Fiscal Policies to Promote Alternative Fuel Vehicles

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Abstract

Several alternative fuel vehicle technologies such as flex-fuel vehicles, hybrid vehicles, and plug-in electric vehicles have been introduced into the mass market during the past two decades amid the heightened concern over oil dependence and the dramatic run-up of gasoline prices. To promote the diffusion of these technologies, governments at various levels in the U.S. and elsewhere have provided incentives to both consumers and automakers such as tax incentives for consumer vehicle purchase and favorable treatment in the compliance of Corporate Average Fuel Economy Standards. There is a now a large body of literature that examines these policies. This article aims to provide a review of the recent findings on the impacts of the fiscal policies to promote alternative fuel vehicles with a focus on the U.S. but also drawing evidence from other regions. Particular attention is paid to questions regarding cost-effectiveness, policy design, and comparison with alternative polices such as the gasoline tax.

Keywords: alternative fuel vehicles, subsidy, policy design

JEL classification:

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1 Introduction

The past two decades witnessed the rapid development and production of different alternative fuel vehicle (AFV) technologies including flex-fuel, electric, natural gas, and fuel cell vehicles. Government agencies around the globe have initiated various policies to promote the adoption of AFVs in order to reduce CO_2 emissions, air pollution and oil dependence from the transportation sector. Government intervention in these markets are often justified from the following three perspectives.

First, AFVs can help addressing global warming, local air pollution and energy security. In the United States, the transportation sector contributes to nearly 30% of the total greenhouse gas emissions, over half of carbon monoxide and nitrogen oxides emissions and about a quarter of hydrocarbons emissions in recent years, most of which are related to burning petroleum fuels. Traditional economic wisdom advocates a Pigovian tax on petroleum consumption with the amount equal to the external costs associated with petroleum use. Due to the political challenging of increasing taxes and the difficulty of quantifying the marginal social harms, the external costs of gasoline consumption in the U.S. and many countries around the world are not properly reflected by the gasoline tax (Parry and Small 2005). By reducing the reliance on gasoline or switching to alternative fuels, some AFV technologies provide potential pathways to mitigate or even eliminate the externalities associated with the petroleum consumption. Thus, a subsidy for AFVs is provided to make consumers internalize the external benefits that AFVs occur (or the external costs they avoid) when they make vehicle purchase decisions and the optimal subsidy level should be equal to all the external benefits that AFVs generate.

Second, AFV subsidies are also justified on the ground that market failure arises as consumers undervalue or miscalculate the fuel cost savings from AFVs. The upfront cost of AFVs are usually higher than their conventional counterparts, but consumers could save future fuel cost by switching to AFVs. Thus, the lifetime holding cost of AFVs is actually lower than their conventional counterparts under most of the fuel price scenarios. However, cognitive biases or search costs might cause consumers to overlook potential fuel cost savings and consumers might under-invest in fuel-efficient vehicles if they place a high discount rate on future fuel cost savings or the current gasoline price is too low to make them perceive enough fuel cost savings from AFVs, which is related to the so-called "energy efficiency gap"(Hausman 1979; Train 1985; Jaffe and Stavins 1994; Allcott and Greenstone 2012). In addition, consumers have long been used to internal combustion engines and the unfamiliarity with the new fueling technology incurs additional search cost or switching cost to AFVs, which holds back consumers from adopting them. The purchase subsidy of AFVs thus intends to reduce the upfront price gap between AFVs and their conventional vehicle counterparts with the optimal amount equaling to the undervalued savings from improved fuel economy. However, to what extent do consumers undervalue future fuel cost savings is still uncertain and the existing empirical literature often finds mixed conclusions (Allcott and Wozny 2014; Busse et al. 2013; Sallee et al. 2016; Grigolon et al. 2015).

Third, subsidizing AFVs addresses the market failures experienced at the early stage of the diffusion of new technologies. Due to technology spillovers, the social returns to R&D are larger than the private returns and market forces often result in under-investment in new technologies from a society's perspective (Stoneman and Diederen 1994). Moreover, in the AFV markets where strong inter-dependency between vehicle adoption and fueling infrastructure investment exists, network effects are particularly pronounced, representing another source of market failure: the marginal consumer/investor only considers the private benefit in their decision and the network size on both sides is less than optimal, resulting in the "chicken and egg problem" (Liebowitz and Margolis 1995; Church et al. 2002; Li et al. 2016).

In practice, AFV subsidies are often carried out through various methods and within various contexts. The effectiveness or the costs and benefits of the subsidy programs depend not only on how the policies are implemented but their interactions with other existing policies. By investigating the most recent findings from the literature, our aim of this paper is to examine the impacts of various policy instruments that seek to promote the adoption of AFVs and propose potential strategies to improve the policy efficacy. We focus on the studies related to the United States but also draw evidence on other countries.

The U.S. Department of Energy defines the following Alternative Fuel Vehicle categories: diesel vehicles, hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), battery electric vehicles (BEVs), flexible-fuel vehicles (FFVs), fuel cell vehicles (FCVs), natural gas vehicles (NGVs), and propane vehicles. In this paper, we focus on HEVs, PHEVs and BEVs while referring to other fuel types occasionally. We choose these three types of AFVs since they are more dominant technologies and subsidy programs are widely available to them in different countries. Typical adoption barriers such as higher upfront cost and fueling station constraints also exist for these AFV technologies, providing sufficient sources for policy-relevant research. The conclusions and the main findings from the large volume of research on them could also be generalized to other AFV technologies.

The paper is structured as follows. In section 2, we discuss the industry background and policy support for AFVs. Section 3 discusses the efficacy of the subsidy policies in terms of boosting AFV demand. Section 4 examines the relative effectiveness of the subsidy policies from a variety of other perspectives. Section 5 discusses alternative subsidy designs and section 6 concludes and offers suggestions for future research.

2 Industry Background for HEVs and PEVs

In 2000, Toyota and Honda introduced their HEVs, Toyota Prius and Honda Insight, into the U.S. market. HEVs are primarily powered by an internal combustion engine that runs on gasoline and an electric motor that uses energy stored in a battery. The battery is charged through regenerative braking and by the internal combustion engine and it not plugged into off-board sources of electricity to charge. Achieving higher fuel economy and lower emissions, HEVs also preserve the power and range of conventional vehicles.

To reduce the price gap between HEVs and their conventional vehicle counterparts, the U.S. government provided a "clean fuel" tax deduction of up to $2,000 for new HEVs purchased during 2001 to 2005. The Energy Policy Act of 2005 replaced the income tax deduction with an income tax credit of up to $3,400 for vehicles purchased after December 31, 2005. The tax credit for each HEV model varies and is based on the improvement of fuel economy provided by that model relative to the non-hybrid counterpart. The credit phased out over five subsequent calendar quarters once the manufacturer sold a total of 60,000 eligible HEVs from January 1, 2006. The credits phased out for Toyota Prius in 2007 and for most of the other HEV models in 2009. All credits expired by the end of 2010. Since the initial rollout in 2000, the market share of HEVs among new vehicle sales has witnessed a large increase to about 3% in 2013 and gradually decreased in more recent years accompanied by lower gasoline price and the termination of subsidy support (Figure 1 & Table 1).

