Should Electric Vehicle Drivers Pay a Mileage Tax?

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Abstract

In many countries the revenue from gasoline taxes is used to fund highways and other transportation infrastructure. As the number of electric vehicles on the road increases, this raises questions about the effectiveness and equity of this financing mechanism. In this paper, we ask whether electric vehicle drivers should pay a mileage tax. Though the gasoline tax has been traditionally viewed as a benefits tax, we take instead the perspective of economic efficiency. We derive a condition for the optimal electric vehicle mileage tax that highlights a key trade-off. On the one hand, there are externalities from driving including traffic congestion and accidents that imply a mileage tax is efficient. On the other hand, gasoline tends to be underpriced, so a low (or even negative) mileage tax might have efficiency benefits in encouraging substitution away from gasoline-powered vehicles. We then turn to an empirical analysis aimed at better understanding the current policy landscape for electric vehicles in the United States. Using newly available nationally-representative microdata we calculate that electric vehicles have reduced gasoline tax revenues by $250 million annually. We show that the foregone tax revenue is highly concentrated in a handful of states and is highly regressive, as most electric vehicles are driven by high-income households, and we discuss how this motivates and informs optimal policy.

Key Words: Electric Vehicles; Gasoline Tax, U.S. Highway Trust Fund, Distributional Impacts

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1 Introduction

In many countries the revenue from gasoline taxes is used to fund highways and other transportation infrastructure. In the United States, for example, the federal gasoline tax of 18 cents per gallon goes to the U.S. Highway Trust Fund and is used to pay for interstate highways, large infrastructure projects, and public transportation. Most U.S. states have a similar direct link between their gasoline tax and spending on transportation infrastructure.

Electric vehicle drivers do not pay the gasoline tax. Thus, as the number of electric vehicles on the road increases, this raises questions about the effectiveness and equity of this financing mechanism. Several states have considered implementing a mileage tax on electric vehicle drivers to make up for the lost revenue. However, there has been little economic analysis, either evaluating the economic efficiency of potential policy responses, or quantifying the revenue shortfall.

In the first half of the paper, we ask whether electric vehicles should pay a mileage tax. Though the gasoline tax has been traditionally viewed as a benefits tax, we take the perspective of economic efficiency. We write down a model of driving that incorporates externalities from gasoline-powered and electric vehicles, pre-existing markups in energy prices, and other features. We then use the model to derive a condition for the optimal electric vehicle mileage tax.

This exercise highlights a key trade-off. On the one hand, there are externalities from driving including traffic congestion and accidents that make it efficient to have a positive mileage tax on electric vehicles. On the other hand, gasoline tends to be underpriced, so a low (or even negative) mileage tax might have efficiency benefits in encouraging substitution away from gasoline-powered vehicles. We present relevant estimates from the empirical literature to shed light on the relative magnitudes of these two effects.

Then in the second half of the paper, we turn to an empirical analysis aimed at better understanding the current policy landscape for electric vehicles in the United States. Using newly available nationally-representative microdata we calculate that electric vehicles have reduced gasoline tax revenue in the United States by about $250 million annually. We show how much of this is federal versus state and local gasoline tax revenue, and we perform sensitivity analysis to show how this estimate changes with alternative assumptions.

We find that the foregone gasoline tax revenue is highly concentrated in a small number of states. In California alone, for example, we calculate $90 million in foregone gasoline tax revenue. This concentration reflects the uneven geographic distribution of electric vehicles across states, as well as the fact that states with more electric vehicles tend to have higher-than-average gasoline taxes (correlation 0.46, p-value $<.01$).

With our microdata, we are also able to examine distributional impacts. We show that electric vehicles are disproportionately driven by high-income households, with more than two-thirds of all foregone gasoline tax revenue coming from households with $100,000+ in annual income. This pattern is consistent with previous research showing that electric vehicles are highly concentrated among high-income households (Borenstein and Davis, 2015).

Our analysis has implications for the U.S. Highway Trust Fund (HTF) which in recent years has faced chronic revenue shortfalls (Langer et al., 2017). Since 2008, the U.S. Treasury has transferred $140 billion in general funds to the HTF in order to keep it solvent (Congressional Budget Office, 2016). Increased electric vehicle adoption threatens to further erode the financial viability of the HTF, so understanding and quantifying the impact of electric vehicles on U.S. federal gasoline tax revenue is a policy priority.

The paper proceeds as follows. Section 2 considers the normative question of whether electric vehicles should pay a mileage tax. We talk about the history of the gasoline tax as a benefits tax, discuss first-best policy, and derive a condition describing the optimal electric vehicle mileage tax. Section 3 introduces the data and presents descriptive statistics about the U.S. electric vehicle sector. Section 4 then calculates the foregone gasoline tax revenue from U.S. electric vehicles, as well as distributional impacts. Section 5 concludes.

2 Economic Efficiency

In this section we take a normative perspective and ask whether electric vehicles *should* pay a mileage tax. From an economic perspective, is it efficient that electric vehicles avoid paying a gasoline tax? Would a mileage tax on electric vehicles increase economic efficiency? Under what conditions? We discuss various considerations that determine the answer to these questions. We begin by describing the gasoline tax as a benefits tax on road use and derive the implications for taxing electric vehicles. We then discuss how externalities influence this view. We then provide a discussion and a mathematical model of second-best considerations that posit how favorable treatment of electric vehicles might be rationalized when the tax on conventional vehicles is too low. We conclude by considering how knowledge spillovers (learning by doing) might influence the optimal tax.

2.1 The Gasoline Tax as a Benefits Tax

The gasoline tax in the United States originated as a benefits tax. The idea of a benefits tax is that publicly provided goods and services should be paid for by the beneficiaries. The purpose of the gasoline tax was to fund transportation infrastructure. Thus, the gasoline tax is a classic benefits tax because the beneficiaries of transportation infrastructure are those who drive. The more one drives, the more one benefits and the more tax one will pay.

The gasoline tax was adopted in lieu of a mileage tax due to its administrative and compliance advantages. When the U.S. federal gasoline tax was first introduced in 1932, it was simply not technologically feasible to tax mileage. The gasoline tax has always been an imperfect proxy for a mileage tax. In particular, fuel economy differs across vehicles, so the implicit tax per mile driven is lower for fuel-efficient vehicles. But the gasoline tax is poised to become a much worse proxy as non-gasoline vehicles gain market share.

According to this benefits view, the fact that electric vehicles do not pay an equivalent road tax is an accident of instrument design. Electric vehicles benefit from transportation infrastructure in the same way as conventional gasoline-powered vehicles and, from a benefits perspective, should contribute proportionally to the funding of the public good. Exempting electric vehicles from the mileage tax that is proxied by the gasoline tax is akin to allowing electric vehicles to skip the tollbooth on a toll road.

It is in the spirit of a benefits tax that several states are now considering implementing a mileage tax.[1] Oregon, for example, passed legislation allowing 5,000 voluntary motorists to pay a mileage tax of 1.7 cents per mile, in lieu of gasoline taxes.[2] California, Washington, and Illinois are conducting mileage tax pilots.[3]

Does this approach make sense? Should electric vehicles pay a mileage tax? Or, is there an economic argument for exempting electric vehicles from road charges? To understand the possible answers to these questions, it is necessary to think about the

[1] Langer et al. (2017) argue that a mileage tax is more efficient than a gasoline tax, which would add an efficiency argument to the benefits rationale for shifting to a mileage tax.

[2] See http://www.myorego.org/. Participants in the Oregon program receive a refund for all gasoline taxes paid in exchange for participating in the program. Oregon previously conducted two pilot experiments for mileage taxes.

[3] See https://waroadusagecharge.org/, http://www.dot.ca.gov/road_charge/resources/final-report/, and http://ilga.gov/legislation/BillStatus.asp?DocTypeID=HB&DocNum=2864&GAID=15&SessionID=108&LegID=119167.

gasoline tax as not just a benefits tax but also a tax that targets externalities.

2.2 Externalities from Driving

Historically the gasoline tax was conceived as an appropriate funding mechanism for transportation infrastructure, but to an economist there is a happy coincidence that the gasoline tax also operates as a tax on externalities from driving. Driving creates several negative externalities, which we briefly review here.

