School Bus Diesel Retrofits, Air Quality, and Academic Performance: National Evidence Using Satellite Data

Wes Austin
Georgia State University
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Introduction

Motivation

Figure: A Major Contributor of Pollution

Motivation

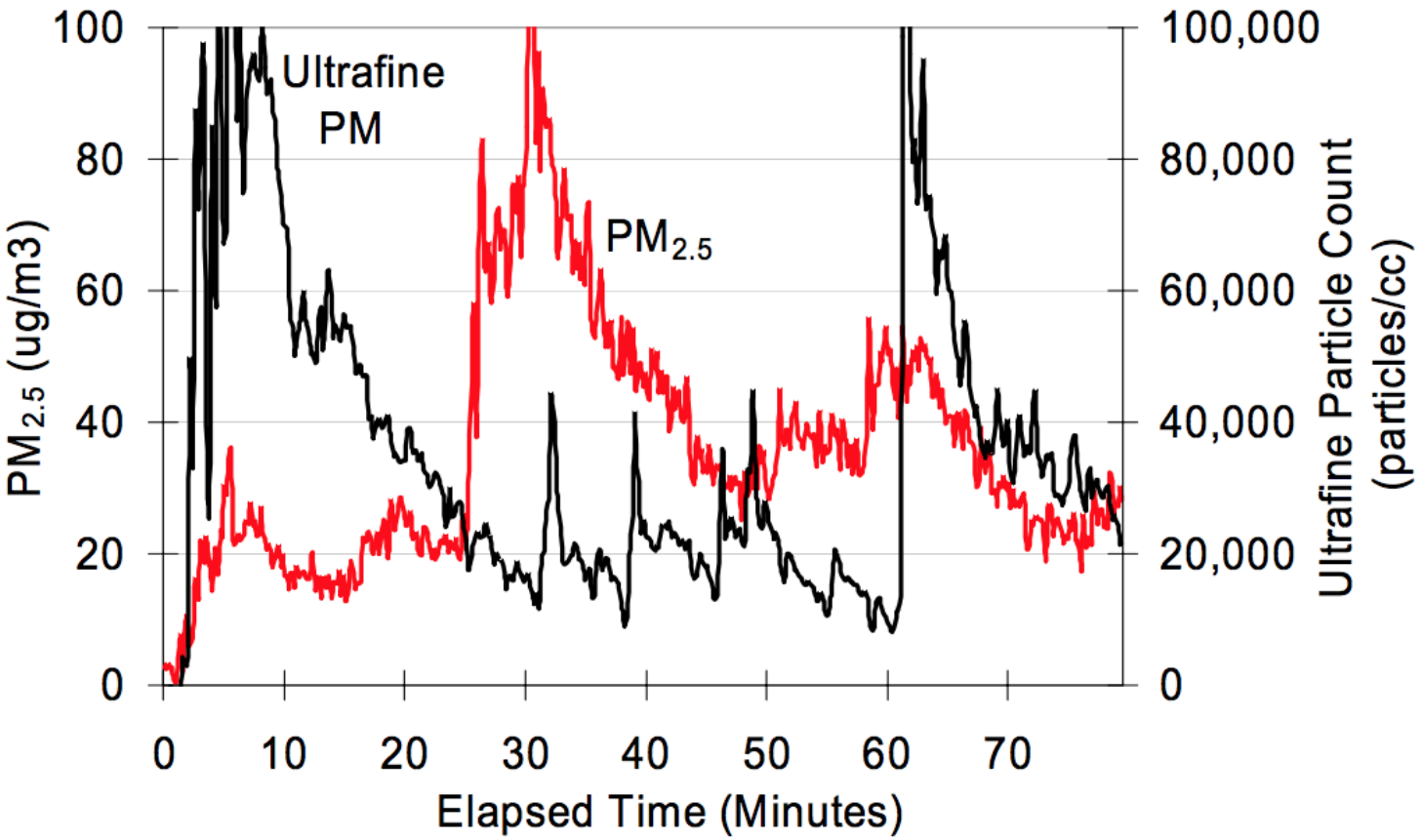


Figure 1: Conventional buses tested showed significant $PM_{2.5}$, ultrafine particle, black cabin and PAH self-pollution. (Ambient concentrations have been subtracted.)

Figure: Ultrafine and Fine PM in a Typical Bus Cabin (Zimmerman 2005)

Motivation

Figure 3: Installation of diesel particulate filter on DeKalb bus prior to testing.

