Association between Residential Distance to Airport and Blood Lead Levels in Children under 6 Living in North Carolina, 1992–2015

Abdul-Nasah Soale [1,2], Rashida Callender, Dennis Guignet, Ron Shadbegian, and Marie Lynn Miranda

[1]Department of Mathematics, Applied Mathematics & Statistics, Case Western Reserve University, OH, USA

[2]Children's Environmental Health Initiative, University of Illinois Chicago, Chicago, Illinois, USA

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Childhood Lead Exposure

- Children get exposed to lead through various sources usually from ingestion and inhalation:
  - lead-based paint dust: homes built before 1978
  - contaminated soil: soil near airports and busy roads
  - drinking water: lead pipes
  - other sources: contaminated foods, some cosmetics, air from industrial sources
- Blood lead levels (BLL) in children is detected through lead testing.
- Lead testing is usually through capillary and venous blood.
- Lead testing is mandatory for children on medicaid.

Effect of Lead Exposure

- Lead is linked to behavioral and cognitive impairment even at low levels [Canfield et al. (2005); Koller et al. (2004)].
- Some studies have demonstrated that BLL $\leq 5\mu g/dL$ are associated with lower IQ [Jusko, et al. (2008)].
- Low lead exposure has also been linked with higher crime rates and antisocial behaviors in adolescents [Boutwell, et al. (2016); Aizer & Currie (2019)].
- Some studies found evidence of higher cardiovascular mortality in older adults (65+) [Klemick, et al. (2022)].
- Exposure to high levels of lead during pregnancy may cause harm to the fetus including birth defects.

BLL Overtime

- Since the 1970s, blood lead levels in children have steadily declined due to increased regulations.
- Between 1976-1980, the median BLL in children age 1-5 years was $15\mu g/dL$ and the 95th percentile was $29\mu g/dL$.
- The largest declines in blood lead levels occurred in the 1990s, following the elimination of lead in gasoline.
- In 2012, CDC introduced the concept of a blood lead "reference value" and set the threshold to $5\mu g/dL$, the 97.5th percentile of BLLs from the NHANES.
- The reference was revised to $3.5\mu g/dL$ based on the 2015-2018 NHANES cycles.
- Research has consistently shown that there is no safe blood lead level for children.

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Aviation Gasoline (Avgas) and Lead Exposure

- There are 72 public airports in NC: 62 general aviation airports and 10 commercial airports
- The EPA estimates that approximately 5.2 million people live within 500m of an airport where avgas is used (EPA, 2022).

Figure: Piston engine aircraft

Previous work in six NC Counties

- Miranda et al. (2011) found that children living within 500m of airports where avgas is used have approximately 4% higher BLLs than children who lived beyond 2000m.
- The effect of avgas on children's BLLs was still detectable at 1000m.

Figure: County map of NC

EPA's Endangerment Findings

- In October 2023, the EPA finalized an endangerment finding as the first step in using its authority to regulate the use of avgas.
- EPA is now required by the Clean Air Act to propose and promulgate regulatory standards for lead emissions from certain aircraft engines.
- Moreover, the Federal Aviation Administration (FAA) must propose avgas that will control or eliminate lead emissions.
- This study provides evidence that is relevant to the EPA's future regulatory proposals.

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Data

- We obtained BLL testing data from the NC Childhood Lead Poisoning Prevention Program.
- Our initial sample (N=3,092,452) consisted of all children born in NC with BLL test by age 6 (1992-2015) —composed of 60.2% on Medicaid and average BLL of 3.06μg/dL.
- We restricted the sample to children with georeferenced home address (N=2,473,183).

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- We restricted the sample to children with georeferenced home address (N=2,473,183).
- Children with missing values for self-reported race (10.5%), and those who self-identified as Non-Hispanic Asian (1.3%) and Non-Hispanic Other (3.2%), were eliminated due to an insufficient number of observations for analysis.
- Of the children with complete information (N=1,996,065), some had multiple lead tests: 2-tests (32.2%), 3-tests (5.9%), and $\geq$ 4-tests (2.1%).

Data

- The residential address was used to link each child to 2010 Census block-group data for median household income and the percentage of houses built before 1980–used as a proxy for lead paint in homes.
- Arguably, house-specific age is a better proxy, but such tax parcel data are only available for 50 of the 100 NC counties.
- Therefore, we used % houses built < 1980 in the main analysis and house-age in 50 counties as part of a sensitivity analysis.
- The final sample was restricted to children who live within 10km of an airport (N=943,602).