First, there are several environmental externalities from driving. In general, driving causes (i) greenhouse gas emissions and (ii) local air pollution. With gasoline-powered vehicles, fuel is combusted in the vehicle and emissions come from the tailpipe. For electric vehicles, fuel use takes place at the power plant. Electric vehicles may be dirtier or cleaner per mile of use, depending on how the electricity is generated. In the United States, fossil-fuel plants are almost always the marginal source of electricity generation so even as more solar and wind capacity is added, it still makes sense to think about electric vehicles being powered by fossil fuels (Holland et al., 2016).[4]

In addition, driving causes (iii) traffic congestion and (iv) accidents. Previous attempts to quantify these externalities have found these to be quite substantial, probably larger in magnitude than the environmental externalities (Harrington et al., 2007).[5] Coady et al. (2018), calculates that the optimal tax for gasoline vehicles in the United States would be $2.23 per gallon, which includes $0.60 per gallon for environmental externalities plus $1.63 per gallon for traffic congestion and accidents. This second class of externalities tends to be similar across electric and

[4] This is true for any marginal vehicle or marginal mile traveled, which increases electricity demand to be met with the existing stock of power plants. Increased demand for electricity from EVs may alter investment in new generation, which might be renewable or may be new fossil generation.

[5] Relatedly, economists have long pointed out that pay-as-you-go vehicle insurance can be welfare improving by reducing mileage-related externalities (Parry, 2005).

gasoline-powered vehicles. Thus, while adopting an electric vehicle can potentially reduce environmental externalities, it does very little to reduce these other negative externalities.

2.2.1 The First-Best Tax

Because driving creates negative externalities, there is a normative case for a corrective tax on driving, regardless of the need for infrastructure funding. First-best would be to tax all externalities using vehicle-specific, time-varying, location-varying dynamic prices. For example, the marginal damages from traffic congestion vary greatly across locations and across time. Driving across a congested bridge at rush hour, for instance, imposes much larger external costs than driving along a quiet highway in the middle of the night.

Environmental externalities also vary widely across locations and across time. Driving a gasoline-powered vehicle in an urban area, for example, is much more damaging than driving in an area with lower population density. With gasoline-powered vehicles, the level of emissions also varies widely across individual vehicles, reflecting the age of the vehicle and the effectiveness of its emissions control equipment (Knittel and Sandler, 2018).

Similarly, the environmental externalities from electric vehicles vary across locations and across time depending on which power plant is on the margin in a given moment. Because the pollution from electric vehicles occurs upstream, it would make sense to tax those externalities at the power plant rather than at the "tailpipe." In a first-best world, electricity would be priced at social marginal cost, reflecting both the private costs of electricity generation as well as location-varying time-varying environmental externalities.[6]

[6]Recent research shows that U.S. electricity prices differ substantially from this Pigouvian ideal. Borenstein and Bushnell (2018) find that the price of electricity is too high in some places (e.g. California), and too low in most other places (e.g. the Midwest). Thus, in general, electricity

Neither gasoline taxes nor mileage taxes are first-best.[7] Gasoline taxes, in particular, are simply not dynamic enough to capture these highly differentiated externalities. As technology advances, it is possible that precisely tailored prices for vehicle use could exist. For example, mileage taxes could be made to be time varying and location varying. In practice, however, we are unlikely to see this degree of differentiation in the near future. Thus, we abstract from these considerations in the analysis that follows and derive implications for taxing electric and gasoline vehicle usage with a focus on the average damages from each.

2.3 Second-Best Considerations

Most economic analyses find that the gasoline tax in the United States is far below the level of external damages (Parry and Small, 2005; Harrington et al., 2007; Coady et al., 2018). As we discussed above, for example, Coady et al. (2018), calculates that the optimal tax for gasoline vehicles in the United States would be $2.23 per gallon, whereas in October 2018 the average U.S. gasoline tax was only $0.49, less than one-fourth as large.

If we take as given that gasoline-powered vehicles are undertaxed, how does this change the optimal tax for electric vehicles? In considering this question, it is useful to remember that electric and gasoline vehicles are close substitutes. We ignored this substitution in the discussion of the first-best outcome above because when gasoline and electric vehicles are both taxed at marginal damages, any induced substitution between types is economically efficient. Substitution has normative implications, however, when taxes are not set at the optimal levels.

In the second-best analysis, the inefficiencies in the transportation sector can be

prices fail to efficiently communicate the correct price signals for electric vehicle drivers.

[7] The second-best uniform tax in the presence of heterogenous damages is a weighted average of those heterogeneous damages, in which weights depend on who responds more to the tax (Diamond, 1973). These second-best considerations have been shown to be important for local pollution (Knittel and Sandler, 2018) and congestion (Martin and Thorton, 2017).

divided into two types. First, if the externalities from driving are insufficiently priced, then there will be too much driving overall (i.e., the "scale" or "market size" is wrong). Second, assuming that electric vehicles are less harmful than conventional vehicles on the margin, the "composition" of travel—how much of travel is electric mileage versus gasoline mileage—is incorrect. The market will use too many conventional vehicles, and not enough electric.

Imposing a mileage tax on electric vehicles thus has two effects. First, holding fixed gasoline miles driven, a tax will reduce how much electric vehicles are driven through a price effect. In general, this will increase efficiency because it corrects an unpriced negative externality from EV use. Second, however, it also causes drivers to substitute from electric vehicles to gasoline-powered vehicles. If the gasoline tax is inefficiently low, this will lead to inefficiencies in both scale and composition. The overall size of the transportation market will still be too large, and too large a fraction of miles will be driven in gasoline vehicles, as opposed to electric ones.

There could even be an argument made for a mileage *subsidy* for electric vehicles. Reducing the mileage tax on electric vehicles will lead to substitution away from gasoline vehicles, which improves composition. But this will also lower the cost of driving overall, which may exacerbate the pre-existing distortion in the overall market size.[8] Whether the tax on electric vehicle mileage should be below marginal damages thus depends on which of these factors dominates.

2.3.1 A Simple Model of the Second-Best Tax

In this section, we develop a simple model to characterize the way that an inadequate tax on miles traveled via gasoline vehicles affects the second-best tax on miles traveled via electric vehicles. We abstract from many important issues in this domain—including technology change, consumer heterogeneity, the vehicle purchase

[8] This is similar to the performance standard logic presented in Holland et al. (2009).

decision and the durable goods nature of vehicles— to deliver clear insight on our core question about mileage taxes.

Our goal here is to understand how electric vehicle usage should be taxed in a world in which policy has migrated away from a gasoline tax towards road charges, and in which the road charge can be different for gasoline and electric vehicles. We hold constant all other features of policy and the transportation system—road construction, traffic and safety laws, insurance regimes, etc. are all fixed in the background.

We model an economy with two goods that cause an externality—miles driven by electric vehicles (e) and miles driven by gasoline vehicles (g)—along with a quasilinear numeraire x. The externalities are constant per unit damages of ϕ_e and ϕ_g. Our focus is on cases where $0 < \phi_e < \phi_g$. That is, both goods have a negative externality, but e is relatively better (relatively "clean").

We assume both goods are produced at constant private marginal cost in competitive markets, so that equilibrium producer prices are P_e and P_g (with the price of x normalized to 1). This is an abstraction that rules out, for example, markups in electricity markets; a topic that we return to later. Income in the economy, denoted Y, is exogenous. Thus, there is no producer surplus and no labor supply distortions. Welfare is determined only by consumer surplus and the externality.

There is a measure one representative consumer with private utility $u(e, g) + x$. Under the budget constraint, consumers choose e and g to maximize $u(e, g) + (Y - P_e \times e - P_g \times g)$—i.e., they ignore the externality when making choices. The social planner accounts for the externality and maximizes social welfare (SWF):

$$SWF = u(e, g) + (Y - P_e \times e - P_g \times g) - (\phi_g \times g + \phi_e \times e).$$

In this setting, a planner can achieve the first-best outcome through standard Pigouvian taxes set equal to marginal damages. Our key question is what the second-best tax on e would be if, for some reason, the tax rate on g was set at the wrong level. This is meant to capture the case where gasoline miles are undertaxed. Does this justify an exemption for electric miles?

Denote taxes on electric miles and gasoline miles as t_e and t_g respectively. The case of interest is when $t_g < \phi_g$ and is fixed. The planner chooses only t_e to maximize social welfare, taking consumer choices conditional on prices as given. The second-best t_e, denoted as t_e^{SB} can be characterized by taking the first-order condition for the planner's problem and rearranging.

The second-best tax can thus be written as:

$$t_e^{SB} = \phi_e + \underbrace{(t_g - \phi_g)}_{-} \times \underbrace{\frac{-\partial g/\partial t_e}{\partial e/\partial t_e}}_{+}. \quad (1)$$

This result features the ubiquitous additivity property for second-best taxes on externalities (Kopczuk, 2003)—the second-best rate is the Pigouvian tax plus a term related to interactions of the price of the good with other distorted markets.

