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King Abdullah Petroleum Studies and Research Center

Commentary

Understanding the Evolution of the Impact and Cost-Effectiveness of Electric Vehicle Subsidies

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Federal subsidies for battery electric vehicles (BEVs) are becoming less impactful and more costly because they are subsidizing the increased market shares of expensive BEVs.

Our previous research (Sheldon and Dua 2018, 2019) found that promoting plug-in electric vehicle (PEV) adoption through financial subsidies is expensive. In this commentary, we explore how the cost-effectiveness of the PEV subsidy program has evolved over time. To understand this evolution, we developed vehicle choice model-based counterfactual simulations using annual United States (U.S.) new vehicle market share and vehicle characteristics data for each of the model years (MYs) from 2011 to 2017. Our results suggest that the federal subsidies for battery electric vehicles (BEVs) are becoming less impactful and more costly because they are subsidizing the increased market shares of expensive BEVs, such as the models produced by Tesla. Our results suggest that it is more impactful and cost-effective to subsidize BEVs than plug-in hybrid electric vehicles (PHEVs). In other words, BEV buyers were less likely than PHEV buyers to have bought a BEV without a subsidy. This is due to a greater willingness among consumers to purchase PHEVs than BEVs, meaning that BEV purchases have to be incentivized by greater subsidies than PHEVs.

Figure 1 shows the evolution of BEV and PHEV market shares in the U.S. new vehicle fleet from MY 2011-2017. MY 2011 saw the Nissan Leaf introduced in the U.S., one of the first PEVs with broad market appeal. Figure 1 also shows the evolution of the sales-weighted average price (without subsidies). It is worth noting that the sales-weighted price for BEVs has been rising due to the introduction and increased sales of higher-priced models, including the Tesla Model S in MY 2013, the Tesla Model X in MY 2016 and the Chevrolet Bolt in 2017. The sales-weighted price (without subsidies) of PHEVs initially declined from 2011 to 2014 because of the drop in the price of the popular Chevrolet Volt. However, after 2014, the sales-weighted PHEV price started increasing because of the introduction and increased sales of higher-end PHEVs, including the Cadillac ELR, the BMW i3 and x5, and the Audi A3, to name a few. It is also worth noting that the average sales-weighted federal subsidy for BEVs stayed constant at $7.5k, while it varied over time for PHEVs because of the introduction of different models with different battery capacities.

We use a vehicle choice model adapted from (Sheldon and Dua 2020) to make predictions for the market shares of PEVs and fleet gasoline consumption under alternative subsidy scenarios. They include a scenario based on the existing PEV subsidies and one based on no subsidies.

The policy impact is measured in terms of the percentage of additional sales, defined as the percentage of total xEV sales that were induced by the subsidy (where *'x=B'* denotes BEV and *'x=PH'* denotes PHEV). In other words, additional sales are the xEV sales that would not have happened without a subsidy. It is calculated using the following formula:

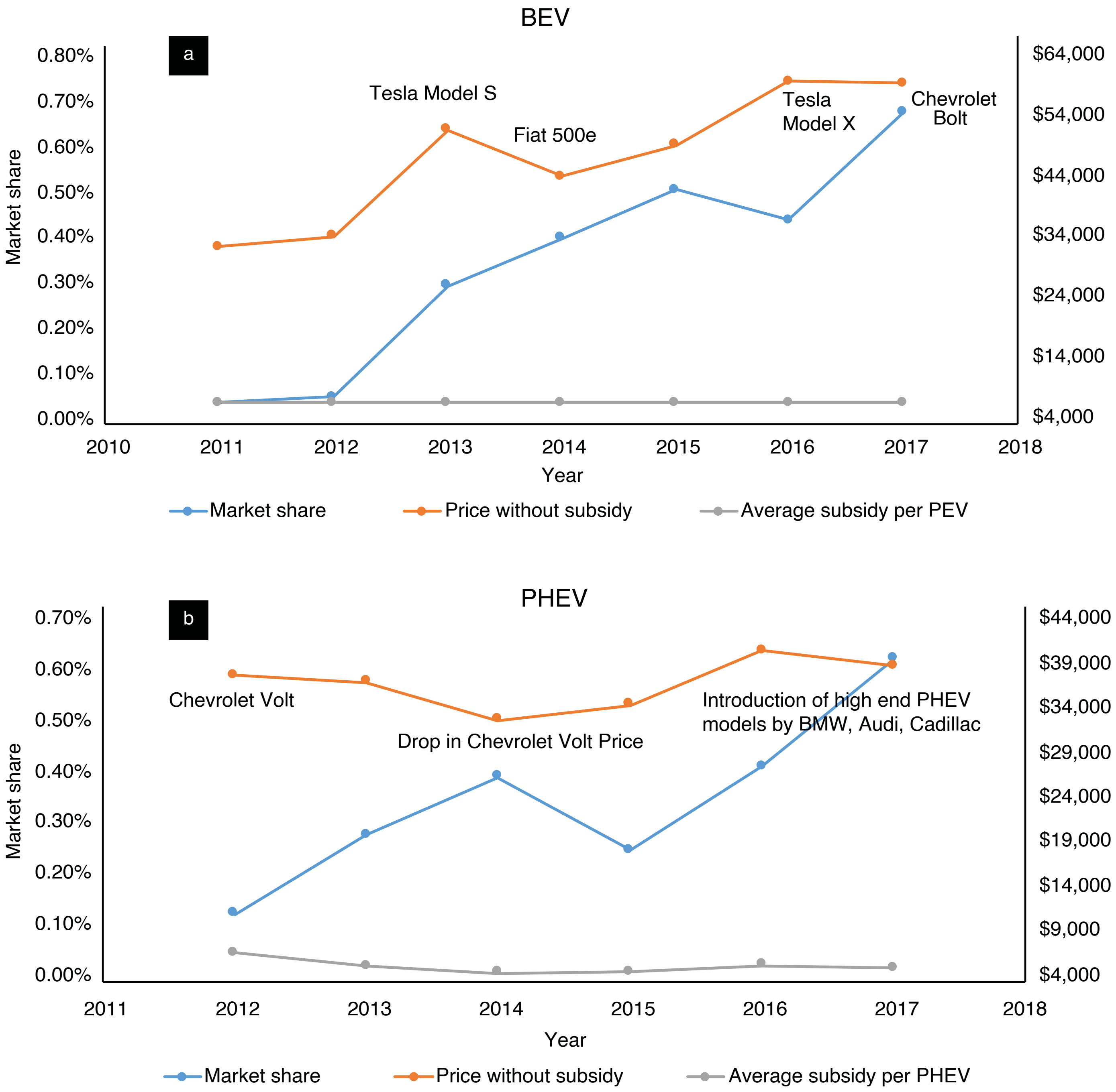
$$Additional\ sales\ percentage_{xEV} = \frac{Sales_{xEV}^{Subsidy} - Sales_{xEV}^{No\ Subsidy}}{Sales_{xEV}^{Subsidy}} * 100 \qquad (1)$$

where

$Sales_{xEV}^{Subsidy}$ denotes the total xEV sales for the existing subsidy case

$Sales_{xEV}^{No\ Subsidy}$ denotes the total xEV sales for the no subsidy case

Figure 1. Market share, sales-weighted price (without subsidy) and sales-weighted subsidy for (a) BEVs and (b) PHEVs.



Source: KAPSARC analysis.

The cost-effectiveness of the PEV subsidy is reported in two ways: (i) $ per additional xEV sold, and (ii) $ per additional gallon ($/additional gallon) of saved gasoline equivalent. $ per additional xEV sold represents the money spent on inducing one additional xEV sale. It is calculated by dividing the total subsidy amount spent by the total number of additional xEV sales, as shown in equation 2. Dividing the numerator and denominator by the total xEV sales for the existing subsidy case gives us the cost effectiveness, which equals the average subsidy per xEV divided by the percentage of additional sales. Thus, if the subsidy per xEV is constant, then its cost effectiveness becomes inversely proportional to the additional sales percentage. This is something that we see later for BEVs.

$$Cost\ Eff_{xEV} = \frac{Sales_{xEV}^{Subsidy} * \overline{Subsidy}}{Sales_{xEV}^{Subsidy} - Sales_{xEV}^{No\ Subsidy}} = \frac{100 * \overline{Subsidy}}{Additonal\ Sales\ Percentage_{xEV}} \quad (2)$$

Where

$Cost\ Eff_{xEV}$ denotes the cost-effectiveness of the xEV subsidy

$\overline{Subsidy}$ denotes the average sales-weighted subsidy per xEV

$Sales_{xEV}^{Subsidy}$ denotes the total xEV sales for the existing subsidy case