Nissan Leaf and Chevrolet Volt were introduced into the U.S. market in December 2010, marking the beginning of the mass market for Plug-in Electric Vehicles (PEVs) [1]. PEVs are comprised of BEVs which run exclusively on high-capacity batteries (e.g., Nissan LEAF) and PHEVs which use batteries to power an electric motor and use gasoline to power a combustion engine to extend the range (e.g., Chevrolet Volt). If operated under all-electric mode, BEVS and PHEVs consume no gasoline and produce zero tailpipe emissions. Therefore, the electrification of the vehicle fleet, together with a clean grid fuel mix, provides a promising

[1] GM introduced over 1000 first-generation PEVs mostly through leases in California from 1996 to 1998 and suspended their EV production in 2003. Tesla Motors introduced an all-electric sport car Tesla Roadster in 2006 and started its general production in March 2008, but the listed price (over $120,000) was out of the price range for average buyers.

pathway to reduce oil dependency and greenhouse gas emissions from the transportation sector.

Similar to HEVs, PEVs are also more expensive than their conventional gasoline vehicle counterparts. The manufacturer's suggested retail prices (MSRP) for the 2015 model of Nissan Leaf and Chevrolet Volt are $29,010 and $34,345, respectively, while the average price for a comparable conventional vehicle (e.g., Nissan Sentra, Chevrolet Cruze, Ford Focus and Honda Civic) is between $16,000 and $18,000. A major reason behind the cost differential is the cost of battery. As the battery technology improves, the cost should come down. Governments around the world have employed a variety of subsides for PEVs in a more generous way than those for HEVs. Those subsidy programs include monetary incentives such as income tax credits and rebates for the purchase of PEVs and non-monetary incentives such as HOV lane access, free parking, free registration, sales tax reduction, emissions inspection waiver, and license quota exemption in some countries [2]. In the United States, the Energy Improvement and Extension Act of 2008, and later the American Clean Energy and Security Act of 2009 grant federal income tax credit for new qualified EVs. The minimum credit is $2,500 and the credit may be up to $7,500, based on each vehicle's battery capacity and the gross vehicle weight rating. Moreover, several states have established additional state-level incentives to further promote PEV adoption. For example, through the Clean Vehicle Rebate Project, California offers a $2,500 rebate to BEV buyers and a $1,500 rebate to PHEV buyers. Colorado provides the highest income tax credits with the amount of $2,500-$6,000 depending on the model. With more BEV and PHEV models being introduced, the market share of PEVs has increased significantly in the U.S. in recent years but still accounts for less than 1% of the total new vehicle sales (Figure 1 & Table 1).

3 AFV Subsidy and Consumer Adoption

This section discusses the findings from current literature which investigates the impact of the subsidy programs on consumer demand of AFVs. We focus on the monetary subsidies such as tax credits and rebates due to the prevalence of this type of subsidy and the large body of existing relevant studies.

A large portion of the literature employ stated preference analysis using data from consumer survey which asks respondents vehicle choices under different hypothetical scenarios of vehicle performance, vehicle upfront cost and fuel cost. Discrete choice models are then

[2] Some cities in China implement a license restriction policy for the registration of new vehicles and some PEV models are exempt from this restriction.

adopted to analyze which variables have significant impact on consumer choices, providing policy implications for more effective subsidies. Some other studies rely on real-world data and use reduced-from approach to estimate the relationship between AFV adoption and a variety of policy designs. Those studies often exploit either cross-sectional variation in AFV sales and the generosity and forms of incentives or temporal variation in the sales for the jurisdictions who have changed incentive policies. The policy impacts are identified through comparing a model's market share over time within the same area as well as across areas while varying the presence and amount of rebates, controlling for vehicle model characteristics and consumer demographic variables. The remaining studies adopt structural approach that estimates the automobile market equilibrium using discrete choice demand of consumers and Bertrand price competition of automakers and then simulate counterfactual vehicle sales under different policy scenarios to estimate the policy impacts. To facilitate presentation, Table 2 provides a summary of the existing studies by listing their methodology and main findings. The remainder of this section will also discuss the studies associated with each of the aforementioned methods in detail.

Although using different estimation approaches, the literature almost consistently find a positive impact of tax credits and rebates on AFV demand. These stated preference studies are especially popular during the early stage of the diffusion of an alternative fuel technology due to the lack of real-world data either because of the short amount of time those AFVs are on the market or the tiny market share they represent in the automobile market. Helveston et al. (2015) model consumer preferences for conventional, HEV, and PEVs in China and U.S. using data from choice-based conjoint surveys and and simulate the market shares of PEVs under different subsidy amounts. They estimate that to achieve a 50% market share of PEVs would require a U.S. subsidy of about $9,000 and a Chinese subsidy of about $18,000 for low-electric-range PHEVs, and more than $20,000 in both countries for larger bettery PHEVs and BEVs. Dimitropoulos et al. (2016) evaluates the effects of the favorable tax treatment of PEVs in the company car market by using data from a new survey among Dutch company car drivers. By analyzing drivers' sensitivity to changes in applicable tax base rates and other vehicle characteristics, they find that drivers are sensitive to changes in tax base rates and there exists substantial heterogeneity in drivers' sensitivity to company car's list prices. DeShazo et al. (2014) use a state-wide survey of new car buyers in California to estimate price elasticities and willingness to pay for different vehicles and then simulate the effects of different rebate designs. They estimate that the rebate policy in California that offered all income classes the same rebate of $2,500 for BEVs and $1,500 for PHEVs lead to a 7% increase in PEV sales.

A major weakness of stated preference analysis is that the hypothetical purchase environment is often different from the real world and the choices the respondents make in a survey may not reflect their true preference in a real vehicle purchase situation and the elasticity estimates would thus be biased. The reduced-form approach is more prevalent in the economic literature by using real-world data and looking at aggregate market outcomes. Diamond (2009) estimates the impact of the U.S. federal and state government tax rebates on the sales of certain HEV models using cross-sectional analysis of registration data over time and finds that doubling the average monetary incentive of $ 830 would have resulted in an 18% increase in average market share. Gallagher and Muehlegger (2011) examines the relative efficacy of state sales tax waivers, income tax credits, and non-tax incentives on HEV sales by exploiting within state-model variation of quarterly state-level HEV sales for eleven models introduced from 2000 to 2006. They find that a tax incentive of $ 1,000 is associated with a 5% increase in HEV sales while a $100 increase in annual fuel savings is associated with a 13% increase in sales. Sallee (2011) studies the incidence of incentives offered to Toyota Prius owners using consumer-level purchase data. Using a differences-in-differences approach by exploiting the variation of federal tax incentives for the Toyota Prius created by the phase-out provision, he finds evidence that consumers capture the majority of the tax incentive. In addition, there exists evidence that consumers strategically shift their purchases into higher subsidy time periods. In Canada, some provinces offered provincial sales tax rebates of different amount. With the large variation in rebate programs both temporally and cross-sectionally, Chandra et al. (2010) are able to identify the impact of provincial sales tax rebates on the market share of HEVs. They estimate that 26% of the HEV sales sold during the rebate programs can be attributed to the rebate.