This additional term has two factors. The first factor $(t_g - \phi_g)$ is the wedge between private and social costs in the market for g, which is assumed negative in our primary case (the gasoline tax is too low). The second factor is a ratio of derivatives that captures how changes in the price of e impacts consumption of g and e. We will denote this ratio as $\theta \equiv -(\partial g/\partial t_e)/(\partial e/\partial t_e)$. As long as the goods are substitutes, θ will be positive (because of the negative sign in the numerator). (As discussed further below, its magnitude depends on how an increase in the price of electric vehicles changes total travel and the composition between e and g.) Thus, the second term in equation (1) is negative for our case of interest, which means that the optimal tax on electric miles is attenuated away from its marginal damages. Moreover, if e is cleaner than g, if gasoline mileage is sufficiently mispriced, and if there is substantial substitution between types of miles, the second-best policy can be a *subsidy* to electric mileage.

2.3.2 Discussion of Specific Cases

A couple of specific cases merit additional discussion. First, if there is no substitution from electric miles into gasoline miles ($\partial g/\partial t_e = 0$), then $\theta = 0$ and the second term in equation (1) goes to zero. In this case, the Pigouvian benchmark prevails: the optimal tax for electric vehicle miles is simply marginal damages. The reason is that, in this extreme case of no substitution, taxing electric vehicles has no impact on externalities from gasoline vehicles, so gasoline vehicle mispricing is irrelevant to the optimal policy for electric vehicles.

Another important case is when $-\partial g/\partial t_e = \partial e/\partial t_e$, so that $\theta = 1$. In this case, a change in the price of e causes a compositional change—gasoline miles rise and electric miles fall—but there is no scale effect (total travel, $e+g$, is fixed). With this type of one-for-one substitution, every reduction in electric vehicle miles travelled is offset exactly by an increase in miles traveled with gasoline-powered vehicles. There is precedent for $\theta = 1$ in the existing literature; for example, Xing et al. (2019) assume that annual vehicle-miles-traveled (VMT) is fixed and is the same for both electric and gasoline-powered vehicles.

When $\theta = 1$, the optimal tax on e is less than marginal damages by the amount that the tax on g falls short of its marginal damages; i.e., $t_e^{SB} - \phi_e = t_g - \phi_g$. In other words, the optimal wedges between private and social cost are equalized across markets. This result echoes results from the theory of the second best (Lipsey and Lancaster, 1956), in which one typically wants to spread tax distortions equally across markets because of the convexity of deadweight loss in tax wedges. In this case of one-for-one substitution, electric miles should be undertaxed to the same degree that gasoline miles are undertaxed.

One-for-one substitution is a useful baseline for interpreting the model, but there are reasons to believe that θ is less than 1. In particular, some of the reduced mileage from electric vehicles would likely be offset by increased travel via public transportation, cycling, walking, and other alternative forms of transportation. In addition, the overall demand for miles is presumably not perfectly inelastic, so drivers may take fewer or shorter trips. In the model, these behaviors are captured by a reduction in the sum $g+e$, and are represented by the case when $\theta < 1$. When $\theta < 1$, then equation (1) reveals that a tax on electric vehicle mileage should be less than the marginal damage ϕ_e, but this attenuation should be only some fraction of the mispricing wedge in gasoline miles $(t_g - \phi_g)$.

2.3.3 The Size and Sign of the Optimal Tax on Electric Miles

As a last modeling exercise, we decompose the second-best tax on electric vehicles into pollution and congestion and accident components. This decomposition facilitates a discussion of the plausible sign and magnitude of a tax on electric vehicle mileage.

As we discussed earlier, analysis of the optimal tax on gasoline has pointed out that taxing gasoline mileage has several components, including impacts on (i) greenhouse gas emissions, (ii) local air pollution, (iii) accidents and (iv) congestion. The latter two are, at least approximately, equal for electric vehicles and gasoline vehicles per mile traveled. To see how this matters for the optimal tax formula, it is useful to decompose the externality into components related to pollution ϕ^p and driving ϕ^d, so that $\phi_e = \phi_e^p + \phi_e^d$. Analogously, for gasoline, we can write $\phi_g = \phi_g^p + \phi_g^d$. If accident and congestion externalities per mile are equal across gasoline and electric vehicles, then $\phi_g^d = \phi_e^d$, and we denote these damages as simply ϕ^d.

In that case, we can rewrite equation (1) as:

$$t_e^{SB} = \phi_e^p + (1-\theta)\phi^d + \theta(t_g - \phi_g^p). \quad (2)$$

This version decomposes the optimal tax on electric miles into three categories.

The first term is a pollution tax. Note that this differs from the formulation in equation (1) because it is only the pollution component, not the accident and congestion component. Pollution from electric vehicles is located in the power sector. If all externalities were priced in the electricity market, then this term would be zero. Electricity prices are typically above private marginal cost because of the way that fixed costs are recovered in electricity markets. Borenstein and Bushnell (2018) find that in many parts of the United States electricity prices are above social marginal cost, while in many other parts electricity prices are below social marginal cost. Thus it probably does not make sense to pick a single value for this ϕ_e^p component and indeed, we would expect the sign of this component to differ across locations.

The second and third terms embody two factors that are weighted by θ, which we expect to be somewhat less than 1. The second term relates to accident and congestion externalities. If $\theta = 1$ (one-to-one substitution), then this term goes to zero. Intuitively, there is no way to reduce accident and congestion externalities through a tax on electric miles when there is complete substitution, as total travel $(e + g)$ is fixed. Alternatively, when a tax on e has no impact on g, then $\theta = 0$ and the full marginal damages from accidents and externalities should be added to the optimal tax. If only a portion of reduced electric miles reappear as gasoline miles, then the optimal tax on electric miles will include some proportion of the marginal damages from accidents and congestion, regardless of whether those externalities are taxed for gasoline miles. Note that $1 - \theta$ is equal to the change in total miles $(g + e)$ resulting from an increase in t_e divided by the change in electric miles resulting from an increase in t_e. The accident and congestion components of the optimal tax are generally thought to be substantial (Harrington et al., 2007; Anderson and Auffhammer, 2014; Coady et al., 2018), so if θ is much less than 1, then this component of the tax will be a large positive value.

The third term is the difference between the tax per mile on gasoline miles and *pollution* externalities from gasoline. This reflects the degree of underpricing of gasoline miles, scaled by the substitution pattern between electric and gasoline miles (θ). As we discussed above, for example, Coady et al. (2018), calculates that for the United States these pollution components (greenhouse gas emissions and local air pollution) are \$0.60 per gallon. In comparison, the average U.S. gasoline tax in October 2018 was \$0.49. Thus at an average fuel economy of 25 miles-per-gallon, this equates to a relatively small gap, $t_g - \phi_g^p$, of negative 2.4 cents per mile. In urban areas where local air pollution is more damaging, the gap is again negative, but in this case potentially quite large.

To summarize, the first term ϕ_e^p is positive in some parts of the United States, and negative in others. The second term is positive, and potentially quite large. The third term is close to zero on average in the United States, but is negative and potentially quite large in places where local air pollution is particularly damaging. Thus in general it is not possible to say whether the overall mileage tax on electric vehicles should be positive or negative. Many of these parameters vary across locations in complicated ways. Also, and perhaps most importantly, we lack guidance on the substitution pattern summarized in θ. This suggests a valuable direction for future research.

2.4 Learning-By-Doing

A final consideration abstracts from the current externalities caused by electric versus gasoline vehicles and instead emphasizes another externality in the production process of a new good. If there are non-appropriable learning by doing effects, then there is potentially good reason to subsidize electric vehicle production.

Exempting electric vehicles from a road charge provides an indirect subsidy for electric vehicle production. From a car buyer's perspective, there are two costs of an electric vehicle, the up-front purchase price and the operating costs, including most prominently the cost of fuel. Exemption from a road tax acts as a subsidy to the fuel cost portion and implicitly subsidizes the purchase of electric vehicles. This amount could be substantial. A simple back of the envelope suggests that exempting a road tax equivalent to the national average tax of 52 cents per gallon has a present discounted value on the order of $1,250 to $2,650.[9]

If learning by doing is driven by the number of vehicles that roll off of the assembly line (and not the number of miles driven), then the natural thing is to target the upfront purchase price, not the per mile fuel cost.[10] The reason is that mileage-related externalities still exist, regardless of learning spillovers. By cutting the price of a mile, a road tax exemption will exacerbate mileage-related externalities in exchange for more electric vehicles sold. This mileage distortion is unnecessary if one can directly target the purchase price through a tax credit.[11]

Given that there is in fact a generous subsidy on the books for each electric vehicle purchased, it seems unlikely to us that any optimal tax scheme for electric vehicles motivated by learning by doing would involve subsidies that come in the form of

[9] A tax of 52 cents per gallon translates into a tax of 1.8 cents per mile if fuel economy is 28.9 MPG, which we use above. We assume a 5% discount rate and 15,000 miles per year over 13 years, consistent with our baseline calculations above, for the high value. For the low value, we assume the same number of years but only 7,000 miles per year.