Figure: Making Dirty Buses Clean with Engine Retrofits

Motivation

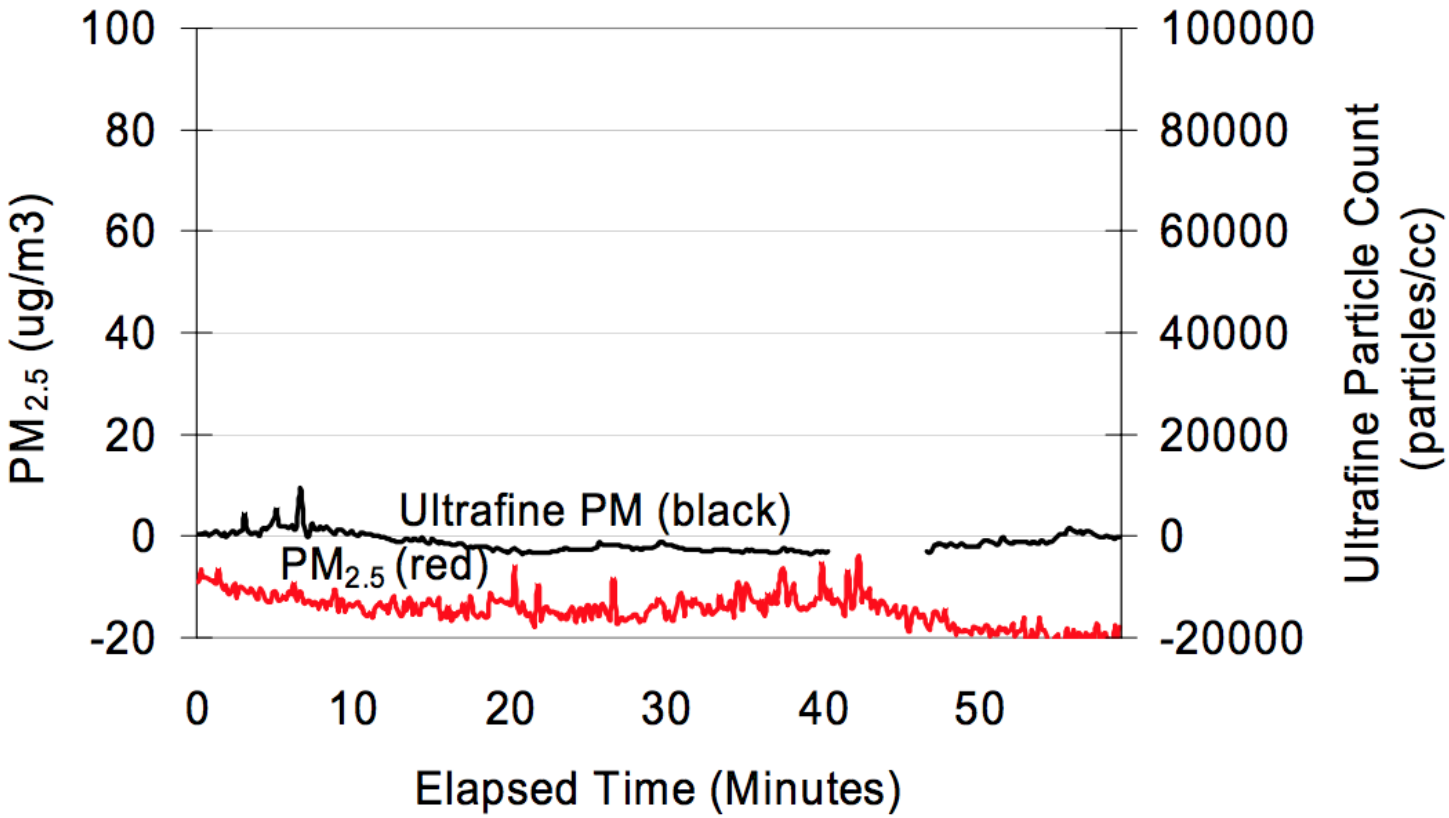


Figure 2: The DPF-ULSD-Spiracle combination eliminated $PM_{2.5}$, ultrafine particles, black carbon, and PAH self pollution from the bus cabin. Ambient concentrations have been subtracted resulting in slightly negative apparent net concentrations. Concentrations below zero should be taken as zero net $PM_{2.5}$ contribution to the bus.