The more recent literature has examined the effects of the similarly designed income tax credits for PEVs. Congressional Budget Office (2012) estimates the effect of income tax credits for PEV buyers based on previous research on the effects of similar tax credits on HEVs and finds that the tax credit could contribute to nearly 30% of PEV sales. Sierzchula et al. (2014) analyze how PEV adoption rates vary across a series of countries using a set of socio-economic variables. They collected and analyzed data from 30 counties for 2012 and did a cross-sectional analysis examining how variation in financial incentives, urban density, education level, fuel price, PEV price, charging infrastructure affects the variation in the PEV market shares. Heterogeneous financial incentives are converted to one uniform financial incentive variable. Their regression results show that a $1,000 increase in financial incentives would increase a country's PEV share by 0.06%. Using market-level sales data, Li et al. (2016) offered the first empirical study in quantifying the role of indirect network effects in the PEV market and the impact of federal subsidy on PEV demand. They estimate that the federal income tax credit of up to $7,500 contributed to about 40% of PEV sales during 2011-2013 with network effects explaining 40% of that increase.

An empirical challenge of this reduced form approach is that various forms of subsidies from different layers of government often exist concurrently, making it hard to isolate the impact of a particular policy. In addition, the reduced-form approach usually focuses on a single AFV model or a subset of vehicles choices, thus restricting the substitution and competition from other fuel types. The structural approach, on the contrary, estimates the new vehicle market equilibrium including other vehicle types and is thus able to estimate which cars are crowded out due to the policy, providing environmental implications and allowing estimation of cost-effectiveness of the policy in terms of environmental benefits. Beresteanu and Li (2011) estimates an equilibrium model of U.S. automobile market using aggregate vehicle sales in 22 metropolitan areas from 1999 to 2006, which allows them to stimulate what would happen to the whole market under different scenarios and to examine the responses from the demand and supply sides separately. They conduct simulations to investigate the effect of federal income tax credits of HEV purchases and find that federal income tax deductions explained less than 5% of hybrid vehicle sales from 2001 to 2005 whereas more generous income tax credits in 2006 accounted for about 20% of HEV sales. Huse and Lucinda (2014) use structural model to quantify the effects of the Swedish Green Car Rebate (GCR) on consumer adoption of FFVs and find that the GCR shifted the demand from high-emission vehicles to FFVs and other low-emission vehicles. Without the subsidy, the market shares of FFVs, low-emission petrol and diesel vehicles would decrease by 1.95%, 1.91% and 1.64% respectively.

4 Other Considerations for Evaluating Policy Effectiveness

This section will discuss other factors that could influence the effectiveness of AFV subsidies in terms of the induced demand and the implied environmental benefits. The relative efficacy will also be assessed by comparing the existing policy with alternative policy tools.

4.1 Forms of Incentives

The effects of a subsidy program depend not only on the exact amount of the incentive, but also on how the incentive is delivered to customers. Some studies exploit the variation in the forms of incentives and find the incentive form plays a critical role in consumer adoption of AFVs.

Unlike a direct rebate or sales tax waiver made upon purchase, income tax credits are not given immediately to new AFV buyers but are claimed during future tax returns, making it not as effective as a point-of-sale rebate as it requires additional work and consumers might discount future tax return.

Diamond (2009) find that upfront exercise or sales tax waivers are more effective than delayed rebates or tax credits in influencing adoption. Gallagher and Muehlegger (2011) separately examine coefficients for income tax credits and sales tax waivers and find that sales tax waivers are much more effective in increasing HEV sales relative to income tax credits with the same amount. As they point out, a sale tax waiver is automatic, immediate and easy to understand, while income tax credits are applied in the following year.

The income tax credit policy does not distribute the subsidy equally across households since the exact credit amount that can be claimed depends on the tax liability of the household. Households with lower income or households who purchase several fuel-efficient products which are eligible for tax returns might not be able to claim the full credit amount. Thus, increasing the subsidy amount is likely to constraint more people from receiving the full amount. Households with lower-income tend to be more responsive to the incentives than those with higher income because low-income households tend to be more price-sensitive, and they often have a stronger preference for fuel-saving technologies and are more likely to be subjects to credit constraints and discouraged by the higher upfront cost of AFVs. Thus, excluding the lower income group from receiving the full credits would reduce the effectiveness of the subsidy programs.

A flat rebate program which provides equal subsidies to all AFV buyers may result in more AFV sales. Beresteanu and Li (2011) conduct simulations to compare the income tax credit program with a rebate program that provides equal subsidy across households who purchase hybrid vehicles and finds that a flat rebate program that achieves the same fuel efficiency for new vehicles as in the current tax credit program would cost over 15% less in government revenues.

4.2 Additionality in AFV Adoption

A potential problem associated with the direct subsidy to consumers is that the policy may not always result in additional AFV sales in the sense that many of the buyers who claim the subsidy may still purchase AFVs even if there were no subsidy policy.

Since early adopters of AFVs are those who favor the newest technology and who have the strongest environmental awareness and usually have higher income, it is more likely that the effect of a uniform subsidy policy, such as the current federal PEV income tax credit, on boosting additional AFV sales is limited [3]. California Clean Vehicle Rebate Program (CVRP) used to offer incentives of $1,500 to PHEVs and $2,500 to BEVs, but the majority of the rebates went to households with high income. In order to direct the rebates towards households who value the rebates most, CVRP has been redesigned such that lower-income households will be able to claim a larger rebate. The households with income less that 300% of Federal Poverty Limit will be able to get $3,000 for PHEVs and $4,000 for BEVs, and the households with gross annul income above certain thresholds are no longer eligible for the rebates: $250,000 for single filers, $340,000 for head-of-household filers and $500,000 for joint filers.

The literature has documented the issue of "non-additionality" in the markets of energy-efficient technologies. Allcott et al. (2015) find that some energy efficiency subsidies are poorly-targeted and are primarily taken up by consumers who are wealthier and more informed about energy costs. They conclude that restricting subsidy eligibility could increase the welfare gains from those subsidies. Boomhower and Davis (2014) find that half of all participants would have adopted the energy-efficient technology even with no subsidy. Diamond (2009) did not find a strong relationship between monetary incentives and consumer adoption of HEVs since the incentive payments were effectively creating a subsidy for the highest income consumers without significantly affecting their purchase decisions. Chandra et al. (2010) argue that the HEV tax rebates offered by Canadian Provinces also subsided many consumers who would have bought HEVs in any case. Sallee (2011) points out that it is reasonable to expect that subsidies will accrue to consumers without influencing quantities when these advanced technology vehicles become popular. Beresteanu and Li (2011) uses the structural approach to estimate the automobile equilibrium and simulate the counterfactual sales if there were no federal income tax credits and find that HEV sales would still be growing dramatically over time even without tax incentives. Huse and Lucinda (2014) finds a substantial share of FFV consumers in Sweden would have purchased FFVs regardless of the cash rebates due to the lower operational cost. Helveston et al. (2015) finds that older, wealthier and more educated consumers, especially those who own multiple vehicles and have children in households, are less sensitive to upfront and operating costs of PEVs. They are

[3] According to California Plug-in Electric Vehicle Owner Survey (2014), among buyers of conventional new vehicles, 15% of households have annual household income over $150,000 while among PEV buyers, that share is 54%. `https://energycenter.org/clean-vehicle-rebate-project/vehicle-owner-survey/feb-2014-survey`.

more likely to purchase PEVs witout the subsidy support. Li et al. (2016) estimates that the federal income tax credits, along with the indirect network effects could account for 40% of PEV sales during 2011-2013, suggesting more than half of the PEV buyers would have adopted PEV in the absence of the subsidy.

