Are There Environmental Benefits from Driving Electric Vehicles?
The Importance of Local Factors

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Purpose

- We analyze whether electric vehicles generate short-term environmental benefits by examining air pollution damages from driving gasoline vehicles and charging electric vehicles
- **We focus on the importance of local factors** by including global and local pollution, spatial heterogeneity of damages, pollution export across political jurisdictions, and policy that may vary by location
- Our study is the first to consider the geographic variation in damages from both local and global pollutants emitted by both gasoline and electric vehicles and to tie this variation to a choice model

Three main considerations motivate our analysis

First

- Prior studies of electric vehicles have focused on calculating the emissions of electric vehicles but have not had a conceptual framework for analyzing electric vehicle subsidies
- We analyze a model of vehicle choice, which gives us the theoretically sound and intuitive result that the subsidy should be equal to the difference in lifetime damages between an electric vehicle and a gasoline vehicle

Three main considerations motivate our analysis

Second

- Despite being treated by regulators as “zero emission vehicles,” electric vehicles are not necessarily emissions free
- In 2014, the US Department of Energy reported that nearly 70 percent of electricity generated in the United States is produced by burning coal and natural gas
- To assess the emissions from charging an electric vehicle, we use an econometric model to estimate the effect of charging an electric vehicle on the marginal emissions of multiple pollutants at each power plant

Three main considerations motivate our analysis

Third

- There are significant physical differences between emissions from gasoline and electric vehicles due to the distributed nature of the electricity grid, the height at which emissions occur, and the chemistry of fuel combustion
- Many prior studies consider only carbon dioxide. We use an integrated assessment model to value damages across local and global pollutants for both electric and gasoline vehicles

Background Information on Electric Grid

- The electricity grid in the contiguous United States consists of three main "interconnections": Eastern, Western, and Texas.
- Since there are substantial electricity flows within each interconnection but quite limited flows between interconnections, we model each interconnection separately.
- We follow the North American Electric Reliability Corporation (NERC) and divide the three interconnections into nine distinct regions
- We use these nine NERC regions to define the spatial scale for measuring emissions per kWh (Our estimation strategy assumes that an electric vehicle charged at any county within a given NERC region has the same marginal emission factors as an electric vehicle charged at any other county within the same region)

General Information

- At the state level, 91 percent of local pollution damages from driving an electric vehicle are exported to states other than the state in which the vehicle is driven.
- In contrast, only 19 percent of local pollution damages from driving a gasoline vehicle are exported to other states.
- Value of a statistical life approximately $8.1 million
- For CO_2, we use the EPA social cost of carbon of $41 per ton

Theoretical Model

- Consider a theoretical discrete choice transportation model in which consumers in the market for a new vehicle choose between a gasoline vehicle and an electric vehicle
- Consumers obtain utility from a composite consumption good x (with price normalized to one) and from miles driven over the life of the selected vehicle, either gasoline miles g or electric miles e
- We allow for several policy variables. The government may provide a subsidy s for the purchase of an electric vehicle, place a tax t_g on gasoline miles, a tax t_e on electric miles, or some combination of these policies
- We hold fuel and vehicle prices fixed

Important caveats

- First, it only captures air pollution emissions associated with driving or charging the vehicles. It does not account for "upstream" environmental externalities associated with producing either fuels or vehicles.
- Second, it is based on the electricity grid in the years 2010–2012 and current gasoline vehicle technology
- Third, it depends on marginal emissions from an increase in the demand for electric power to charge electric vehicles. This may not be appropriate when electric vehicles comprise a substantial fraction of the vehicle fleet.
- Fourth, it ignores preexisting environmental polices such as the Corporate Average Fuel Economy (CAFE) standards and cap-and-trade markets for various local pollutants
- For each of these caveats, we consider the degree to which they affect our calculated environmental benefits. For example, accounting for CAFE standards leads to an additional environmental cost of $1,555 per vehicle, whereas if there were a binding cap on SO_2 the additional environmental benefit would be $2,280 per vehicle

Vehicles

- Our set of electric vehicles includes each of the 11 pure electric vehicles in the EPA fuel efficiency database for the 2014 model year
- Our set of gasoline vehicles is meant to capture the closest substitute in terms of non-price attributes to each electric vehicle
- Wherever possible, we use the gasoline-powered version of the identical vehicle, e.g., the gasoline-powered Ford Focus for the electric Ford Focus

Proposition 1: The second-best differentiated subsidy on the purchase of the electric vehicle in location i is given by

$$s_i^* = \left(\delta_{gi} g_i - \delta_{ei} e_i\right).$$

The difference between the full damages over the driving lifetime of a gasoline vehicle and the full damages over the driving lifetime of an electric vehicle

