 miles	0.858**	0.823**	0.830**
	[0.740, 0.996]	[0.707, 0.957]	[0.713, 0.966]
1 to 1.5 miles	0.830**	0.793***	0.779***
	[0.716, 0.963]	[0.681, 0.924]	[0.668, 0.909]
Near Angle RHV (Reference North)			
East	1.768***	1.888***	2.374***
	[1.533, 2.048]	[1.626, 2.193]	[1.979, 2.848]
PEA Traffic	2.020***	2.030***	1.298***
	[1.811, 2.252]	[1.817, 2.267]	[1.122, 1.502]
Observations	17,162	17,162	17,162
Block FE	Yes	Yes	Yes
Distance	Yes	Yes	Yes
PEA Traffic	Yes	Yes	Yes
Near Angle FE	Yes	Yes	Yes
Demography	Yes	Yes	Yes
Draw Controls	Yes	Yes	Yes
Other Exposures	No	Yes	Yes
SES	No	No	Yes
Timing Controls	No	No	Yes

Notes: Estimates are presented as odds ratios; 95% Confidence intervals in square parentheses, bootstrapped standard errors *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; All models limited to children ≤ 18 years of age at the time of blood draw, residing < 1.5 miles RHV, and observed from January 1st, 2011 to December 31st, 2020; Dependent variable is child BLL categories defined in Section 5.1; Demography includes child's age (years) and sex (1=female, 0=otherwise); Draw controls includes: draw method (1=capillary, 0=otherwise), limit of quantification (1=BLL ≤ limit of quantification, 0=otherwise), and repeated sample (0=singleton observation, 1,...,n=repeated n times); Other exposures includes: count of TRI facilities ≤ 2 miles from residential address, and percent of neighborhood housing stock built ≤ 1960; SES is the neighborhood socioeconomic status index; Timing controls include a set of indicators for season and year-quarter of the date of draw;

Figure 14: Predicted Probabilities of Child BLLs by Distance, Near Angle, and PEA Traffic



Note: Across all panels, predictions are from model (3) in Table 7, with all other model variables fixed at their sample means.

means. Results displayed in Panels A (light blue) for each test variable of interest – distance, near angle, and PEA traffic exposure – correspond to predicted probabilities that a sampled child presents with a BLL <1.5 μg/dL. Results in Panels B (dark blue) pertain to predicted probabilities of a sampled child exceeding the CDPH-defined threshold of action of ≥ 4.5 μg/dL. Graphics in Panels A versus B by indicator of aviation gasoline exposure risk are mirror-like opposites of each other.

Focusing on Panels B, we find that the probability of a sampled child presenting with a BLL in excess of the CDPH-defined threshold decreases measurably with distance from Reid-Hillview Airport, all else held equal. Specifically, we estimate that the probability of exceedance for sampled children in the nearest orbit is 20% and 27% higher than children in outer orbits of 0.5 to 1 mile and 1 to 1.5 miles, respectively. With respect to near angle, the probability of a blood lead sample taken from a child East (and predominantly downwind) of Reid-Hillview Airport is about 200% higher than samples from children West (and predominantly upwind) of Reid-Hillview Airport. With respect to PEA traffic exposure, children exposed to maximum traffic have an estimated probability of exceeding 4.5 μg/dL that is about 29% higher than children sampled in moments of minimum PEA traffic exposure.

5.1.1 Results Summary, Section 5.1

Overall, results on threshold effects reported in Table 7 and Figure 14 are consistent with linear model results reported in Section 4. All indicators of aviation gasoline exposure risk – residential proximity to Reid-Hillview Airport, residing East and predominately downwind of Reid-Hillview Airport, and exposure to high PEA traffic – meaningfully increase the odds that a sampled child presents with a BLL ≥ 4.5 μg/dL relative to combined odds of presenting with a lower category of blood lead.

5.2 PEA Traffic Exposure × Residential Distance

Next, we consider a statistical interaction between piston-engine aircraft traffic exposure and residential distance. Insofar as aviation gasoline exposure is a source of risk, we expect that the BLLs of sampled children proximate to Reid-Hillview Airport will be more responsive to the flow of PEA traffic than children more distant from the airport. Toward this analytic aim, we estimate the following:

$$\begin{aligned} Y_{ijt} = \beta_0 + \beta_1 D_{it}^{nf} + \beta_2 CT_{it} + \beta_3 W_{it}^{e} + \beta_4 W_{it}^{s} + \beta_5 W_{it}^{w} + \delta \left(D_{it}^{nf} \times CT_{it} \right) \\ + \Gamma_1 G_i + \Gamma_2 A_{it} + \Gamma_3 C_{it} + \Gamma_4 S_i + \Gamma_5 Z_{it} + \Gamma_6 L_{it} \\ + \lambda_1 F_{it} + \lambda_2 H_{jt} + \lambda_3 I_{jt} + \lambda_4 Q_{it} + \gamma_j + \varepsilon_{ijt} \end{aligned} \quad (6)$$

where, the meaning of all terms carry from Equation 2 with the exception of D_{it}^{nf} that now assumes a value of 1 if a sampled child resides in the outer orbit of 0.5-1.5 miles of Reid-Hillview Airport and 0 if a sampled child resides within 0.5 miles of Reid-Hillview Airport. Outer orbits are collapsed given insignificance of difference observed in Table 3. We expect β_1 corresponding D_{it}^{nf} to be negative, reflecting lower BLLs among distant children (0.5-1.5 miles) relative to proximate children ($<$ 0.5 miles). CT_{it} is the statistically centered value of PEA traffic exposure that is equal to $T_{it} - \bar{T_{it}}$ or the observed PEA traffic exposure (T_{it}) minus the mean of PEA traffic exposure($\bar{T_{it}}$). We expect the corresponding parameter β_2 to be positive, indicating that BLLs increase with the PEA traffic exposure. Finally, we expect δ corresponding to $D_{it}^{nf} \times CT_{it}$ to be negative, indicating that the BLLs of sampled children proximate to Reid-Hillview Airport ($<$ 0.5 miles) are more responsive to PEA traffic than children distant from Reid-Hillview Airport (0.5-1.5 miles).

As before, Table 8 presents coefficients for many different models that increase successively in the saturation of control variables. Across models (1) through (6), estimated coefficients behave as theoretically expected and are distinguishable from chance. Concentrating interpretation on model (6), the main effect of residential distance indicates that sampled children at 0.5 to 1.5 miles from Reid-Hillview Airport present with BLLs

Table 8: PEA Traffic × Residential Distance at Reid-Hillview Airport and Child BLLs

BLL (μg/dL)	(1)	(2)	(3)	(4)	(5)	(6)
Distance (Reference < 0.5 miles)						
0.5 to 1.5 miles	-0.164**	-0.158**	-0.161**	-0.183**	-0.190***	-0.196***
	(0.077)	(0.076)	(0.076)	(0.072)	(0.072)	(0.072)
PEA Traffic	1.002***	1.005***	1.009***	0.964***	0.970***	0.833***
	(0.195)	(0.196)	(0.195)	(0.192)	(0.193)	(0.190)
0.5 to 1.5 miles × PEA Traffic	-0.670***	-0.670***	-0.661***	-0.709***	-0.711***	-0.712***
	(0.205)	(0.206)	(0.206)	(0.201)	(0.202)	(0.202)
Constant	1.986***	1.980***	1.902***	2.197***	2.147***	2.238***
	(0.075)	(0.081)	(0.087)	(0.094)	(0.096)	(0.302)
Observations	17,162	17,162	17,162	17,162	17,162	17,162
Block FE	Yes	Yes	Yes	Yes	Yes	Yes
Distance	Yes	Yes	Yes	Yes	Yes	Yes
PEA Traffic	Yes	Yes	Yes	Yes	Yes	Yes
Near Angle FE	No	Yes	Yes	Yes	Yes	Yes
Demography	No	No	Yes	Yes	Yes	Yes
Draw Controls	No	No	No	Yes	Yes	Yes
Other Exposures	No	No	No	No	Yes	Yes
SES	No	No	No	No	No	Yes
Timing Controls	No	No	No	No	No	Yes

Notes: Bootstrapped standard errors in parentheses *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; All models limited to children ≤ 18 years of age at the time of blood draw, residing < 1.5 miles RHV, and observed from January 1st, 2011 to December 31st, 2020; Dependent variable is child BLL (μg/dL); Distance groups are assigned using the distance (miles) between RHV and the child's place of residence; PEA traffic is average daily PEA operations at nearest airport, calculated over 60 days from child's date of draw and converted to percentiles then centered (mean=0) for ease of interpretation; Demography includes child's age (years) and sex (1=female, 0=otherwise); Draw controls includes: draw method (1=capillary, 0=otherwise), limit of quantification (1=BLL ≤ limit of quantification, 0=otherwise), and repeated sample (0=singleton observation, 1,...,n=repeated n times); Other exposures includes: count of TRI facilities ≤ 2 miles from residential address, and percent of neighborhood housing stock built ≤ 1960; SES is the neighborhood socioeconomic status index; Timing controls include a set of indicators for season and year-quarter of the date of draw;

that are about $1/5^{th}$ of a μg/dL lower than children nearest to the airport. Because PEA traffic is centered at the mean, the coefficient on PEA traffic exposure indicates that a doubling of PEA traffic from the mean is associated with a 0.833 μg/dL increase in child BLLs, all else held equal. The estimated coefficient of interaction is negative ($\widehat{\delta}$ = -0.712), implying that an increase in PEA traffic exposure affects the BLLs of sampled children more distant from Reid-Hillview Airport less than children proximate to Reid-Hillview Airport.

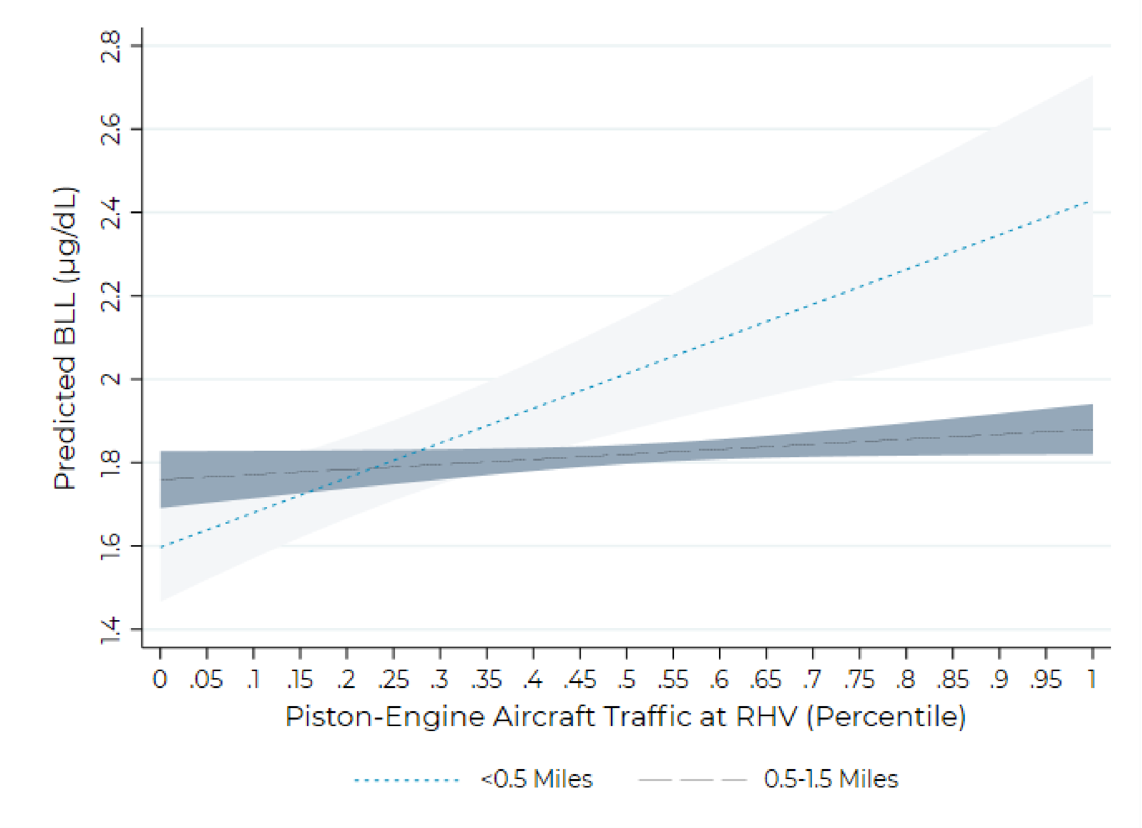
Figure 15 visualizes the effects reported in Table 8, showing predicted BLLs of sampled children at two distances – within 0.5 miles and 0.5-1.5 miles from Reid-Hillview Airport – over the range of observed PEA traffic exposure. Predictions are from model (6) in Table 8, with all other model covariates set to their means. Figure 15 shows that, all else held equal, a movement from the minimum to maximum PEA traffic exposure increases the BLLs of sampled children proximate to Reid-Hillview Airport by 0.83 μg/dL (1.60 to 2.43 μg/dL). By comparison, children more distant from Reid-Hillview Airport (0.5 to 1.5 miles) experience a more modest increase in BLLs of about $1/10^{th}$ of μg/dL (1.76 to 1.88 μg/dL) for an increase in PEA traffic from the minimum to the maximum.

In Figure 16 we visualize results where we substitute our PEA traffic variable for aviation gasoline sales at Reid-Hillview Airport. Recall, the quantity of lead-formulated gasoline sold to fixed-base operators at Reid-Hillview Airport is measured monthly and available from January 2011 till July of 2019. As before, predicted BLLs are from model (6) with other model covariates set at their sample means. Results in Figure 16 are qualitatively similar to results displayed in Figure 15, showing that BLLs of sampled children proximate to Reid-Hillview Airport increase more substantially in response to aviation gasoline sales than children more distant from the airport.