Instead of a one-size-fits-all policy, a subsidy policy that targets marginal buyers who are more responsive to the subsidy and would only purchase AFVs with the subsidy could improve the policy efficacy. Those marginal buyers should be those who consider higher upfront cost as the only obstacle to the adoption of AFVs or the subsidy amount is enough to compensate for utility loss from the other drawbacks they may experience with AFVs (e.g.,inconvenience of refueling and limited range). Identifying the marginal buyers and estimating potential efficiency gains from a targeted policy would require further research using more detailed data than used in the existing literature.

4.3 Environmental Benefits

One of the justifications for AFV subsidies is to reduce the emissions from the transportation sector by replacing fuel-inefficient vehicles with AFVs. However, when upstream emissions are taken into account, substantial heterogeneity of the environmental benefits could exist. For example, PEVs may not have an advantage over conventional vehicles in locations where the electricity is generated through fossil fuels. Thus, even if the PEV subsidy results in additional PEV purchases, the reduction of overall emissions would be limited. By incorporating spatial heterogeneity of damages and pollution export across jurisdictions, Holland et al. (2016) find considerable heterogeneity in environmental benefits of PEV adoption depending on the location and argue for regionally differentiated PEV policy. They find the environmental benefits of PEVs being the largest in California due to large damages from gasoline vehicles and a relatively clean electric grid and the benefits to be negative in places such as North Dakota where the conditions are reversed.

The fuel economy of the vehicles that get replaced by AFVs due to subsidy will determine the effectiveness of the AFV subsidy in terms of addressing the environmental externalities. An potential efficiency loss could arise if the subsidy does not induce people to switch from a gas guzzler to an AFV but from another fuel-efficient gasoline vehicle to an AFV, or another AFV to the targeted AFV, making little net gain of environmental benefits. Holland et al. (2016) evaluate the heterogenous environmental benefits of PEVs by comparing the externalities of PEVs with their gasoline counterparts. However, the relative environmental benefits would be smaller if a higher fuel-efficient vehicle such as a HEV is compared. At the national average fuel mix, BEVs and PHEVs do not have an advantage over HEVs in the emission reduction and PHEVs even generate more emissions than HEVs (Table 3). With the expiration of the tax credits for HEVs, the income tax credits for PEVs are very likely to encourage consumers who would otherwise purchase HEVs to purchase PEVs. As the gasoline price increases, the efficacy of the government subsidy for AFVs in terms of reducing emissions is further weakened since more consumers would be induced by the market incentive to adopt AFVs in the absence of subsidy. Chandra et al. (2010) find that the rebate programs in Canada primarily subsidize people who would have bought HEVs or fuel-efficient cars in any case and they may not be the most effective way to encourage people to switch away from fuel-inefficient vehicles like large SUV's or luxury sport passenger cars, at least in the short or medium run.

The net benefits of the policy would be larger when the subsidy makes consumers switch from a gas-guzzler to a PEV. However, consumers who have a strong preference for large vehicles are not likely to be motivated by the PEV subsidy to alter their choice. A potentially effective alternative could be similar to the design of the "cash-for-clunkers" program, which provides cash incentives to consumers who retire their old vehicle and replace it with a new vehicle. The "cash-for-clunkers" program implemented in U.S. in 2009 did not restrict the new vehicle purchased under the plan to be an AFV, but required the new car to have a combined fuel economy of at least 22 mpg. A modified tax credit or rebate could be provided to consumers who retire their old less-fuel-efficient vehicles and replace them with fuel-efficient AFVs [4].

4.4 Fuel Usage and Vehicle Usage

Although AFV subsidy could affect consumer's vehicle choice when they make the purchase decision, it does not have a direct impact on consumer's future vehicle usage. For vehicles that piggyback on gasoline vehicles and run both gasoline and the alternative fuel, "fuel arbitrage" could also weaken the effectiveness of the subsidies. Consumer could switch to the cheapest one between gasoline and alternative fuels. With a relatively low gasoline price, FFV drivers and PHEV drivers are more enticed to choose gasoline due to the lack of ethanol and electric fueling infrastructure. As pointed out in Huse and Lucinda (2014), policy makers need to take into account of the fuel switching of FFV technology when designing policies since it increases the policy cost of reducing emissions. They estimate that the CO_2

[4] The "cash-for-clunkers" program implemented in U.S. between July 1, 2009 and August 24, 2009 had the average fuel efficient of trade-ins being 15.8 mpg and the new vehicles purchased being 24.9 mpg, resulting in a 58% fuel efficiency improvement, according to Department of Transportation.

savings fall by 14% and 18% if gasoline usage among FFV drivers increases to 50% and 75% respectively. A possible solution is to adjust the subsidy amount to those AFV technologies based on their actual frequency of running on alternative fuels.

To reduce the externalities associated with gasoline consumption, economist have advocated a gasoline tax which not only encourages people to adopt fuel efficient vehicles in the new vehicle market as what AFV subsidy does, but also affects the entire 250-million on-road vehicle fleet by encouraging drivers to drive fewer miles. The reduction in vehicle miles traveled is an critical channel for reducing oil consumption and it is an often ignored channel by policy makers (Knittel 2012). The implementation of higher gasoline tax, however, faces political obstacles in the U.S. where people rely heavily on vehicle transportation. The federal-level gasoline tax has remained at 18.4 cents per gallon over 20 years. Although the AFV subsidies could provide incentives to consumers to adopt fuel-efficient vehicles, it has no impact on the driving behaviors of the existing vehicle fleet, failing to mitigate the externalities related to vehicle miles, such as pollution, congestion and accidents.

The AFV subsidy could even exacerbate the externalities from vehicle usage as it might induce people who adopt AFVs to drive more, resulting in the "rebound effects"(Greening et al. 2000; Small and Dender 2007; Sorrel and Dimitropoulos 2008; Borenstein 2015; Chan and Gillingham 2015). With improved fuel economy and less gasoline usage, adopting AFVs essentially reduce the marginal cost of driving conditional on the same gasoline price, creating incentives for drives to drive more. Even if driving AFVs does not lead to as much pollution as conventional vehicles with the increased mileage, the other externalities associated with congestion and accidents could be increased with the additional travel induced and the increase in miles traveled could more than offset the reduction in external costs associated with greenhouse gas emissions (Sallee and Anderson 2015). In the presence of a mileage-based tax or congestion pricing which internalize all these externalities, the efficiency loss from "rebound effects" could be alleviated.