Figure: Making Dirty Buses Clean with Engine Retrofits

Motivation

Figure: A Diesel Particulate Filter at the End of its Life

Contribution and Research Questions

What we know:

- Air pollution affects cognitive performance in the short- and long-term (Lavy, Ebenstein, Roth 2016) (Zhang, Chen, Zhang 2018) (Marcotte 2017) (Heissel, Persico, Simon 2019).
- Reducing school bus emissions decreases clinic visits for lung conditions, improves student lung functioning, and increases test scores. (Beatty & Shimshack 2011) (Adar et al 2015) (Austin, Heutel, Kreisman 2019).

Lingering questions:

- How much do school bus retrofits improve ambient atmospheric air quality?
- Do the academic improvements associated with Georgia retrofits generalize to other states?

Research Methods

A Natural Experiment – School Bus Retrofit Grants

17,901 buses were retrofitted in 137 counties nationwide from 2008-2016.

- Average of 73 retrofits per grant, or 21% of the bus fleet.
- Can test for changes to satellite-based estimates of fine particulate matter.
- Can test for achievement effects.
- Can compare benefits to the total cost of the grants ($170 million).

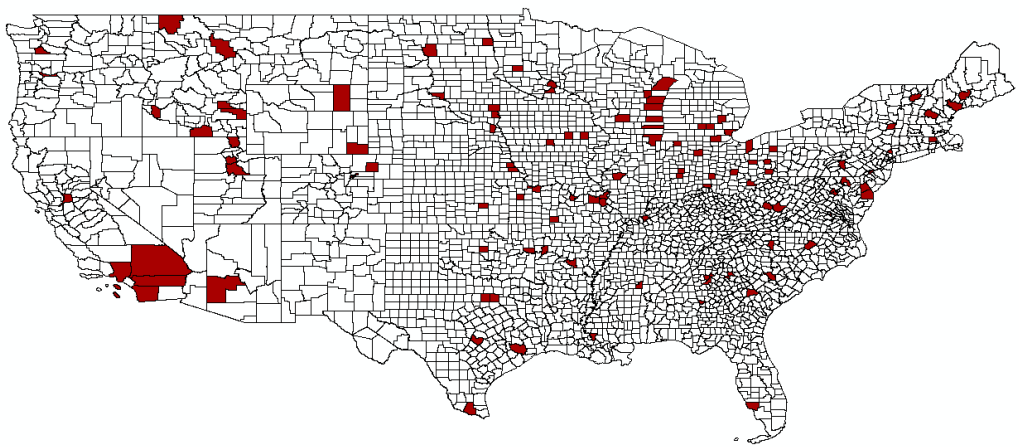


Figure: Retrofitting Counties (2008-2016)

Data: Three Sources, County Level

1. **Environmental Protection Agency** (2008-2016)
   - Retrofit type, number, affected counties, year.
2. **Atmospheric Composition Analysis Group** (2000-2017)
   - Fine particulate matter (PM 2.5) county-month estimates.

▸ See heat map for December 2016.

3. **Stanford Education Data Archive** (2009-2016)
   - Math/ELA test score estimates, student demographics.

Summary Statistics

	(1) Non-Retrofitting		(2) Retrofitting	
Retrofits, Air Pollution, and Test Scores				
English Language Arts Z-scores	-0.041	(0.236)	0.021	(0.193)
Math Z-scores	-0.040	(0.267)	0.046	(0.224)
Particulate Matter 2.5 $[\mu g/m^3]$	8.825	(2.300)	9.122	(2.361)
Vehicles Retrofitted in year t	-		73.401	(141.99)
Proportion Fleet Retrofitted	-		0.2087	(0.2725)
County Characteristics				
Total Enrollment, Grades 3-8, thousands	5.890	(15.696)	46.001	(93.738)
% Free or reduced lunch	0.553	(0.160)	0.489	(0.148)
% ELL Students	0.037	(0.059)	0.066	(0.074)
% Special Ed Students	0.137	(0.038)	0.131	(0.035)
% Urban Schools	0.067	(0.201)	0.299	(0.314)
% Rural Schools	0.533	(0.371)	0.220	(0.260)
% Afr. American	0.113	(0.195)	0.154	(0.184)
% Hispanic	0.119	(0.175)	0.153	(0.174)
% White	0.730	(0.250)	0.648	(0.258)

School Bus Retrofits and Fine Particulate Matter

I observe retrofits at the county-year and air pollution at the county-month.

$$PM_{imst} = \beta Buses_{imt} + \tau_{im} + \tau_{st} + \eta_i + \epsilon_{imst}. \quad (1)$$

- PM_{imst} is the average concentration of atmospheric PM 2.5 in $\mu g/m^3$ in county i, month m, state s, and year t.
- $Buses_{imt}$ is the number of retrofitted buses in county i and year t or the cumulative number of buses ever retrofitted in county i and year t.
- Fixed effects for county, η_i, county-month, τ_{im}, and state-year, τ_{st}.