5.2.1 Results Summary, Section 5.2

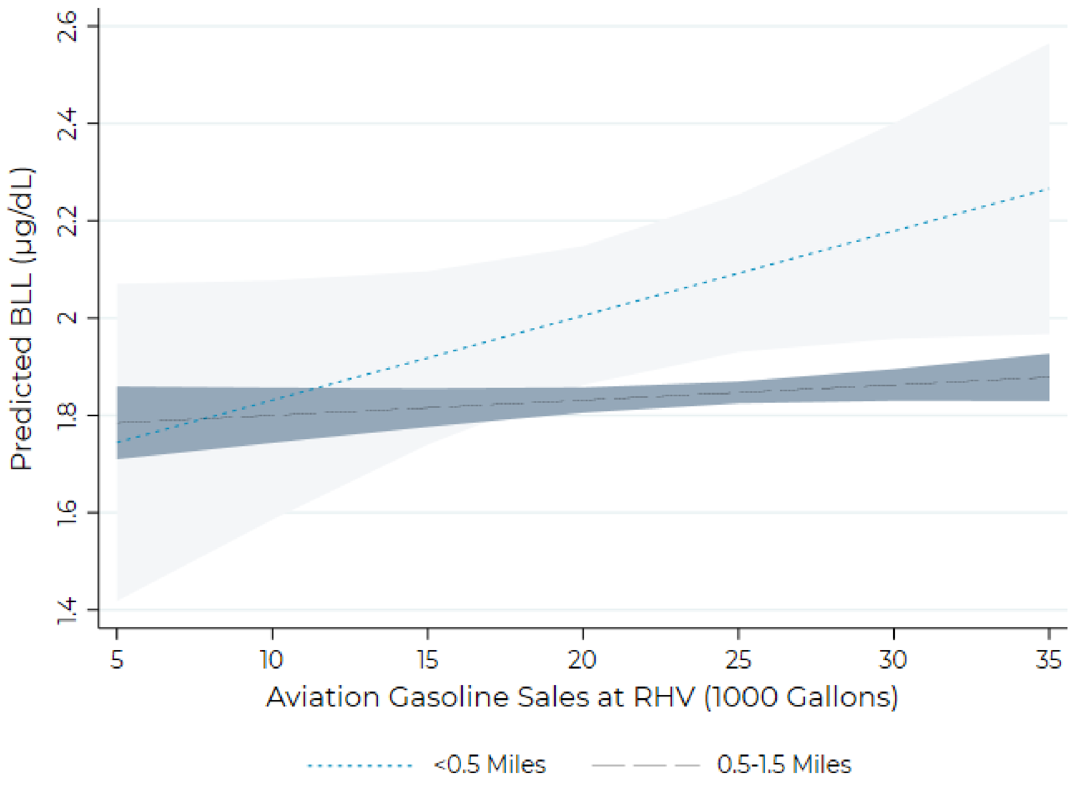
On balance, the evidence suggests that children residing within 0.5 miles of Reid-Hillview Airport are especially vulnerable to increases in PEA traffic. Increasing the distance of

Figure 15: PEA Traffic × Residential Distance and Predicted Child BLLs



Note: Predictions are from model (6) in Table 8, with all other model variables fixed at their sample means.

Figure 16: Aviation Gasoline Sales × Residential Distance and Predicted Child BLLs



Note: Predictions are based on model (6) in Table 8 with aviation gasoline sales replacing PEA traffic. All other model variables fixed at their sample means.

a child from Reid-Hillview Airport (beyond 0.5 miles) appears to insulate that sampled child from the BLL effects of an increase in the volume of PEA traffic. Children more distant from Reid-Hillview Airport (0.5 to 1.5 miles) experience a modest increase in BLLs of about $1/10^{th}$ of μg/dL from an increase in PEA traffic from the minimum to the maximum. By contrast, among children at $<$ 0.5 miles of Reid-Hillview Airport, an increase from the minimum to maximum exposure to PEA traffic is associated with an estimated 0.83 μg/dL increase in BLLs. These results are supported by ancillary analyses involving the statistical interaction between distance and aviation gasoline sales at Reid-Hillview Airport.

5.3 PEA Traffic Contraction

As the COVID-19 pandemic gripped the country, state and local governments enacted various restrictions on the behavior of households and firms to limit the spread of the disease. Corresponding with these efforts, PEA traffic declined measurably at Reid-Hillview Airport over the months of February to July of 2020. As compared to three baseline control periods – 2011-2019, 2015-2019, and 2018-2019 – PEA traffic declined by 34 to 44%. Intriguingly, PEA traffic at Reid-Hillview Airport returned to pre-pandemic levels in August to December of 2020. The pandemic-caused dynamics in piston-engine aircraft operations at Reid-Hillview Airport present us with a natural experiment.

Insofar as aviation gasoline exposure is a source of risk, then we should observe a reduction in the BLLs of children sampled in this PEA traffic contraction period, other things held equal. To test whether child blood levels behaved differently in the contraction moment, we estimate the following linear model:

$$\begin{aligned} Y_{ijt} = \; & \beta_0 + \beta_1 D^n_{it} + \beta_2 D^f_{it} + \beta_3 T_{it} + \beta_4 W^e_{it} + \beta_5 W^s_{it} + \beta_6 W^w_{it} + \beta_7 COV_t \\ & + \Gamma_1 G_i + \Gamma_2 A_{it} + \Gamma_3 C_{it} + \Gamma_4 S_i + \Gamma_5 Z_{it} + \Gamma_6 L_{it} \\ & + \lambda_1 F_{it} + \lambda_2 H_{jt} + \lambda_3 I_{jt} + \lambda_4 Q_{it} + \gamma_j + \varepsilon_{ijt} \end{aligned} \tag{7}$$

where, all terms carry from Equation 2 with the exception COV_t that is an indicator variable equal to 1 if a child is sampled in the PEA traffic contraction moment and 0 otherwise. Other things held equal, we expect the coefficient β_7, corresponding to COV_t, to be negative, indicating that children sampled in the PEA traffic contraction moment present with lower BLLs than children not sampled in this period.

A reasonable concern with this analytic exercise is that the kind of children sampled in the PEA contraction moment may be characteristically different than children sampled outside this moment. Table 9 compares means on model variables by children sampled in versus out of the PEA traffic contraction period. Sampled children are statistically indistinguishable in terms of residential distance to Reid-Hillview Airport (0.93 vs 0.94 miles, $p = 0.442$), fraction living East of Reid-Hillview Airport (0.07 vs 0.07, $p = 0.294$), child age (2.81 vs 2.91, $p = 0.180$), the proportion children that are female (0.49 vs 0.51, $p = 0.199$), and sample order (0.82 vs 0.87, $p = 0.136$). We do observe significant differences on the proportion of samples drawn by capillary method (0.27 vs 0.17, $p < 0.001$), the percentage of housing stock in a child's residential neighborhood at-risk of presenting with lead-based paint (27.79 vs 24.41, $p < 0.001$), and neighborhood socioeconomic status (-0.27 vs 0.33, $p < 0.001$). Importantly, across every variable for which we observe differences, all function to increase the BLLs of children sampled outside the contraction period relative to children sampled in the PEA traffic contraction period, likely rendering our test results conservative.

Table 10 presents estimated coefficients pertaining to the PEA traffic contraction period. As expected from an aviation gasoline exposure risk standpoint, and other things held equal, the BLLs of sampled children in the PEA traffic contraction moment are significantly lower vis-à-vis children sampled outside this moment. Across models (1-6), we find that BLLs decreased by 0.22 to 0.35 μg/dL, depending on the presence of control variables. The period indicator coefficient attenuates intuitively with the inclusion of measured PEA traffic exposure in model (7). Figure 17 illustrates results from model (6) in Table 10, showing predicted BLLs for children sampled inside versus outside the PEA

Table 9: Comparison of Means on Variables by Contraction Period, (t-Test)

	Non-Contraction Period	Contraction Period	p value
PEA Traffic Exposure	0.52	0.15	<0.001
Distance to RHV	0.93	0.94	0.442
Residence East of RHV	0.07	0.07	0.294
Age (years)	2.81	2.91	0.180
Female	0.49	0.51	0.199
Capillary Blood Draw	0.27	0.17	<0.001
Sample Order	0.82	0.87	0.136
Tri Facilities < 2 miles	2.50	2.55	0.059
Neighborhood % Stock < 1960	27.79	24.41	<0.001
Neighborhood SES	-0.27	0.33	<0.001

Note: p values correspond to one-tailed t-tests with equal variances assumed across variables.

traffic contraction period. Fixing other covariates at their means, we find that child BLLs decreased by around 1/4^{th} μg/dL in the contraction period.

5.3.1 Results Summary, Section 5.3

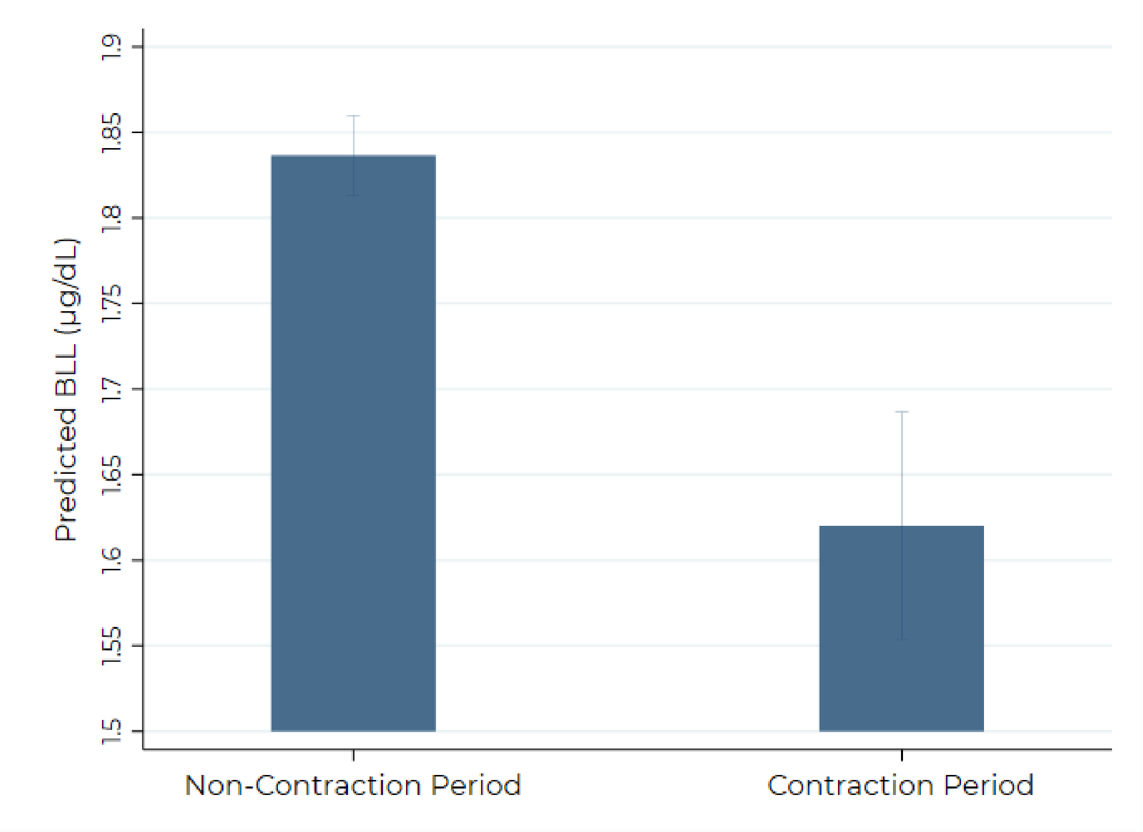
PEA traffic at Reid-Hillview Airport declined measurably from February to July in 2020, recovering to historically normal levels in August through December. Children sampled in this PEA traffic contraction period presented with significantly lower BLLs – about 1/4^{th} of a μg/dL lower – than children not sampled in this contraction window. Given the reduction in PEA traffic of ~34 to 44%, the size of the estimated reduction in BLLs of 1/4^{th} of a μg/dL is approximately equal in magnitude to what we observe in main results pertaining to PEA traffic. The estimated statistical association may be understated given characteristic differences in children sampled across periods.

Table 10: PEA Traffic Contraction Period at Reid-Hillview and Child BLLs

BLL (μg/dL)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Contraction Period	-0.348***	-0.348***	-0.349***	-0.352***	-0.217***	-0.216***	-0.066
	(0.040)	(0.040)	(0.040)	(0.040)	(0.034)	(0.034)	(0.051)
Constant	1.840***	1.987***	1.983***	1.905***	2.192***	2.167***	2.084***
	(0.013)	(0.075)	(0.081)	(0.087)	(0.094)	(0.094)	(0.323)
Observations	17,241	17,241	17,241	17,241	17,241	17,241	17,162
Block FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Distance	No	Yes	Yes	Yes	Yes	Yes	Yes
PEA Traffic	No	No	No	No	No	No	Yes
Near Angle FE	No	No	Yes	Yes	Yes	Yes	Yes
Demography	No	No	No	Yes	Yes	Yes	Yes
Draw Controls	No	No	No	No	Yes	Yes	Yes
Other Exposures	No	No	No	No	No	Yes	Yes
SES	No	No	No	No	No	No	Yes
Timing Controls	No	No	No	No	No	No	Yes

Notes: Bootstrapped standard errors in parentheses *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; All models limited to children ≤ 18 years of age at the time of blood draw, residing < 1.5 miles of RHV, and observed from January 1st, 2011 to December 31st, 2020; Dependent variable is child BLL (μg/dL); Contraction period is an indicator equaling 1 if draw date occurs February, 2020 thru July, 2020, zero otherwise; Demography includes child's age (years) and sex (1=female, 0=otherwise); Draw controls includes: draw method (1=capillary, 0=otherwise), limit of quantification (1=BLL $\leq$ limit of quantification, 0=otherwise), and repeated sample (0=singleton observation, 1,...,n=repeated n times); Other exposures includes: count of TRI facilities $\leq$ 2 miles from residential address, and percent of neighborhood housing stock built $\leq$ 1960; SES is the neighborhood socioeconomic status index; Timing controls include a set of indicators for season and year-quarter of the date of draw;

Figure 17: PEA Traffic Contraction Period at RHV and Predicted Child BLLs



Note: Predictions are from model (6) in Table 10, with all other model variables fixed at their sample means.