4.5 Interaction with the Fuel Economy Standards

In the absence of the first-best policy, a mandate on the producer side that sets the minimum fuel economy requirement on the auto manufacturers has been widely adopted around the world. Nine governments including United States, China, Japan, and the European Union have established or proposed fuel economy or greenhouse-gas emission standards for passenger vehicles and light trucks. In the United States, the Corporate Average Fuel Economy (CAFE) standards were first enacted in 1975, after Arab Oil Embargo, to improve the average fuel economy of cars and light trucks sold in the United States. The standard were set by the National Highway Traffic Safety Administration (NHTSA) and was largely unchanged between 1990 and 2010, but was set to increase from model year 2011 to 2021 and is scheduled to reach an average of 41 miles per gallon by model year 2021. In addition, the Environmental Protection Agency (EPA) has set parallel standards to limit greenhouse gas emissions from new vehicles through model year 2025, equivalent to 54.5 miles per gallon. An automaker's standard is determined by computing the harmonic mean of the mileage targets for individual vehicles in a manufacturer's fleet. The requirements for individual vehicles vary based on their footprint with the target for smaller vehicles being larger (higher MPG).

Some state governments set additional mandates which require a certain proportion of the entire fleet each automaker sells to be zero-emissions vehicles (ZEVs). California requires the industry to sell enough ZEVs (PEVs and FCVs) to reach approximately 15.4% of California's new passenger-vehicle fleet. Nine other states, including New York, have also adopted California's ZEV regulation. These mandates put additional compliance burden on automakers and are more restrictive than federal CAFE standard since they target on specific technologies instead of giving automakers flexibility in choose technologies to improve the fuel economy of their entire fleet.

The fuel economy mandates increase the cost of producing vehicles that are less fuel-efficient and encourage automakers to lower the price of AFVs to attract consumers to buy AFVs. Under the current credit-based policy design, some AFVs are treated more favorably and selling one additional AFV actually allows more than one gas-guzzler to be sold. Under EPA programs, in 2017, each BEV and FCV distributed for sales by a manufacturers will count as two vehicles. With an effective AFV subsidy in place, the automakers would feel less pressure to increase the price of gas-guzzlers or decrease the price of AFVs to adjust sales mix to make the average fuel economy compliant with the standard. Therefore, the AFV subsidies essentially work as a subsidy for automakers that reduces their CAFE compliance cost and a subsidy for gas-guzzler buyers that reduces their purchase cost.

Since the CAFE standards are binding for domestic firms (Jacobsen 2013), the subsidy for AFVs has little impact on reducing energy use and GHG emissions as CAFE has already achieved the intended reductions. When AFV subsidies induce additional AFV sales, the CAFE stringency is relaxed and auto manufacturers can then sell more gas-guzzlers. The AFV subsidy works as encouraging a small group of consumers to adopt AFVs so that more gas-guzzlers could be sold. Unlike a gasoline tax which alters consumers' preference by not only encouraging consumers to adopt AFVs but discouraging people who prefer gas-guzzlers from choosing them, the subsidy for AFVs does not have a direct channel to discourage the sales of gas-guzzlers. On the contrary, AFV subsides make it easier to sell gas-guzzlers by implicitly subsidizing them through the CAFE channel. One possible solution is to exclude the subsidized AFVs from the CAFE calculation so that the average fuel economy only takes into account of the conventional cars that are not being subsidized.

Although the AFV subsidies have little effect on reducing gasoline consumption and greenhouse gas emissions in the short run when the CAFE standard is binding, the AFV subsidies could decrease gasoline consumption and GHG emissions in the long run if the expanding AFV market lead policymakers to set CAFE standards for 2022 and beyond at a higher level than they would otherwise. The effects of current AFV subsidies on future gasoline consumption and GHG emission thus depends on the extent to which policymaker's form expectation of future AFV market conditions based on past and current AFV sales when designing CAFE standards (Congressional Budget Office 2012).

5 Alternative Subsidy Designs

In this section, we discuss some other forms of fiscal policy instruments that have been adopted to encourage the adoption of AFVs. Some of the policy instruments may demonstrate an efficiency advantage while others may not have a significant impact on consumer choice or could even result in unintended consequences.

5.1 HOV Lane Access

To promote the adoption of AFVs, some cities issue stickers or special license plates to AFVs to allow them to drive in high occupancy vehicle (HOV) lanes without carpooling. The benefits of the HOV lane access vary across cities and are larger in locations where the congestion is more severe. A commuter might save as much as $1,500 per year with the HOV access (McConnell and Turrentine 2010).

The literature finds mixed results of the impact of HOV access on the AFV demand. Some previous studies do not find the access to HOV lanes as effective as direct monetary subsidies in encouraging AFV adoption. In a stated preference study, Potoglou and Kanaroglou (2007) find that consumers do not seem to respond to non-monetary incentives such as parking and HOV lane privileges in decisions over vehicle choices. Gallagher and Muehlegger (2011) finds little evidence that allowing single HEV occupancy in HOV lane has a significant impact on HEV sales, except for Virginia. HOV access in Virginia is associated with a 92% increase in HEV sales prior to the HOV-3 restriction (which restricted HEV travel in HOV-3 lanes during rush hour beginning in July 2006), and 49% following the HOV-3 restriction.

Diamond (2008) explores how the impact of the HOV incentive on HEV adoption varies among different jurisdictions within the state, taking into account local variation in other factors such as income, environmental awareness, and commuting habits. He finds the policy impact of HOV lane incentive on the adoption of HEVs depends on the commuting time, the time savings and congestion level from the HOV lanes. In areas where the congestion is less severe and the commuting time is shorter, the HOV incentive is less effective.

Non-monetary incentives such as the HOV lane access are sometimes preferred to monetary incentives due to the perceived lower or zero administrative costs. Nevertheless, the hidden cost of these non-financial incentives needs to be carefully evaluated. Their effectiveness may be much lower if the opportunity cost is taken into account. For example, the forgone revenue of granting HOV lane access to AFV drivers could be huge if consumers have a high willingness to pay for the access. Shewmake and Jarvis (2014) find that consumers place a high value on the stickers in California. The availability of the sticker was limited and not all eligible vehicles received stickers, which allows them to compare the price of used HEVs with and without stickers to estimate the willingness-to-pay for HOV access. They show that the 85,000 stickers could have been sold for $5,800 per sticker set in August 2005 indicating the program had an implicit cost of roughly $490 million. They find the value of the air pollution reductions achieved by the program are worth much less than the values of the space in HOV lane. In China, cities such as Beijing and Shanghai limit the registration of new vehicles and a lottery or auction system have been implemented to distribute the limited license plates. To encourage the diffusion of clean fuel vehicles, new PEV buyers could receive a license plate without going though the auction or lottery. The implicit cost of this policy could be considerable as the willingness-to-pay for a vehicle license is extremely high in those cities (Li 2015).

