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in the United States**

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# Plug-in vehicles and the future of road infrastructure funding in the United States

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## Abstract

In the United States, the road infrastructure funding is declining due to an increase in fuel efficiency and the non-adjustment of fuel taxes to inflation. Propositions to tax plug-in vehicles have been proposed or implemented in several states. Those propositions are contrary to policies to promote the sale of fuel efficient vehicles. This paper assesses (1) the magnitude of the decline in federal fuel tax revenue caused by plug-in vehicles and (2) quantifies the amount of revenue that could be generated from a federal plug-in vehicle registration fee. We find that the contribution of plug-in vehicles to the decline of the federal fuel tax revenue is at most 1.56% and that the majority of the shortfall can be attributed to the non-adjustment of the fuel tax rate by 2040. An additional tax of \$50-\$200 per plug-in vehicle per year in the reference case would generate \$188-\$745 million in 2040 which represents an increase of 1.7% - 6.7% in federal fuel tax revenue compared to no tax. The lesson for policy makers is that plug-in vehicles do not contribute significantly to the funding shortfall in the short- and medium-run and a supplemental tax would generate a small percentage of additional revenue.

## 1 Introduction

Many countries rely on gasoline and diesel taxes to finance their road infrastructure. This funding model is not viable in the long-run if an increasing number of highly fuel efficient plug-in vehicles replaces the current vehicle stock. In the United States, the promotion of plug-in vehicles, i.e., plug-in hybrid and battery electric vehicles, receives considerable attention and funding due to concerns about energy independence,

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energy efficiency, and greenhouse gas emissions (EISA, 2007). The U.S. federal government provides income tax credits as high as \$7,500 to incentivize the purchase of battery electric vehicles (Krause et al., 2013). Similarly, state and local governments provide credits or exemptions to sales taxes, excise taxes, registration fees, and parking fees (Gallagher and Muehlegger, 2011). At the same time, expenditures for transportation infrastructure have risen as the source of revenues to fund that infrastructure have remained stagnant.

There is growing concern that government incentives to increase the plug-in vehicle fleet have, and will continue to, negatively impact revenues from gasoline and diesel taxes; the two primary sources of revenue dedicated to road construction and maintenance. Previous research suggests that state and federal fuel tax revenue, under various scenarios, could decrease by as much as 5% and 12.5% by 2020 and 2030, respectively (Hajjamiri and Wachs, 2010). Though, plug-in vehicles are not the only factor affecting gasoline and diesel tax revenues. At least three other factors have contributed to the stagnation in transportation revenues over past decades. Those factors include: (1) the general increase in fuel efficiency of conventional gasoline vehicles; (2) a recent stagnation in annual vehicle miles traveled (VMT) (Federal Highway Administration Office of Highway Policy Information, 2012b); and (3) the inflexibility of the tax base, i.e., fuel taxes are fixed per gallon of consumption with no adjustment for inflation at the federal level and in most states.

This paper focuses on the impact of the expected growth in the plug-in vehicle fleet within the context of fuel taxes that are not adjusted for inflation. We also compare the potential of an annual tax or registration fee at the federal level on plug-in vehicles under current sale projections. Adding that context provides valuable information about the expected impact of funding mechanisms on revenue over time. Specifically, we extend the current research in this area in two ways: First, we quantify the magnitude of the road construction and maintenance funding shortfall associated with an increase in plug-in vehicles. We compare that shortfall to the continued practice of not adjusting fuel taxes to inflation. Second, we forecast how much revenue may be expected from an annual tax or registration fee on plug-in vehicles under the current sales projections to determine if such a tax could alleviate the expected funding shortfall.

For our analysis, we build a simulation model based on projections from the 2014 Annual Energy Outlook (AEO) by the U.S. Energy Information Administration (EIA). The scenarios include variations in the economic framework, (e.g., economic growth, oil price, and vehicle miles traveled), and policy framework, (e.g., carbon price and extension of current policies). We show that the majority of the funding shortfall is due to the non-adjustment of fuel taxes. Little can be attributed to the presence of plug-in vehicles and a registration fee would not alleviate the funding shortfall. Given the tension between the desire of policy makers to increase alternative fuel vehicles and transportation infrastructure funding, the lesson for decision makers is that in the context of energy security and energy efficiency, policies to promote plug-in vehicles are at least in the short- to medium-run adequate.

