Environmental Benefits from Transportation Electrification
Preliminary results
Do not circulate or quote

Stephen P. Holland—University of North Carolina Greensboro & NBER

Erin Mansur—Dartmouth College & NBER

Nicholas Z. Muller—Carnegie Mellon University & NBER

Andrew J. Yates—University of North Carolina

Transportation electrification: Step 1

Transportation electrification: small & Big

Transportation electrification: buses

Where should policy focus?

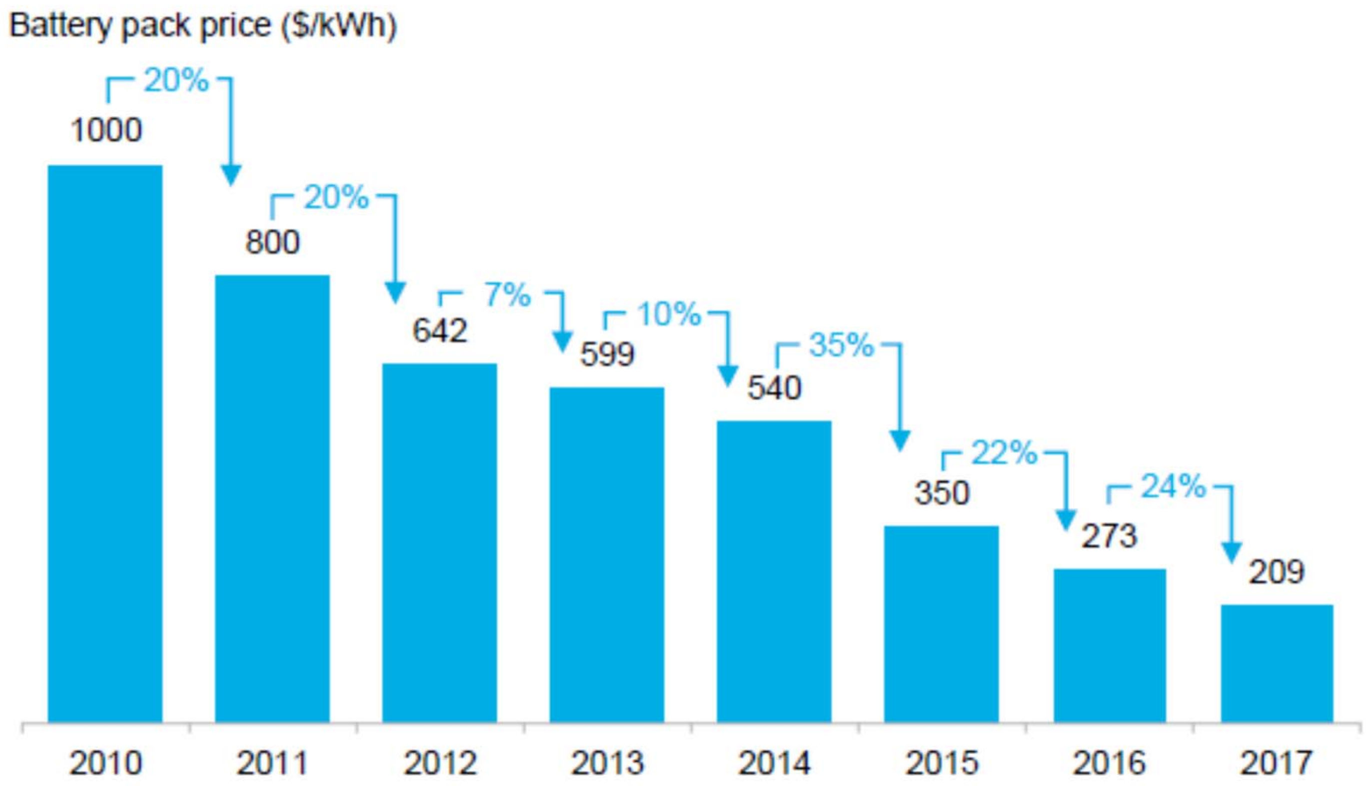
- Technological progress in batteries, charging, motors, and materials makes electrification feasible
  - Dynamics of adoption (Holland et al. 2018)

- Environmental benefits of electrification are possible and largest in West & urban areas (Holland et al. 2016)

- Which modes of transportation have most potential for environmental benefits from electrification?
  - Cars? Buses (gas and diesel)? Trucks?