Besides the high implicit cost of the HOV lane incentive policy, allowing single hybrid vehicle drivers in the car pool lanes also increases the congestion on the carpool lanes, creating a disincentive to carpooling. Bento et al. (2014) use traffic sensor data from Los Angeles to estimate the welfare effects of the Clean Air Access program on carpoolers in the HOV lane and find hybrid vehicles entering the HOV lanes in Los Angeles slowed down the existing carpoolers, resulting in a negative net welfare impact. Moreover, single-occupant of hybrid vehicles in HOV lanes might also consume more gasoline per mile and per person, on average, than carpoolers in less efficient vehicles with two or three passengers (Diamond

2008).

5.2 Exemption from Congestion Charge

A similar design to the HOV lane access is to exempt AFVs from the congestion charge. In countries where the congestion charge is implemented, the exemption of AFVs from congestion charges is one possible way to encourage the adoption of AFVs. With the objective to reduce congestion in inner city areas, the city of Stockholm introduced congestion tax on a permanent basis in August 2007 after a seven-month trial period. Vehicles running on ethanol and electricity were exempt from the congestion charge. The amount of payable depends on the time of the day a motorist enters or exits the congestion charge area.

Whitehead et al. (2014) finds that the congestion charge exemption appears to have been the most significant incentive policy introduced in Stockholm in terms of increasing the demand for the exempt AFVs. By comparing the predicted AFV market shares from the two scenarios when the charge exemption was active and when the exemption was absent, they estimate that the congestion charge exemption increased the demand for exempt AFVs by 10.7%. However, same as allowing single AFV occupants to drive HOV lanes, exempting AFVs from the congestion charge could have unintended consequences such as eroding the primary goal of the congestion charge, which is to control traffic volume (Hultkrantz and Liu 2012).

5.3 Consumer Education Programs

As mentioned in the introduction, cognitive bias and search cost may cause consumers to undervalue the future fuel cost savings, resulting in under-investment of AFVs. Increasing the public awareness of the potential fuel cost savings and environmental benefits of AFVs serves as a straightforward strategy to address the "energy efficiency gap".

Previous literature has documented the role of consumer environmental awareness and the effect of consumer learning in AFV adoption (Kahn 2007; Kahn and Vaughn 2009; Sexton and Sexton 2014; Heutel and Muehlegger 2012). The government could design policies that influence consumer preference or the discount rates for future fuel cost savings and target the group of people who are more likely to underestimate the fuel cost savings from AFVs. Examples include information sessions, advertising, and labeling that help consumers evaluate potential fuel cost savings and assist them in making a comparison between the life-time holding costs of different vehicle models. Currently, new cars sold in the United States must display information on vehicle fuel efficiency and an estimate of annual gasoline expenditure. The similar "Energy Guide" labels are required to be displayed in other major appliances in the U.S. as well. However, these government-mandated labels only report coarse information based on national average prices and typical national usage while the substantial heterogeneity of energy prices and usage across locations makes the information provided highly inaccurate for many consumers. Davis and Metcalf (2016) find that state-specific labels lead to significant better choices by consumers with more investment in energy efficiency in high-usage and high-price states and less investment in low-usage and low-price states. Considering both the vast temporal and spatial variation in fuel prices, providing most updated location-specific fuel efficiency labels could be a critical channel to help consumers make vehicle choices.

Education programs could also increase the efficacy of the existing subsidies of AFVs by better informing consumers the existing policy incentives. Some studies find that the majority of people are actually unaware of the existence of purchase incentives for some of the AFVs. Krause et al. (2013) surveyed adult drivers in 21 large U.S. cities and found that 75% of respondents underestimated the values and advantages of PEVs and 94.5% of them had no knowledge of state and local incentives for the purchase and use of these vehicles. Unlike Europe where a large fraction of vehicle sales are made to companies or fleet buyers, the U.S. automobile market is dominated by individual households who choose vehicles according to their own preference and family needs. Therefore, consumer education programs could play a larger role in the U.S. market. However, those education programs are currently scarce and their effects on consumers' choice are difficult to quantify.

5.4 Subsidizing Alternative Fueling Infrastructure

While some AFV models that piggyback on gasoline vehicles could be just fueled at gasoline stations (such as HEVs, FFV, and PHEVs), the diffusion of some other AFV models rely heavily on the deployment of the alternative fueling infrastructure. The interdependence between the fueling station investment and the AFV adoption gives rise to the "chicken and egg" problem during the early deployment stage of a new technology.

Gasoline vehicles could easily travel over 300 miles with full tank and could fuel in within five minutes. Most of the affordable BEV models currently on the market have a range round 80 miles, which could cover the average commute length of household daily travel (approximately 30 miles). However, the desire to drive long-distance without worrying about running out of fuel before reaching the destination still holds back some consumers from purchasing those vehicles. Although the charging station network is rapidly expanding across the U.S. with about 15,000 public charging stations available by October 2016, the availability of public charging is still considered scarce compared to a gasoline fueling network of about 120,000 stations.

While the installation of home charging for PEVs could reduce their dependence on the public fueling stations, the fueling of FCVs may depend completely on public hydrogen stations. FCVs are powered by hydrogen and are fueled with pure hydrogen gas from hydrogen fueling stations. They can fuel in less than 10 minutes and have a driving range of around 300 miles. By October 2016, there are only 29 hydrogen stations in the U.S. and the FCV market will not witness significant penetration unless mass deployment of hydrogen stations occurs.

In addition to subsidizing consumers' adoption, the government has also been playing an activate role in subsiding the building of AFV fueling stations. Whether subsidizing consumers or subsidizing fueling stations incurs lower cost of each AFV increased actually depends on consumers' responsiveness to subsidy, the actual cost of the fueling stations, and which side of the market (AFVs or fueling stations) has a larger network effects (Li et al. 2016). At the early deployment stage, subsidizing the fueling infrastructure might be more effective because early adopters are less price sensitive and concern more about whether they could drive normally and refuel conveniently wherever they drive. In practice, governments often subsidize both sides of the market concurrently. In the United States, the federal, state, and local governments have been using various incentives to encourage the private investment of AFV fueling stations. Currently under the federal Alternative Fuel Infrastructure Tax Credit policy, fueling equipment for natural gas, propane, hydrogen, electricity, E85 and diesel fuel blends is eligible for a tax credit of 30% of the cost, not to exceed $30,000. Besides, other financial assistance such as loans and funding for either installation of AFV fueling stations or research and demonstration are also available.