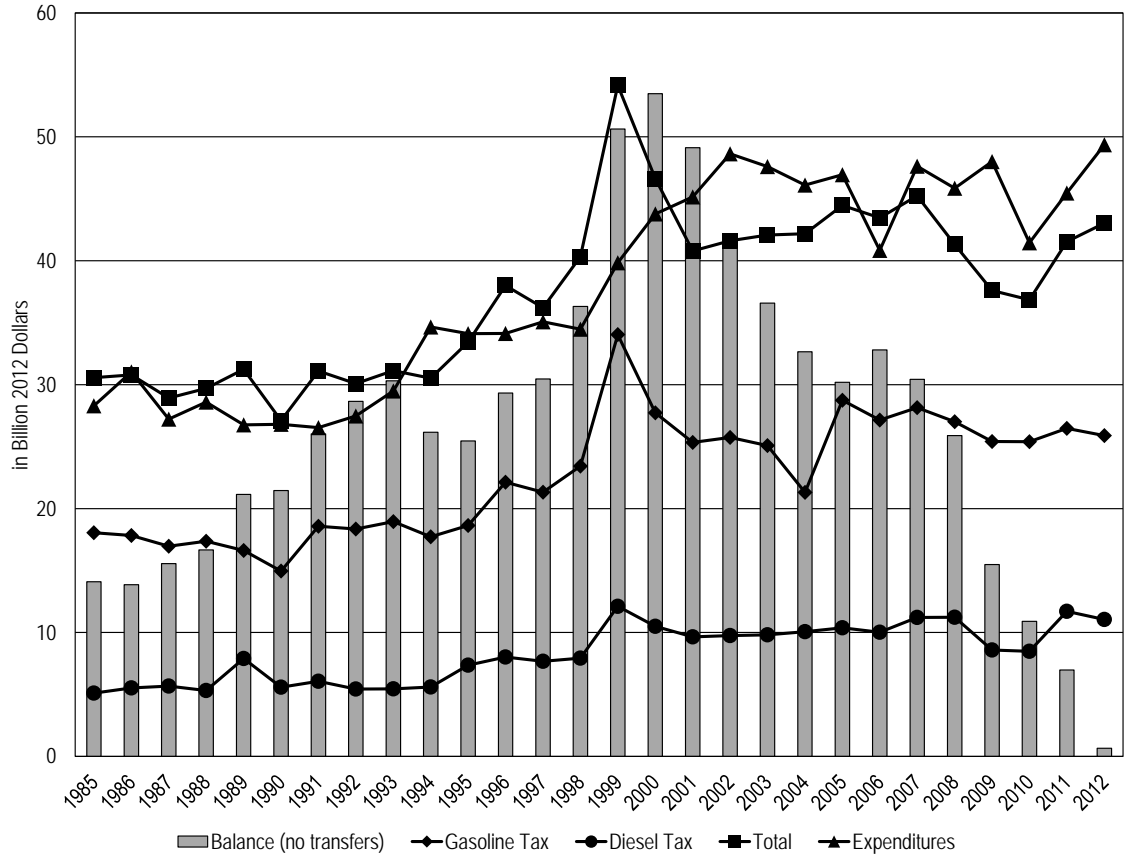


Figure 1: Evolution of the Highway Trust Fund. “Gasoline” and “Diesel” refers to the net income from fuel taxes. The “Total” includes both fuel taxes as well as all other income from excise taxes. ”Outlays” refers to the expenditures by the Highway Trust Fund (Federal Highway Administration Office of Highway Policy Information, 2012a). The revenue shortfall is calculated based on the starting balance in 1984 and the subsequent excise tax revenue and expenditures. Transfers from U.S. Congress to the Highway Trust Fund are not included.

## 2 Background

The consumption-based tax revenue raised at the federal level contributes to the Highway Trust Fund which was established by the Highway Revenue Act of 1956 (DOT/FHWA, 1998). The current federal taxes are \$0.184 and \$0.244 per gallon of gasoline and diesel, respectively. In addition to the federal fuel taxes, states collect gasoline and diesel taxes as well to fund local infrastructure projects. Generally, the growing concern is that expenditures associated with road construction and maintenance are outpacing revenues (Kile, 2011; Ungemah et al., 2013). The current primary revenue-related issue for transportation infrastructure is the extent to which transportation construction and maintenance is tied to gasoline and diesel consumption. Between 1980 and 2012, average fleet fuel efficiency increased from 15.97 to 23.31 miles per gallon which

represents a 30% reduction in fuel consumption (U.S. DOT Bureau of Transportation Statistics, 2015). The number of vehicle miles traveled (VMT) also has stagnated over the past decade. Perhaps part of the general reduction in VMT may be explained by the recent economic recession. While there may be an increase in VMT in future years, the extent of that increase is expected to be inconsequential (Federal Highway Administration Office of Highway Policy Information, 2012b). Finally, gasoline and diesel taxes are set as a fixed amount per gallon without being adjusted to inflation at the federal level and in most states, i.e., the real tax rate is declining over time. The last adjustment at the federal level occurred in 1993 and some states have not adjusted their per-gallon gasoline tax since 1961 (ITEP, 2014). The federal fuel tax rate effectively decreased by 30% due to inflation since the last adjustment. The effects of those developments on the Highway Trust Fund are shown in Figure 1.

Since 2008, U.S. Congress had to authorize an augmentation from the United States' General Fund to keep the Highway Trust Fund solvent; transferring \$8 billion in 2008, \$7 billion in 2009, and \$19.5 billion in 2010. It is estimated that the Highway Trust Fund will become insolvent if no further augmentations are made by Congress (Cawley, 2013). In 2012, the U.S. Federal Highway Administration (FHWA) reported that over 5,000 bridges in the national highway system were "structurally deficient." The total cost of replacing all structurally deficient bridges was estimated at over \$17 billion. To rehabilitate the current structures to bring them out of the deficient category would cost an estimated \$11.6 billion (Federal Highway Administration, 2012). Given the solvency issues associated with the Highway Trust Fund at the federal level and the fuel tax revenue at the state level, plug-in vehicles have been identified as a fourth possible problem associated with decrease in funding available for road construction and maintenance.

Given the erosion of the tax base, some states have addressed the current loss in transportation-related revenue by charging an additional annual registration fee for plug-in vehicles. For instance, North Carolina's battery electric vehicle owners pay an annual fee of \$100 to partially compensate for the absence of fuel tax contributions. Similarly, an "Electric Vehicle Plug-In Registration" for fully electric vehicles that "is not lower than \$100" was introduced in Massachusetts (MA Legislature, 2014). Virginia and Washington have introduced a tax on battery electric vehicles. Other states are discussing a tax as well (Bloomberg, 2013). There is a lack of empirical evidence to suggest that these fees will adequately address the funding shortfalls and this paper aims to close that knowledge gap at the federal level.

### 3 Methods

The EIA's 2014 Annual Energy Outlook projections are our primary source of data to model the impact of plug-in vehicles on the current and future funding gap of the Highway Trust Fund as well as the effects of possibly taxing plug-in vehicles at the federal level. The EIA provides projections for a reference case which assumes current policies with a 2.4% average gross domestic product (GDP) growth rate between 2012 to

2040 and a \$141 (in 2012 dollars) oil price by the end of the projection period (EIA, 2014). The EIA models 29 scenarios for comparison to the reference model. Those different scenarios reflect potential variation in policies, GDP growth, and oil price evolution. We selected data from 12 scenarios (including the reference case) that are directly related to transportation funding for our models.<sup>1</sup> Specifically, the retained scenarios include vehicle stocks for gasoline, plug-in hybrid, and battery electric vehicles that differ more than 5% from the baseline (Figure 2). Building our simulation around the EIA scenarios allows us to analyze the sensitivity associated with different assumptions, such as oil price evolution, economic growth, or vehicle miles traveled.