Proposition 2: Assume that prices, income, and the functions h and g are the same across locations. The second-best uniform subsidy on the purchase of an electric vehicle is given by

$$\tilde{s} = \left(\left(\sum \alpha_i \delta_{gi}\right) g - \left(\sum \alpha_i \delta_{ei}\right) e\right).$$

Furthermore, let $\mathcal{W}(S^*)$ be the weighted average of welfare from using the second-best differentiated subsidies s_i^* in each location and let $\mathcal{W}(\tilde{S})$ be the weighted average of welfare from using the second-best uniform subsidy $\tilde{s}$ in each location. To a second-order approximation, we have

$$\mathcal{W}(S^*) - \mathcal{W}(\tilde{S}) \approx \frac{1}{2}\pi(1-\pi)\left(\frac{1}{\mu}\sum \alpha_i (s_i^* - \tilde{s})^2 - \frac{1}{\mu^2}(1-2\pi)\sum \alpha_i (s_i^* - \tilde{s})^3\right),$$

where π is evaluated at the uniform subsidy.

Power Plant i's Hourly emissions at time t

$$y_{it} = \sum_{h=1}^{24} \sum_{j=1}^{J(i)} \beta_{ijh} HOUR_h LOAD_{jt} + \sum_{h=1}^{24} \sum_{m=1}^{36} \alpha_{ihm} HOUR_h MONTH_m + \varepsilon_{it},$$

To determine the emissions per mile for each gasoline vehicle, we integrate data from several sources

- For CO_2 and SO_2, emissions are directly proportional to gasoline usage, so we use conversion factors in the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model scaled. We differentiate urban and nonurban counties by using the EPA's city and highway mileage
- For NO_x emissions, we use the Tier 2 emission standards for the vehicle "bin."
- For $PM_{2.5}$ and VOCs, we combine the Tier 2 standards with GREET estimates of $PM_{2.5}$ emissions from tires and brakes and VOC emissions from evaporation.

The implication of this procedure is that emissions per mile for each gasoline vehicle only differ across urban and nonurban counties

To determine the emissions per mile for each electric vehicles, determining emissions per mile is more complicated

- We begin with the EPA estimate of mpg equivalent (i.e., the estimated kWh per mile).
- We adjust this figure to account for the temperature profile of each county, because electric vehicles use more electricity per mile in cold and hot weather
- We use an econometric model to estimate the marginal emissions factors (e.g., tons per kWh) for each of our pollutants at each of 1,486 power plants due to an increase in regional electricity load
- We combine these estimates with an assumed daily charging profile to determine the emissions per mile at each power plant due to the charging of an electric vehicle in a given county

The implication of this procedure is that emissions per mile for each electric vehicle may differ across any two counties

RESULTS

- Our first set of results documents the considerable heterogeneity in the environmental benefits of an electric vehicle relative to a gasoline vehicle
- These benefits can be _ depending on the location

1. large and positive California
2. large and negative North Dakota
3. Negligible

- If we account only for greenhouse gases, then electric vehicles are superior to gasoline vehicles almost everywhere

Results

- The final set of results assesses the deadweight loss of various policies as well as the welfare gains from differentiated policy.
- Our theoretical analysis reveals that the welfare gains from differentiated subsidies depend on the higher order moments of the distribution of environmental benefits.
- Calibrating this model gives us an estimate of the magnitude of these gains.

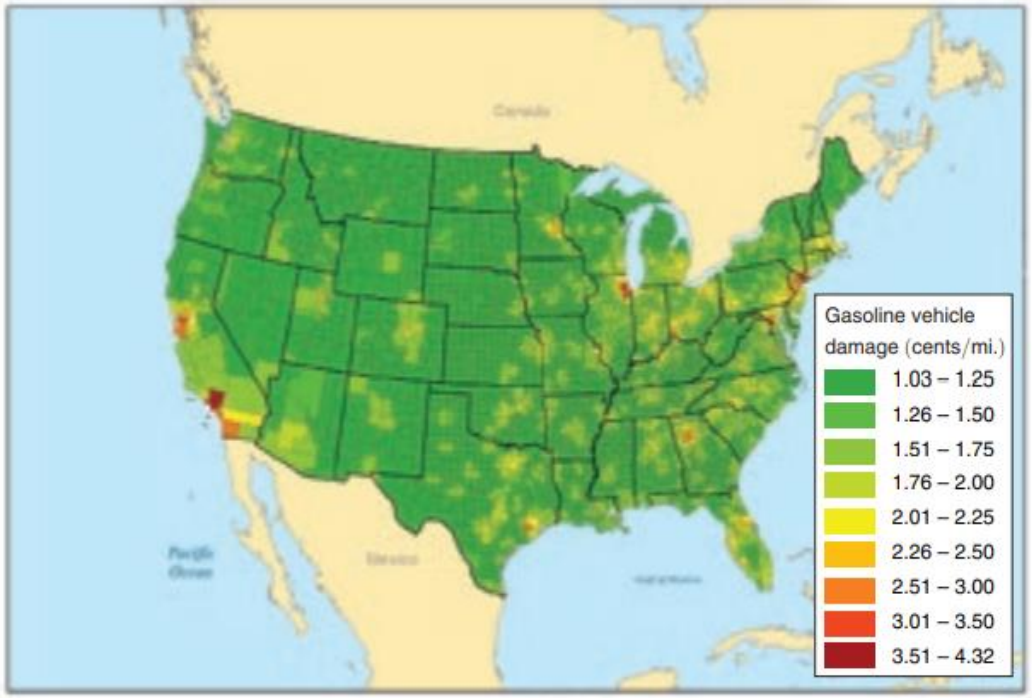
1. For electric vehicle subsidies, we find large deadweight loss and small welfare gains from differentiation.
2. For taxes on gasoline miles, we find small (or zero) deadweight loss and larger welfare gains from differentiation