Although the literature on the effectiveness of the government subsidy on the building of AFV infrastructure is lacking, there have been studies which look at the importance of the fueling infrastructure on consumer's adoption of AFVs. Using a discrete choice model, Langer and McRae (2014) estimate driver's choice of gasoline station locations and evaluate how drivers trade off between fuel price and the excess time needed to deviate from their route. They then use their model to calculate the values to consumers of AFVs (assuming lower price but longer distance) relative to gasoline vehicles and stimulate the AFV penetration under different assumptions of the fueling station density. They suggest that the government can subsidize AFV purchasing or fueling stations to the point when the market reaches a sustainable point. They also find that although the total cost of subsiding vehicles is lower than subsidizing stations, the minimum self-sustaining level of stations could be achieved earlier. Sierzchula et al. (2014) analyze how PEV adoption rates vary across a series of countries using a set of socio-economic variables and find an additional charging station per 100,000 residents would increase PEV share by 0.12%. They argue that the installation of charging stations is more effective in stimulating PEV adoption but both financial incentive and charging infrastructure should be supported since they complement each other. Shriver (2015) estimates the network effects in the market of ethanol fuel vehicles by modeling the simultaneous determination of vehicle demand and fuel supply in local markets using zip-code panel data from four U.S. states over nine years. He finds an additional ethanol retailer leads to a 6% increase in the probability of ethanol vehicle purchase and the first fueling station entrant needs a local installed base of 300 ethanol vehicles to be profitable. The study also concludes that subsidizing ethanol fueling stations could be an effective way to stimulate ethanol vehicle sales in some locations. Dimitropoulos et al. (2016) find potential early adoptes of PHEVs are sensitive to changes in the extra detour time to reach a fast-charging station and argue that policies that intend to expand fast-charging stations can be an effective stimulus for the early adoption of BEVs, which could potentially further save public spending for the stimulation of the adoption of electric vehicles. Li et al. (2016) quantify the indirect network effects in the PEV market in U.S. metropolitan areas and find that the network effects of charging stations on the PEV adoption are larger than the other direction during the early deployment of PEVs because early adopters are less price sensitive and prefer more charging locations given the shorter range of the early PEV models and the scarcity of charging stations. Their results suggest that subsidizing charging stations is more effective in speeding up the PEV diffusion at the initial rollout stage.

Further research needs to investigate how the exact location of fueling stations matters for consumers' adoption of AFVs. The PEV market is more complicated since public charging serves as a complement to home charging, and when and where consumers need those complementary charging should be considered during the station sitting stage.

6 Conclusion

This paper provides a review of the growing literature which investigates the effectiveness of the fiscal policies to promote alternative fuel vehicles with an emphasize on the subsidy programs on the consumer side. The purchase subsidies in the form of income tax credits and rebates are widely adopted in many countries and are largely documented to have a positive impact on AFV demand. Some other non-monetary incentive policies could also stimulate AFV demand while the hidden cost of non-monetary policies should be seriously considered when designing the most efficient programs. During the early deployment stage of a new AFV technology, supporting the fueling infrastructure is extremely critical due to the lack of fueling facilities and the issue of range anxiety. By investigating the existing literature, we have the following important findings regarding the evaluation of the effectiveness of various subsidy programs.

First, the subsidy may not bring significant environmental benefits if many of the consumers would purchase the targeted AFVs anyways or would purchase another fuel-efficient vehicle in the absence of the subsidy. Better policy design and implementation such as targeting "marginal buyers" and restricting eligibility could potentially improve the policy effectiveness.

Second, "fuel arbitrage" and the "rebound effects" could erode the effectiveness of the subsidy policies in terms of addressing the externalities associated with vehicle usage and mileage traveled. Policy makers should take into account of the "fuel arbitrage" behavior when designing subsidy programs for the affected AFV technologies. Mileage-based tax and congestion pricing should be advocated to address the "rebound effect" when AFV are being subsidized.

Third, with a binding fuel economy standard imposed on auto manufacturers, the consumer subsidy programs for AFVs might have little effect on reducing overall emissions and gasoline consumption in the short run since more gas-guzzlers could be sold due to the relaxed mandate stringency from selling more AFVs. Policy makers should also pay closer attention to the interactions between existing policies which intend to target different angles of the market when first-best policies are absent.

We suggest some areas for future research. The cost-effectiveness of subsidy policies critically hinges on how well these programs target "marginal buyers" who would not adopt the technology in the absence of the subsidy. Identifying these consumers from careful analyses of consumer choices with rich demographics information can provide guidance for designing more cost-effective subsidy programs. Future work might also investigate the vehicle types that are getting crowded out by the targeted AFV technologies and the substitution between AFVs and conventional vehicles is important in evaluating the environmental impacts of the subsidy programs. In addition, consumer education programs which increase consumer awareness of the environmental benefits of AFVs and help consumers evaluate the true cost savings of AFVs could be an effective strategy to promote AFVs. These programs should be paid more attention and the effectiveness of those programs should be more carefully examined in the future.

References

Allcott, Hunt and Michael Greenstone, "Is There an Energy Efficiency Gap?," *Journal of Economic Perspectives*, 2012, *26* (1), 3–28.

_ **and Nathan Wozny**, "Gasoline Prices, Fuel Economy, and the Energy Paradox," *The Review of Economics and Statistics*, 2014, *96* (5), 779–795.

_ **, Christopher Knittel, and Dmitry Taubinsky**, "Tagging and Targeting of Energy Efficiency Subsidies," *American Economic Review, Papers and Proceedings*, 2015, *105* (5), 187–191.

Bento, Antonio, Daniel Kaffine, Kevin Roth, and Matthew Zaragoza-Watkins, "The Effects of Regulation in the Presence of Multiple Unpriced Externalities: Evidence form the Transport Sector," *American Economic Journal: Economics Policy*, 2014, *6* (3), 1–29.

Beresteanu, Arie and Shanjun Li, "Gasoline Prices, Government Support, and the Demand for Hybrid Vehicles," *International Economic Review*, 2011, *52* (1), 161–182.

Boomhower, Judson and Lucas W. Davis, "A Credible Approach for Measuring Inframarginal Participation in Energy Efficiency Programs," *Journal of Public Economics*, 2014, *113*, 67–79.

Borenstein, Severin, "A Microeconomic Framework for Evaluating Energy Efficiency Rebound and Some Implications," *Energy Journal*, 2015, *36* (1), 1–21.

Busse, Meghan R., Christopher R. Knittel, and Florian Zettelmeyer, "Are Consumers Myopic? Evidence from New and Used Car Purchases," *American Economic Review*, 2013, *103* (1), 220–256.

Chan, Nathan W. and Kenneth Gillingham, "The Microeconomic Theory of the Rebound Effect and Its Welfare Implications," *Journal of the Association of Environmental and Resource Economists*, 2015, *2* (1), 133–159.

Chandra, Ambarish, Sumeet Gulati, and Milind Kandlikar, "Green drivers of free riders? An analysis of tax rebates for hybrid vehicles," *Journal of Environmental Economics and Management*, 2010, *60*, 78–93.

Church, Jeffrey, Neil Gandal, and David Krause, "Indirect Network Effects and Adoption Externalities," 2002. Foerder Institute for Economic Research Working Paper.

Congressional Budget Office, "Effects of Federal Tax Credits for the Purchase of Electric

Vehicles," 2012.

Davis, Lucas W. and Gilbert E. Metcalf, "Does Btter Information Lead to Better Choices? Evidence from Energy-Efficiency Labels," *Journal of the Association of Environmental and Resource Economists*, 2016, *3* (3), 589–625.