We focus on the light-duty vehicle stock in general and more specifically examine the impact of four plug-in vehicles on transportation funding: “100 Mile Electric Vehicle” (BEV100), “200 Mile Electric Vehicle” (BEV200), “Plug-in 10 Gasoline Hybrid” (PHV10), and “Plug-in 40 Gasoline Hybrid” (PHV40).<sup>2</sup> All four vehicle technologies are expected to grow the fastest with projected average annual growth rates of 13% for battery electric vehicles and 14.9% for plug-in hybrid vehicles between 2012 and 2040 (EIA, 2014).<sup>3</sup> We compare the plug-in vehicles to their conventional counterparts, i.e., gasoline, diesel, and E85 vehicles including conventional hybrids. For its projections, the EIA distinguishes between “cars” and “light truck” in the light duty vehicle category. We uphold this distinction for gasoline, diesel, and E85 vehicles but not for the conventional hybrids and plug-in vehicles. In the EIA reference case, the share of light trucks in the plug-in and conventional hybrid categories is less than 4% and 7%, respectively. Thus, we expect the impact on our simulation results to be small when grouping the conventional hybrid, plug-in hybrid, and battery electric vehicles in the car category. Grouping the vehicles has the advantage that fewer parameters are necessary in the simulation part of our analysis.

To determine the effects of plug-in vehicles on fuel tax revenue in the simulation model, we vary the vehicle stock and the VMT as a function of the price of gasoline, diesel, and E85. Note that other factors affecting VMT, such as economic growth or policies, are already taken into account by the projections from the EIA. The gasoline, diesel, and E85 consumption is a direct function of the fuel economy (MPG), vehicle stock ( $S$ ), and VMT. The gasoline consumption for cars ( $gas_c$ ), trucks ( $gas_t$ ), conventional gasoline hybrids ( $hyg$ ), and plug-in hybrid vehicles ( $PHV10$  and  $PHV40$ ) is written as

$$C_{gas} = \sum_{i \in \{gas_c, gas_t, hyg\}} S_i \cdot \frac{VMT_i}{MPG_i} + \sum_{j \in \{PHV10, PHV40\}} S_j \cdot \frac{VMT_j \cdot uf_j}{MPG_j}$$

where  $uf_j$  refers to the utility factor dividing the energy consumption of plug-in hybrid vehicles into a charge sustaining and charge depleting mode. The charge sustaining mode refers to the condition where

<sup>1</sup>We eliminate scenarios that do not directly impact the road transportation sector such as nuclear and coal policies, coal cost, rail technology, and residential and commercial sector equipment efficiency.

<sup>2</sup>The numbers 10 and 40 for the PHEV10 and PHEV40 refer to the all-electric range in miles before switching to gasoline.

<sup>3</sup>The other alternative fuel vehicles analyzed by the EIA are expected to have a share of less than 0.15% in 2040.

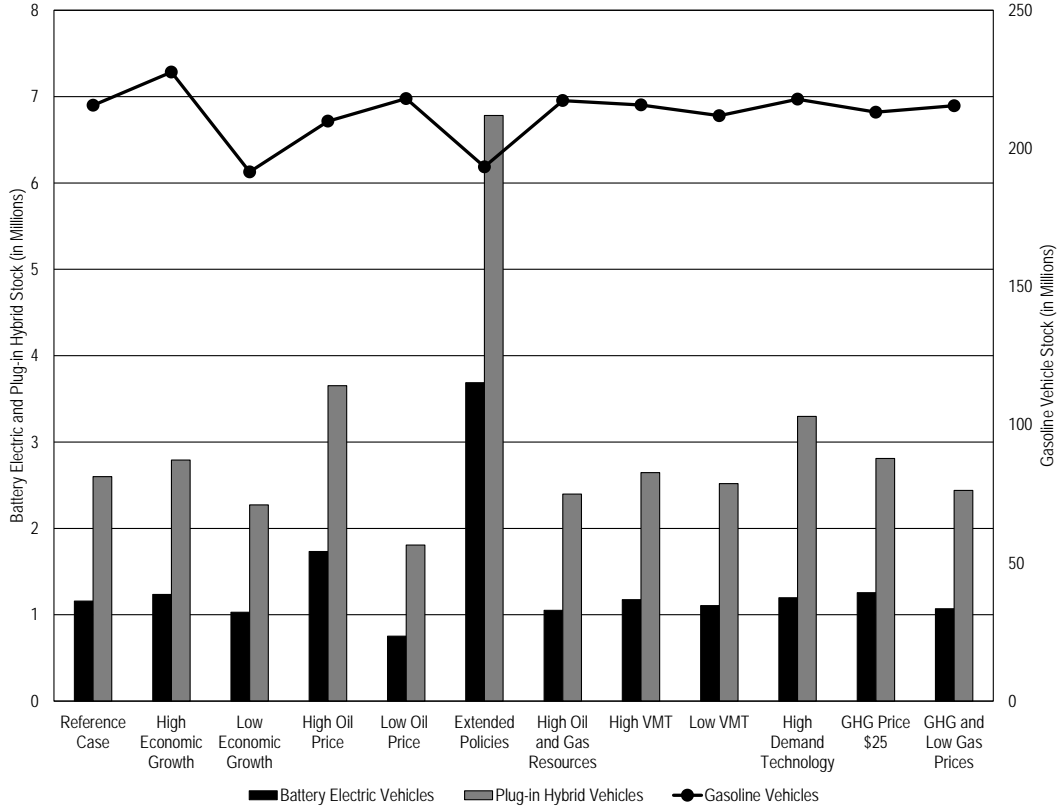


Figure 2: Vehicle Stock Summary for the Analyzed Scenarios. The total number of battery electric vehicles (BEV100 and BEV200) and Plug-in Vehicles (PHV10 and PHV40) are summarized on the left axis and the number of gasoline vehicles is summarized on the right axis. The scenario “Extended Policies” assumes the extension of all existing tax credits including the tax credit of \$7,500 for the purchase of qualifying plug-in vehicles that would otherwise be phased out after a manufacturer-specific sales quota is met.