Dose-responsiveness of BLL to airport proximity

- We estimated the relationship between lnBLL and residential proximity to an airport using the generalized additive model:

$$\ln BLL_i = \alpha + \mathbf{X}_i \boldsymbol{\beta} + s(D_i) + \epsilon_i, \quad (1)$$

where for the ith child,

  - $\mathbf{X}_i$ is the vector of control variables (age, race, sex, Medicaid enrollment, blood specimen type, test year and season, median household income and % houses built < 1980)
  - D_i is distance to the nearest airport and $s(.)$ is a penalized cubic spline function
  - (α, β) are unknown parameters,
  - the noise $\epsilon_i \overset{i.i.d.}{\sim} N(0, \sigma^2)$.

A spatial first-difference approach

- To estimate the effect of residential proximity to airport on BLL, we created “exposed” and “control” groups.
- Children living within 2.5km of the nearest airport centroid were categorized as the “exposed” group, while those living between 8-10km were categorized as the control based on the results in Model (1).

A spatial first-difference approach

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- Children living within 2.5km of the nearest airport centroid were categorized as the "exposed" group, while those living between 8-10km were categorized as the control based on the results in Model (1).
- Children who lived between 2.5–8km were eliminated from the sample.
- We estimated the effect of avgas exposure on BLL using the linear model:

$$\ln BLL_i = \eta + \tau Z_i + \mathbf{X}_i\theta + \epsilon_i, \tag{2}$$

where Z denotes the exposure indicator (1 if $D \leq 2.5$ km, 0 otherwise). τ is the effect of avgas exposure.

Matching and Sensitivity Analysis

- To minimize bias in estimating τ, we balanced the distributions of all observed confounders ($\mathbf{X}$) using a many-to-one coarsened exact matching (CEM) algorithm [Iacus et al. (2012)].
- After CEM, we still retain a relatively large sample (N=210,246) consisting of 60% on Medicaid and average BLL of 3.1µg/dL.
- In the sensitivity analysis, in 50 counties, we replaced % houses built < 1980 in $\mathbf{X}$ with house-age, binned into three categories: < 1950, $[1950, 1980)$, ≥ 1980.
- All models were estimated using R statistical software.

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Dose-responsiveness of BLL to airport proximity

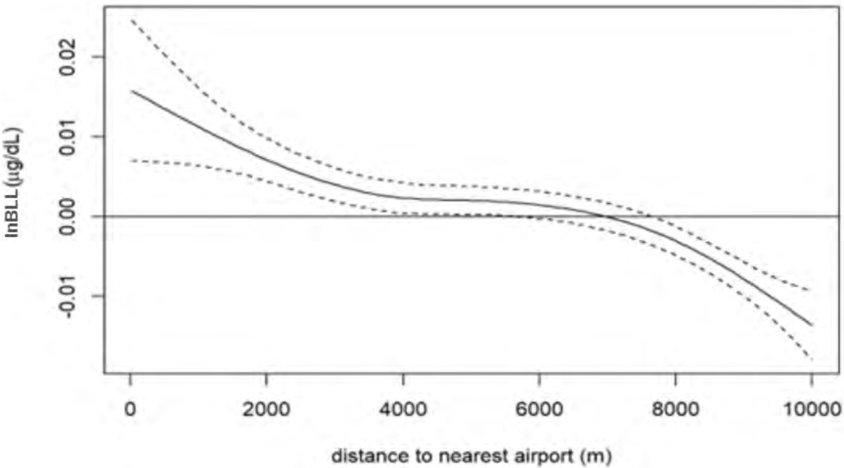

Figure: relationship between BLL and distance to airport

A spatial first-difference approach

Table 1. Results of the linear regression with CEM matched data based on the full and partial samples examining the association between residential proximity to airport(s) and blood lead levels (BLL) in children under 6 in North Carolina (NC), 1992–2015.

