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How Much Are Electric Vehicles Driven?

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Abstract

The prospect for electric vehicles as a climate change solution hinges on their ability to reduce gasoline consumption. But this depends on how many miles electric vehicles are driven and on how many miles would have otherwise been driven in gasoline-powered vehicles. Using newly-available U.S. nationally representative data, this paper finds that electric vehicles are driven considerably fewer miles per year on average than gasoline and diesel-powered vehicles. The difference is highly statistically significant and holds for both all-electric and plug-in hybrid vehicles, for both single- and multiple-vehicle households, and both inside and outside California. The paper discusses potential explanations and policy implications. Overall, the evidence suggests that today's electric vehicles imply smaller environmental benefits than previously believed.

Key Words: Electric Vehicles; Plug-in Hybrids; Vehicle Miles Traveled, Rebound Effect

JEL Codes: D12, L62, Q41, Q54, Q55

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1 Introduction

Many studies have pointed out that where in the country you drive an electric vehicle has important implications the environment. This point has been made repeatedly – both in the economic (Zivin et al., 2014; Holland et al., 2016) and engineering literatures (Tessum et al., 2014; Tamayao et al., 2015). Another important factor is how much you drive. This has received far less attention, but has major implications for the environmental impact of electric vehicles.

After all, it isn't the manufacturing of electric vehicles that gives them their environmental edge. If anything, the copper, aluminum, lithium, cobalt, and other materials used to build batteries actually make electric vehicles more resource intensive (Notter et al., 2010). Altogether, the negative externalities from manufacturing have been calculated to be $1,500+ higher for electric vehicles than for gasoline-powered vehicles (Michalek et al., 2011).

Instead, the prospect for electric vehicles as a climate change solution hinges on their ability to reduce gasoline consumption. But how much gasoline is actually saved when a driver buys an electric vehicle? This depends, crucially, on how many miles the electric vehicle is driven and on how many miles the driver would have otherwise driven in a gasoline vehicle.

This paper uses newly-available nationally representative data from the U.S. Department of Transportation's *National Household Travel Survey* (NHTS) to provide some of the first evidence on how much electric vehicles are driven. 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 to measure vehicle miles traveled (VMT) for electric vehicles.

These data show that electric vehicles are driven considerably less on average than gasoline- and diesel-powered vehicles. In the complete sample, electric vehicles are driven an average of 7,000 miles per year, compared to 10,200 for gasoline and diesel-powered vehicles. The difference is highly statistically significant and holds for both all-electric and plug-in hybrid vehicles, for both single- and multiple-vehicle households, and both inside and outside California.

This pattern is surprising because electric vehicles tend to cost less to operate per mile, so should be attractive to high-mileage drivers (Sivak and Schoettle, 2018). Instead, it appears that the exact opposite has happened, with low-mileage drivers being more likely to buy electric vehicles. Limited range, particularly for the first generation of electric vehicles, has likely played a key role, so this pattern may change over time as more long-range electric vehicles are introduced.

The evidence suggests that today's electric vehicles imply smaller environmental benefits than previously believed. The less electric vehicles are driven, the smaller the implied reductions in gasoline consumption, and thus the smaller the implied reductions in carbon dioxide emissions. Current policies like the U.S. federal $7,500 electric vehicle tax credit treat low- and high-mileage drivers uniformly, so don't provide the right incentive to induce adoption by high-mileage drivers.

2 Preliminary Evidence

Figure 1 shows average miles driven per year for four different categories of vehicles. This figure was constructed using data from the 2017 *National Household Travel Survey* (U.S. Department of Transportation, 2018). A valuable feature of the NHTS is that respondents fill out an "Odometer Mileage Record Form" which requires them to write down the current odometer reading for all vehicles in the household. For this analysis, these odometer readings were divided by the age of each vehicle to calculate the average number of miles driven per year.

Thus according to these data, electric vehicles are driven considerably less than other types of vehicles. All-electric and plug-in hybrid vehicles are driven 6,300 and 7,800 miles annually, respectively, compared to 10,200 for gasoline and diesel vehicles, and 12,000 for conventional hybrids.[1]

This pattern is somewhat surprising. Purchasing any vehicle requires a buyer to make an intertemporal tradeoff between purchase price and operating costs.[2] Relative to gasoline-powered vehicles, electric vehicles tend to cost more to purchase but less to operate, so consumer guides recommend electric vehicles for high-mileage drivers (McDonald, 2016). Thus the basic economics of electric vehicles implies the exact opposite of what is observed in Figure 1, with electric vehicles being driven more miles per year than other vehicles.