plug-in hybrids use gasoline to operate. In the charge depleting mode, i.e., depleting its battery, the plug-in hybrid vehicle uses the electric motor only. The equations for the consumption of diesel and E85 are written as

$$C_{tdi} = \sum_{i \in \{tdi_c, tdi_e, hyd\}} S_i \cdot \frac{VMT_i}{MPG_i}$$

$$C_{E85} = \sum_{i \in \{E85_c, E85_e\}} S_i \cdot \frac{VMT_i}{MPG_i}$$

We assume that the vehicle miles traveled for vehicle type  $j$  is a constant elasticity function of the price



of fuel type  $i$ , i.e., gasoline, diesel, or E85 depending on the vehicle:

$$VMT_j = \alpha_j(p_i + t_i)^{\eta_i}$$

The 2014 Annual Energy Outlook already takes into account the influence of policies and macroeconomic parameters, e.g., economic growth, policies, on the vehicle miles traveled. Similarly, we assume a constant elasticity supply function for gasoline, diesel, and E85 that is written as

$$M_i = \alpha p_i^{\beta_i} \quad \text{for } i \in \{gas, tdi, E85\}$$

To parameterize the model, we rely on estimates from previous literature and the 2014 Annual Energy Outlook itself. The complete parametrization as well as the solution algorithm can be found in the supplemental materials. Some of the data provided in the 2014 AEO had to be transformed to be more suitable for the simulation model. The consumption of gasoline and diesel was transformed from British Thermal Units (BTU) to gallons using a lower heating value energy content of 116,090 BTU gal.<sup>-1</sup> and 128,488 BTU gal.<sup>-1</sup>, respectively (U.S. DOE Alternative Fuels Data Center, 2015). The energy content of E85 is calculated as the weighted average of the energy content of ethanol, i.e., 76,330 BTU gal.<sup>-1</sup>, and gasoline. For E85, the reduction in fuel economy compared to a gasoline vehicle varies between 15% and 30% depending on the content of ethanol in the fuel mix (DOT, 2015). We use the maximum value of 30% reduction in our model.

The 2014 AEO reports only the fuel economy of new cars sold to the market. For the first year in our simulation model, we take fuel economy estimates from the literature and index the fuel economy to the evolution of the fuel economy in the 2014 AEO which reports the vehicle miles traveled as well as the consumption of light-duty gasoline cars. For the fuel economy of conventional gasoline vehicles, we assume 23.3 and 17.1 MPG for cars and trucks, respectively (U.S. DOT Bureau of Transportation Statistics, 2015). For conventional hybrids, we use a fuel economy of 43.7 and 40.6 MPG for highway and urban driving, respectively (Al-Alawi and Bradley, 2013). For plug-in hybrid vehicles, the utility factors for PHV10 and PHV40 mid-sized vehicles are taken from Al-Alawi and Bradley (2013). The utility factor for urban and highway are 0.32 and 0.12 for PHV10 and 0.79 and 0.41 for PHV40. Assuming highway driving of 45%, we calculate a weighted utility factor of 0.1829 and 0.5575 for PHEV10 and PHEV40, respectively. The highway and urban driving MPG for PHEV10 in charge sustaining mode is 40.75 and 45.40, respectively. The values for the PHEV40 are 41.65 and 48.4 MPG. For the diesel consumption of the current fleet, we assume that the ratio of gasoline to diesel fuel economy is the same as for new cars sold which is reported by the AEO. We then calculate the implicit diesel fuel economy of vehicles currently on the road that match the AEO projections. This results in a diesel fuel economy of 44.15 and 34.26 MPG for cars and light trucks, respectively.

At the beginning of the simulation period, we assume an average annual vehicle miles traveled for cars and trucks of 10,614 and 14,596 miles (FHWA, 2011). We assume that those parameters are also valid for cars and trucks fueled by diesel and E85. The AEO only provides aggregate data for the vehicle miles traveled and does not differentiate between cars and trucks. As for the fuel economy, we index the VMT per vehicle to the 2014 AEO data for those three vehicle types. The vehicle miles traveled for conventional hybrids and plug-in vehicles can be calculated directly given the data we have.

The supply of gasoline is relatively inelastic and estimates range from 0.2 to 0.5 (Rajagopal et al., 2007, 2009; de Gorter and Just, 2009; Coyle et al., 2012). We use the average value of 0.35 but include upper and lower bounds of 0.2 and 0.5 in the sensitivity analysis. The vehicle miles traveled elasticity with respect to the price of gasoline vary from -0.05 to -0.4 (Parry and Small, 2005; Greene, 2011). We assume a value of -0.225 but include the lower and upper values in the sensitivity analysis. Based on the data from the 2014 AEO, we calibrate the simulation model such that all markets are in equilibrium in each scenario and each year at the beginning of the simulation in the absence of any stock or gasoline tax modifications.

