The Environmental Benefits from Transportation Electrification: Urban Buses

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Motivation

- Transportation causes substantial global (CO_2) and local (SO_2, NO_X, $PM_{2.5}$, VOC) air pollution
- Why study buses?
  - Old diesel buses are dirty (dollar per mile air pollution damages)
  - Recent technological advances allow for alternative transition paths
  - Replace old diesel buses with new diesel or electric?
  - Compare both air pollution damages as well as NPV of total costs

Summary of Results

- We calculate the air pollution damages by bus type and county in the US
- Compare tailpipe emissions to emissions from electric power plants
  - On average, damages from diesel buses are 15 cents per mile
  - On average, damages from electric buses are 11 cents per mile
- We calculate NPV of total costs by bus type and county in the US
- Total costs include initial purchase price, operations and maintenance, and air pollution damages
  - On average, electric buses have $8k cost advantage on diesel

Methodology: Air Pollution Damages

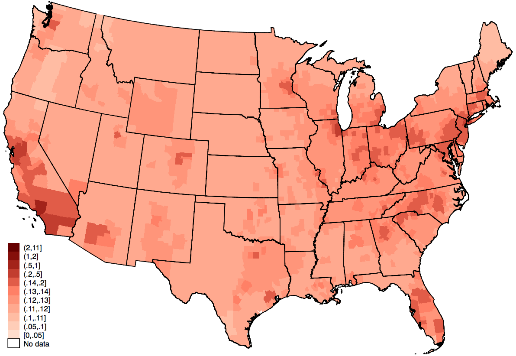
- Diesel Air pollution damages = Emissions per mile × damages per unit emissions
- Electric Air pollution damages = kWh per mile × damages per kWh
  - Assumption: charging electric bus causes marginal change in electricity demand
  - Regression of power plant damages on electricity demand
- Damages from AP3 Integrated Assessment Model
  - Emissions map to ambient pollution concentrations (physics, chemistry)
  - Ambient concentrations map to mortality (epidemiology)
  - Mortality maps to damages in dollars (economics)
  - County level resolution

Diesel Bus Emissions Per Mile

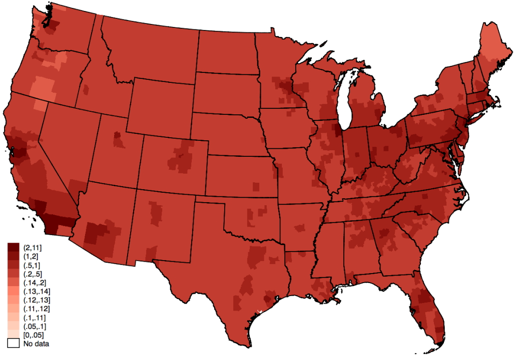
- Diesel emissions meet 2010 federal emission standards (Lowell 2013)
- Old Diesel emissions represent pre-2010 fleet (Cooper et al. 2012)
- 2018 National Transit Database: 35% buses are older than 10 years

	MPGe	NO_X	$PM_{2.5}$	VOCs	SO_2	CO_2
Diesel	4.68	1.178	0.0065	0.0258	0.020	2171
Old Diesel	3.79	19.619	0.493	0.659	0.0249	2678

Air Pollution Damages from Diesel Buses ($ per mile)



(a) Diesel



(b) Old Diesel

Electric Bus Damages (cents per kWh)

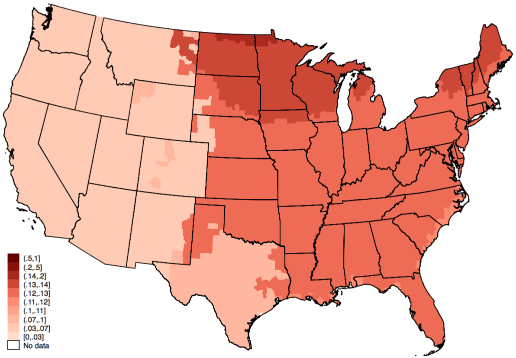
- Estimating equation

$$D_t = \beta Load_t + \alpha_{mh} + \varepsilon_t$$

Interconnection	Total	Global	Local	SO_2	NO_X	$PM_{2.5}$
East	5.336	2.625	2.711	1.850	0.483	0.378
	(0.168)	(0.048)	(0.129)	(0.117)	(0.015)	(0.007)
West	2.789	2.048	0.741	0.222	0.259	0.259
	(0.074)	(0.056)	(0.022)	(0.013)	(0.010)	(0.011)
Texas	3.537	2.055	1.482	1.069	0.222	0.191
	(0.171)	(0.087)	(0.102)	(0.093)	(0.010)	(0.008)