[10] As an aside, if consumers are myopic in their valuation of future fuel costs, as is sometimes suggested in the literature on the energy efficiency gap, then it would be fiscally inefficient to subsidize future fuel costs. One gets more bang for the buck by subsidizing the purchase price directly.

[11] One countervailing point is that implicit subsidies for electric vehicles through exemption from a mileage tax implies that high mileage drivers get a larger subsidy than low mileage drivers. This might have welfare benefits if it tilts EV adoption towards higher mileage drivers (in contrast to the current pattern of low mileage adoption (Davis, forthcoming)), though we suspect these welfare implications are small.

reducing the cost of mileage below social marginal cost. Instead, the strongest case for exempting electric vehicles from road charges appears to lie in the second-best considerations stemming from an inefficiently low tax on conventional vehicle use.

3 Electric Vehicles in the United States

In this section, we turn to the empirical analysis. Focusing on the United States, we examine the geographic pattern of electric vehicles and compare it to state-level gasoline tax rates. To estimate the foregone gasoline tax from electric vehicles we also need information about vehicle miles traveled and fuel economy, and we present relevant evidence. Our objective in this section is to introduce the policy landscape for electric vehicles in the United States, including some of the key evidence that motivates increased policy interest in a mileage tax for electric vehicles.

3.1 Household-Level Microdata

The primary dataset for our analysis is the newly-released 2017 *National Household Travel Survey* (NHTS) from the U.S. Department of Transportation. The NHTS is a large-scale nationally representative household survey with several features that make it particularly well-suited for this exercise.[12]

[12] Later we also compare some of our estimates to a report published by the Department of Energy based on registered vehicles. Researchers have on occasion worked directly with microdata on registered vehicles. For example, Archsmith et al. (2017) perform an analysis using California vehicle registration records from 2001-2007. But data on registered vehicles instead typically take more aggregated form. For example, Davis and Knittel (2019) uses data from Polk Automotive on census-tract level vehicle type counts for 2012. Another potential approach would be to use microdata from vehicle emissions testing. For example, Knittel and Sandler (2018) and Jacobsen et al. (forthcoming) use data from California's *Smog Check* program. However, electric vehicles are exempt from emissions testing, making this data source unhelpful in our context. Moreover, any analysis using emissions testing data would necessarily be restricted to the states that have such programs. In contrast, the NHTS is publicly available nationally-representative microdata with detailed information both on vehicle type and household characteristics.

Most importantly, the NHTS has detailed information about all household vehicles. For our analysis we consider three vehicle categories: (1) all-electric vehicles (e.g. the Nissan Leaf), (2) plug-in hybrid vehicles which can run on either electricity or gasoline (e.g. the Chevy Volt), and (3) all other vehicles. The NHTS has much more information, including the exact make, model, and vintage of all vehicles but we do not use that information in this analysis.

The NHTS also has information about household characteristics. Each household reports annual family income—which we use for the distributional analysis. Each household also reports its state of residence—information which allows us to incorporate state-level gasoline tax rates (see Section 3.3).

Surveying for the 2017 NHTS took place during 2016 and 2017, though for expositional simplicity we describe the results as being for 2017. Prior to the 2017 NHTS, the most recent NHTS was conducted back in 2009, when there were virtually no electric vehicles on the road, so this represents one of the first opportunities for such an analysis.

A nice feature of the 2017 NHTS is the large sample size. In this latest wave of the NHTS, there are almost 130,000 total households, and 256,000 total vehicles, including 400+ all-electric and 400+ plug-in hybrid vehicles. This sample size ends up being large enough to make relatively precise statements, particularly at a national level and for large states. The sample for the NHTS is selected using stratified sampling, so sampling weights are used throughout the paper in all calculations.

A notable limitation of the NHTS is the low response rate. The 2017 NHTS has a lower response rate than previous waves, only 15.6% according to the survey documentation. The NHTS sampling weights attempt to correct for non-response by balancing observable household characteristics, but, of course, respondents and non-respondents can also differ along other dimensions. The implied total number of electric vehicles in the 2017 NHTS is consistent with aggregate data on electric vehicle sales, so the data seem to provide a reasonable description of the broader pattern of electric vehicles, but it is impossible to rule out concerns about non-response bias, so this is worth highlighting as an important caveat.

3.2 The Geographic Pattern of U.S. Electric Vehicles

Figure 1 plots the density of electric vehicles by U.S. states, measured as the number of electric vehicles per 1000 vehicles. Here and for most of the analysis we include both all electric vehicles and plug-in hybrids. The figure shows that electric vehicles are highly concentrated in a relatively small number of states.

Table 1 reports the top U.S. states for electric vehicles. California has by far the most electric vehicles of any state, with about 40% of all electric vehicles. Another state near the top of the list is Georgia, where electric vehicles have long received extra subsidies. Overall, these top ten states account for 75% of the estimated total 782,000 electric vehicles in the United States as of 2017.

With the large sample size in the 2017 NHTS, these statistics are estimated relatively precisely for larger states, but should be interpreted cautiously for smaller states. The broader pattern in Figure 1 and Table 1 is consistent with data from vehicle registrations. In particular, the Department of Energy reports electric vehicle registrations by state, and the overall pattern is quite similar with California, Washington, Arizona, Georgia, and Maryland all having many more electric vehicles than other states.[13]

[13] U.S. Department of Energy, "PEV registrations U.S. Department of Energy Analysis of IHS Automotive Data," December 10, 2018.

3.3 U.S. Gasoline Taxes

Figure 2 plots gasoline taxes by state. This map was constructed using information on gasoline taxes by state for October 2018 from the *American Petroleum Institute*. The figure reports the total combined gasoline tax including the federal tax of 18 cents per gallon as well as all state and local taxes.

Figure 3 plots the distribution of gasoline taxes across states. The average total combined tax is 52 cents per gallon, but ranges widely from Pennsylvania at 77 cents per gallon to Alaska at 33 cents per gallon. The distribution is modestly right-skewed, with Pennsylvania, California, Washington, Hawaii, New York, Michigan, Connecticut and Indiana all charging gasoline taxes at least one standard deviation above the mean.

We calculate gasoline tax impacts using the actual geographic distribution of electric vehicles across U.S. states. As Figure 1 shows, this geographic distribution is highly uneven with, for example, large numbers of electric vehicles in relatively high gasoline tax states like California, Washington, and New York. The correlation between the number of electric vehicles per 1000 vehicles and the gasoline tax is positive, strong (0.46), and statistically significant (p-value $<.01$).

Figure 4 is a scatterplot of electric vehicles versus the gasoline tax. Each observation is a U.S. state and the figure includes a least squares regression line from regressing the number of electric vehicles on the gasoline tax. The figure illustrates the pronounced positive correlation, with more electric vehicles in states with higher gasoline taxes.

There is, of course, a plausible causal relationship. Choosing whether to purchase an electric vehicle is, like most durable good decisions, an intertemporal trade-off between purchase price and operating costs (Hausman, 1979; Dubin and McFadden, 1984). Gasoline taxes increase the operating cost of gasoline-powered vehicles, making electric vehicles more attractive. Moreover, vehicle buyers have been shown to be relatively attentive to gasoline prices in choosing which gasoline-powered vehicle to purchase (Busse et al., 2013; Allcott and Wozny, 2014; Sallee et al., 2016; Grigolon et al., 2018), so it would make sense that buyers would also pay attention to gasoline prices when choosing whether to buy a gasoline-powered vehicle at all.

Still the positive correlation likely also reflects omitted variables. Many of the states in the upper right quadrant of the scatterplot could be characterized as "green," mostly democratic states with long-standing support for environmental issues. Previous research has shown that environmental ideology is a major determinant of adoption of energy-efficient vehicles (Kahn, 2007), and these preferences likely also influence opinions about the gasoline tax. Regardless of the exact mechanism, this positive correlation implies that the total level of foregone gasoline tax is higher than what would be calculated with a naive estimate ignoring this correlation. We show in Section 4.4 that this is quantitatively important.