Given our model and the parametrization, we run a baseline that leaves all the parameters at their status quo values. When compared with the values from the 2014 AEO reference case, the consumption of gasoline and diesel are within 1.5% and 5.6%, respectively.<sup>4</sup>

## 4 Results

To evaluate the contribution of the declining real fuel tax rate and plug-in vehicles on tax revenue, we proceed in three steps. For each of the 12 selected EIA scenarios, we (1) keep the gasoline and diesel tax rates constant in real terms (“Real Tax”), (2) assume all plug-in vehicles to be gasoline cars (“No PV”) without adjusting the fuel tax rates, and (3) combine the real fuel tax rates with all plug-in vehicles as gasoline cars (“Total”). To assess the revenue potential of an additional registration fee on plug-in vehicles, we impose three different levels of annual taxes that are consistent with current state proposals. The legislation in Massachusetts called for a fee of \$100 which is the same amount levied in North Carolina. We also consider a fee of \$50 which is close to the \$64 Virginia charges. In addition, we impose a \$200 fee which is significantly higher than the \$83.72 the average gasoline car driver pays in federal taxes in our model in 2012. Lastly, a sensitivity analysis is provided to evaluate the stability of our results.

### 4.1 Contribution to Fuel Tax Revenue Decrease

Our model indicates that based on the 2014 AEO reference case projections, the annual federal fuel tax revenue will decrease from \$25.23 billion dollars in 2012 to \$11.09 billion in 2040. This represents a decrease

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<sup>4</sup>The data provided in the 2014 AEO for E85 led to unrealistically high estimates for the fuel economy. Thus we relied on the fuel economy being 30% their conventional counterparts.

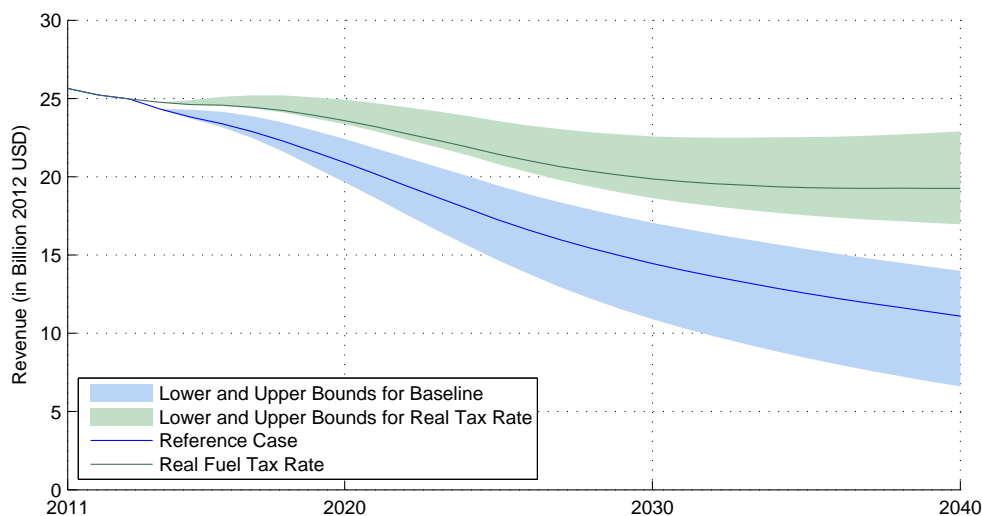


Figure 3: Evolution of the Federal Fuel Tax Revenue 2011-2040. The baseline refers to the reference case of the EIA. The “Real Fuel Tax Rate” scenario assumes a gasoline and diesel tax of \$0.184 and \$0.224 per gallon remaining constant in real terms over the projection period. The lower bound refers to the “Low Economic Growth” scenario and the upper bound refers to the “Low Oil Price” scenario.

of 56.03% which can be attributed to the gains in fuel efficiency as well as the decline in the real fuel tax rate. As shown in Table 1, the smallest and largest decreases are observed in the low oil price scenario (decrease of 44.6%) and the low economic growth scenario (decrease of 73.8%). Given the decrease in revenue across all projections, the question is under what conditions and policies can the stream of revenue dedicated to transportation infrastructure be stabilized.

If the federal fuel tax were adjusted to inflation, the gasoline and diesel tax would remain at \$0.184 and \$0.224 per gallon in real terms. The results for this scenario can be found in the column “Real Tax” in Table 1. Figure 4 shows that there would be significant additional revenue in the reference case at the end of the projection period in 2040. For all other AEO scenarios, additional revenue varies between \$7.54 and \$10.36 billion in 2040. Despite the additional revenue, the overall trend in gasoline and diesel tax revenue is still declining between 9.2% and 38.5% compared to 2012 levels.

The column “No PV” assesses the contribution of fuel taxes declining in real terms and all plug-in vehicles as gasoline cars. In the EIA reference case, the share of plug-in vehicles is highest for the PHEV40 at 0.62%. Thus, we would expect that the impact of plug-in vehicles in general is small. It might be argued that buyers of plug-in vehicles would most likely switch to conventional hybrids if they had to. Though, in this analysis, we are interested in the upper bound. As can be seen in the column “No PV” (Table 1), the additional revenue is negligible even under the assumed case that all plug-in vehicles are switching to the gasoline car

EIA Scenario	Baseline	Additional Revenue (in billion \$)			Percentage Change		
		Real Tax	No PV	Total	Tax	No PV	Total
Reference Case	11.09	8.17	0.06	8.27	73.65%	0.52%	74.55%
High Economic Growth	12.31	7.55	0.06	7.65	61.28%	0.52%	62.14%
Low Economic Growth	6.60	10.36	0.03	10.45	156.94%	0.51%	158.25%
High Oil Price	9.02	7.54	0.07	7.67	83.62%	0.76%	85.03%
Low Oil Price	13.98	8.92	0.05	9.00	63.77%	0.34%	64.34%
Extended Policies	10.37	7.61	0.16	7.90	73.45%	1.56%	76.17%
High Oil and Gas Resources	11.90	8.33	0.06	8.42	69.97%	0.47%	70.77%
High VMT	11.68	8.60	0.06	8.71	73.63%	0.52%	74.55%
Low VMT	8.95	6.56	0.05	6.64	73.31%	0.50%	74.19%
High Demand Technology	11.13	8.05	0.07	8.16	72.32%	0.59%	73.35%
GHG Price \$25	10.01	7.85	0.06	7.95	78.35%	0.57%	79.37%
GHG and Low Gas Prices	11.35	8.31	0.05	8.41	73.27%	0.48%	74.11%