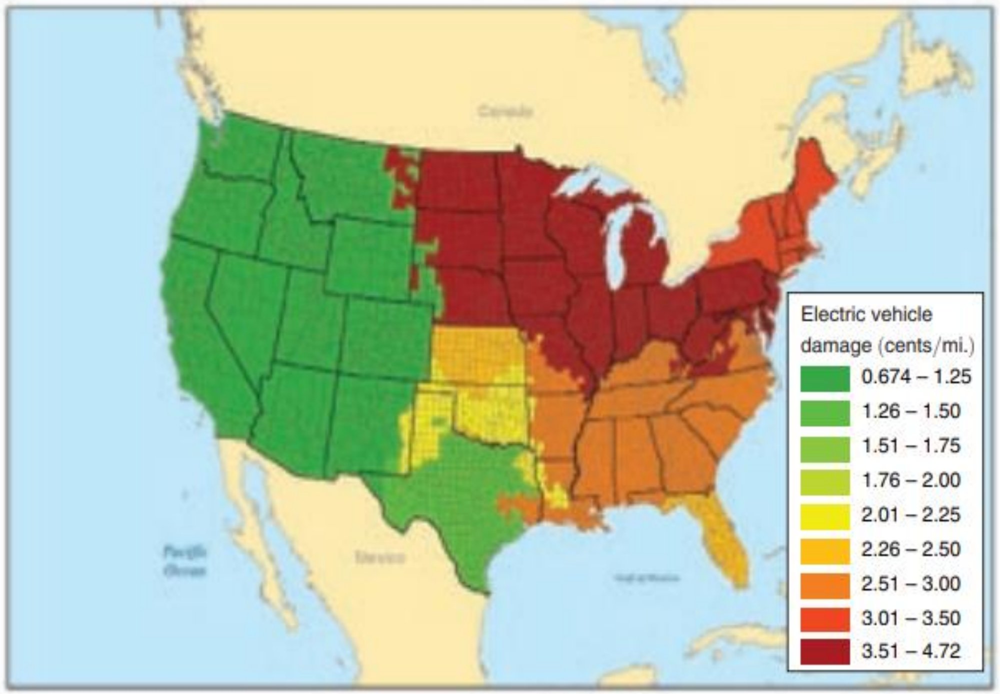
Metropolitan statistical area	Environmental benefits per mile	VMT (percent)	Damage per mile (gasoline)	Damage per mile (electric)	Purchase subsidy
Highest benefit MSAs					
Los Angeles, CA	3.16	2.69	3.85	0.69	$4,743
Oakland, CA	2.21	0.75	2.89	0.68	$3,315
San Jose, CA	2.11	0.54	2.80	0.69	$3,166
San Francisco, CA	1.91	0.45	2.59	0.68	$2,867
Santa Ana, CA	1.87	0.93	2.54	0.67	$2,800
Other high VMT MSAs					
San Diego, CA	1.85	0.97	2.53	0.68	$2,770
Riverside, CA	1.17	1.35	1.88	0.71	$1,756
Phoenix, AZ	0.74	1.16	1.77	1.03	$1,112
Houston, TX	0.67	1.74	2.01	1.35	$1,003
Dallas, TX	0.62	1.52	1.91	1.29	$926
New York, NY	−0.02	1.97	3.16	3.18	−$32
Atlanta, GA	−0.36	1.92	2.38	2.73	−$535
Chicago, IL	−0.74	1.75	2.98	3.72	−$1,116
Washington, DC-VA	−0.89	1.40	2.19	3.08	−$1,335
Minneapolis, MN	−2.39	1.06	2.08	4.46	−$3,578
US and nonurban					
US average	−0.73	100	1.86	2.59	−$1,095
Nonurban	−1.67	20	1.20	2.87	−$2,500
Lowest benefit MSAs					
St. Cloud, MN	−2.87	0.08	1.62	4.49	−$4,310
Bismarck, ND	−2.97	0.04	1.52	4.49	−$4,456
Fargo, ND-MN	−3.07	0.07	1.54	4.61	−$4,605
Duluth, MN-WI	−3.09	0.10	1.47	4.56	−$4,635
Grand Forks, ND-MN	−3.14	0.03	1.52	4.66	−$4,711