$\overline{Sales_{xEV}^{No\ Subsidy}}$ denotes the total xEV sales for the no subsidy case

The $ per additional gallon of saved gasoline equivalent represents the amount of money spent on saving one additional gallon of gasoline equivalent. It is calculated by dividing the total subsidy amount spent by total additional gallons of gasoline equivalent saved. The total additional gallons of gasoline equivalent saved is denoted by the difference in fleet fuel consumption under the existing subsidy and no subsidy cases. For the annual fleet fuel consumption calculation, we assumed a vehicle life of 16 years (Davis, Diegel, and Boundy 2013) and an average of 11,500 annual miles traveled (Federal Highway Administration [FHWA] 2019).

$$Cost\ per\ additional\ gallon\ of\ gasoline\ equivalent\ saved = \frac{Sales_{PEV}^{Subsidy} * \overline{Subsidy}}{FFC^{Subsidy} - FFC^{No\ Subsidy}} \quad (3)$$

$$FFC = \frac{Sales * VMT * Veh\ Life}{FFE_{Pred}} \quad (4)$$

where

$\overline{Subsidy}$ denotes the sales-weighted average subsidy per PEV

$Sales_{PEV}^{Subsidy}$ denotes the total PEV sales for the existing subsidy case

FFC denotes the total fleet fuel consumption

$Sales$ denotes the total annual vehicle sales

VMT denotes the annual vehicle miles traveled, assumed to be 11,500 miles

Veh Life denotes the vehicle life, assumed to be 16 years

FFE denotes the harmonic average fleet fuel economy calculated using the market shares, predicted by the vehicle choice model

It is worth noting that the federal subsidy for all the BEVs was constant at $7.5k, while the federal subsidy for PHEVs varied according to the battery capacity. We also calculated a fleet subsidy percentage (equation 5), defined as the sales-weighted average discount per PEV, where the discount is denoted by the subsidy divided by the vehicle price.

$$Subsidy\ Percentage_{xEV} = 100 * \frac{\sum_{i=1}^{n_{xEV}} Sales_i * Discount_i}{\sum_{i=1}^{n_{xEV}} Sales_i} \tag{5}$$

$$Discount_i = \frac{Subsidy_i}{Price_i} \tag{6}$$

where

$Sales_i$ denotes the total sales for the i^{th} xEV

$Discount_i$ denotes the discount on the i^{th} xEV

$Subsidy_i$ denotes the subsidy for the i^{th} xEV

$Price_i$ denotes the price (before subsidy) for the i^{th} xEV

The policy impact and cost-effectiveness results for BEVs and PHEVs are shown in figures 2a and 2b, respectively. The results indicate that the impact and cost-effectiveness of BEV and PHEV subsidies are decreasing over time. In other words, subsidies are becoming less effective and more costly in inducing additional sales, especially BEV sales.

The decline in the federal subsidy policy's impact and its cost-effectiveness is due to the introduction and increased sales of high-priced BEVs, including Tesla models. It is worth noting that the introduction of the higher-priced Tesla Model S in MY 2013, the Tesla Model X in MY 2016 and Chevrolet Bolt in MY 2017 were characterized by falls in the impact of subsidies and a corresponding rise in subsidy costs. Moreover, the decline in the impact of the subsidies correlates with a decline in the fleet subsidy percentage: the amount of federal subsidy remained constant, at $7.5k, while the sales-weighted vehicle price increased, as shown in Figure 1a.

The decline in policy performance is expected, as the percentage discount on the vehicle price as a result of the subsidy is lower for higher-priced vehicles than lower-priced vehicles. For example, the federal subsidy of $7.5k represents a 25% discount for a ~$30k Nissan Leaf, while it represents only a 10% discount for a ~$75k Tesla Model S. Thus, the fixed federal subsidy is more likely to influence additional purchases of lower-priced rather than higher-priced BEVs. Moreover, the higher-priced BEVs are often purchased by higher-income consumers. Though they might welcome the subsidy, they