3.4 Vehicle Miles Traveled

To estimate the foregone gasoline tax revenue from electric vehicles, we need to make an assumption about how much electric vehicles are driven. Or, more specifically, we need to make an assumption about how much drivers with electric vehicles would have *otherwise* driven in gasoline-powered vehicles. For our baseline estimates we assume that all vehicles are driven 15,000 miles per year, following Holland et al. (2016).

This level of driving intensity is consistent with several previous studies. For example, Archsmith et al. (2015) assume that vehicles have a total lifetime of 159,700 miles, equivalent to about 10 years at 15,000 miles per year. Moreover, Federal CAFE standards use an assumed lifetime for cars and trucks of 195,000 miles (Leard and McConnell, 2017), equivalent to 13 years at 15,000 miles per year. Estimates from the U.S. Federal Highway Administration imply that U.S. vehicles are driven somewhat less, an average of 12,000 miles annually.[14]

We also report estimates assuming vehicles are driven 7,000 miles per year. This lower driving intensity comes from data from the 2017 NHTS. NHTS respondents fill out an "Odometer Mileage Record Form" which requires them to write down the current odometer reading for all vehicles in the household. Dividing odometer readings by the age of each vehicle yields 7,000 annual miles traveled for electric vehicles compared to 10,200 miles traveled for gasoline-powered vehicles. See Davis (forthcoming) for details.

If indeed it were true that electric vehicles are driven much less than other vehicles, it would be a bit surprising. Electric vehicles tend to cost less to operate per mile than gasoline-powered vehicles (Sivak and Schoettle, 2018), so the "rebound effect" (see, e.g. Borenstein, 2015) implies that drivers should use them more. Still, several other potential explanations could explain lower miles traveled by electric vehicles.

Probably the most obvious potential explanation is limited range. The first generation Nissan Leaf, for example, has a range of less than 80 miles, making it impractical for longer trips. While public charging stations are becoming more common, electric vehicle charging remains nowhere near as convenient as filling up a gasoline-powered vehicle (Li et al., 2017; Li, 2018). Limited range thus could affect both who buys an electric vehicle and how electric vehicles are used.

Another potential explanation is substitution across vehicles for multiple-vehicle households. Only 10% of U.S. households with an electric vehicle are single-vehicle households (Davis, forthcoming). Thus in most cases, electric vehicle drivers are

[14]U.S. Federal Highway Administration, *Highway Statistics 2016* estimates that total U.S. miles traveled in 2016 were 3.2 trillion. *Highway Statistics 2016* reports that in that same year there were 269 million total registered vehicles in the United States, implying an average of 11,896 miles traveled per vehicle.

able to substitute between electric- and non-electric vehicles. Multiple-vehicle households may prefer to use their electric vehicles for short trips, while using their gasoline-powered vehicles for longer trips.[15]

A final potential explanation is selection. It could be that the type of households who tend to buy electric vehicles tends to live in more urban areas, or in areas with stronger "green" preferences, where people tend to drive fewer miles per year. This is broadly consistent with the geographic pattern of electric vehicles in Figure 2 with high- numbers of electric vehicles in states like California, Washington, and New York.

3.5 Fuel Economy

To calculate gasoline tax revenue impacts, we also need to make an assumption about the fuel economy of the counterfactual vehicle. What would electric vehicle drivers otherwise be driving? If they otherwise would have been driving highly fuel-efficient vehicles, this reduces the gasoline tax revenue impact. As mentioned before, electric vehicle drivers may tend to live in urban areas and be motivated in part by "green" ideology, so there is reason to believe these counterfactual vehicles may tend to be smaller and more fuel-efficient than the average U.S. vehicle.

For this assumption we follow a recent working paper aptly titled "What Does an Electric Vehicle Replace?" which sets out to answer this exact question (Xing et al., 2019). The paper leverages rich data from a household survey of new vehicle buyers in which buyers are asked about their second-choice vehicles. Xing et al. (2019) use this information together with aggregate data on vehicle sales and a random coefficients discrete choice model to simulate what purchases would have been were electric vehicles not available.

[15] In related work, Archsmith et al. (2017) shows that households substitute between vehicle attributes when deciding which vehicles to purchase. For example, a household with one fuel-efficient vehicle may be more likely to purchase a second vehicle that is less fuel-efficient.

The authors find that electric vehicles replace relatively fuel-efficient vehicles. In particular, the authors find that electric vehicles replace vehicles with an average fuel economy of 28.9 miles-per-gallon. As a point of comparison, the authors point out that among all new U.S. vehicles, the average fuel economy is 23 miles-per-gallon, so counterfactual vehicles are on average 27% more fuel-efficient than the national average.

The substitution patterns are interesting too. The authors find that only 12% of replaced vehicles are conventional hybrids like the Toyota Prius. Instead, they find that most electric vehicle drivers would have otherwise purchased relatively fuel-efficient mid-sized cars like the Honda Accord, Honda Civic, and Toyota Corolla, with few electric vehicle buyers otherwise buying a large SUV or truck. It is worth noting that their data comes from vehicle model years 2010-2014 before most sales of the Tesla Model S or the introduction of the Tesla Model X, so substitution patterns may have changed somewhat since the period of their data.

In the results that follow we use 28.9 miles-per-gallon as our baseline assumption, while also reporting alternative results for 25 and 35 miles-per-gallon.

4 Foregone Gasoline Tax Revenue from U.S. EVs

4.1 Baseline Estimates of Foregone Tax

We calculate the foregone gasoline tax revenue from U.S. electric vehicles using the following formula,

$$\Delta R = \sum_{s=1}^{S} \{(\tau^F + \tau_s^S) * VMT * \frac{1}{MPG} * EV_s\}$$

where variables are defined as follows:

ΔR	change in annual gasoline tax revenue, in dollars
τ^F	federal gasoline tax, measured in dollars per gallon
τ_s^S	state gasoline tax in state s, measured in dollars per gallon
VMT	annual miles driven per vehicle in counterfactual
MPG	miles per gallon of the vehicle in counterfactual
EV_s	number of electric vehicles in state s.

In our baseline results, we assume that electric vehicle drivers would have otherwise driven a 28.9 miles-per-gallon vehicle 15,000 miles per year, i.e. $MPG = 28.9$ and $VMT = 15,000$. In this counterfactual each electric vehicle driver would have otherwise used 519 gallons of gasoline annually,

$$= VMT * \frac{1}{MPG} = 15,000 * \frac{1}{28.9} = 519.$$

Table 2 reports baseline estimates. Total annual foregone tax revenue is $249 million. This is equivalent to $318 annually for each of the 782,000 electric vehicles in the United States as of 2017. Of this, 30% ($75 million) is foregone federal tax, and the other 70% ($174 million) is foregone state and local tax. As a point of comparison, total state fuel tax receipts were $41 billion in 2015[16], so this is less than half of 1%, reflecting the relatively small number of electric vehicles.

Table 3 ranks the top ten most affected states. California is by far the most affected state, with an estimated $86 million in foregone gasoline tax revenue. The rest of the top ten are states with large numbers of electric vehicles, states with high gasoline tax rates, and both. Washington State enters the top three, for example, because it has both a large proportion of electric vehicles and one of the highest gasoline tax rates. Altogether these ten states experience 80% of the all foregone state and local tax revenue.

[16] U.S. Federal Highway Administration, "Highway Statistics", *State Motor Fuel Tax Receipts.*

4.2 Comparison to Naive Estimate

Table 4 shows how the baseline results change under alternative assumptions. Total foregone tax revenue is 20% lower ($199 million) under a naive calculation which ignores the geographic distribution of electric vehicles across states. As we showed in Figure 4, there is a pronounced positive correlation between gasoline tax rates and electric vehicles.

Our baseline estimate accounts for the observed positive correlation between τ_s and EV_s, while assuming that the other variables VMT and MPG are the same across states. In contrast, with the naive estimate we instead use the *average* U.S. gasoline tax rate, where weights are equal across states. This results in a smaller estimate because it ignores the positive correlation between electric vehicles and gasoline taxes, putting too much weight on states with low gasoline taxes, and too little weight on states with high gasoline taxes.

Using the standard properties of expectations,

$$E(\tau * EV) = E(\tau) * E(EV) + Cov(\tau, EV).$$

The expectation of the product of two variables is only equal to the product of the expectations if the two variables are independent. In this case, the two variables have a positive covariance so our baseline estimate using $E(\tau * EV)$ is larger than the naive estimate using $E(\tau) * E(EV)$.