Identification Assumption: No factors are correlated with the number of school buses retrofitted that also lead to county-level improvements in air quality in retrofit completion years.

School Bus Retrofits and Test Scores

I observe retrofits and test scores at the county-year. Effects should be larger when a larger share of buses are retrofitted. For county i in year t:

$$y_{it} = \beta Retrofit_{it} + \tau_{st} + \eta_i + \epsilon_{it}. \tag{2}$$

- y_{it} is ELA and math test z-scores.
- $Retrofit_{it}$ is either the proportion of the bus fleet retrofitted in year t or the cumulative proportion of buses ever retrofitted in county t.
- Fixed effects for state-year, τ_{st}, and county, η_i.

Identification Assumption: No factors are correlated with the percent of a district bus fleet retrofitted that also lead to test score improvements in retrofit years.

Results

School Bus Retrofits and Fine Particulate Matter (2000-2017)

	(1) Monthly Average PM	(2) Monthly Average PM
Buses Retrofitted in Year t	-0.00042**	
	(0.0002)	
Cumulative Buses Retrofitted		-0.00036***
		(0.0003)
Δ PM Concentration	0.0356	0.0619
% Change from Mean	0.39%	0.68%
County-Year-Months	636,072	636,072
Counties & County Equivalents	3,118	3,118

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Clustered standard errors at the county level. Fixed effects for the county, state-year, and county-month. Δ PM Concentration is the implied change in particulate matter when scaled by the typical buses retrofitted per county per cycle or throughout the sample (73 or 172). Mean PM is 9.12

School Bus Retrofits and Academic Performance (2009-2016)

	(1) ELA	(2) Math	(3) ELA	(4) Math
Proportion Retrofitted in Year t	0.0678*	0.0860**		
	(0.0361)	(0.0408)		
Cumulative Proportion of Fleet Retrofitted			0.0549**	0.0603**
			(0.0245)	(0.0246)
County-Year Observations	19,477	19,266	23,133	22,961
State-Year Observations	309	305	372	369

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Clustered standard errors at the county level. County and state-year fixed effects in all models.

▸ See results from Austin, Heutel, and Kreisman (2019).

Back-of-the-Envelope Cost-Benefit Analysis

- **Costs:** The EPA disbursed $170 million to retrofit or replace school buses.
- **Air Quality Benefits:** According to Deryugina et al. (2019), a 1 $\mu g/m^3$ increase in PM 2.5 over three days leads to a cost of $320,000 in terms of clinic visits and lost life years → decrease in particulate matter concentration of 0.0481 over a year and 219 retrofit cycles → $245 million benefit.
- **Test Score Benefits:** A one percentile increase in test scores is valued at $1,041 over a working life after discounting → average percentile increases of 0.43 in ELA and Math for 46,000 students over 219 retrofit cycles → $4.5 billion benefit.