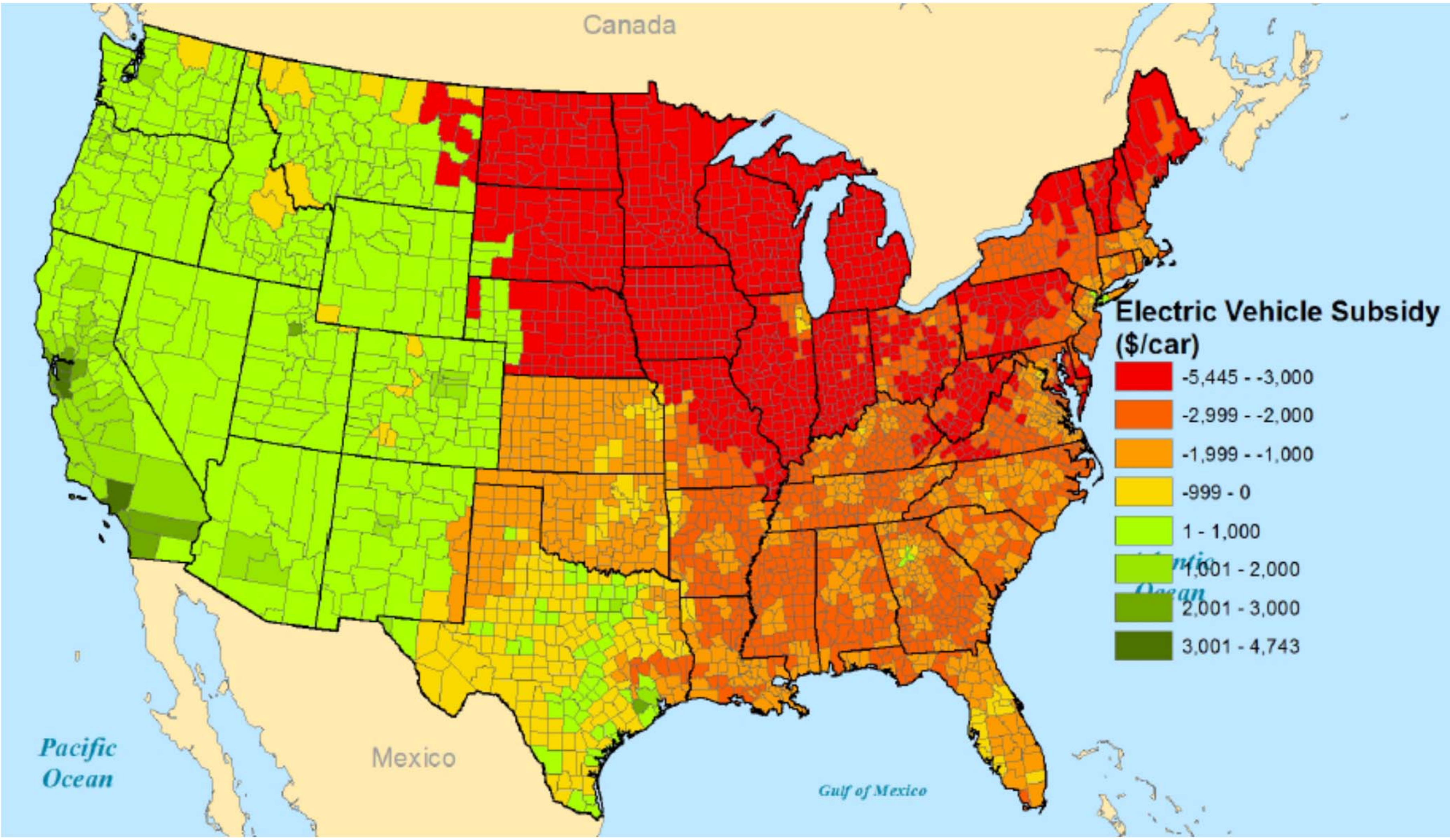
Battery price decline

Figure 11: BNEF lithium-ion battery price survey results – volume-weighted average



Source: Bloomberg New Energy Finance. Note: Prices are a weighted average for BEV and PHEV and energy storage and include both cells and packs. As of 2017, cell prices were around $147/kWh.

Environmental benefit of an EV (car)



Electric v. Gasoline 2014 Ford Focus (Source Holland et al 2016)

Methods: Damages for Diesel Buses

- Diesel bus emissions: grams per mile of SO_2, CO_2, $PM_{2.5}$, NO_x, and VOCs

- Electric buses: charging in kWh/mile
  - $PM_{2.5}$, NO_x, SO_2, CO_2 (grams/MWh) estimated from:

$$y_{it} = \sum_{h=1}^{24} \sum_{j=1}^{J(i)} \beta_{ijh} HOUR_h LOAD_{jt} + \sum_{h=1}^{24} \sum_{m=1}^{M} \alpha_{ihm} HOUR_h MONTH_m + \varepsilon_{it},$$

- Damages: SCC of CO_2, plus AP2's county-level damages (\$/gram) of $PM_{2.5}$, NO_x, VOCs, and SO_2
- Aggregation across counties' bus mileage (national transit database)

Methodological challenges

- Earlier work aggregated loads to nine NERC regions
  - New York, NY and Boston, MA in same NERC region
    - Similarly, (Raleigh, NC & Mobile, AL) and (Minneapolis, MN & Detroit, MI) and (Seattle, WA & Phoenix, AZ) in same NERC regions
  - This aggregation may be appropriate for some hours, regions, or questions

- Can we decrease the spatial scale and let the data determine aggregation?
  - Large number of regressors that are i) serially correlated over hours and ii) spatially correlated over regions
  - Model overfitting?