Table 1: Contribution of decreasing real fuel tax rates and plug-in vehicles on the federal fuel tax revenue in 2040. The “baseline” refers to the gasoline and diesel tax revenue in the absence of any changes. The additional revenue compared to the baseline refers to the revenue generated from keeping the fuel tax rates constant in real terms and from assuming all plug-in vehicles being gasoline cars.

category. The biggest change in revenue would be under the “Extended Policies” scenario which keeps the tax credit for battery electric vehicles in place. The extended policies continue to provide the tax credit of up to \$7,500 over the projection period which results in a significant number of plug-in vehicles, i.e., 10.47 million as opposed to 3.76 million in the baseline. But even in this case, the additional revenue would only amount to 1.56% more than in the presence of plug-in vehicles. From our extended projections, it is clear that the revenue increase from eliminating plug-in vehicles is minimal. In other words, plug-in vehicles are expected to have a small effect on the base of revenue dedicated to transportation infrastructure. Our results suggest that plug-in vehicles do not significantly contribute to the decline of gasoline and diesel tax revenue. In fact, it is clear from our projections that the real tax may alleviate part of the impact of the eroding tax base.

Although the impact on fuel tax revenues are substantial, the impact on gasoline prices is moderate and could range from \$0.04 and \$0.07 (Table 2). The price impact for diesel is similar and can be found in the supplemental materials. Note that the “Extended Policies” would shift a significant number of plug-in vehicles into the gasoline car category. This would increase the demand for gasoline and subsequently would raise the price of gasoline by \$0.24.

## 4.2 Additional Tax on Plug-in Vehicles

Our second research question assesses the additional revenue that could be generated from an additional registration fee on plug-in vehicles. There are two possibilities to levy the fee: Either, existing cars are

EIA Scenario	Baseline	Price Increase			Percentage Change		
		Tax	No PV	Total	Tax	No PV	Total
Reference Case	3.90	0.05	0.06	0.11	1.22%	1.64%	2.86%
High Economic Growth	4.02	0.04	0.07	0.11	1.06%	1.66%	2.73%
Low Economic Growth	3.67	0.07	0.06	0.13	1.87%	1.64%	3.50%
High Oil Price	5.04	0.05	0.12	0.18	1.01%	2.47%	3.48%
Low Oil Price	2.61	0.04	0.03	0.07	1.69%	1.07%	2.76%
Extended Policies	3.71	0.05	0.19	0.24	1.29%	5.20%	6.49%
High Oil and Gas Resources	3.49	0.05	0.05	0.10	1.33%	1.48%	2.81%
High VMT	3.95	0.05	0.07	0.11	1.21%	1.67%	2.87%
Low VMT	3.68	0.05	0.06	0.11	1.30%	1.62%	2.92%
High Demand Technology	3.85	0.05	0.07	0.12	1.23%	1.88%	3.10%
GHG Price \$25	4.52	0.05	0.08	0.13	1.09%	1.82%	2.91%
GHG and Low Gas Prices	3.68	0.05	0.06	0.10	1.29%	1.53%	2.82%

Table 2: Change in gasoline prices due to real fuel tax rates and plug-in vehicles. The “baseline” refers to the gasoline and diesel tax revenue in the absence of any changes. The additional revenue compared to the baseline refers to the revenue generated from keeping the fuel tax rates constant in real terms and from assuming all plug-in vehicles being gasoline cars.

grand-fathered in and the fee is only collected from new plug-in vehicle sales, or the fee is applied to all plug-in vehicles on the road, i.e., also those in service at the beginning of the projection period. We present the results for the later scenario because the stock of vehicles in service is low relative to the stock at the end of the projection period and thus, the differences between the two cases is small. To determine the effect of the registration fee on sales, we use the projected prices of the “mid-sized” cars for the four plug-in vehicles of interest. The additional revenue generated for the \$50, \$100, \$200 per year plug-in vehicle tax is summarized in figure 4. In the reference case, this leads to an increase in revenue compared to the baseline of 1.69%, 3.37%, and 6.71% for the \$50, \$100, \$200, respectively. The smallest increase in revenue is observed for the low oil price case where the increase ranges from 0.91% to 3.63%. For the extended policies, this increase ranges from 5.03% to 19.96%. The additional revenue has two components: First, the direct effect of collection the tax from plug-in vehicles, and second, the additional fuel tax revenue from consumers switching to gasoline cars instead of plug-in vehicles. For a \$100 fee, the additional revenue would be \$255 million in the low oil price scenario and \$1,041 million in the “Extended Policies” scenario. Note that the revenue from the additional gasoline cars that are bought because of the price increase of plug-in vehicles is small compared to the revenue generated directly by the plug-in vehicles.

### 4.3 Sensitivity Analysis

Differences in our results in the previous sections are largely driven by the AEO scenarios in terms of economic growth, oil prices, vehicle miles travelled and policies. In this section we focus on parameter choices that are