4.3 Alternative Assumptions

Table 4 also shows results for a variety of additional alternative parameters. Perhaps the two hardest factors to verify empirically are the counterfactual mileage VMT and miles-per-gallon MPG. If we assume drivers would have otherwise driven only

7,000 miles annually (instead of 15,000), then the estimate of foregone tax is much smaller, only $116 million. This underscores that electric vehicles reduce gasoline tax revenues to the degree to which their adoption reduces driving in gasoline-powered vehicles.

The table also performs sensitivity analyses about the MPG assumption. If we assume electric vehicle drivers would have otherwise been driving a 35 miles-per-gallon vehicle (rather than 28.9 miles-per-gallon), this reduces the foregone tax to $206 million. In contrast, if electric vehicles are replacing relatively fuel-inefficient gasoline-powered vehicles (25 miles-per-gallon rather than 30), then the foregone gasoline tax revenue is $288 million.

Foregone tax scales linearly with VMT and GPM (i.e. the inverse of MPG). Accordingly, when we use VMT which is 53% lower (7,000 instead of 15,000), the foregone tax revenue is 53% lower. Similarly, when we use GPM which is 16% higher (1/25 instead of 1/28.9), the foregone tax revenue is 16% higher. Thus for these two parameters it is relatively straightforward to scale the effects with regard to alternative scenarios. In contrast, the other parameters vary by state and thus are more difficult to scale.

Finally, our baseline estimate treats all-electric vehicles (e.g. the Nissan Leaf) and plug-in hybrid vehicles (e.g. the Chevy Volt) equivalently. But, plug-in hybrids can also be operated using gasoline. We have not seen any systematic evidence on driving behavior by plug-in hybrid drivers, i.e. the fraction of miles driven using electricity and gasoline. Our baseline estimate implicitly assumes that these plug-in hybrids are always driven using electricity but in the final sensitivity analysis in the table we instead assume that plug-in hybrids are driven 50% of the time using gasoline. About half of the electric vehicles in our data are plug-in hybrids, so this change reduces the estimate by about 25% to $192 million.

Table 4 provides a sense of how our results vary with alternative assumptions, but the table is also useful for thinking about how tax revenue impacts might change in the future. For example, if we expect electric vehicles in the future to increasingly substitute for high-VMT vehicles (e.g. taxi fleets), this will increase the impact on gasoline tax revenues. Or, as another example, if the overall stock of gasoline-powered vehicles continues to become more fuel-efficient, this will decrease the implied gasoline tax revenue impacts of electric vehicles.

4.4 Distributional Impact

Finally, Figures 5 and 6 describe the distributional pattern. As illustrated in Figure 5, high-income households are much more likely to drive electric vehicles. Electric vehicles as a percentage of all vehicles increases from close to 0% for annual incomes below $25,000, to 1% for annual incomes $75,000-$125,000, to 4% for annual incomes above $200,000.[17]

The pattern for foregone tax revenue in Figure 6 is very similar. The average foregone gasoline tax is less than $2 per household annually for households with annual income below $100,000, increasing to $12 per household annually for households with annual income above $200,000. In terms of aggregate impacts, more than two-thirds of all foregone tax comes from households with $100,000+ in annual income. Moreover, the very top income category ($200,000+) is responsible for 31% of all foregone tax despite representing only 5% of U.S. households.

In related work, Muehlegger and Rapson (2018) measure the effect of subsidies on electric vehicle adoption using evidence from a California program aimed at low- and middle-income households. They find that demand for electric vehicles is less elastic than previous estimates in the literature for conventional hybrid vehicles

[17] This pattern is consistent with previous evidence on income tax credits for electric-vehicles. In particular, Borenstein and Davis (2015) find that the top income quintile received 90% of all U.S. federal electric vehicle tax credits between 2009 and 2012. For previous studies on the distributional impact of gasoline taxes see, for example, Poterba (1991), West (2004), Bento et al. (2009), and McMullen et al. (2010).

(Chandra et al., 2010; Gallagher and Muehlegger, 2011), perhaps reflecting range anxiety and other barriers that exist with electric vehicles but not conventional hybrids. Results from Muehlegger and Rapson (2018) imply that large subsidy increases would be necessary for electric vehicle adoption to spread widely beyond high-income households.

5 Conclusion

Almost one million electric vehicles have now been sold in the United States.[18] Some industry observers expect this to accelerate. California, for example, aims to have 1.5 million electric vehicles on the road by 2025, and 5 million electric vehicles on the roads by 2030 (California Office of the Governor, 2018). Internationally, there is perhaps even greater enthusiasm. A recent report from the International Energy Agency (IEA), for example, highlights a goal of 30% electric vehicle penetration by 2030 (International Energy Agency, 2017).

We provide an economic analysis of what this growth could mean for gasoline tax revenue. Even though U.S. gasoline taxes are the lowest among all OECD countries (Knittel, 2012), each electric vehicle still results in $300+ in foregone gasoline tax revenue annually, according to our calculations. Electric vehicles are still less than 1% of all U.S. registered vehicles so the aggregate impacts are relatively modest ($250 million annually), but this could scale quickly under rapid increased adoption of electric vehicles.

For example, the International Energy Agency's reference scenario has the global stock of electric vehicles increasing 2x by 2020, 6x by 2025, and 12x by 2030 (International Energy Agency, 2017). Assuming a proportional increase in the United

[18] *Inside EVs* estimates total cumulative U.S. electric vehicles sales to be 930,000 as of December 31, 2018. See *https://insideevs.com/monthly-plug-in-ev-sales-scorecard-historical-charts/*. This includes plug-in hybrids and all-electric models.

States, and holding everything else equal, this would increase the annual gasoline tax revenue impacts to $500 million, $3 billion, and $6 billion, respectively. It is always hard to make accurate predictions about emerging technologies but it is worth noting that this is the *least* optimistic of the scenarios considered by IEA, with other scenarios predicting 20x, 30x and even 40x increases by 2030.

The more important and probably more interesting question is whether electric vehicles *should* be exempt. We ask, in particular, whether electric vehicles should pay a mileage tax, along the lines of Oregon's *OreGO* program in which participants pay 1.7 cents per mile in lieu of paying the gasoline tax. This turns out to be a much harder question than we first envisioned. Indeed, it is not even clear based on our analysis whether the optimal mileage tax for electric vehicles is positive or negative.

Our model illuminates several key factors that are worth considering in future analyses. Perhaps most important, gasoline is not efficiently priced, and this is a significant baseline distortion to take into account. In particular, our results highlight that when gasoline is priced well below social marginal cost as it is in the United States, then it is probably not efficient to tax electric vehicle mileage because this leads to substitution toward gasoline vehicles.

If policymakers have two instruments, there is an argument for combining a purchase subsidy with a usage tax. For example, the U.S. federal $7,500 income tax credit for electric vehicles could be combined with a mileage tax for electric vehicles, thereby encouraging substitution toward electric vehicles, while discouraging driving thereby reducing externalities.