Conclusion

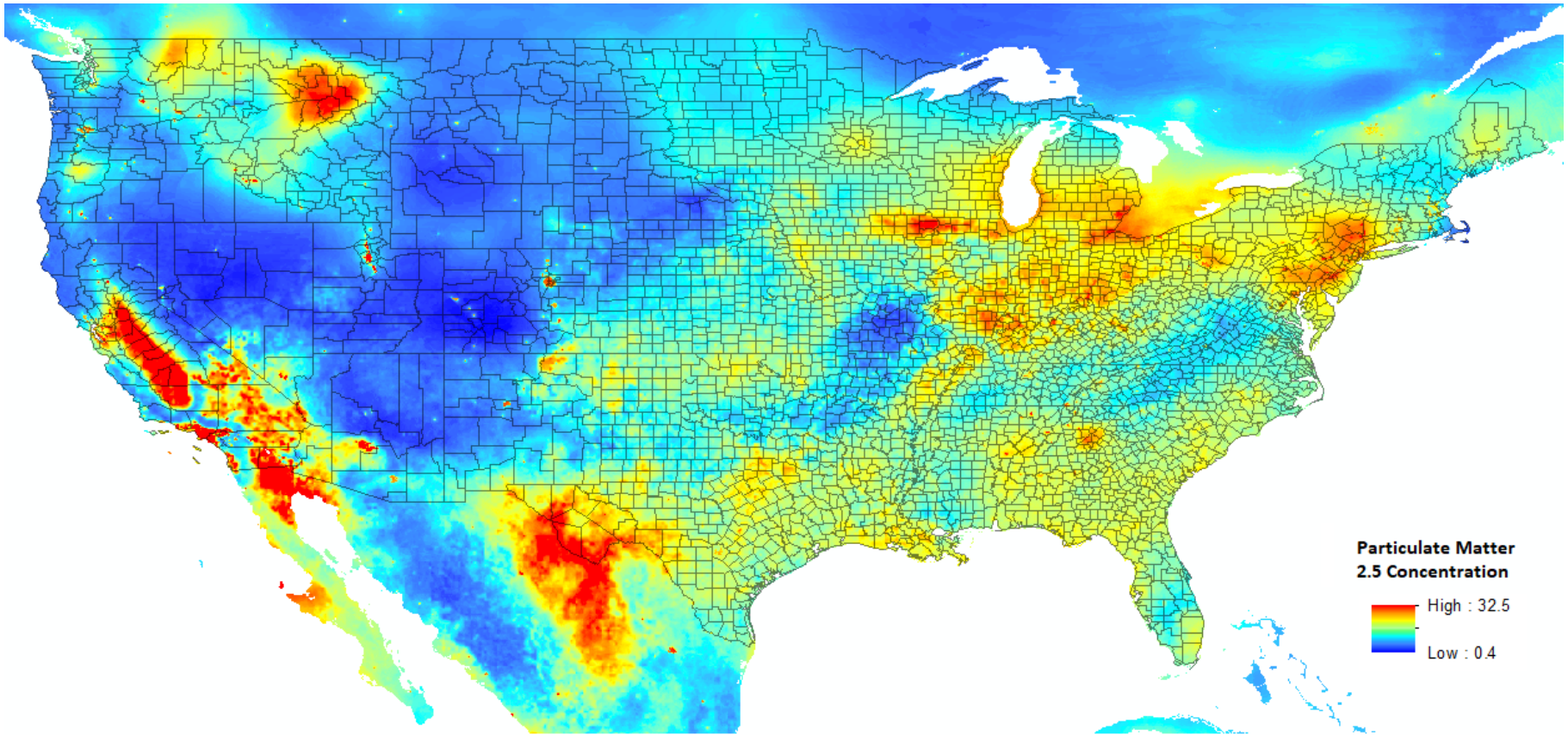
Relatively cheap school bus retrofits grants are associated with economically meaningful improvements in ambient air quality and academic performance.

- School bus retrofit cycles reduce one of the most harmful diesel emissions, fine particulate matter, by between 0.4% and 0.7%.
- Retrofitting all buses in a county is associated with gains of 0.055 standard deviations in ELA and 0.06 standard deviations in math.
- Benefits of the retrofits in terms of reduced mortality and clinic costs may be valued at $245 million; test score improvements may be valued at $4.5 billion.
- Benefits, together, are over 25 times the cost of the retrofits.

Thank you!

Questions/comments?
gaustin4@gsu.edu
@WesAustin7

Fine Particulate Matter Heat Map (December 2016)



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Fine Particulate Matter and Academic Performance (2009-2016)

	(1) ELA	(2) Math
Average Annual PM	-0.00588***	-0.00558***
Concentration	(0.0010)	(0.0013)
County Fixed Effects	✓	✓
State-year Fixed Effects	✓	✓
County-Year Observations	22,707	22,672
State-Year Observations	364	361

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Clustered standard errors at the county level. County and state-year fixed effects in all models.

Academic Outcomes

	Δ ELA Z-Score	Δ Math Z-Score	Δ Attendance
% Retrofit	0.090***	0.047	0.183
	(0.03)	(0.03)	(0.25)
Bus Chars.	✓	✓	✓
Demog.	✓	✓	✓
R2	0.058	0.023	0.097
N	1,800	1,800	1,800
n	180	180	180

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Clustered standard errors at the district level. Year fixed effects included. For reference, the observed difference in elementary student test score gains from a teacher with five years of experience and a rookie teacher is 0.12 z-scores. Go back.