[1]The overall average of about 10,000 miles driven per year is consistent with previous studies using data from the 2009 NHTS (see, e.g. Archsmith et al., 2015). Similarly, Levinson (forthcoming), shows using data from the 2009 NHTS that conventional hybrids tends to be driven more than gasoline- and diesel-powered vehicles, consistent with the two right-most bars in Figure 1.

[2]A related literature on gasoline-powered vehicles finds that vehicle buyers are relatively attentive to future operating costs (Busse et al., 2013; Allcott and Wozny, 2014; Sallee et al., 2016). These studies are closely related to an older literature on a broader class of energy-related investments (Hausman, 1979; Dubin and McFadden, 1984).

The pattern in Figure 1 also goes against what would be implied by the "rebound effect" (see, e.g. Borenstein, 2015). Electric vehicles tend to cost less to operate per mile (Sivak and Schoettle, 2018), so drivers should use them more.[3] Thus the rebound effect provides another reason why to expect, *ceteris paribus*, the exact opposite of what is observed in Figure 1, with electric vehicles being driven *more* than other vehicles.

Figure 2 examines whether this pattern is different for vehicles owned by California households. About half of all U.S. electric vehicles are in California, so this breakdown is of significant intrinsic interest. Moreover, electricity rates in California are higher-than-average (Borenstein and Bushnell, 2018), so one might have expected to see lower mileage for California electric vehicles. As it turns out, however, the pattern is roughly similar for California- and non-California electric vehicles. In both cases, these data show that all-electric and plug-in hybrid vehicles are driven considerably less than other types of vehicles.

3 Additional Analyses

Table 1 compares average annual miles driven for electric- and non-electric vehicles. Across the entire sample, electric vehicles are driven an average of 7,000 miles per year, compared to 10,200 miles per year for gasoline and diesel vehicles. Thus, in the 2017 NHTS electric vehicles are driven 30% less than other vehicles.

This pattern holds for several different subsamples. First, although plug-in hybrids tend to be driven more than all-electric vehicles, both types of electric vehicles are driven significantly less than other types of vehicles. Second, the pattern holds both for single-vehicle and multiple-vehicle households, suggesting that the pattern cannot be completely explained by within-household substitution across vehicles. Third, the pattern holds both in California, and outside California, consistent with the evidence in Figure 2.

These differences cannot be explained by sampling variation. For each row the table reports the p-value from a test that the means in the two subsamples are equal. In all cases the differences are highly statistically significant. In the latest wave of

[3] Early electric vehicle adopters were even able in some cases to charge their vehicles for free. During its early years, Tesla famously offered buyers unlimited free charging for life on its fast-charging network, though this practice was ended for buyers placing an order after January 1, 2017. See, e.g., Tim Higgins, "Tesla Motors Plans to Charge for Its Quick-Charge Access" *Wall Street Journal*, November 6, 2016.

the NHTS there are 400+ all-electric and 400+ plug-in hybrid vehicles, so there are enough electric vehicles to make these comparisons precisely.

Before proceeding, it is worth noting a couple of features about the NHTS. The sample for the NHTS is selected using stratified sampling, so sampling weights are used throughout the paper in all calculations. A notable advantage of the National Household Travel Survey is the large sample size – 129,696 households in the 2017 survey. This large sample size is the reason why there are enough electric vehicles in order to make these comparisons.

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 electric vehicle ownership rate in the 2017 NHTS is consistent with aggregate data on electric vehicle sales (Davis, forthcoming), so at a minimum the data does seem to provide a reasonable description of the broader pattern of electric vehicle ownership, but it is impossible to rule out concerns about non-response bias, so this is worth highlighting as an important caveat.

4 Potential Explanations

Thus the evidence shows that in the United States, electric vehicles tend to be driven considerably fewer miles per year than other vehicles. This section discusses possible explanations and then the following section considers policy implications.

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 impact both who buys an electric vehicle and how electric vehicles are used.

It is not clear how much limited range should matter for plug-in hybrids. With a plug-in hybrid, a driver always has the option to run on gasoline, so they are not subject to the same range limitations as all-electric vehicles. Still, many plug-in hybrid vehicle drivers purchased their vehicles with the intention to use primarily powered by electricity, so this may affect both the type of driver who buys a plug-in and how these vehicles are used.

A related issue is substitution across vehicles for multiple-vehicle households. Table 2 shows that households with electric vehicles are much more likely to be multiple-vehicle households. In particular, 90% of all households with an electric vehicle are multiple-vehicle households. Thus in most cases, electric vehicle owners are substituting between electric- and non-electric vehicles, just like households have been shown to substitute between other vehicle attributes (Archsmith et al., 2017). Multiple-vehicle households may prefer to use their electric vehicles for short trips, while using their gasoline-powered vehicles for longer trips. This type of substitution thus could help explain the lower average annual mileage for electric vehicles.