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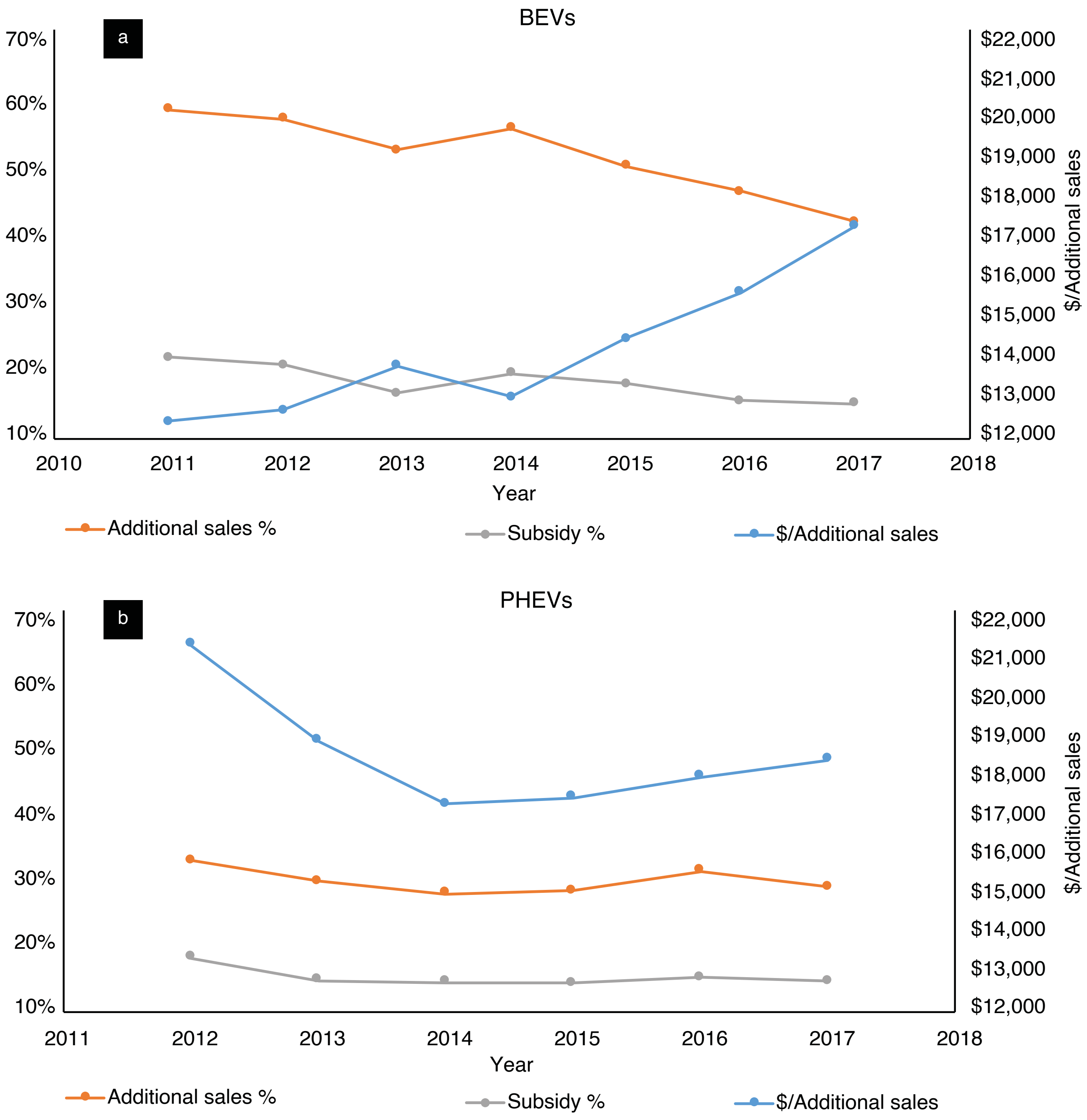
may not necessarily need it to make the purchase (Sheldon and Dua 2019). This is due to their lower price elasticity of demand (i.e., they are less price sensitive) and their stronger preference for upscale BEVs (DeShazo, Sheldon, and Carson 2017). In other words, higher-income consumers would likely have bought BEVs even without a subsidy. Thus, subsidizing higher-income consumers' purchases of higher-priced vehicles is likely to result in reduced policy effectiveness.

Figure 2. Evolution of the federal subsidy's impact and cost-effectiveness for (a) BEVs and (b) PHEVs.



Source: KAPSARC analysis.