Possible solutions?

$$y_{it} = \sum_{h=1}^{24} \sum_{j=1}^{J(i)} \beta_{ijh} HOUR_h LOAD_{jt} + \sum_{h=1}^{24} \sum_{m=1}^{M} \alpha_{ihm} HOUR_h MONTH_m + \varepsilon_{it},$$

- Machine learning (e.g., ridge regression & LASSO) can regularize & select variables to improve predictive power
  - Dropping correlated regressors may not be appropriate

- Impose constraints from technology on coefficients
  - e.g., Require distant load regions all have same effects or decay by distance. Use structure from a

- Condition on other covariates, e.g., temperature
  - Estimate relationship between residual load and emissions

Very preliminary findings: Substantial damages from diesel buses

Table 1. Damages from Diesel Buses in Selected Metropolitan Statistical Areas

Metropolitan Statistical Area	Total Damages ($ millions)	Diesel Bus Miles (millions)	Damages per bus mile
New York, NY	$38.03	164.10	$0.23
Oakland, CA	$23.71	31.99	$0.74
Newark, NJ	$20.67	107.30	$0.19
Denver, CO	$18.49	40.94	$0.45
Milwaukee, WI	$18.10	41.78	$0.43
San Francisco, CA	$15.95	29.29	$0.54
Washington, DC	$13.10	64.36	$0.20
Salt Lake City, UT	$11.82	19.55	$0.60
Seattle, WA	$11.32	71.71	$0.16
Philadelphia, PA	$9.82	43.48	$0.23
Houston, TX	$8.94	47.69	$0.19
Charlotte, NC	$7.38	23.23	$0.32
Los Angeles, CA	$6.40	10.62	$0.60
Austin, TX	$5.82	17.83	$0.33
Kansas City, MO	$5.79	11.56	$0.50
Pittsburgh, PA	$5.36	28.61	$0.19
Phoenix, AZ	$4.57	10.68	$0.43
San Antonio, TX	$4.46	22.25	$0.20
Detroit, MI	$4.32	22.10	$0.20
Louisville, KY	$3.85	8.15	$0.47

Very preliminary findings: Trucks are dirty too!

Table 1: Distributions across counties of damages per mile for 2008 fleet average vehicles.

Vehicle	CO2 contribution	mean	med	std. dev.	min	max	VMT (billions)	Total Damages (billions)
Gasoline car	\$0.014	\$0.033	\$0.026	\$0.020	\$0.015	\$0.138	1577.5	\$51.539
Light truck	\$0.020	\$0.042	\$0.034	\$0.023	\$0.020	\$0.167	1022.3	\$43.037
Heavy Duty IIb	\$0.029	\$0.069	\$0.056	\$0.036	\$0.030	\$0.210	97.2	\$6.680
Heavy Duty III	\$0.040	\$0.074	\$0.064	\$0.030	\$0.040	\$0.214	30.3	\$2.248
Heavy Duty VI	\$0.056	\$0.116	\$0.101	\$0.050	\$0.057	\$0.376	57.5	\$6.682
Heavy Duty VIIb	\$0.075	\$0.179	\$0.151	\$0.087	\$0.078	\$0.653	130.3	\$23.268

Notes: Damages are from tailpipe emissions of NOx, VOCs, PM2.5, SO2, and CO2e. VMT and Total damages are annual. CO2 contribution, which does not vary across counties, is the amount of the damages from CO2e. Emissions for a 2008 fleet average vehicles. Damages are weighted by VMT for the relevant vehicle class. Vehicle types are: Heavy Duty IIb (gasoline) e.g., Large Pick-Up, Utility Van; Heavy Duty III (diesel) e.g., panel truck, small enclosed delivery trucks; Heavy Duty VI (diesel) e.g., City Delivery, School Bus; and Heavy Duty VIIIb (diesel) e.g., Tractor-Trailer.

Summary and moving forward

- Technological progress in batteries, charging, motors, and materials makes transportation electrification feasible

- We ask: What are environmental benefits of electrification of different transportation modes?
  - Better (newer) emissions data for buses and trucks
  - Improved techniques for estimating electricity emissions
    - Machine learning? Model restrictions? Residuals?