Most other potential explanations are variations on the type of person who buys an electric vehicle (i.e. selection). For example, urban vs rural differences could help explain the pattern. Urban households may be more likely to buy electric vehicles, perhaps because of stronger green preferences in urban areas, and may also tend to drive fewer miles per year.[4] In addition to urban vs rural, the pattern could be influenced by other differences between "green" and less "green" communities. Previous research has shown that environmental ideology is a major determinant of adoption of energy-efficient vehicles (Kahn, 2007), and it could simply be that these tend to be places where people drive less.

5 Policy Implications

> "It seems a foregone conclusion, both in policy and media representations, that electric vehicles are a climate change solution. However determining the potential greenhouse gas benefit from electric vehicles is complicated." -Archsmith et al. (2015).

Americans have now purchased more than 800,000 electric vehicles, counting both plug-in hybrids and all-electric models. Although this is still less than one percent of all U.S. registered vehicles, policymakers see electric vehicles as having great

[4]Income differences, in contrast, are unlikely to explain the pattern. Previous research has shown that electric vehicle ownership is strongly correlated with income. Borenstein and Davis (2015), for example, shows using data from U.S. income tax returns, that the top income quintile has received 90% of all electric vehicle tax credits. But high-income drivers tend to drive *more* than other households (Bento et al., 2005; Levinson, forthcoming), so if anything income differences tend to lead electric vehicles to be driven more.

potential to reduce carbon dioxide emissions and other forms of pollution, and are supporting tax credits and other policies to encourage people to buy electric vehicles. 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).

How much electric vehicles are driven has major implications for the effectiveness of these policies. In particular, the less electric vehicles are driven, the smaller the environmental benefits from electric vehicle adoption.

Take the following example. Holland et al. (2016) finds that the environmental benefits from replacing a gasoline vehicle with an electric vehicle in California are worth $2,800 over the lifetime of the vehicle. The authors make this calculation assuming that all vehicles are driven 15,000 miles per year. If, instead, each electric vehicle is avoiding only 7,500 miles per year driven in a gasoline vehicle, then the benefits are half as large, only $1,400.

The assumption by Holland et al. (2016) that vehicles are driven 15,000 miles per year is not unusual in the literature. Another well-known model in this space is the GREET model, which assumes that electric vehicle batteries are used for a lifetime of 160,000 miles (Michalek et al., 2011). Archsmith et al. (2015) assumes that all vehicles have a total lifetime of 257,000 kilometers (159,700 miles). Moreover, Federal CAFE standards use an assumed lifetime for cars and trucks of 195,000 and 225,000 miles, respectively (Leard and McConnell, 2017). All of these measures seem high relative to the newly-available evidence from the 2017 NHTS. For example, dividing 195,000 by 7,500 mile per year, implies an implausibly long average lifetime of 26 years.

The broader point is that mileage matters for electric vehicle policy. The goal is to reduce gasoline consumption, but current policies like the $7,500 federal tax credit treat low-mileage and high-mileage drivers uniformly. A better approach would be a carbon tax (or, equivalently, increasing the gasoline tax). Making gasoline more expensive would incentivize electric vehicles for all drivers, but the biggest incentive would be for people who drive a lot of miles.

Figure 1: How Much Are Electric Vehicles Driven?