The subsidy impact and cost-effectiveness for PHEVs are lower than for BEVs. The additional sales percentage for BEVs declined from 60% to 40%, while for PHEVs they varied between 28% to 33%. In terms of cost-effectiveness, the $ per additional sales for BEVs increased from $12k to $17k, while it varied between $21k to $17k for PHEVs. The greater success of the subsidy in inducing BEV sales could be attributed to the larger set of concerns (range, resale value, refueling) surrounding BEV purchases compared with PHEV purchases (Dua, White, and Lindland 2019). Because of these concerns, potential BEV buyers are less likely to buy BEVs without a subsidy than potential PHEV buyers.

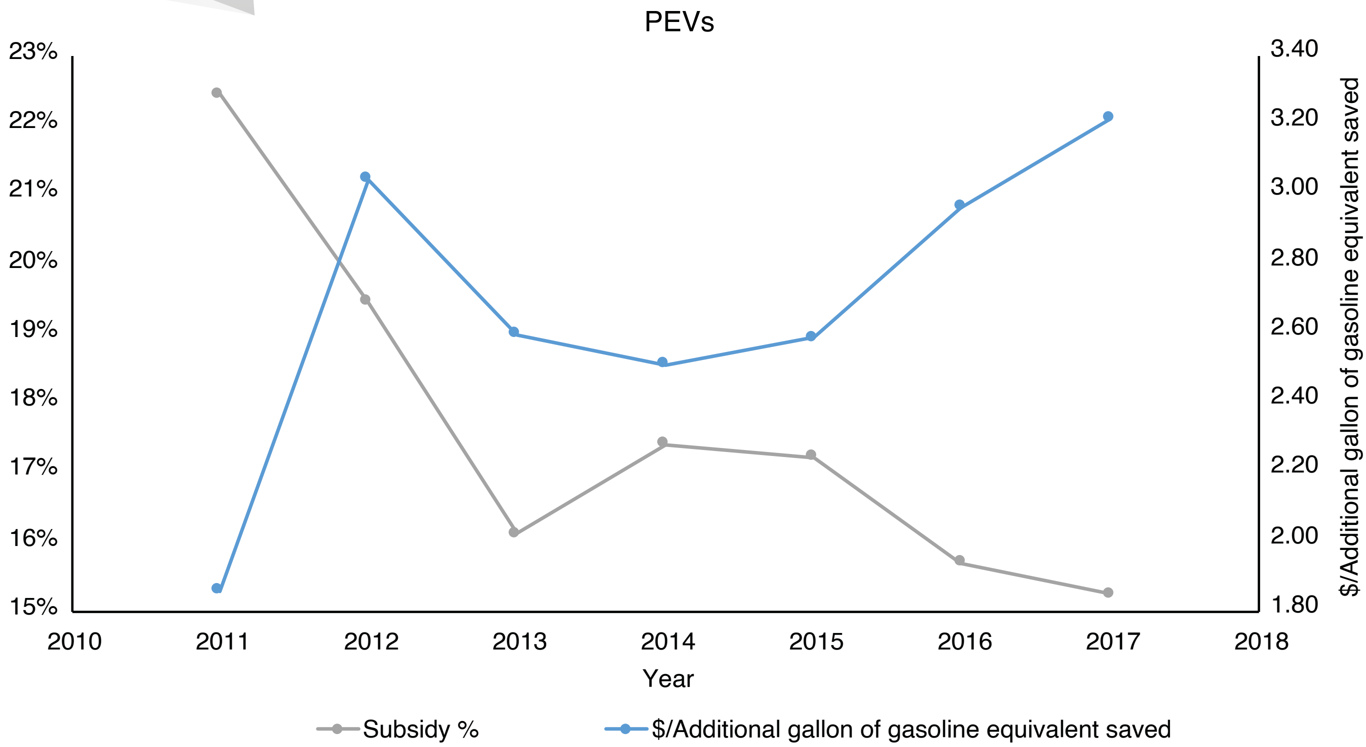
The PHEV subsidy's impact and its cost-effectiveness over time are non-linear because of the non-linear nature of the value of the subsidy percentage. The subsidy percentage has a non-linear trend because both (i) the subsidy amount per PHEV and (ii) the sales-weighted PHEV price (without subsidies) change over time. The subsidy per PHEV varies over time because of the introduction of different PHEV models with varying battery capacities. As mentioned previously, the sales-weighted PHEV price (without subsidies) initially declines until 2014 because of the reduction in the price of the Chevrolet Volt. However, it then starts to increase because of the introduction of higher-end PHEV models (including but not limited to BMW, Audi and Cadillac).