Air Pollution Damages from Electric Buses ($ per mile)

- Includes temperature adjustment



Damages by Bus Type ($ per mile, weighted by bus VMT)

	Mean	Std. Dev.	Min	Max
Diesel	0.151	0.067	0.106	0.696
Old Diesel	1.003	1.194	0.167	10.381
Electric	0.112	0.023	0.061	0.141
Advantage of Electric vs.				
Diesel	0.039	0.076	-0.029	0.634
Old Diesel	0.891	1.199	0.032	10.318

Damages by MSA

MSA	Damages Diesel	Damages Electric	Electric Benefit	Benefit per mile	Bus VMT
Los Angeles, CA	71.4	6.4	65.0	0.634	102.5
New York, NY	33.8	16.7	17.1	0.127	135.1
Chicago, IL	41.5	25.5	16.0	0.080	200.2
Atlanta, GA	48.8	35.9	12.9	0.043	298.7
Newark, NJ	29.7	18.5	11.1	0.074	149.6
Phoenix, AZ	18.9	8.0	10.9	0.089	122.0
Riverside, CA	15.5	5.5	10.0	0.118	85.2

Damages and benefits in millions of $ per year, Benefit per mile in $, Bus VMT in millions of miles per year

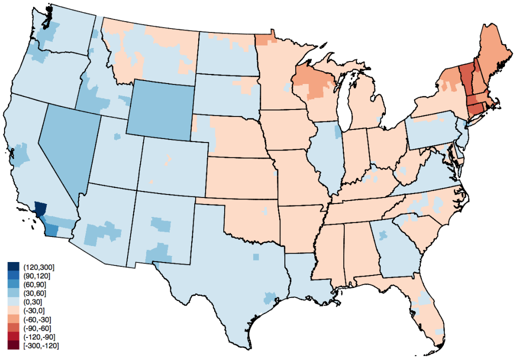
Methodology: NPV of Total Costs

- NPV for bus of type b in location i with lifetime ℓ at interest rate r

$$NPV_{bi} = Price_b + (Maintenance_b + Operating_{bi} + Damages_{bi})(\frac{1}{r})(1 - (1+r)^{-\ell}$$

- Price and Maintenance from literature
- Operating from fuel consumption and fuel price data
- Damages from above
- Electric buses are more expensive, generally have lower damages and operating costs, and are expected to have lower maintenance costs

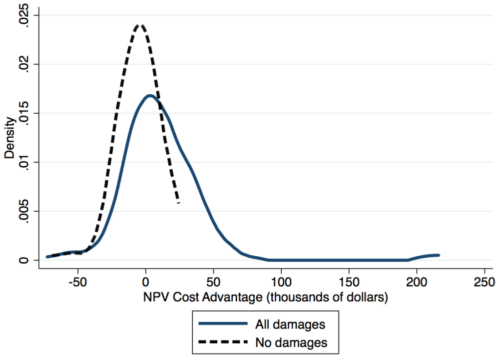
NPV Cost Advantage of Electric Bus by County (thousands of Dollars, $r = 3\%$)



Mean of NPV Calculations Across Counties (thousands of dollars, weighted by bus VMT)

	Purchase	Annual O & M	Annual Damages	NPV $r = 5\%$	$r = 3\%$	$r = 1\%$
Diesel	342.9	52.9	5.4	859.8	923.5	999.3
Electric	604.5	27.2	4.0	881.4	915.4	956.1
Advantage of Electric Bus vs.						
Diesel	-261.6	25.7	1.4	-21.5	8.0	43.3

Distribution of NPV Cost Advantage in Urban Counties



Caveats

- Complete life cycle emissions
- Battery replacement
- Charging infrastructure costs
- Grid may be cleaner in future
- Electric bus purchase price may fall in future

Conclusion

- Old diesel buses are dirty
- Electric buses are generally cleaner than diesel buses
- Including damages from air pollution can be critical in NPV cost calculation