5.4 Relative School Distance

When schools are in session, school-aged children spend a considerable amount of their day away from home. In our context, the school a child attends may be more or less distant from Reid-Hillview Airport than their place of residence. Insofar as aviation gasoline exposure is a source of risk, school-aged children that commute away from Reid-Hillview Airport to attend school might present with lower BLLs, other things held constant.

With a complete inventory of elementary, middle and high schools in Santa Clara County from the National Center for Education Statistics, we assigned each school-aged child ($\geq$ 4 years of age) at the time of blood draw to the nearest grade-serving school. This matching process assumes that a child attends the nearest available school, and that all children are in typical age-based grades. To test whether the blood lead levels of sampled children behave differently by the relative distance of their residence and assigned school to Reid-Hillview Airport, we estimate the following linear model:

$$\begin{aligned} Y_{ijt} = \ & \beta_0 + \beta_1 D^n_{it} + \beta_2 D^f_{it} + \beta_3 T_{it} + \beta_4 W^e_{it} + \beta_5 W^s_{it} + \beta_6 W^w_{it} + \beta_7 SC_{it} \\ & + \Gamma_1 G_i + \Gamma_2 A_{it} + \Gamma_3 C_{it} + \Gamma_4 S_i + \Gamma_5 Z_{it} + \Gamma_6 L_{it} \\ & + \lambda_1 F_{it} + \lambda_2 H_{jt} + \lambda_3 I_{jt} + \lambda_4 Q_{it} + \gamma_j + \varepsilon_{ijt} \end{aligned} \tag{8}$$

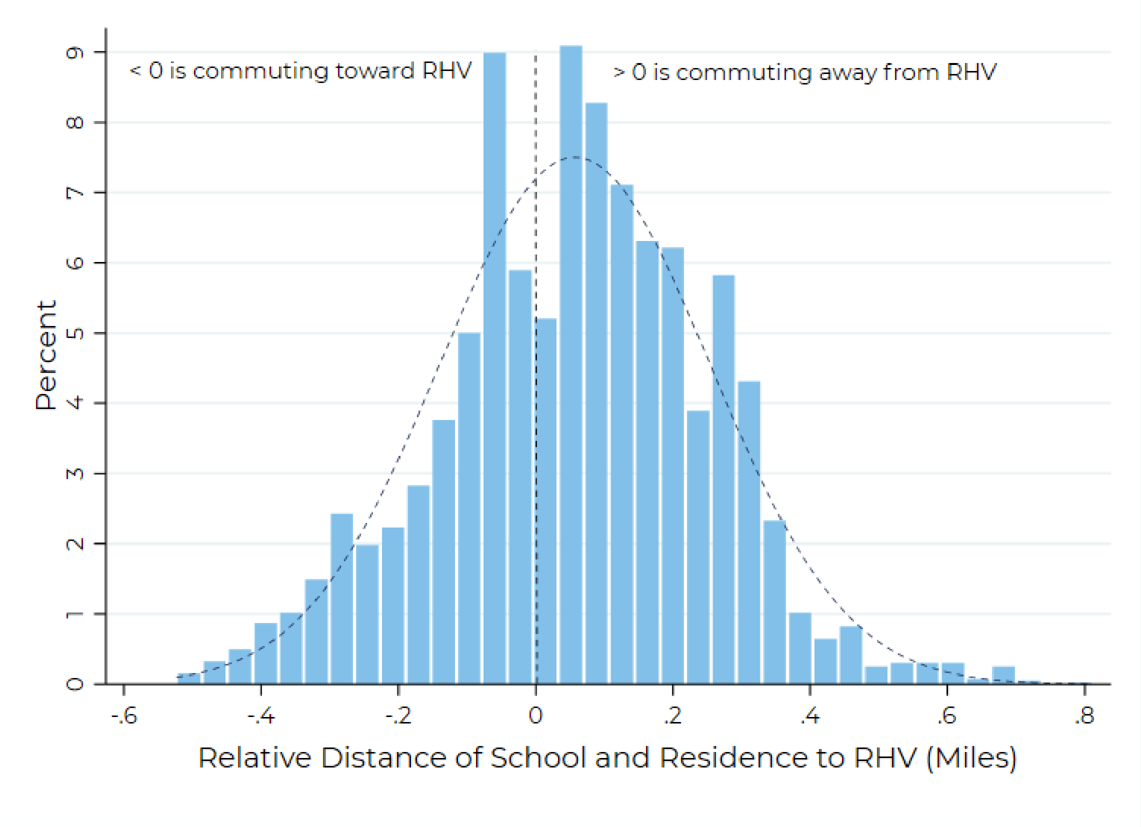
where, all terms carry from Equation 2 with the exception SC_{it}, our school commute variable, measuring the relative distance between a child's assigned school and residence in time t to Reid-Hillview Airport. Relative distance is calculated by subtracting the residential distance of a sampled child to Reid-Hillview Airport from the distance of the assigned school to Reid-Hillview Airport. Negative values indicate that a child commutes toward Reid-Hillview Airport during the school day, and positive values mean that a child commutes away from Reid-Hillview Airport during the school day. Other things held equal, we expect the coefficient of β_7 corresponding to SC_{it} to be negative, indicating that the BLLs of children decrease as one increases the distance that they commute away from Reid-Hillview Airport during the school day.

We extend this test by reconstituting our school commute variable into a series of tercile indicators, dividing the distribution into three even piles. Denoting medium (m) and high (h) terciles of school commuting and letting the first tercile be the reference group, we modify Equation 8 by replacing the continuous variable SC_{it} with dummy variables SC_{it}^m and SC_{it}^h for medium and high commuting terciles, respectively. We expect β_{3a} and β_{3b}, corresponding to SC_{it}^m and SC_{it}^h, to be negative, indicating that BLLs are lower among sampled children that commute longer distances away from Reid-Hillview Airport than children that commute toward Reid-Hillview Airport for school, other things held equal.

Figure 18 is a histogram of the school commuting behavior of elementary and middle school-aged children that reside within 1.5 miles of Reid-Hillview Airport. On the x-axis we plot relative distance, which recall is the distance of the assigned school to Reid-Hillview Airport minus the distance of residence to Reid-Hillview Airport. The distribution is approximately normal with faint kurtosis (K = 3.13) and the absence of skew (S = -0.05). Of all observable characteristics, only child age and residential distance are correlated with relative distance, with older children (particularly children of high school age) traveling longer distances away from Reid-Hillview Airport, and with children residing 1 to 1.5 miles being more likely to travel toward Reid-Hillview Airport for school. With these exceptions, moving toward or away from Reid-Hillview Airport appears to be statistically independent of observable child characteristics.

Table 11 reports coefficients for relative distance measured continuously (in miles) – models (1) to (3) – and categorically (in terciles) in models (4) to (6). Models (1) and (4) report results for all school-aged children. Beginning with model (1), we find that a 1-mile increase in relative distance is associated with a reduction in child BLLs of 0.32 μg/dL. Sampled children that commute away from Reid-Hillview Airport to attend school witness a reduction in their BLLs, and vice-versa. The results in model (4) show that as compared to children that commute toward RHV for school – our reference group of Low Tercile – children in the Medium Tercile (that commute shorter distances away from RHV) and the High Tercile (that commute longer distances away from Reid-Hillview Airport)

Figure 18: Histogram of Relative Distance of School and Residence to RHV



Note: The calculation of relative distance involves taking the distance of the assigned nearest school to Reid-Hillview Airport minus the residential distance of the sampled child to Reid-Hillview Airport. Negative values indicate that a child commutes toward Reid-Hillview Airport and a positive value indicates that a child commutes away from Reid-Hillview Airport during the school day.

Table 11: School and Residential Distance Difference to Reid-Hillview Airport and Child BLLs

BLLs (μg/dL)	(1)	(2)	(3)	(4)	(5)	(6)
Difference (miles)	-0.318***	-0.340***	-0.248			
	(0.069)	(0.080)	(0.152)			
Difference (Reference Low Tercile)						
Medium Tercile				-0.190**	-0.225***	0.055
				(0.081)	(0.085)	(0.182)
High Tercile				-0.330***	-0.359***	-0.131
				(0.075)	(0.084)	(0.139)
Constant	2.550***	2.743***	3.033***	2.812***	3.005***	2.962**
	(0.572)	(0.655)	(1.140)	(0.568)	(0.655)	(1.197)
Observations	4,347	3,352	995	4,315	3,325	990
Block FE	Yes	Yes	Yes	Yes	Yes	Yes
Distance	Yes	Yes	Yes	Yes	Yes	Yes
PEA Traffic	Yes	Yes	Yes	Yes	Yes	Yes
Near Angle FE	Yes	Yes	Yes	Yes	Yes	Yes
Demography	Yes	Yes	Yes	Yes	Yes	Yes
Draw Controls	Yes	Yes	Yes	Yes	Yes	Yes
Other Exposures	Yes	Yes	Yes	Yes	Yes	Yes
SES	Yes	Yes	Yes	Yes	Yes	Yes
Timing Controls	Yes	Yes	Yes	Yes	Yes	Yes
School in Session	Yes	Yes	No	Yes	Yes	No

Notes: Bootstrapped standard errors in parentheses *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; All models limited to children $\leq$ 18 years of age at the time of blood draw, residing < 1.5 miles RHV, and observed from January 1st, 2011 to December 31st, 2020; Dependent variable is child BLL (μg/dL); Difference is distance from child's place of residence to RHV less the distance of assigned school to RHV (miles); Demography includes child's age (years) and sex (1=female, 0=otherwise); Draw controls includes: draw method (1=capillary, 0=otherwise), limit of quantification (1=BLL $\leq$ limit of quantification, 0=otherwise), and repeated sample (0=singleton observation, 1,...,n=repeated n times); Other exposures includes: count of TRI facilities $\leq$ 2 miles from residential address, and percent of neighborhood housing stock built $\leq$ 1960; SES is the neighborhood socioeconomic status index; Timing controls include a set of indicators for season and year-quarter of the date of draw;

present with BLLs that are -0.19 and -0.33 μg/dL lower, respectively.

Models (2) and (5) restrict analysis to children sampled in periods when school *is* in session. Models (3) and (6) censor observations to children sampled in periods when school *is not* in session.[13] As expected, and as compared to models (1) and (3) where all school-aged children are observed, coefficients in models (2) and (5) amplify with the *exclusion* of children sampled in periods when school is not session. In models (3) and (6), we observe an attenuation of relative distance coefficients when restricting to children sampled in periods when school is not in session. Subgroup analyses behave logically, with the relative distance mechanism operating statistically significantly in periods when school is in session.

Figure 19 and Figure 20 visualize results from models (1) and (4) in Table 11. On the x-axis in Figure 19 we plot the relative distance of a child's assigned school and residence to Reid-Hillview Airport, and on the y-axis we have predicted BLL. As before, all other model covariates in Equation 8 are fixed at their sample means. Other things held equal, sampled children that *commute toward* Reid-Hillview Airport for school by 1 mile have predicted BLLs of 2.37 μg/dL (95% CI: 2.15, 2.59). By contrast, sampled children that *commute away* Reid-Hillview Airport for school by 1 mile have predicted BLLs of 1.72 μg/dL (95% CI: 1.53, 1.92). Figure 20 divides our distribution of relative distance into terciles. In support of the linear dose-response displayed in Figure 19, we find that the predicted BLLs of sampled child decrease incrementally across relative distance terciles, going from 2.20 to 2.03 to 1.85 μg/dL, respectively.