	Main analysis (sample from all 100 NC counties; $n = 210{,}246$)			Sensitivity analysis (sample from 50 NC counties, $n = 114{,}179$)		
Variable	Variable summary [n (%)]	Estimate	95% CI	Variable summary [n (%)]	Estimate	95% CI
Intercept	—	4.003	3.919, 4.089	—	3.984	3.881, 4.089
Aviation gas exposure						
Ref: No	134,201 (64%)	—	—	78,485 (69%)	—	—
Yes	76,045 (36%)	1.018	1.013, 1.024	35,694 (31%)	1.018	1.011, 1.026
Child age						
Ref: [0, 1)	8,672 (4%)	—	—	4,502 (4%)	—	—
(1, 2)	127, 010 (60%)	1.105	1.091, 1.116	71,268 (62%)	1.105	1.086, 1.124
(2, 3)	43,542 (21%)	1.371	1.353, 1.389	23,044 (20%)	1.372	1.348, 1.397
(3, 4)	6,430 (3%)	1.231	1.208, 1.254	3,125 (3%)	1.221	1.190, 1.253
(4, 6)	24,592 (12%)	1.122	1.107, 1.139	12,240 (11%)	1.115	1.093, 1.137
Sex at birth						
Ref: Female	103,262 (49%)	—	—	56,003 (49%)	—	—
Male	106,984 (51%)	1.037	1.032, 1.042	58,176 (51%)	1.034	1.027, 1.041
Race						
Ref: non-Hispanic white	123,750 (59%)	—	—	64,540 (57%)	—	—
non-Hispanic black	57,664 (27%)	1.104	1.097, 1.111	32,558 (29%)	1.110	1.101, 1.119
Hispanic	28,832 (14%)	0.933	0.926, 0.940	17,081 (14%)	0.938	0.928, 0.947
Medicaid enrollment						
Ref: No	83,089 (40%)	—	—	46,318 (41%)	—	—
Yes	127,157 (60%)	1.169	1.162, 1.176	67,861 (59%)	1.153	1.144, 1.162
Specimen type						
Ref: Capillary blood	208,472 (99%)	—	—	113,097 (99%)	—	—
Venous blood	1,774 (1%)	0.895	0.872, 0.919	1,082 (1%)	0.898	0.868, 0.929
Years screened						
Ref: 1992–1995	12,289 (6%)	—	—	6,376 (6%)	—	—
1996–1999	30,012 (14%)	0.699	0.691, 0.708	15,255 (13%)	0.709	0.697, 0.721
2000–2005	65,731 (31%)	0.584	0.577, 0.591	34,599 (30%)	0.593	0.584, 0.603
2006–2010	56,489 (27%)	0.418	0.413, 0.423	31,729 (28%)	0.429	0.422, 0.436
2011–2015	45,725 (22%)	0.286	0.282, 0.289	26,220 (23%)	0.296	0.291, 0.301
Season screened						
Ref: Fall	52,493 (25%)	—	—	28,476 (25%)	—	—
Spring	52,982 (25%)	0.985	0.978, 0.991	28,789 (25%)	0.982	0.973, 0.991
Summer	59,327 (28%)	1.035	1.028, 1.042	32,086 (28%)	1.034	1.024, 1.043
Winter	45,444 (22%)	1.013	1.006, 1.020	24,828 (22%)	1.016	1.007, 1.026
Median household income[a]	Mean: $4.0	—	—	Mean: $4.1	—	—
(× $10,000)	SD: $1.4	0.968	0.966, 0.971	SD: $1.4	0.967	0.965, 0.970
% of houses built <1980[a]	Mean: 47%; SD: 22%	1.134	1.119, 1.149	—	—	—
Actual house age						
Ref: ≥1980	—	—	—	54,180 (47%)	—	—
<1950	—	—	—	15,818 (14%)	1.152	1.140, 1.164
1950–1980	—	—	—	44,181 (39%)	1.047	1.039, 1.055
Total n	210,246 (100%)	—	—	114,179 (100%)	—	—
R^2	—	0.325	—	—	0.320	—
R^2 adjusted	—	0.325	—	—	0.320	—

Summary of findings

- The average BLL for "exposed" children was 1.8% (0.018µg/dL) higher compared to those in the control group.
- The effect does not disappear when house-specific age as potential household lead exposure is used in the model.
- The findings are complementary to and consistent with the results of Miranda et al. (2011), who focused on six NC counties, and Zahran et al. (2017) for children in Michigan.

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Study Limitations

- First, we did not account for wind direction which could potentially bias our estimates towards zero [Zahran et al. (2023)].
- Second, we did not control for airport size because the traffic volume available in the traffic flow management system was limited in terms of airports and types of flights, and the FAA's 5010 forms were also not regularly updated.
- Thus, using airport proximity to measure exposure introduces the possibility of measurement error.
- Lastly, our sample was likely biased towards children at the highest risk for lead exposure because BLL testing is only mandatory for children on Medicaid

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Conclusion

- Children who live near an airport have higher BLLs on average compared to those who live farther away.
- We observe a significant adverse effect of avgas use on children's BLLs that can inform the ongoing policy discussions regarding EPA's avgas endangerment finding and future FAA and EPA regulatory proposals.
- Paper is currently published in Environmental Health Perspectives, 132(8), 087701.
- The findings and conclusions in this publication are those of the author(s) and do not necessarily represent the views of the North Carolina Department of Health and Human Services, Division of Public Health.

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Collaborators

- All work was conducted under the aegis of a human subjects research protocol approved by the Institutional Review Board at the University of Notre Dame and University of Illinois Chicago.
- **Prof. Marie Lynn Miranda**: Dept. of Pediatrics, Univ. of Illinois Chicago & CEHI
- **Profs. Dennis Guignet & Ron Shadbegian**: Dept of Economics, Appalachian State Univ.
- **Rashida Callender**: Dept of Environmental Health and Engineering, Johns Hopkins Univ.
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Thank You!