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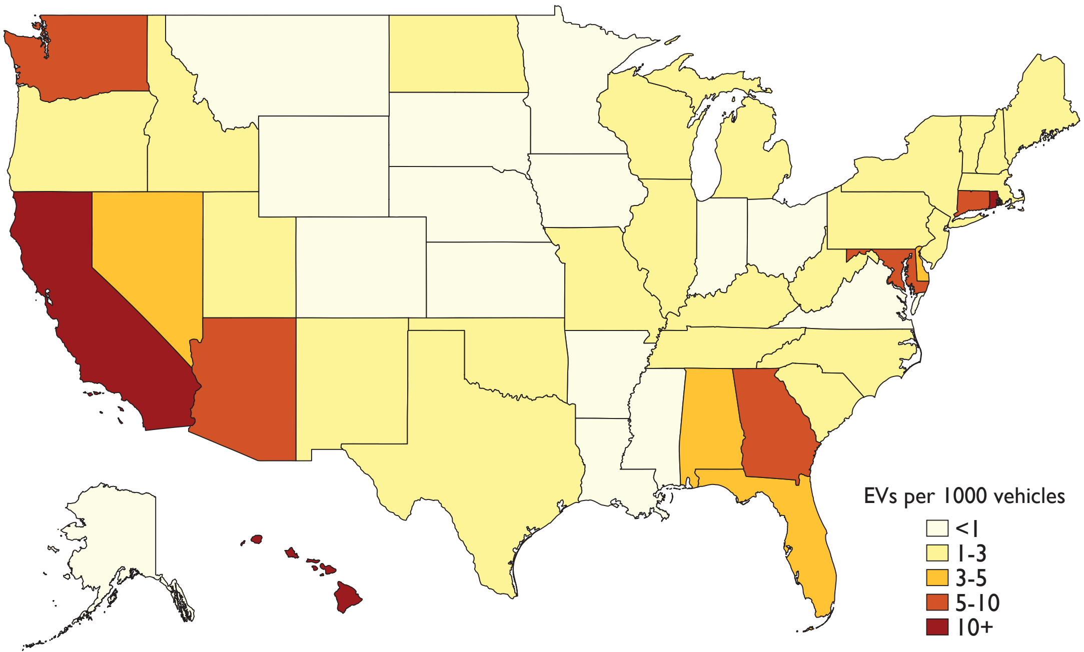
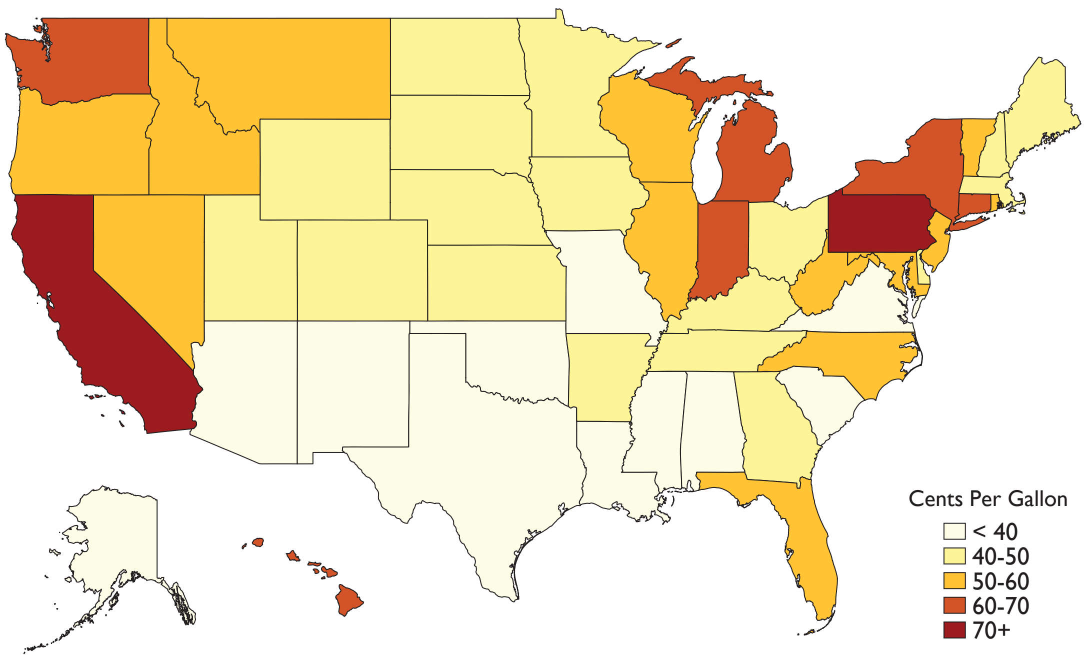
Figure 1: Electric Vehicles By State, 2017



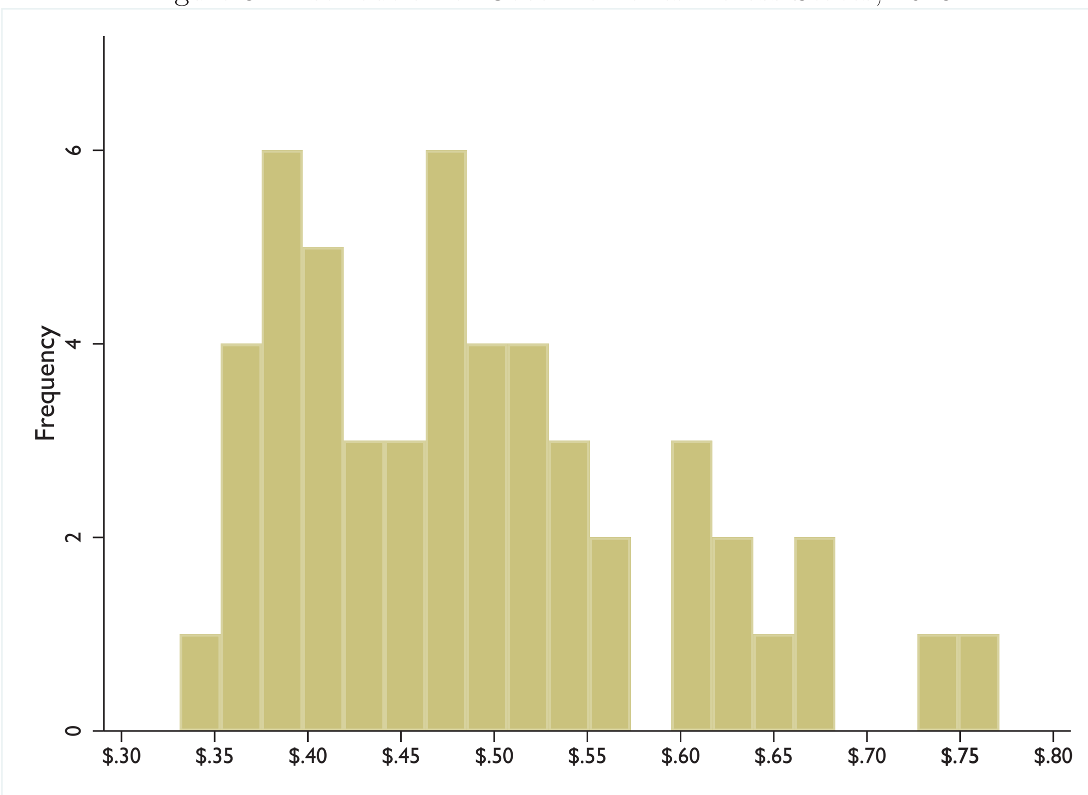
Note: This map plots the number of electric vehicles per 1000 vehicles. This map was constructed by the authors using data from the 2017 National Household Travel Survey. All estimates were calculated using NHTS sampling weights. Electric vehicles include plug-in hybrids and all-electric vehicles.

Figure 2: Gasoline Tax By State, 2018



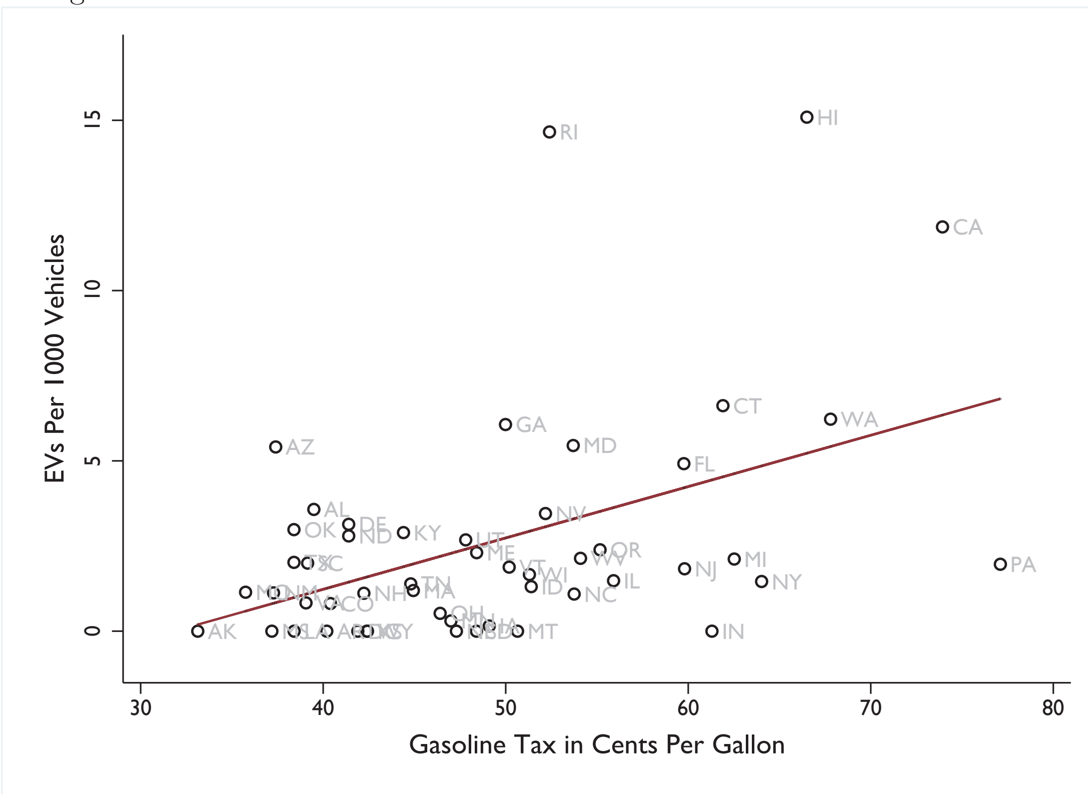
Note: This map was constructed by the authors using data from the *American Petroleum Institute* and include all local, state, and federal taxes as of October 2018.