5.4.1 Results Summary, Section 5.4

By matching school-aged children to the nearest grade-serving school, we tested whether the blood lead levels of sampled children decline measurably with the distance that they

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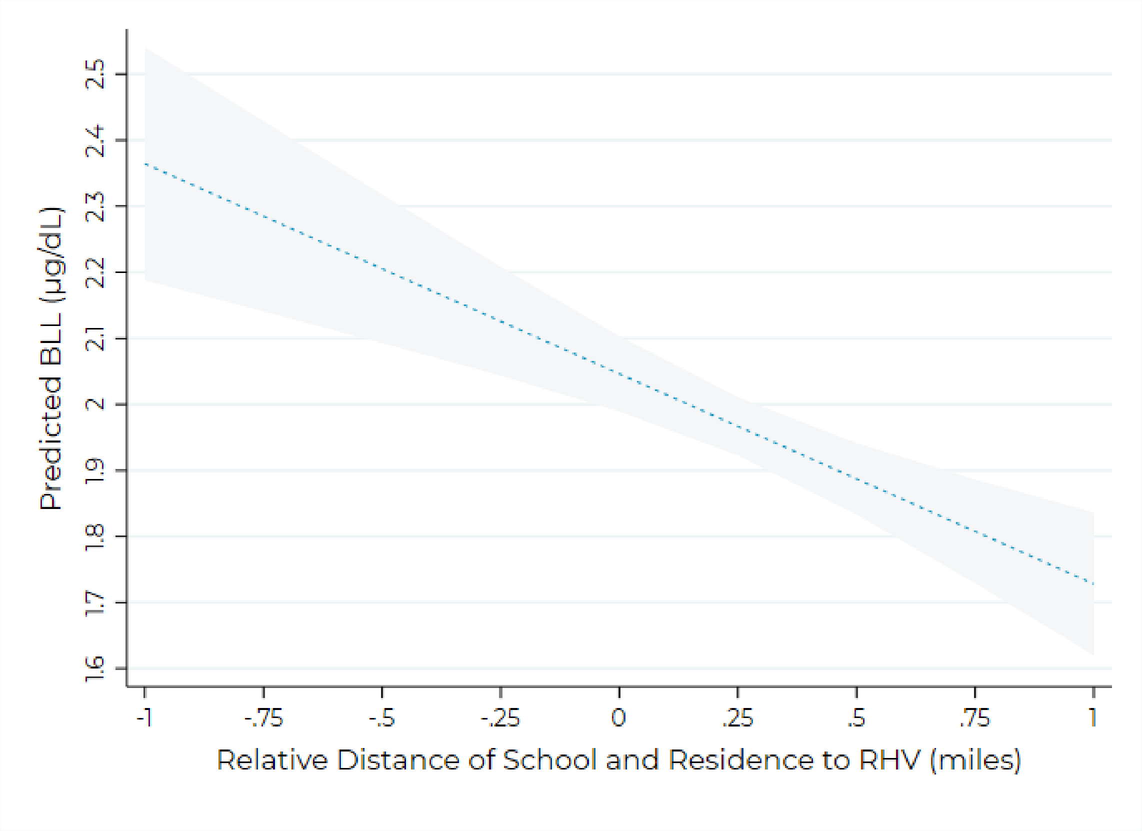
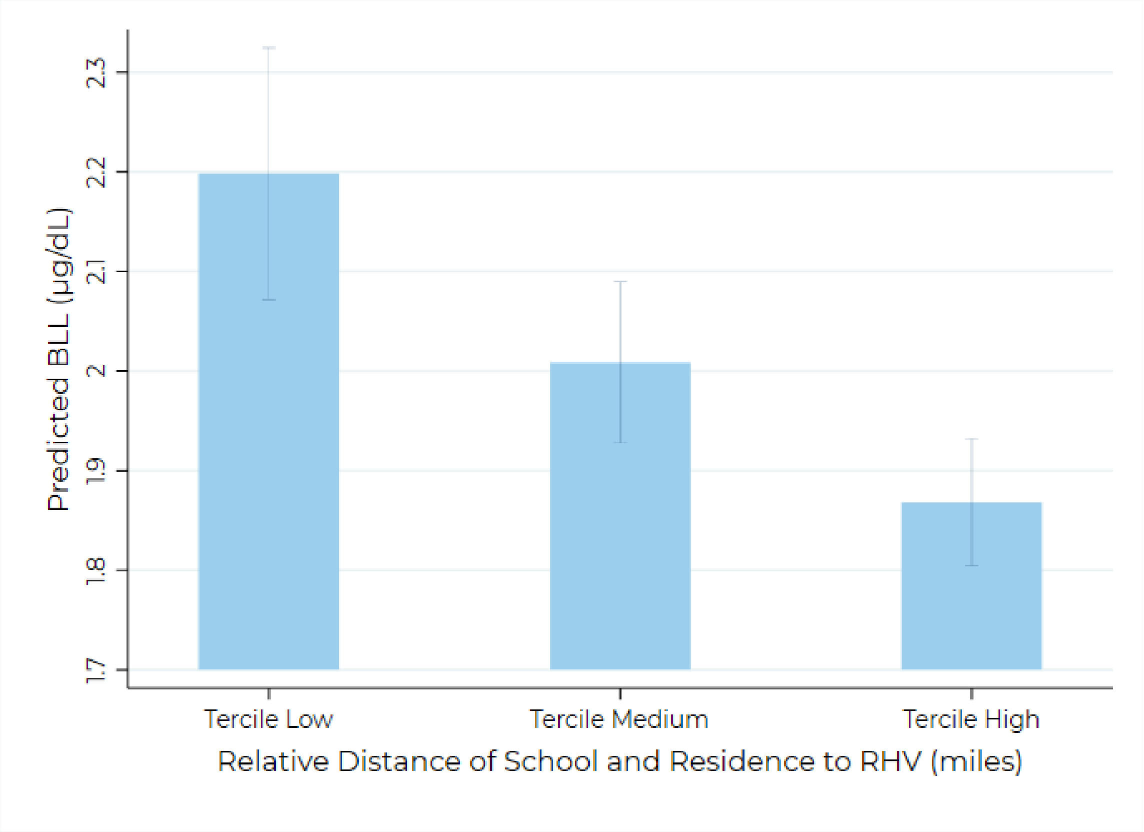
[13] In Santa Clara County, public schools are typically not in session from the first week of June till the second week of August – extended summer break – and closed from the third week of December till the first week of January – extended winter break.

Figure 19: Relative Distance of School and Residence to RHV and Predicted Child BLLs



Note: Predictions are from model (1) in Table 11, with all other covariates fixed at their sample means. The calculation of relative distance involves taking the distance of the assigned nearest school to Reid-Hillview Airport minus the residential distance of the sampled child to Reid-Hillview Airport. Negative values indicate that a child commutes toward Reid-Hillview Airport and a positive value indicates that a child commutes away from Reid-Hillview Airport during the school day.

Figure 20: Relative Distance Terciles of School and Residence to RHV and Predicted Child BLLs



Note: Predictions are from model (4) in Table 11, with all other covariates fixed at their sample means. Terciles divide the distribution of relative of school and residence to Reid-Hillview Airport into three even piles. The average relative distances in Terciles Low, Medium and High are -0.17, 0.07, and 0.32 miles, respectively.

commute away from Reid-Hillview Airport to attend school. Results reported in Table 11 and Figure 19 corroborate the notion that exposure to aviation gasoline is likely a statistically independent source of risk. Children commuting toward Reid-Hillview Airport to attend school present with substantially higher BLLs than sampled children commuting away from Reid-Hillview Airport for school. This relative distance effect appears to be dose-responsive.

5.5 Extension to All Airports

As indicated in FAA data, four other airports located in Santa Clara County service piston-engine aircraft, including NUQ, PAO, SJC, and E16. As with RHV, we extracted all valid CDPH records on children $\leq$ 18 years of age, residing within 1.5 miles of acnuq, PAO, SJC, or E16, and sampled in the last 10 years (January 1, 2011 to December 31, 2011). By adding the 2,500 records obtained from this extraction process to our set of observations, we test the persistence of results reported in Section 4 and Section 5 pertaining to Reid-Hillview Airport.

Figure 21 displays the medley of analyses pursued in Section 4, pertaining to residential distance (Panel A), residential near angle (Panel B), and piston-engine aircraft traffic exposure (Panels C and D). Detailed tables with estimated coefficients corresponding to Panels A through D in Figure 21 are presented in the Appendix.[14]

As shown in Figure 21, the results reported in Section 4 are robust to the inclusion of children proximate to other airports in Santa Clara County that service piston-engine aircraft. Again, we find that child BLLs decrease with distance from the nearest airport, are significantly higher among children residing East (and predominantly downwind) of the nearest airport, and increase with the volume of PEA traffic (whether measured continuously or categorically).

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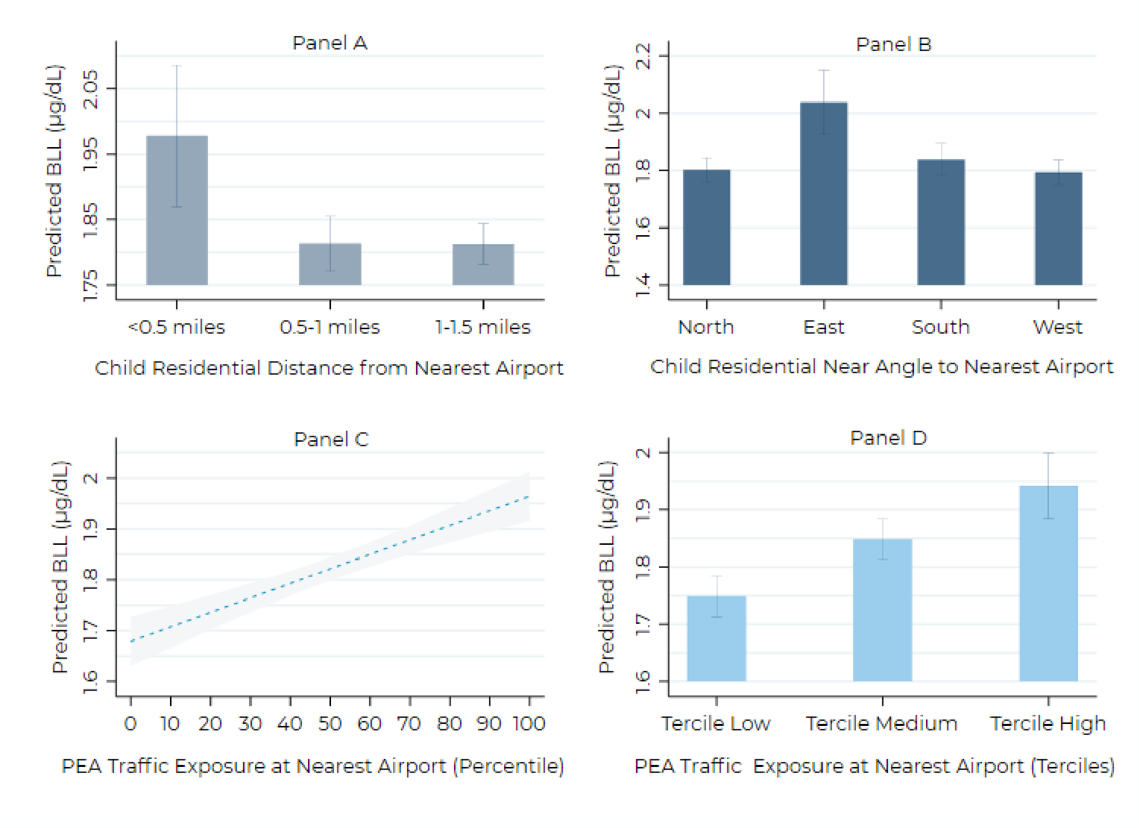
[14] See Appendix Table A.2, Table A.3, Table A.4, Table A.5, Table A.6, and Table A.7.

Figure 21: Main Results on Aviation Gasoline Exposure Risk at Nearest Airports



Note: Residential distance (Panel A) and residential near angle (Panel B) pertain to the nearest airport. PEA traffic in percentile terms (Panel C) and division into terciles (Panel D) correspond to observed PEA traffic at the nearest airport. Across predictions, other model variables are fixed at their sample means.

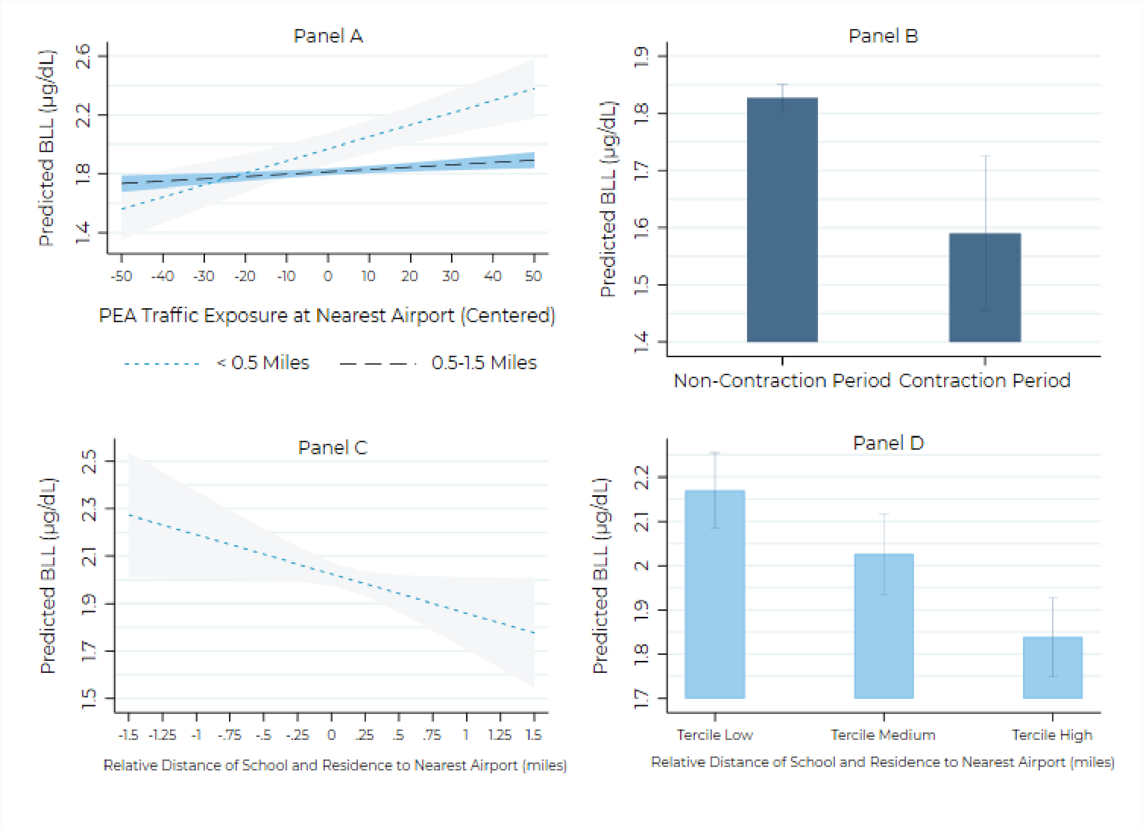
Figure 22 presents an assortment of extended analyses pursued in Section 5, including the statistical interaction of piston-engine aircraft traffic and residential distance (Panel A), the behavior of BLLs of sampled children during the PEA traffic contraction period in 2020 corresponding with the onset of protection efforts to limit the spread of COVID-19 (Panel B), and exposure insulation effects of commuting away from the nearest airport to attend school (Panels C and D). Again, detailed tables with estimated coefficients corresponding to Panels A through D in Figure 22 are presented in the Appendix.