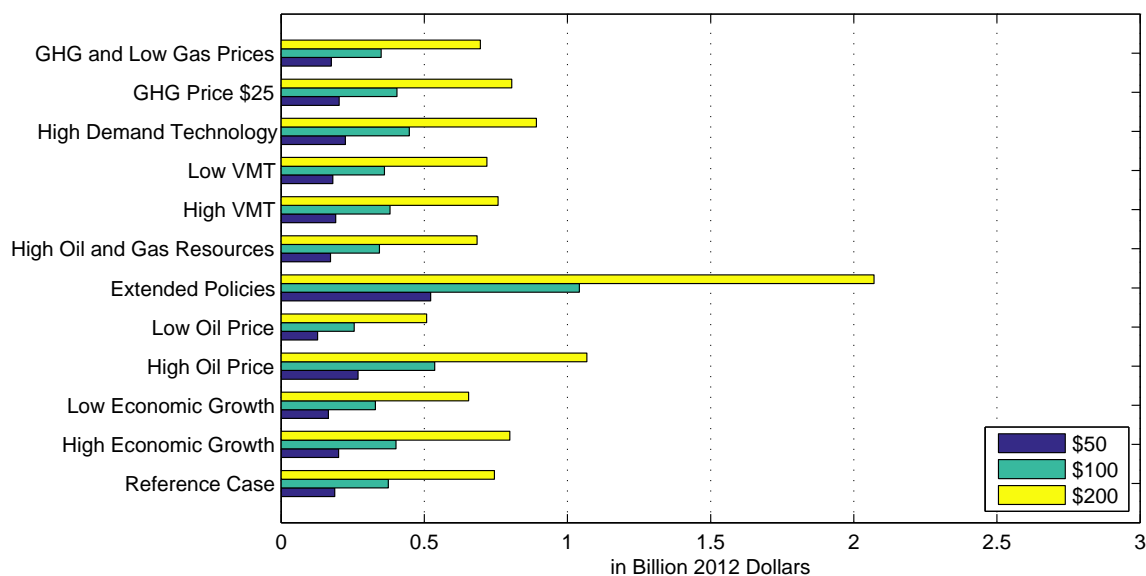


Figure 4: Taxing Plug-in Vehicle Stock and Additional Revenue in 2040

outside the scope of the AEO models. We conduct a sensitivity analysis to assess the variability of our results based on key parameters: (1) supply elasticities with respect to gasoline, diesel, and E85, (2) VMT elasticity, (3) plug-in vehicle price elasticity, and (4) discount rate. Figure 5 summarizes the additional revenue in 2040 for the reference case from setting the elasticities for the vehicle miles traveled and the supply elasticities of gasoline, diesel, and E85 to their upper and lower bounds. The difference in revenue is less than 0.5% in all cases.

The supplemental materials include the detailed results for the sensitivity analysis with respect to the plug-in vehicle price elasticity and discount rate. A decrease in the price elasticity for plug-in vehicles would result in more plug-in vehicles because buyers are not dissuaded from a higher price for plug-in vehicles. A high discount rate a similar effect because buyers discount the future more heavily which lowers the additional cost of the plug-in vehicles at the beginning. The change in revenue is less than \$0.819 million in all cases.

Our results are very stable given the parameters chosen for our simulation model. Although the different scenarios assessed by the EIA, especially the “Extended Policies” scenario have a significant effect on the tax revenue. Despite those effects being substantial in some cases, they are small compared to the loss of revenue associated with the unadjusted gasoline and diesel taxes.

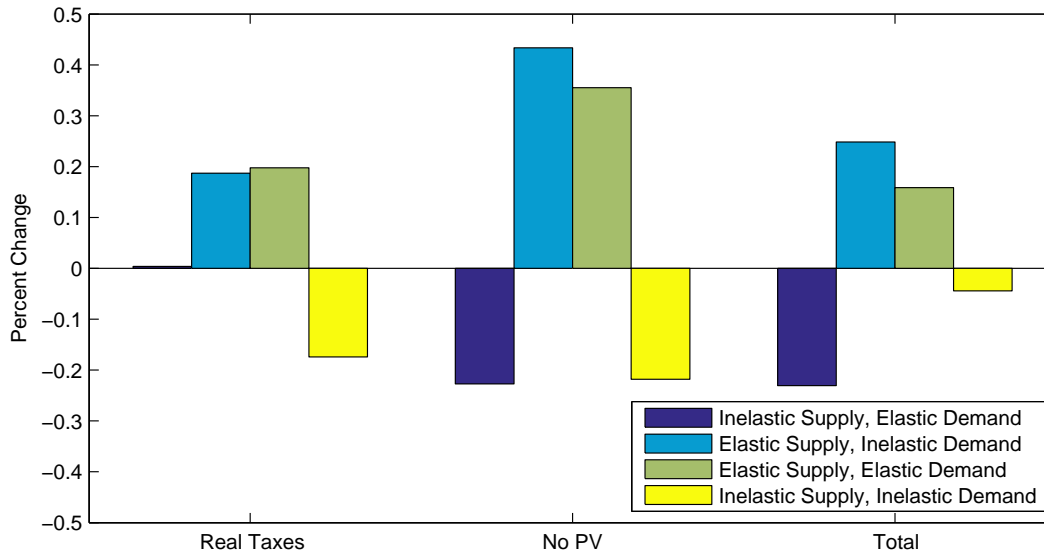


Figure 5: Results of the sensitivity analysis with respect to fuel supply elasticities and vehicle miles traveled elasticities

## 5 Discussion

The United States currently relies on gasoline and diesel taxes to fund federal road infrastructure. Based on our research questions and the results, several other issues require further discussion. In particular (1) how do other countries finance their infrastructure, (2) what is the impact at the state level, and (3) how much road damage is done by plug-in vehicles.

Currently, most European countries favor a system much like the United States when it comes to collecting revenue from their roads and the vehicles that use them. France, Germany, Spain, and the United Kingdom all tax gas and diesel. Those countries also use registration fees and tolls as supplemental sources of revenue. Therefore, other funding sources are in place to help supplement the revenue when the gas tax revenue fluctuates. Gomez and Vassallo (2013) review highway use taxes and fees across Europe and the United States between 2004 and 2009 and report that Europeans pay on average about three times what each United States citizen pays to use their national interstates. The average United States citizen pays around \$450 per year in the form of gas tax, tolls, registration, and purchase taxes compared to \$1,300 in France, \$1,275 in Germany, and \$1,400 in the United Kingdom. Interestingly, the European drivers from the nations highlighted earlier still have a majority of their annual user fee coming from the gas tax: France (76%), Germany (88%), United Kingdom (74%), compared to the United States (45%). The stark difference is that the European citizens pay more in separate fees, tolls, registration, and purchase taxes, than the average

United States citizen's pays in all their taxes/fees combined. Some European countries such as France have begun to completely remove their governments from the maintenance of highways (Albalade et al., 2009). Starting in the 1960's, France began contracting with private companies to build new highways. They also began to sell off their existing national highways in favor of having private companies raise the revenue, via toll, and maintain the infrastructure. A user fee based on distance and weight charges the driver not only for what they use, but for how much impact they have on roadways. In this system, the driver has a vested self-interest in driving a lighter, higher MPG vehicle, as this will save them money not only on the highway tolls, but on the gas tax as well.