As in the case of the BEV subsidy, the impact of the PHEV subsidy, in terms of additional sales percentage, correlates with the PHEV subsidy percentage. However, unlike the BEV subsidy, the cost-effectiveness of the PHEV subsidy is not inversely related to the impact of the PHEV subsidy. This is because the average subsidy per PHEV is not constant over time, unlike the average subsidy per BEV.

If the policymaker's objective is not to maximize PEV adoption, subject to the policy budget, but to maximize the environmental benefits of PEVs (i.e., reducing local air pollution and greenhouse gases), then a more relevant metric is the policy cost in terms of $/additional gallon of gasoline equivalent saved by PEV adoption. Figure 3 shows the evolution of the federal subsidy's cost-effectiveness measured in terms of $/additional gallon of gasoline equivalent saved. As can be seen, the policy has become more costly over time, with the initial peak in 2012 coinciding with the introduction of PHEVs. In 2017, it cost ~$3.2 to save an additional gallon of gasoline through subsidizing PEVs, while the cost of gasoline at the time was ~$2.4/gallon. The policy cost-effectiveness correlates negatively with the subsidy percentage.

There are several caveats to the results. First, the generally decreasing subsidy effectiveness found above could also, at least in part, be due to changing consumer preferences and awareness. For example, early adopters may have been more skeptical about the technology and, hence, might have been less likely to have purchased a PEV without a subsidy. In contrast, later adopters with more knowledge of the technology might have been more willing to purchase a PEV, regardless of whether it was subsidized. Second, while the current cost-effectiveness of the subsidy may appear low, the subsidy might be justified by knowledge spillovers (e.g., learning by doing, research and development, among others). Such knowledge spillovers could lead to future cost reductions through both additional research and gains in production efficiency, thereby resulting in increased future adoption (Gillingham and Stock 2018). To summarize, our results suggest that PEV subsidies are becoming less impactful and more costly over time. To overcome this issue of their reduced impact and cost-effectiveness, policymakers are likely to adopt more targeted subsidy designs, wherein higher-priced PEVs, such as the Tesla models S and X, and higher-income consumers buying PEVs, might not get any subsidies going forward. In December 2019, California tweaked its subsidy design to restrict PEV subsidies to vehicles priced below $60k (Hussain 2019). At the federal level, this has already happened for Tesla, as subsidies for purchases of each manufacturers' PEVs were limited to the first 200,000 PEVs it produced. Tesla reached this level in 2018 (Lekach 2019). Ironically, this means that subsidies are no longer available to buyers of the lower-priced Tesla Model 3, the purchases of which could have been additionally influenced by the federal subsidy. Most of the federal subsidies for Tesla buyers were used for purchases of the higher-priced Tesla models. It is worth highlighting that the plea by Tesla and General Motors to continue the federal subsidy beyond the 200,000 PEVs has been ignored by the U.S. Congress (Gardner 2019).

Figure 3. Evolution of the federal subsidy's cost-effectiveness for PEVs, measured in terms of the cost of saving an additional gallon of gasoline through subsidizing PEVs.



Source: KAPSARC analysis.

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About the Project

Promoting the adoption of energy-efficient vehicles has become a key policy imperative in both developed and developing countries. Understanding the impact of various factors on adoption rates of energy-efficient vehicles forms the backbone of KAPSARC's research into light-duty vehicle demand. These factors include (i) consumer-related factors – demographics, behavior, and psychographics; (ii) regulatory factors – policies, incentives, rebates, and perks; and (iii) geo-temporal factors – weather, infrastructure, and network effects. Our team is currently developing models at different levels: micro-level models using large-scale data comprising new car buyers' profiles, and macro-level models using aggregated adoption data to understand and project the various factors that affect the adoption rate of energy-efficient vehicles.

About KAPSARC

The King Abdullah Petroleum Studies and Research Center (KAPSARC) is a non-profit global institution dedicated to independent research into energy economics, policy, technology and the environment, across all types of energy. KAPSARC's mandate is to advance the understanding of energy challenges and opportunities facing the world today and tomorrow, through unbiased, independent, and high-caliber research for the benefit of society. KAPSARC is located in Riyadh, Saudi Arabia.

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