With the inclusion of sampled children proximate to other airports in Santa Clara County, Panel A in Figure 22 shows, once again, that children residing within 0.5 miles of the nearest airport are especially vulnerable to fluctuations in PEA traffic. In Panel B we find that children sampled in the PEA traffic contraction moment present with substantially lower BLLs than statistically similar children sampled outside this moment. In Panels C and D we find that school-aged children commuting away from the nearest airport to attend school realize substantially lower BLLs than children commuting toward PEA-servicing airports for school.

5.5.1 Results Summary, Section 5.5

Across an ensemble of tests that incorporate children proximate to other airports in Santa Clara County with non-zero piston-engine aircraft activity, we find that all results reported in Section 4 and Section 5 pertaining to Reid-Hillview Airport are statistically upheld. Estimated coefficients are similar in direction and magnitude, supporting the hypothesis that exposure to aviation gasoline is a significant source of risk for children proximate to PEA-servicing airports.

Figure 22: Extended Results on Aviation Gasoline Exposure Risk at Nearest Airports



Note: PEA Traffic × Residential distance (Panel A) and contraction period (Panel B) pertain to the nearest airport. Relative distance (Panel C) and division into terciles (Panel D) correspond to relative distances from residence and assigned school to the nearest airport. Across predictions, other model variables are fixed at their sample means.

6 Reduction Scenario

To provide additional quantitative meaning to our results, we conservatively estimate the social benefits of a simulated reduction in PEA traffic from the 50^{th} (observed median) to the 1^{st} percentile (observed minimum). Social benefits are quantified with a standard syllogism in environmental health economics (PEA Traffic → Child BLLs → IQ → Lifetime Earnings) linking lead exposure source to child BLLs to IQ points and to the net present value of future earnings (Schwartz, 1994; Gould, 2009; Grosse et al., 2002).

With coefficients from our Distance × PEA Traffic test reported in Table 8 and visualized in Figure 15, we calculate that a reduction in PEA traffic from the 50^{th} to the 1^{st} percentile results in an estimated reduction in average BLLs from 2.01 to 1.60 μg/dL among sampled children residing within 0.5 miles of Reid-Hillview Airport, and a reduction of 1.82 to 1.76 μg/dL among sampled children within 0.5-1.5 miles of the airport. These expected reductions in average BLLs are a health benefit conferred on the population of children ($\leq$ 18 years) residing around Reid-Hillview Airport. This calculation completes the first step of the syllogism of PEA Traffic → Child BLLs.

In an international pooled analysis of low-level environmental lead exposure and children's intellectual function, Lanphear et al. (2005) report that 1 μg/dL increase of lead in a child's bloodstream is statistically associated with a 0.56 point (95% CI: 0.35, 0.78) reduction in measured IQ [15]. With the Lanphear et al. (2005) estimate of 0.56 IQ points (95% CI: 0.35, 0.78) for every μg/dL of lead, one can translate the estimated reduction in average BLLs from our PEA traffic reduction scenario of 0.41 μg/dL into an expected gain in IQ for children within 0.5 miles of RHV, and 0.06 μg/dL for children at 0.5-1.5 miles, completing the second step of the syllogism of Child BLLs → IQ.

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[15] It should noted that this coefficient of 0.56 IQ points is likely underestimated in the context of aviation gasoline exposure at Reid-Hillview Airport. Recall, Figure 1 showing that the relationship between IQ and child BLL is non-linear, with the steeper losses in IQ at lower BLLs. At ≤ 5 μg/dL, the relationship approaches and possibly exceeds 1 to 1. Therefore, we may regard the final tally of potential gains from a reduction in PEA traffic presented in Table 12 as likely conservative.

The final step of the syllogism, IQ → Lifetime Earnings, involves the known statistical relationship between IQ and lifetime earnings. Following other (Schwartz, 1994; Salkever, 1995; Grosse et al., 2002; Nevin et al., 2008), each IQ point gained corresponds to an estimated gain in the present discounted value of lifetime earnings of $22,871 (2020 U.S.$). One can complete the social benefits exercise by translating the expected gain in IQ over the estimated number of children residing around Reid-Hillview Airport (over the observation period of January 1st, 2011 to December 31st, 2020) to get the expected gain in lifetime earnings resulting from a simulated reduction in piston-engine aircraft traffic from the 50^{th} to 1^{st} percentile.

Table 12 summarizes calculated social benefits for a simulated reduction in PEA traffic from the 50^{th} (observed median) to the 1^{st} percentile (observed minimum). To illustrate the logic, take the first row corresponding to children residing within 0.5 miles of Reid-Hillview. Column (A) is the estimated number of children ≤ 18 years of age residing $<$ 0.5 miles of Reid-Hillview Airport from January 1st, 2011 to December 31st, 2020 of 3,000. Column (B) is the expected reduction in child BLLs of 0.41 μg/dL resulting from the simulated reduction in piston-engine aircraft traffic from the 50^{th} to 1^{st} percentile. Column (C) is the expected gain in IQ for each μg/dL reduced in a child's bloodstream of 0.56 IQ points. In parentheses we report the interval of confidence around this estimated gain of 0.56 IQ points (of 0.35 to 0.78). Data in Column (C) are from the Lanphear et al. (2005) international pooled analysis of low-level environmental lead exposure and children's intellectual function.

Column (D) is the estimated IQ points gained over the cohort of children ≤ 18 years of age residing within 0.5 miles of Reid-Hillview Airport from the simulated reduction in piston-engine aircraft traffic from the 50^{th} to the 1^{st} percentile. The number of 347 is derived by Column (A) × Column (B) × Column (C). The numbers in parentheses in Column (D) of 213 and 481 correspond to the intervals of confidence in Column (C), providing a range estimate of the cohort gain in IQ from the PEA traffic reduction scenario.

Table 12: Estimated Gain in Cohort Lifetime Earnings from IQ Gain from PEA Traffic Reduction of 50th to 1st Percentile

Distance	(A) Cohort $\leq$ 18 yrs	(B) Expected BLL Decrease	(C) IQ Gain per μg/dL	(D) Cohort IQ Points Gained	(E) Lifetime \$ per IQ Point	(F) Cohort Benefit (\$ Millions)
0-0.5 Miles	1,500	0.41 μg/dL	0.56 (0.35, 0.78)	347 (213, 481)	\$22,871	\$7.9 (\$4.9, \$11.0)
0.5-1.5 Miles	13,000	0.06 μg/dL	0.56 (0.35, 0.78)	440 (270, 610)	\$22,871	\$10.1 (\$6.2, \$14.0)

Notes: The cohort of potentially affected children in Column A is estimated from American Community Survey data on age structure for neighborhoods around RHV over the ten-year period of Jan 1st, 2011 to December 31st, 2020. Column D is derived by A × B × C. Column F is calculated by D × E. Estimated range in Column F is from the estimated intervals on BLL to IQ relationship in (C).

Finally, Column (F) completes the syllogism by taking the cohort gain in IQ in column (D) and multiplying by the estimated gain in lifetime earnings for a unit gain in IQ (E). From this, we arrive at the estimated gain in discounted net present value of earnings of \$11.0 to \$24.9 million for the cohort of children $\leq$ 18 years of age residing within 0.5 miles of Reid-Hillview Airport. If one assumes that this PEA traffic reduction scenario is permanent, the estimated gain in lifetime earnings would benefit all subsequent cohorts of children in the vicinity of Reid-Hillview Airport going forward.

We repeat the exercise but this time imagining a reduction in monthly aviation gasoline sales at Reid-Hillview Airport from the 50^{th} (25,000 gal) to the 1^{st} (9,000 gal) percentile. This reduction aviation gasoline usage is approximately equal to what is accomplishable by the percentage of piston-engine aircraft that can safely transition to an unleaded fuel alternative (Kessler, 2013). Leveraging underlying coefficients in Figure 16, Table A.8 summarizes calculations, indicating a cohort gain of about \$15.3 million for a reduction in aviation gasoline sales at Reid-Hillview Airport from the 50^{th} to the 1^{st} percentile.

Importantly, these estimates are not meant to be a full accounting of the social benefits associated with a reduction in population exposure to leaded aviation gasoline. Our estimates are not comprehensive since they reflect gains to a subset of the population (children ≤ 18 years of age), and only one benefit channel (lifetime earnings from an expected gain in IQ). Including health care and special education costs averted, as well as behavioral, physical health, and mortality costs saved, and more than one age stratum of the population would lead to substantially higher estimates (Schwartz, 1994; Gould, 2009).

7 Conclusions

In this study, we assessed whether the BLLs of sampled children around Reid-Hillview Airport are statistically associated with indicators of aviation-related lead exposure, net of other lead exposure pathways. In service of this assessment effort, data were amassed from various sources and analyzed with established statistical and econometric technologies. The conclusions one can reach with applied statistical analyses of this kind rest on the consistency of an ensemble of evidence.

7.1 Main Results

Controlling for other known sources of lead exposure both explicitly and indirectly, demographic characteristics, and neighborhood conditions, the evidence from main analyses (in Section 4) of a statistical link between aviation gasoline exposure risk and child blood lead levels includes:

1. As evidenced in Section 4.2, the BLLs of sampled children increase significantly and dose-responsively with proximity to Reid-Hillview Airport. As shown in Table 4, this relationship between child BLLs and distance to Reid-Hillview Airport is robust to various linear and nonlinear transformations of both input and response variables. Children residing within 0.5 miles of Reid-Hillview Airport present with significantly higher BLLs than children more distant of Reid-Hillview Airport.

2. As evidenced in Section 4.3, BLLs are significantly and substantively higher among sampled children residing East (and predominantly downwind) of Reid-Hillview Airport, and significantly increase in the estimated downwind days drifting in the residential direction of a sampled child from the date of blood draw.

3. As evidenced in Section 4.4, the BLLs of sampled children increase significantly with the volume of measured piston-engine aircraft traffic at Reid-Hillview Airport from the date of blood draw. Moreover, the BLLs of sampled children increase sig-

nificantly with monthly quantities of aviation gasoline sold to fixed-base operators at Reid-Hillview Airport from the date blood draw.

Estimated relationships between BLLs and our main indicators of aviation gasoline exposure risk are quantitatively similar to results of other studies (Miranda et al., 2011; Zahran et al., 2017a). As shown in Table A.9 all main results are robust to the use of clustered errors by sample order, high confidence geo-coded records, richly sampled neighborhoods, and the inclusion of lab fixed effects to account for unmeasured factors present in laboratories performing blood lead tests. Results across main indicators also behave similarly when limiting the analysis to children $\leq$ 6 years of age, as shown in Table A.10, Table A.11, and Table A.12. Finally, results are robust to various single imputation operations in accounting for possible biases from test detection, as shown in Table A.13.

7.2 Extended Results

Again, controlling for other known sources of lead, child demographic characteristics and neighborhood conditions, the evidence for a statistical link between child BLLs and aviation gasoline exposure from extended analyses (in Section 5), include:

1. As evidenced in Section 5.1 the probability that a sampled child's BLL exceeds the CDPH-defined threshold of 4.5 μg/dL increases significantly with proximity to Reid-Hillview Airport, is higher among children residing East of Reid-Hillview Airport, and increases with the volume of piston-engine aircraft traffic.

2. As evidenced in Section 5.2, the BLLs of sampled children proximate to Reid-Hilview are significantly more dose-responsive to piston-engine aircraft traffic and aviation gasoline sales at Reid-Hillview Airport than quantitatively similar children more distant from the airport.

3. Subsequent to social distancing efforts in Santa Clara County to stem the spread of COVID-19, piston-engine aircraft traffic declined significantly in the months of

February to July at Reid-Hillview Airport. As evidenced in Section 5.3, the BLLs of children sampled in this PEA traffic contraction period declined significantly.

4. As evidenced in Section 5.4, children commuting toward Reid-Hillview to attend school present with substantially higher BLLs than sampled children commuting away from Reid-Hillview for school.

5. As evidenced in Section 5.5, all main and extended results pertaining to Reid-Hillview are statistically upheld with the inclusion of sampled children proximate to other piston-engine aircraft servicing airports in Santa Clara County.

While it is statistically improbable that the ensemble of evidence presented above arises for chance alone, there are important caveats to note. First, the generalization of our analysis to San Martin Airport (E16) independent of observations from Reid-Hillview is limited. In CDPH data, we observe only 68 blood lead samples for children ≤ 18 years of age and residing < 0.5 miles of E16 over the 10 year window of analysis. Future analyses of other GA airports in California on the list of EPA-tracked airports (i.e., McClellan-Palomar Airport, San Carlos Airport) can help adjudicate the generalization question.