This paper assess the impact of an increase in plug-in vehicles on road infrastructure funding at the federal level. At the state level, the situation is comparable in the sense that a significant number of states do not adjust their fuel taxes on a regular basis (ITEP, 2014). We hypothesize that the impact of plug-in vehicles at the state level is as small as at the federal level in relative terms. Imposing an additional registration fee at the state level will likely have a very small impact on government finances coming from fuel tax revenue.

Our research questions are based on the assumption that there is a perceived inequality of infrastructure funding, i.e., plug-in vehicles use/damage the road, yet do not contribute in funding the repairs. A first step in exploring the dollar amount plug-in vehicles should be paying to use the United States highway system is to determine the impact these vehicles have on the roads they travel on. The most reliable way of estimating vehicle impact on the roads is to look at the findings from a study by the American Association of State Highway and Transportation Officials (AASHTO). In 1960, the AASHTO undertook the largest study of its kind in regards to the impact different vehicles have on the highways they use (TRB, 2007). The AASHTO study concluded that while the weight of a vehicle contributed to how much it impacted the highway, the more important figure was the weight bearing down on each axle. Therefore, a vehicle with an even weight distribution would do less damage than one that had most of its weight bearing down on one axle. The study completed by the AASHTO also found that the damage caused by vehicle weight increased exponentially, specifically to the fourth power. This became known as the Fourth Power Rule; stating that the difference in wear on a highway could be expressed by looking at the weight differences between vehicle axles. For example, assume vehicle *A* that has 1,000 pounds per axle to vehicle *B* that has 2,000 pounds per axle. Given the fourth power rule, vehicle *B* causes sixteen times more damage than vehicle *A*. The validity of the Fourth Power Rule has been questioned and several studies have looked into revising it. All of the new data shows that the power factor lies somewhere between 3.6 to 7 depending upon a myriad of factors. Thus, these new studies have shown that 4 is a safe number to work with when working in generalities concerning overall road impact (Hjort et al., 2008; Anani and Madanat, 2010a,b). Plug-in vehicles are comparable in weight to their conventional counterparts. Even with the small discrepancies in weight, the



damage imposed by plug-in vehicles is roughly the same as standard gasoline vehicles. Semi trucks exert an extraordinary amount of stress and damage on highways compared to all of the passenger vehicles that are currently being driven on highways given the fourth power rule. It should be noted that “All Light Duty Vehicles” are traveling 2,677,771 million miles whereas “Single-Unit 2-Axle 6-Tire and Combination Trucks” are responsible for 275,018 million miles in 2013 (Federal Highway Administration Office of Highway Policy Information, 2013). The last comparison between semi-trucks and standard vehicles that needs explored is the amount each contributes to the Highway Trust Fund; as mentioned earlier, this is the fund that is responsible for building and maintaining our national highways and bridges. The total tax revenue for Fiscal 2012 was \$39 billion received from all gasoline and diesel taxes (Federal Highway Administration Office of Highway Policy Information, 2012a). In 2013, diesel vehicles contributed 30% to the fuel tax revenue.

## 6 Conclusions and Policy Implications

In the long-run, the United States should charge an annual registration fee for high MPG vehicles or plug-in vehicles; this would help capture the lost revenue from the fuel taxes and also ensure these vehicles are paying at least some monetary value for the use of the highways. A minority of individuals who buy plug-in hybrid or battery electric vehicles are influenced by the current tax incentives to purchase them. Although, any registration tax linked to higher fuel efficiency vehicles would act as a disincentive for consumers from buying those vehicles and would also undermine the United States’ goal for energy security and a sound environmental policy. Our results indicate that any annual plug-in vehicle tax would make very little fiscal impact.

The level of future sales will be influenced by many factors. The AEO projections show that an extension of the income tax credit has the biggest effect on the numbers of plug-in vehicles purchased. If the U.S. government decides to raise the gas tax from the current level of \$0.184, a corresponding increase in plug-in vehicle sales is expected. The establishment of a national registration fee imposed on plug-in vehicles would result in a slight decrease in sales erasing the benefits of the registration tax.

The total amount collected from any new plug-in vehicle fees is small in comparison to the funding needed to keep the Highway Trust Fund solvent. This paper shows that an increase in the federal fuel tax rate would generate significantly more revenue than the tax on plug-in vehicles. In addition, any discussion with respect to plug-in vehicles needs to analyze the amount of damage done by those vehicles. The taxes implemented or proposed for plug-in vehicles refer to issues of “fairness” in most cases. The “Fourth Power Rule” shows that the plug-in vehicles exert as much wear and tear on the highways as do their gasoline counterparts. It is important to ensure that owners of plug-in vehicles are paying their fair share into the Highway Trust Fund. However, if fairness is the ultimate goal, then there might be a need to reevaluate how much semi-trucks are paying into the fund as well given their weight and axles. Policies aimed at creating fairness for the

use of the highways would need to potentially reconsider how much each vehicle type is paying into the system. European countries specifically have many different means of collecting revenue. Therefore, while their plug-in vehicle sales should continue to increase along with the United States, they still have the means of collecting some revenue from those vehicles; especially in France where their toll system is based on a tiered system tailored toward vehicle type. As the Highway Trust Fund projections continue to be negative, action will eventually need to be taken on stabilizing the fund for the long term; however, levying a tax on plug-in vehicles alone will not adequately produce the revenue needed for that stabilization.

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