Notes: The environmental benefits are the difference in damages between the gasoline-powered Ford Focus and the electric Ford Focus. Environmental benefits are weighted by VMT by county within each MSA. Nonurban includes all counties that are not part of an MSA. The purchase subsidy assumes vehicle is driven 150,000 miles.

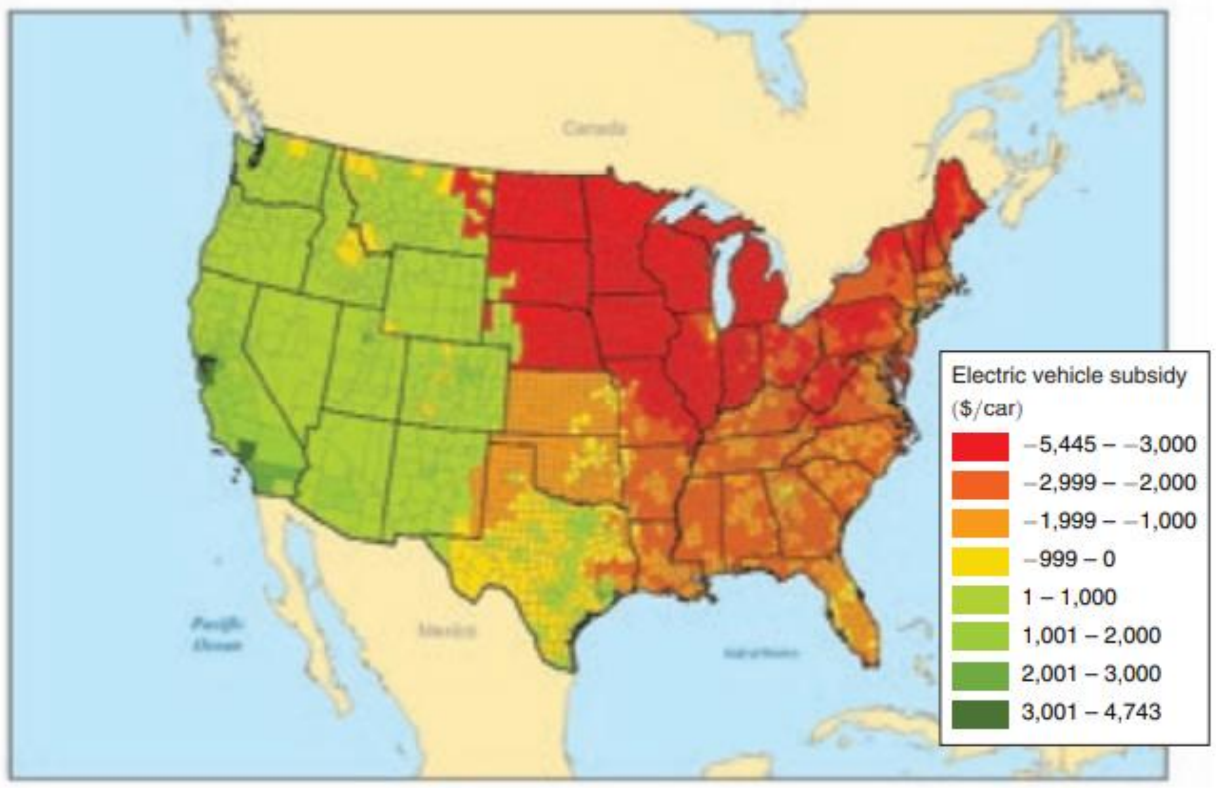
Environmental Benefits in Cents per Mile by Metropolitan Statistical Areas for a 2014 Ford Focus (Electric versus Gasoline)

Damage by type and location





Second-Best Electric Vehicle Subsidy by County



Conclusion

- The comparison of environmental externalities from driving gasoline and electric vehicles depends critically on damages from local pollution.
- Ignoring local pollution leads to an overestimate of the benefits of electric vehicles and an underestimate of the geographic heterogeneity