Second, and following the EPA's (2020) procedure of taking 3-month averages, we find that the measured count of piston-engine aircraft traffic in Federal Aviation Administration data as well as the monthly quantity of aviation gasoline sold to fixed-base operators at Reid-Hillview Airport are puzzlingly modestly positively correlated with measured levels of atmospheric lead at Reid-Hillview Airport (from Feb 2012 to March 2018). While beyond the scope of the current study, more research is needed in the direction of atmospheric sampling and modeling of lead emissions in and around general aviation airports.

More research on the BLLs of sampled children proximate to other general aviation airports in California tracked by the EPA, coupled with research on best atmospheric sampling and modeling of lead emissions around PEA-servicing airports can help provide scientific support on options for reducing aviation-related lead exposure. On the matter of aviation gasoline exposure risk to families and children proximate to general aviation airports, the National Academies of Sciences, Engineering, and Medicine maintains: “Because lead does not appear to exhibit a minimum concentration in blood below which there are no health effects, there is a compelling reason to reduce or eliminate aviation lead emissions.” The ensemble evidence compiled in this study supports the “compelling” need to limit aviation lead emissions to safeguard the welfare and life chances of at-risk children.

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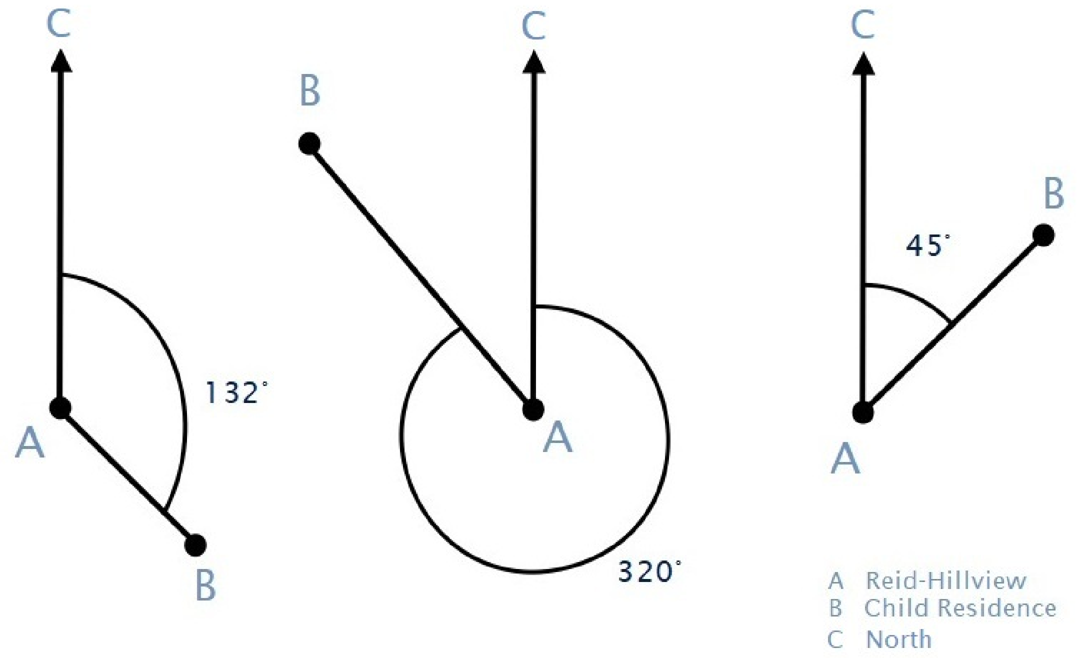
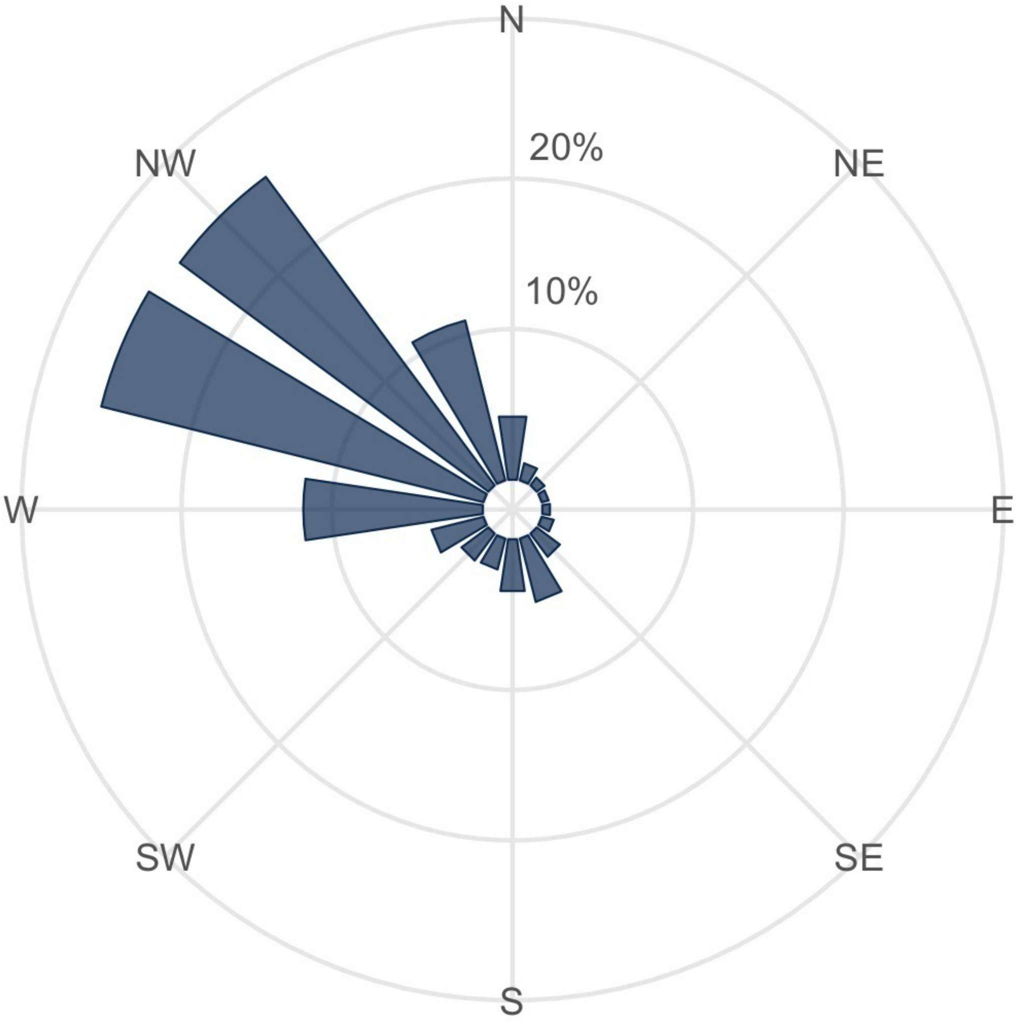
Appendix

Figure A.1: Examples of Residential Near Angle Calculations at Reid-Hillview Airport



Note: Near angles are calculated relative to Reid-Hillview Airport (A), and the angle created between due North (vector C) and a given address (B).

Figure A.2: Prevailing Wind Direction at Reid-Hillview Airport



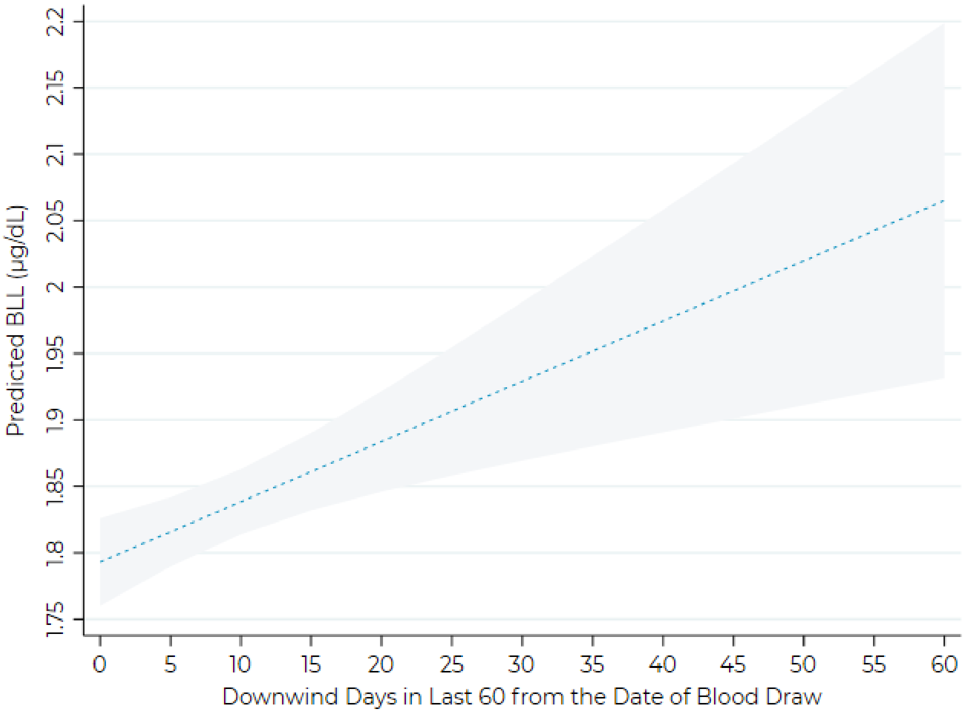
Note: Prevailing wind data are over observation period 1/1/2011 to 12/31/2020 as measured from Reid-Hillview Airport. Wind direction reflects the compass bearing of origination relative to the origin. Data collected from ©Dark Sky API.

Table A.1: Sample Descriptive Statistics

	Mean	Std. Dev.		Mean	Std. Dev.
Response Variables			Demographic Variables		
BLL (μg/dL)	1.83	1.689	Age (Years)	2.816	2.29
BLL (< 1.5)	0.426	0.494	Male	0.512	0.5
BLL (1.5 to 3)	0.463	0.499	Female	0.488	0.5
BLL (3 to 4.5)	0.095	0.293	Timing Controls		
BLL (> 4.5)	0.017	0.128	2011	0.1	0.301
Exposure Risk Variables			2012	0.094	0.291
Distance to RHV (Miles)	1.019	0.315	2013	0.088	0.284
Distance (0-0.5 miles)	0.062	0.241	2014	0.083	0.276
Distance (0.5-1 miles)	0.375	0.484	2015	0.119	0.323
Distance (1-1.5 miles)	0.563	0.496	2016	0.125	0.33
PEA Traffic (Percentile)	0.505	0.289	2017	0.12	0.325
Tercile (low)	0.346	0.476	2018	0.106	0.308
Tercile (Medium)	0.328	0.47	2019	0.103	0.305
Tercile (High)	0.325	0.469	2020	0.06	0.238
Aviation Gasoline (1,000 Gallon)	23.935	5.72	2021	0.001	0.038
North	0.346	0.476	Spring	0.255	0.436
East	0.068	0.252	Summer	0.274	0.446
South	0.203	0.402	Fall	0.246	0.431
West	0.384	0.486	Winter	0.225	0.418
Draw Controls			Neighborhood SES		
Non-Capillary Draw	0.737	0.44	Median Household Income	$69,147.62	$19,888.28
Capillary Draw	0.263	0.44	Median Home Values	$456,985.9	$118,451.1
Sample Order	0.822	1.074	College Educated	13.101	5.981
			Other Exposure Sources		
			Pre-1960 Homes	27.688	21.444
			TRI Facilities (<2 Miles)	2.503	0.73

Notes: Data for all children residing $\leq$ 1.5 miles of RHV with a valid address, date of birth, and date of sample between Jan 1st, 2011 and Dec. 31st, 2020. Total sample size of 17,241 observations;

Figure A.3: Downwind Days in Last 60 and Predicted Child BLLs



Note: Predictions are from model (7) in Table 5, with all other model variables fixed at their sample means.