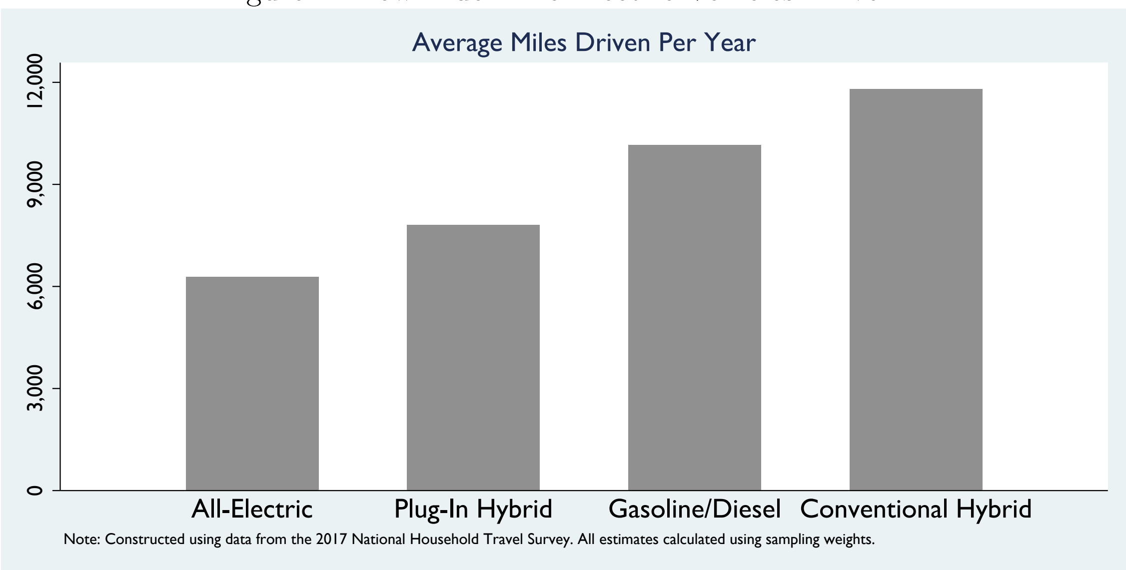

Figure 2: Is This Pattern Different in California?

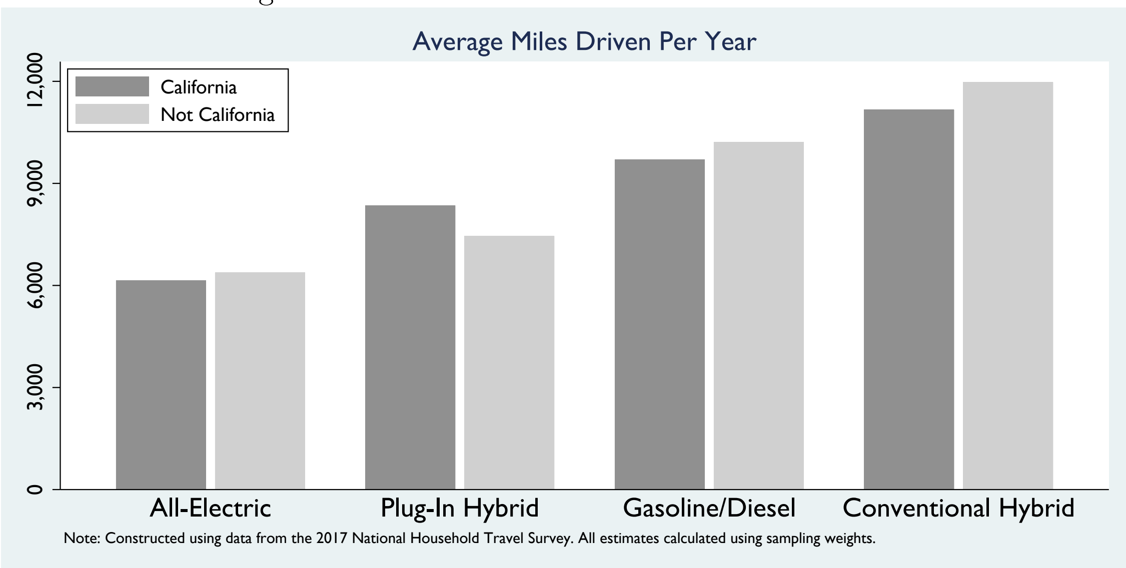

Table 1: How Much Are Electric Vehicles Driven?

	(1) Electric Vehicles	(2) All Other Vehicles	(3) p-value (1) vs (2)
Entire Sample	7,000	10,200	0.00
All-Electrics Only	6,300	10,200	0.00
Plug-in Hybrids Only	7,800	10,200	0.00
Single-Vehicle Households	7,600	10,000	0.00
Multiple-Vehicle Households	7,000	10,200	0.00
California Only	7,200	9,800	0.00
Excluding California	6,900	10,200	0.00

Note: This table reports average miles driven per year for electric- and non-electric vehicles in the 2017 *National Household Travel Survey*. Except where indicated, electric vehicles include both all-electric and plug-in hybrids. The last column reports p-values from tests that the means in the two subsamples are equal. All estimates are calculated using sampling weights and have been rounded to the nearest 100.

Table 2: Number of Vehicles Per Household

	U.S. Households with at least one vehicle	U.S. Households with at least one electric vehicle
Single Vehicle	37%	10%
Two Vehicles	36%	46%
Three Vehicles	16%	26%
Four or More Vehicles	10%	18%

Note: This table was constructed using data from the 2017 *National Household Travel Survey*. Electric vehicles include both all-electric and plug-in hybrids. All percentages are calculated using sampling weights.

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