Figure 3: Distribution of Gasoline Taxes Across States, 2018



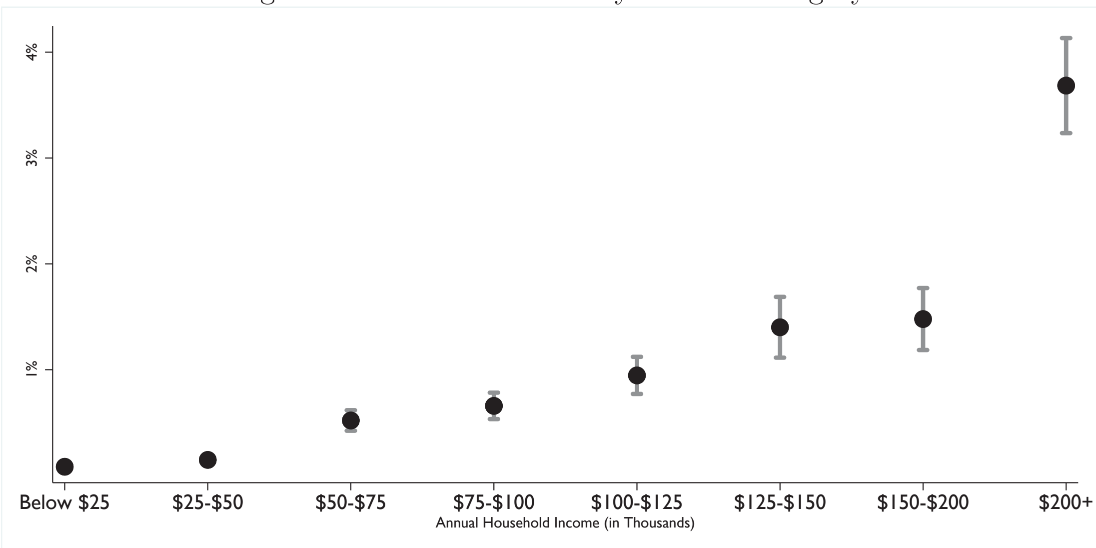
Note: This histogram was constructed by the authors using data from the *American Petroleum Institute* and include all local, state, and federal taxes as of October 2018.

Figure 4: Positive Correlation Between Electric Vehicles and Gasoline Taxes



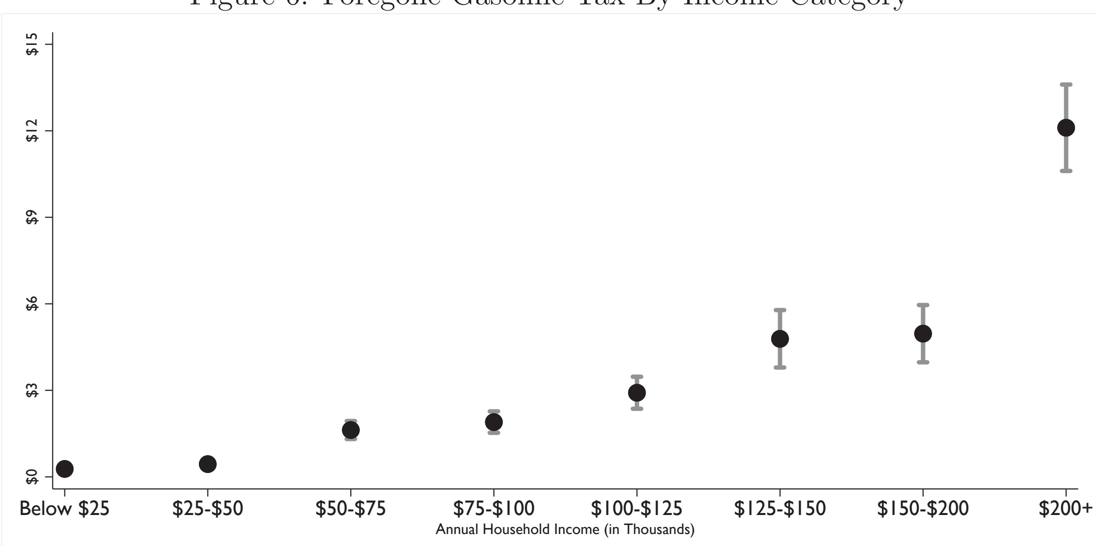
Note: This figure was constructed by the authors using vehicle information from the 2017 National Household Travel Survey and gasoline tax data from the *American Petroleum Institute*. The number of electric vehicles per 1000 vehicles was calculated using NHTS sampling weights, and includes both plug-in hybrids and all-electric vehicles. The gasoline tax data are from October 2018 and include all local, state, and federal taxes.

Figure 5: Electric Vehicles By Income Category



Note: This figure reports electric vehicles as a percentage of all vehicles, by household income category. This information was calculated by the authors using the 2017 National Household Travel Survey. Estimates were calculated using NHTS sampling weights, and include both plug-in hybrids and all-electric vehicles.

Figure 6: Foregone Gasoline Tax By Income Category



Note: This figure was constructed by the authors assuming electric vehicle drivers would have otherwise driven a 28.9 miles-per-gallon gasoline-powered vehicle 15,000 miles per year. Gasoline tax data are from the *American Petroleum Institute* for October 2018 and include all local, state, and federal taxes. See Figure 5 notes for additional details.

Table 1: Top U.S. States for Electric Vehicles

	Total Number of Electric Vehicles
California	310,000
Florida	63,000
Georgia	44,000
Texas	38,000
Washington	34,000
Arizona	26,000
Maryland	24,000
Pennsylvania	18,000
New York	17,000
Michigan	16,000
Total Top Ten States	589,000
Total All Other States	192,000
U.S. Total	**782,000**

Note: This table reports estimates of the number of electric vehicles by state. The top ten states are listed. Numbers are rounded to the nearest thousand. This information was constructed by the authors using data from the 2017 National Household Travel Survey. Numbers were calculated using NHTS sampling weights. Electric vehicles include plug-in hybrids and all-electric vehicles.

Table 2: Foregone Gasoline Tax Revenue

Federal	\$ 75 million
State and Local	\$ 174 million
Total	**\$ 249 million**

Note: This table reports the estimated impact of electric vehicles on U.S. gasoline tax revenue in 2017. Estimates assume electric vehicle drivers would have otherwise driven a 28.9 miles-per-gallon gasoline-powered vehicle 15,000 miles per year. Electric vehicles include plug-in hybrids and all-electric vehicles.

Table 3: Foregone Gasoline Tax Revenue, By State

	Foregone State and Local Gasoline Tax Revenue (in Millions of Dollars)
California	89.3
Florida	13.6
Washington	8.6
Georgia	7.2
Pennsylvania	5.6
Maryland	4.4
New York	4.0
Texas	3.9
Michigan	3.7
Connecticut	3.6

Note: This table reports estimated impacts on state and local tax gasoline tax revenue in 2017. The top ten states are listed. Estimates assume electric vehicle drivers would have otherwise driven a 28.9 miles-per-gallon internal combustion vehicle 15,000 miles per year. Electric vehicles include plug-in hybrids and all-electric vehicles.

Table 4: Foregone Gasoline Tax Revenue, Robustness

Baseline Estimate	$ 249 million
Naive Estimate Ignoring Where Electric Vehicles Driven	$ 199 million
Assuming 7,000 miles Driven Annually	$ 116 million
Assuming Otherwise 35MPG Vehicle	$ 206 million
Assuming Otherwise 25MPG Vehicle	$ 288 million
Assuming Plug-In Hybrids Driven 50% Gasoline	$ 192 million

Note: This table reports the estimated impact of electric vehicles on U.S. gasoline tax revenue in 2017, under alternative assumptions. In the baseline estimates, electric vehicle drivers are assumed to have otherwise driven a 28.9 miles-per-gallon gasoline-powered vehicle 15,000 miles per year.