Table A.2: Residential Distance to Nearest Airport and Child BLLs

BLL (μg/dL)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Distance (Reference < 0.5 miles)							
0.5 to 1 miles	-0.138*	-0.137**	-0.127*	-0.133**	-0.159**	-0.171***	-0.172***
	(0.073)	(0.064)	(0.065)	(0.065)	(0.062)	(0.062)	(0.062)
1 to 1.5 miles	-0.137*	-0.136**	-0.131**	-0.136**	-0.145**	-0.171***	-0.173***
	(0.072)	(0.067)	(0.066)	(0.066)	(0.063)	(0.063)	(0.063)
Constant	1.950***	1.756***	1.746***	1.673***	2.027***	1.966***	2.393***
	(0.068)	(0.067)	(0.071)	(0.075)	(0.087)	(0.091)	(0.298)
Observations	19,818	19,725	19,725	19,725	19,725	19,725	19,725
Block FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Distance	Yes	Yes	Yes	Yes	Yes	Yes	Yes
PEA Traffic	No	Yes	Yes	Yes	Yes	Yes	Yes
Near Angle FE	No	No	Yes	Yes	Yes	Yes	Yes
Demography	No	No	No	Yes	Yes	Yes	Yes
Draw Controls	No	No	No	No	Yes	Yes	Yes
Other Exposures	No	No	No	No	No	Yes	Yes
SES	No	No	No	No	No	No	Yes
Timing Controls	No	No	No	No	No	No	Yes

Notes: Bootstrapped standard errors in parentheses *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; All models limited to children ≤ 18 years of age at the time of blood draw, residing < 1.5 miles to Santa Clara County, CA airport, and observed from January 1st, 2011 to December 31st, 2020; Dependent variable is child BLL (μg/dL); Nearest airport is assigned by the minimum distance between child's place of residence to each airport, among: RHV, E16, SJO, PAO; Distance is child's place of residence to nearest airport (miles); Demography includes child's age (years) and sex (1=female, 0=otherwise); Draw controls includes: draw method (1=capillary, 0=otherwise), limit of quantification (1=BLL ≤ limit of quantification, 0=otherwise), and repeated sample (0=singleton observation, 1,...,n=repeated n times); Other exposures includes: count of TRI facilities ≤ 2 miles from residential address, and percent of neighborhood housing stock built ≤ 1960; SES is the neighborhood socioeconomic status index; Timing controls include a set of indicators for season and year-quarter of the date of draw;

Table A.3: Residential Near Angle to Nearest Airport and Child BLLs

BLL (μg/dL)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Near Angle (Reference North)							
East	0.127***	0.124***	0.123***	0.118***	0.225***	0.255***	0.238***
	(0.046)	(0.048)	(0.044)	(0.044)	(0.045)	(0.044)	(0.048)
South	-0.008	-0.006	0.008	0.01	0.052	0.039	0.034
	(0.033)	(0.035)	(0.036)	(0.036)	(0.036)	(0.034)	(0.035)
West	-0.021	-0.018	-0.013	-0.008	-0.028	-0.032	-0.029
	(0.028)	(0.027)	(0.029)	(0.029)	(0.028)	(0.027)	(0.027)
Constant	1.821***	1.943***	1.746***	1.673***	2.027***	1.966***	2.393***
	(0.017)	(0.074)	(0.071)	(0.075)	(0.087)	(0.091)	(0.298)
Observations	19,818	19,818	19,725	19,725	19,725	19,725	19,725
Block FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Distance	No	Yes	Yes	Yes	Yes	Yes	Yes
PEA Traffic	No	No	Yes	Yes	Yes	Yes	Yes
Near Angle FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Demography	No	No	No	Yes	Yes	Yes	Yes
Draw Controls	No	No	No	No	Yes	Yes	Yes
Other Exposures	No	No	No	No	No	Yes	Yes
SES	No	No	No	No	No	No	Yes
Timing Controls	No	No	No	No	No	No	Yes

Notes: Bootstrapped standard errors in parentheses *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; All models limited to children ≤ 18 years of age at the time of blood draw, residing < 1.5 miles to Santa Clara County, CA airport, and observed from January 1st, 2011 to December 31st, 2020; Dependent variable is child BLL (μg/dL); Nearest airport is assigned by the minimum distance between child's place of residence to each airport, among: RHV, E16, SJO, PAO; Near angle groups are defined in Section 2.2.2 and assigned using the angle between nearest airport and child's place of residence; Demography includes child's age (years) and sex (1=female, 0=otherwise); Draw controls includes: draw method (1=capillary, 0=otherwise), limit of quantification (1=BLL $\leq$ limit of quantification, 0=otherwise), and repeated sample (0=singleton observation, $1,...,n$=repeated n times); Other exposures includes: count of TRI facilities ≤ 2 miles from residential address, and percent of neighborhood housing stock built ≤ 1960; SES is the neighborhood socioeconomic status index; Timing controls include a set of indicators for season and year-quarter of the date of draw;

Table A.4: Piston-Engine Aircraft Traffic at Nearest Airport and Child BLLs

BLL (μg/dL)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
PEA Traffic	0.387***	0.387***	0.385***	0.396***	0.287***	0.313***	0.216***
	(0.054)	(0.054)	(0.053)	(0.053)	(0.057)	(0.056)	(0.053)
Constant	1.628***	1.756***	1.746***	1.673***	2.027***	1.966***	2.590***
	(0.033)	(0.067)	(0.071)	(0.075)	(0.087)	(0.091)	(0.291)
Observations	19,725	19,725	19,725	19,725	19,725	19,725	19,725
Block FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Distance	No	Yes	Yes	Yes	Yes	Yes	Yes
PEA Traffic	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Near Angle FE	No	No	Yes	Yes	Yes	Yes	Yes
Demography	No	No	No	Yes	Yes	Yes	Yes
Draw Controls	No	No	No	No	Yes	Yes	Yes
Other Exposures	No	No	No	No	No	Yes	Yes
SES	No	No	No	No	No	No	Yes
Timing Controls	No	No	No	No	No	No	Yes

Notes: Bootstrapped standard errors in parentheses *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; All models limited to children $\leq$ 18 years of age at the time of blood draw, residing $<$ 1.5 miles to Santa Clara County, CA airport, and observed from January 1st, 2011 to December 31st, 2020; Dependent variable is child BLL (μg/dL); Nearest airport is assigned by the minimum distance between child's place of residence to each airport, among: RHV, E16, SJO, PAO; PEA traffic is average daily PEA operations at nearest airport, calculated over 60 days from child's date of draw and converted to percentiles; Demography includes child's age (years) and sex (1=female, 0=otherwise); Draw controls includes: draw method (1=capillary, 0=otherwise), limit of quantification (1=BLL $\leq$ limit of quantification, 0=otherwise), and repeated sample (0=singleton observation, $1,...,n$=repeated n times); Other exposures includes: count of TRI facilities $\leq$ 2 miles from residential address, and percent of neighborhood housing stock built $\leq$ 1960; SES is the neighborhood socioeconomic status index; Timing controls include a set of indicators for season and year-quarter of the date of draw;

Table A.5: PEA Traffic × Residential Distance at Nearest Airport and Child BLLs

BLL (μg/dL)	(1)	(2)	(3)	(4)	(5)	(6)
Distance (Reference < 0.5 miles)						
0.5 to 1.5 miles	-0.130**	-0.123**	-0.128**	-0.144**	-0.164***	-0.164***
	(0.062)	(0.061)	(0.061)	(0.058)	(0.058)	(0.058)
PEA Traffic	1.038***	1.043***	1.044***	0.956***	0.948***	0.859***
	(0.192)	(0.191)	(0.190)	(0.184)	(0.184)	(0.180)
Distance × PEA Traffic	-0.689***	-0.696***	-0.686***	-0.708***	-0.674***	-0.684***
	(0.202)	(0.202)	(0.201)	(0.193)	(0.193)	(0.193)
Constant	1.944***	1.932***	1.865***	2.165***	2.119***	2.706***
	(0.061)	(0.067)	(0.071)	(0.079)	(0.082)	(0.291)
Observations	19,725	19,725	19,725	19,725	19,725	19,725
Distance	Yes	Yes	Yes	Yes	Yes	Yes
PEA Traffic	Yes	Yes	Yes	Yes	Yes	Yes
Near Angle FE	No	Yes	Yes	Yes	Yes	Yes
Demography	No	No	Yes	Yes	Yes	Yes
Draw Controls	No	No	No	Yes	Yes	Yes
Block FE	Yes	Yes	Yes	Yes	Yes	Yes
Other Exposures	No	No	No	No	Yes	Yes
SES	No	No	No	No	No	Yes
Timing Controls	No	No	No	No	No	Yes

Notes: Bootstrapped standard errors in parentheses *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; All models limited to children ≤ 18 years of age at the time of blood draw, residing < 1.5 miles to Santa Clara County, CA airport, and observed from January 1st, 2011 to December 31st, 2020; Dependent variable is child BLL (μg/dL); Nearest airport is assigned by the minimum distance between child's place of residence to each airport, among: RHV, E16, SJO, PAO; Distance is child's place of residence to nearest airport (miles); PEA traffic is average daily PEA operations at nearest airport, calculated over 60 days from child's date of draw and converted to percentiles then centered (mean=0) for ease of interpretation; Demography includes child's age (years) and sex (1=female, 0=otherwise); Draw controls includes: draw method (1=capillary, 0=otherwise), limit of quantification (1=BLL ≤ limit of quantification, 0=otherwise), and repeated sample (0=singleton observation, 1,...,n=repeated n times); Other exposures includes: count of TRI facilities ≤ 2 miles from residential address, and percent of neighborhood housing stock built ≤ 1960; SES is the neighborhood socioeconomic status index; Timing controls include a set of indicators for season and year-quarter of the date of draw;

Table A.6: School and Residential Distance Difference to Nearest Airport and Child BLLs

BLLs (μg/dL)	(1)	(2)	(3)	(4)	(5)	(6)
Difference (miles)	-0.156***	-0.170**	-0.227			
	(0.060)	(0.068)	(0.146)			
Difference (Reference Low Tercile)						
Medium Tercile				-0.177**	-0.221***	0.087
				(0.072)	(0.073)	(0.167)
High Tercile				-0.304***	-0.320***	-0.169
				(0.068)	(0.075)	(0.124)
Constant	2.863***	2.733***	5.072***	2.986***	2.827***	5.056***
	(0.505)	(0.593)	(0.985)	(0.470)	(0.565)	(0.996)
Observations	4,980	3,804	1,176	4,929	3,762	1,167
Block FE	Yes	Yes	Yes	Yes	Yes	Yes
Distance	Yes	Yes	Yes	Yes	Yes	Yes
PEA Traffic	Yes	Yes	Yes	Yes	Yes	Yes
Near Angle FE	Yes	Yes	Yes	Yes	Yes	Yes
Demography	Yes	Yes	Yes	Yes	Yes	Yes
Draw Controls	Yes	Yes	Yes	Yes	Yes	Yes
Other Exposures	Yes	Yes	Yes	Yes	Yes	Yes
SES	Yes	Yes	Yes	Yes	Yes	Yes
Timing Controls	Yes	Yes	Yes	Yes	Yes	Yes
School in Session	Yes	Yes	No	Yes	Yes	No

Notes: Bootstrapped standard errors in parentheses *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; Models limited to children $\leq$ 18 years at blood draw, residing < 1.5 miles to Santa Clara County, CA airport, and observed from 1/1/2011 to 12/31/2020; Dependent variable is child BLL (μg/dL); Nearest airport is minimum distance between child's residence to each airport (RHV, E16, SJO, NUQ, PAO); Difference is distance from child's residence to nearest airport less the distance of school to child's nearest airport; Demography includes child's age (years) and sex (1=female, 0=otherwise); Draw controls includes: draw method (1=capillary, 0=otherwise), limit of quantification (1=BLL $\leq$ limit of quantification, 0=otherwise), and repeated sample (0=singleton observation, 1,...,n=repeated n times); Other exposures includes: TRI facilities $\leq$ 2 miles from child address, and % of neighborhood housing stock built $\leq$ 1960; SES is neighborhood socioeconomic status index; Timing controls include a set of indicators for season and year-quarter of the date of draw;

Table A.7: PEA Traffic Contraction Period at Nearest Airport and Child BLLs

BLL (μg/dL)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Contraction Period	-0.327***	-0.327***	-0.328***	-0.329***	-0.197***	-0.194***	-0.069
	(0.040)	(0.040)	(0.040)	(0.040)	(0.036)	(0.036)	(0.052)
Constant	1.830***	1.959***	1.952***	1.886***	2.176***	2.134***	2.537***
	(0.012)	(0.068)	(0.074)	(0.078)	(0.085)	(0.088)	(0.312)
Observations	19,818	19,818	19,818	19,818	19,818	19,818	19,725
Block FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Distance	No	Yes	Yes	Yes	Yes	Yes	Yes
PEA Traffic	No	No	No	No	No	No	Yes
Near Angle FE	No	No	Yes	Yes	Yes	Yes	Yes
Demography	No	No	No	Yes	Yes	Yes	Yes
Draw Controls	No	No	No	No	Yes	Yes	Yes
Other Exposures	No	No	No	No	No	Yes	Yes
SES	No	No	No	No	No	No	Yes
Timing Controls	No	No	No	No	No	No	Yes

Notes: Bootstrapped standard errors in parentheses *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; All models limited to children $\leq$ 18 years of age at the time of blood draw, residing < 1.5 miles to Santa Clara County, CA airport, and observed from January 1st, 2011 to December 31st, 2020; Dependent variable is child BLL (μg/dL); Nearest airport is assigned by the minimum distance between child's place of residence to each airport, among: RHV, E16, SJO, PAO; Contraction period is an indicator equaling 1 if draw date occurs February, 2020 thru July, 2020, zero otherwise; Demography includes child's age (years) and sex (1=female, 0=otherwise); Draw controls includes: draw method (1=capillary, 0=otherwise), limit of quantification (1=BLL $\leq$ limit of quantification, 0=otherwise), and repeated sample (0=singleton observation, 1,...,n=repeated n times); Other exposures includes: count of TRI facilities $\leq$ 2 miles from residential address, and percent of neighborhood housing stock built $\leq$ 1960; SES is the neighborhood socioeconomic status index; Timing controls include a set of indicators for season and year-quarter of the date of draw;

Table A.8: Estimated Gain in Cohort Lifetime Earnings from IQ Gain from Aviation Gasoline Sales Reduction of 50th to 1st Percentile

Distance	(A) Cohort $\leq$ 18 yrs	(B) Expected BLL Decrease	(C) IQ Gain per μg/dL	(D) Cohort IQ Points Gained	(E) Lifetime \$ per IQ Point	(F) Cohort Benefit (\$ Millions)
0-0.5 Miles	1,500	0.27 μg/dL	0.56 (0.35, 0.78)	228 (140, 317)	$22,871	$5.2 ($3.2, $7.2)
0.5-1.5 Miles	13,000	0.06 μg/dL	0.56 (0.35, 0.78)	440 (270, 610)	$22,871	$10.1 ($6.2, $14.0)

Notes: The cohort of potentially affected children in Column A is estimated from American Community Survey data on age structure for neighborhoods around RHV over the ten-year period of Jan 1st, 2011 to December 31st, 2020. Column D is derived by A × B × C. Column F is calculated by D × E. Estimated range in Column F is from the estimated intervals on BLL to IQ relationship in (C).

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A.1 Robustness Tests: Restrictions and Clustering

We begin with a recapitulation of Equation 2, then successively restrict observations to highest-confidence geocoded residences, then highly sampled neighborhoods (≥ 100 blood lead samples), and then introducing a new variable that accounts for possible variation in BLL measurement precision across laboratories. We also introduce clustering of standard errors by sample order.

Again, we estimate the responsiveness of child blood lead Y_{ijt} to indicators of aviation gasoline exposure risk with the following linear model:

$$\begin{aligned} Y_{ijt} = \; & \beta_0 + \beta_1 D^n_{it} + \beta_2 D^f_{it} + \beta_3 T_{it} + \beta_4 W^e_{it} + \beta_5 W^s_{it} + \beta_6 W^w_{it} \\ & + \Gamma_1 G_i + \Gamma_2 A_{it} + \Gamma_3 C_{it} + \Gamma_4 S_i + \Gamma_5 Z_{it} + \Gamma_6 L_{it} \\ & + \lambda_1 F_{it} + \lambda_2 H_{jt} + \lambda_3 I_{jt} + \lambda_4 Q_{it} + \gamma_j + \phi_i + \varepsilon_{ijt} \end{aligned} \tag{A.3}$$

where, the meaning of all terms carry from Equation 2 with the exception of ϕ_i, which is a fixed effect for one of twenty-three laboratories performing analyses on blood samples from children residing in Santa Clara County. The inclusion of ϕ_i accounts for unobservable factors present in laboratories that may systematically affect measured BLLs in children. Table A.9 summarizes results from four models that successively restrict observations, introduce clustering of errors by sample order, and add our new control variable. Across all tests executed, coefficients with respect to our three main indicators of aviation gasoline risk behave as expected.

Table A.9: Robustness Tests: Restrictions and Clustering

BLL (μg/dL)	(1)	(2)	(3)	(4)
Distance (Reference < 0.5 miles)				
0.5 to 1 miles	-0.179**	-0.183**	-0.200**	-0.132*
	(0.074)	(0.075)	(0.079)	(0.077)
1 to 1.5 miles	-0.202***	-0.206***	-0.215***	-0.152**
	(0.073)	(0.077)	(0.076)	(0.073)
PEA Traffic	0.163**	0.167***	0.153**	0.243***
	(0.067)	(0.062)	(0.062)	(0.076)
Near Angle (Reference North)				
East	0.405***	0.400***	0.393***	0.255***
	(0.068)	(0.059)	(0.065)	(0.069)
South	0.00	-0.006	-0.002	0.016
	(0.039)	(0.039)	(0.040)	(0.041)
West	-0.052	-0.057*	-0.057*	0.025
	(0.033)	(0.031)	(0.031)	(0.032)
Constant	2.131***	2.114***	2.128***	1.551***
	(0.371)	(0.349)	(0.366)	(0.407)
Observations	17,162	16,823	15,807	15,807
Fully Saturated	Yes	Yes	Yes	Yes
Bootstrapped Errors	No	Yes	Yes	No
Clustered Errors	Yes	No	No	Yes
Confident Geocoding	No	Yes	Yes	Yes
Highly Sampled	No	No	Yes	Yes
Lab Effects	No	No	No	Yes

Notes: Standard errors in parentheses $^{***}p < 0.01, ^{**}p < 0.05, ^{*}p < 0.1$; Models (1) and (4) standard errors are clustered by sample order; Models (2) and (3) standard errors are bootstrapped; All models limited to children residing < 1.5 miles RHV, and observed from January 1st, 2011 to December 31st, 2020, and ≤ 18 years of age unless noted otherwise; Dependent variable is child BLL (μg/dL); Fully saturated controls include all covariates; Lab effects include fixed effect indicators for unique lab id;

A.2 Robustness Tests: Children Under 6 Years of Age

Next we recapitulate Equation 2, restricting observations to children ≤ 6 years of age. Results are presented in three successive tables, beginning with residential distance, then piston-engine aircraft traffic, and then child residential near angle to Reid-Hillview Airport. Across all tests rendered, results behave similarly to what is reported in the manuscript pertaining to all children ≤ 18 years of age.

Table A.10: Distance to Reid-Hillview Airport and Child BLLs, Age 0-6

BLL (μg/dL)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Distance (Reference < 0.5 miles)							
0.5 to 1 miles	-0.161**	-0.166**	-0.171**	-0.178**	-0.202**	-0.213***	-0.214***
	-0.082	-0.08	-0.081	-0.081	-0.079	-0.079	-0.078
1 to 1.5 miles	-0.162**	-0.168**	-0.170**	-0.173**	-0.191**	-0.211***	-0.218***
	-0.079	-0.082	-0.081	-0.081	-0.079	-0.078	-0.078
Constant	1.967***	1.770***	1.771***	1.611***	2.000***	1.908***	2.184***
	-0.076	-0.08	-0.085	-0.094	-0.108	-0.103	-0.346
Observations	16,169	16,092	16,092	16,092	16,092	16,092	16,092
Block FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Distance	Yes	Yes	Yes	Yes	Yes	Yes	Yes
PEA Traffic	No	Yes	Yes	Yes	Yes	Yes	Yes
Near Angle FE	No	No	Yes	Yes	Yes	Yes	Yes
Demography	No	No	No	Yes	Yes	Yes	Yes
Draw Controls	No	No	No	No	Yes	Yes	Yes
Other Exposures	No	No	No	No	No	Yes	Yes
SES	No	No	No	No	No	No	Yes
Timing Controls	No	No	No	No	No	No	Yes

Notes: Bootstrapped standard errors in parentheses *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; All models limited to children ≤ 6 years of age at the time of blood draw, residing < 1.5 miles RHV, and observed from January 1st, 2011 to December 31st, 2020; Dependent variable is child BLL (μg/dL); Distance groups are assigned using the distance (miles) between RHV and the child's place of residence; Demography includes child's age (years) and sex (1=female, 0=otherwise); Draw controls includes: draw method (1=capillary, 0=otherwise), limit of quantification (1=BLL ≤ limit of quantification, 0=otherwise), and repeated sample (0=singleton observation, $1,...,n$=repeated n times); Other exposures includes: count of TRI facilities ≤ 2 miles from residential address, and percent of neighborhood housing stock built ≤ 1960; SES is the neighborhood socioeconomic status index; Timing controls include a set of indicators for season and year-quarter of the date of draw;

Table A.11: Piston-Engine Aircraft Traffic to Reid-Hillview Airport and Child BLLs, Age 0-6

BLL (μg/dL)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
PEA Traffic	0.402***	0.403***	0.403***	0.406***	0.310***	0.317***	0.195***
	(0.061)	(0.061)	(0.061)	(0.061)	(0.066)	(0.063)	(0.063)
Constant	1.614***	1.770***	1.771***	1.611***	2.000***	1.908***	2.184***
	(0.037)	(0.077)	(0.081)	(0.090)	(0.103)	(0.094)	(0.340)
Observations	16,092	16,092	16,092	16,092	16,092	16,092	16,092
Block FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Distance	No	Yes	Yes	Yes	Yes	Yes	Yes
PEA Traffic	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Near Angle FE	No	No	Yes	Yes	Yes	Yes	Yes
Demography	No	No	No	Yes	Yes	Yes	Yes
Draw Controls	No	No	No	No	Yes	Yes	Yes
Other Exposures	No	No	No	No	No	Yes	Yes
SES	No	No	No	No	No	No	Yes
Timing Controls	No	No	No	No	No	No	Yes

Notes: Bootstrapped standard errors in parentheses *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; All models limited to children $\leq$ 6 years of age at the time of blood draw, residing < 1.5 miles RHV, and observed from January 1st, 2011 to December 31st, 2020; Dependent variable is child BLL (μg/dL); PEA traffic is average daily PEA operations at RHV, calculated over 60 days from child's date of draw and converted to percentiles; Demography includes child's age (years) and sex (1=female, 0=otherwise); Draw controls includes: draw method (1=capillary, 0=otherwise), limit of quantification (1=BLL $\leq$ limit of quantification, 0=otherwise), and repeated sample (0=singleton observation, 1,...,n=repeated n times); Other exposures includes: count of TRI facilities $\leq$ 2 miles from residential address, and percent of neighborhood housing stock built $\leq$ 1960; SES is the neighborhood socioeconomic status index; Timing controls include a set of indicators for season and year-quarter of the date of draw;

Table A.12: Residential Near Angle to Reid-Hillview Airport and Child BLLs, Age 0-6

BLL (μg/dL)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Near Angle (Reference North)							
East	0.002	0	0.012	0.013	0.148***	0.167***	0.250***
	(0.030)	(0.030)	(0.031)	(0.031)	(0.033)	(0.034)	(0.042)
South	-0.039	-0.038	-0.032	-0.03	0.012	-0.01	-0.018
	(0.038)	(0.040)	(0.040)	(0.039)	(0.041)	(0.035)	(0.038)
West	0.011	0.017	0.019	0.022	0.005	-0.027	-0.032
	(0.030)	(0.029)	(0.031)	(0.031)	(0.030)	(0.034)	(0.033)
Constant	1.819***	1.971***	1.771***	1.611***	2.000***	1.908***	2.184***
	(0.017)	(0.083)	(0.081)	(0.090)	(0.103)	(0.094)	(0.340)
Observations	16,169	16,169	16,092	16,092	16,092	16,092	16,092
Block FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Distance	No	Yes	Yes	Yes	Yes	Yes	Yes
PEA Traffic	No	No	Yes	Yes	Yes	Yes	Yes
Near Angle FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Demography	No	No	No	Yes	Yes	Yes	Yes
Draw Controls	No	No	No	No	Yes	Yes	Yes
Other Exposures	No	No	No	No	No	Yes	Yes
SES	No	No	No	No	No	No	Yes
Timing Controls	No	No	No	No	No	No	Yes

Notes: Bootstrapped standard errors in parentheses *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; All models limited to children $\leq$ 6 years of age at the time of blood draw, residing < 1.5 miles RHV, and observed from January 1st, 2011 to December 31st, 2020; Dependent variable is child BLL (μg/dL); Near angle groups are defined in Section 2.2.2 and assigned using the angle between RHV and child's place of residence; Demography includes child's age (years) and sex (1=female, 0=otherwise); Draw controls includes: draw method (1=capillary, 0=otherwise), limit of quantification (1=BLL $\leq$ limit of quantification, 0=otherwise), and repeated sample (0=singleton observation, 1,...,n=repeated n times); Other exposures includes: count of TRI facilities $\leq$ 2 miles from residential address, and percent of neighborhood housing stock built $\leq$ 1960; SES is the neighborhood socioeconomic status index; Timing controls include a set of indicators for season and year-quarter of the date of draw;

A.3 Robustness Tests: Detection Limit

While our statistical models explicitly control for the limit of test detection and the method of blood draw throughout, we nonetheless perform a series of additional tests to address possible concerns that test detection limits drive our reported results. First, we find that the likelihood of a child receiving an under-powered test is statistically independent of child residential distance (Odds Ratio = 0.96, 95% CI: 0.86 to 1.08) and piston-engine aircraft traffic at the point of blood draw (Odds Ratio = 1.01, 95% CI: 0.89 to 1.14). We do find that children residing East of RHV are 1.24X (95% CI: 1.06 to 1.45) more likely to receive an under-powered test, suggesting that absent explicit control for test detection, our near angle coefficients would be overstated. Additionally, we recapitulate Equation 2, introducing a series of standard single imputation operations for test results at or below the limit of quantification, including: 1) BLL/2; 2) BLL/$\sqrt{2}$; and an extreme deflation of the observed value by 3) BLL/5. The results are presented in the table below. With the exception of a deflation in the size of the coefficient pertaining to child residence East of RHV under the extreme suppression scenario of BLL/5, results behave similarly throughout. Importantly, even under extreme scenario, BLLs are substantively and statistically significantly higher among sampled children East of the airport.

Table A.13: Robustness Tests: Detection Limit

BLL (μg/dL)	(1)	(2)	(3)	(4)
Distance (Reference < 0.5 miles)				
0.5 to 1 miles	-0.179***	-0.160**	-0.168**	-0.149**
	(0.069)	(0.067)	(0.068)	(0.067)
1 to 1.5 miles	-0.202***	-0.177***	-0.187**	-0.161**
	(0.073)	(0.071)	(0.072)	(0.071)
PEA Traffic	0.163***	0.167***	0.166***	0.170***
	(0.058)	(0.055)	(0.056)	(0.054)
Near Angle (Reference North)				
East	0.405***	0.268***	0.325***	0.186***
	(0.062)	(0.058)	(0.060)	(0.057)
Constant	2.131***	2.254***	2.203***	2.328***
	(0.307)	(0.293)	(0.297)	(0.291)
Observations	17,162	17,162	17,162	17,162
All Controls	Yes	Yes	Yes	Yes
BLL/2	No	Yes	No	No
BLL/$\sqrt{2}$	No	No	Yes	No
BLL/5	No	No	No	Yes

Notes: Bootstrapped standard errors in parentheses *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; All models limited to children residing < 1.5 miles RHV, and observed from January 1st, 2011 to December 31st, 2020, and $\leq$ 18 years of age unless noted otherwise; Distance groups are assigned using the distance (miles) between RHV and the child's residence; Near angle groups are defined in Section 2.2.2 using the angle between RHV and child's residence; PEA traffic is average daily PEA operations at RHV, calculated over 60 days from child's date of draw; Fully saturated controls include: child's age (years) and sex (1=female, 0=otherwise), draw method (1=capillary, 0=otherwise), limit of quantification (1=BLL $\leq$ limit of quantification, 0=otherwise), sample order (0=singleton observation, 1,...,n=repeated n times), TRI facilities $\leq$ 2 miles from residential address, housing stock built $\leq$ 1960, neighborhood socioeconomic status index, a set of season and year-quarter indicators corresponding to date of draw;