DeShazo, J.R., Tamara Sheldon, and Richard T. Carson, "Designing Policy Incentives for Cleaner Technologies: Lessons from California's Plug-in Electric Vehicle Rebate Program," 2014. working paper.

Diamond, David, "Impact of High Occupancy Vehicle (HOV) Lane Incentives for Hybrids in Virginia," *Journal of Public Transportation*, 2008, *11* (4), 39–58.

_ , "The Impact of Government Incentives for Hybrid-electric Vehicles: Evidence from US States," *Energy Policy*, 2009, *37* (3), 972–983.

Dimitropoulos, Alexandros, Jos N. van Ommeren, Paul Koster, and Piet Rietveld, "Not fully charged: Welfare effects of tax incentives for employer-provided electric cars," *Journal of Environmental Economics and Management*, 2016, *78*, 1–19.

Gallagher, Kelly Sims and Erich Muehlegger, "Giving Green to Get Green? Incentives and Consumer Adoption of Hybrid Vehicle Technology," *Journal of Environmental Economics and Management*, 2011, *61*, 1–15.

Greening, Lorna A., David L. Greene, and Garmen Difiglio, "Energy Efficiency and Consumption-the Rebound Effect- A Survey," *Energy Policy*, 2000, *28* (6-7), 389–401.

Grigolon, Laura, Mathias Reynaert, and Frank Verboven, "Consumer Valuation of Fuel Costs and the Effectiveness of Tax Policy: Evidence from the European Car Market," 2015. Working Paper.

Hausman, Jerry A., "Individual Discount Rates and the Purchase and Utilization of Energy-Using Durables," *The Bell Journal of Economics*, 1979, *10* (1), 33–54.

Helveston, John Paul, Yimin Liu, Elea McDonnel Feit, Erica Fuchs, Erica Klampfl, and Jeremy J. Michalek, "Will Subsidies Drive Electric Vehicle Adoption? Measuing Consumer Preferences in the U.S. and China," *Transportation Research Part A*, 2015, *73*, 96–112.

Heutel, Garth and Erich Muehlegger, "Consumer Learning and Hybrid Vehicle Adoption," 2012. forthcoming, *Environmental and Resource Economics*.

Holland, Stephen P., Erin T. Mansur, Nicholas Z. Muller, and Andrew J. Yates, "Are There Environmental Benefits from Driving Electric Vehicles? The Importance of Local Factors," 2016. Forthcoming, *American Economic Review*.

Hultkrantz, Lars and Xing Liu, "Green cars sterillize congestion charges: A model analysis of the reduced impact of Stockholm road tolls," *Transport Policy*, 2012, *21*, 110–118.

Huse, Cristian and Claudio Lucinda, "The Market Impact and the Cost of Environmental Policy: Evidence from the Swedish Green Car Rebate," *The Economic Journal*, 2014, *124*, F393–F419.

Jacobsen, Mark, "Evaluating U.S. Fuel Economy Standards in a Model with Producer and Household Heterogeneity," *American Economic Journal: Economic Policy*, 2013, *5* (2), 148–187.

Jaffe, Adam B. and Robert N. Stavins, "The Energy-Efficiency Gap: What Does It Mean?," *Energy Policy*, 1994, *22* (1), 804–810.

Kahn, Matthew, "Do greens drive Hummers or hybrids? Environmental ideology as a determinant of consumer choice," *Journal of Environmental Economics and Managment*, 2007, *54* (2), 129–145.

_ **and Ryan Vaughn**, "Green Market Geography: The Spatial Clustering of Hybrid Vehicles and LEED Registered Buildings," *The B.E. Journal of Economic Analysis and Policy*, 2009, *9* (2), 1935–1682.

Knittel, Christopher R., "Reducing Petroleum Consumption from Transportation," *Journal of Economic Perspectives*, 2012, *26* (1), 93–118.

Krause, Rachel M., Sanya R. Carley, Bradeley W. Lane, and John D. Graham, "Perception and Reality: Public Knowledge of Plug-in Electric Vehicles in 21 U.S. Cities," *Energy Policy*, 2013, *63*, 433–440.

Langer, Asheley and Shaun McRae, "Fueling Alternatives: Evidence from Real-World Driving Data," 2014. Working Paper.

Li, Shanjun, "Better Lucky Than Rich? Welfare Analysis of Automobile License Allocations in Beijing and Shanghai," 2015. Working Paper.

_ **, Lang Tong, Jianwei Xing, and Yiyi Zhou**, "The Market for Electric Vehicles: Indirect Network Effects and Policy Impacts," 2016. Forthcoming, *Journal of the Association of Environmental and Resources Economists*.

Liebowitz, S.J. and Stephen E. Margolis, "Are Network Externalities A New Source of Market Failure," *Research in Law and Economics*, 1995, *17*, 1–22.

McConnell, Virginia and Tom Turrentine, "Should Hybrid Vehicles Be Subsidized?," 2010. RFF Discussion Paper.

Parry, Ian and Kenneth Small, "Does Britain or the United States Have the Right Gasoline Tax?," *American Economic Review*, 2005, *95* (4), 1276–1289.

Potoglou, Dimitris and Pavlos S Kanaroglou, "Household Demand and Wilingness to Pay for Clean Vehicles," *Transportation Research Part D: Transport and Environment*, 2007, *12* (4), 264–274.

Sallee, James, "The Surprising Incidence of Tax Credits for the Toyota Prius," *American Economics Journal: Economics Policy*, 2011, *3*, 189–219.

Sallee, James M. and Soren T. Anderson, "Designing Policies to Make Cars Greener: A Review of the Literature," 2015. Forthcoming.

_ **, Sarah E. West, and Wei Fan**, "Do Consumers Recognize the Value of Fuel Economy? Evidence from Used Car Prices and Gasoline Price Fluctuations," *Journal of Public Economics*, 2016, *135*, 61–73.

Sexton, Steven and Alison Sexton, "Conspicuous Conservation: the Prius Halo and Willingness to Pay for Environmental Bona Fides," *Journal of Environmental Economics and Management*, 2014, *67*, 303–317.

Shewmake, Sharon and Lovell Jarvis, "Hybrid cars and HOV lanes," *Transportation Research Part A: Policy and Practice*, 2014, *67*, 304–319.

Shriver, Scott K., "Network Effects in Alternative Fuel Adoption: Empirical Analysis of the Market for Ethanol," *Marketing Science*, 2015, *34* (1), 78–97.

Sierzchula, William, Sjoerd Bakker, Kees Maat, and Bert van Wee, "The influence of financial incentives and other socio-economic factors on electric vehicel adoption," *Energy Policy*, 2014, *68*, 183–194.

Small, Kenneth A. and Kurt Van Dender, "Fuel Efficiency and Motor Vhicle Travel: The Declining Rebound Effect," *Energy Journal*, 2007, *28* (1), 25–51.

Sorrel, Steve and John Dimitropoulos, "The Rebound Effect: Microeconomic Definitions, Limitations and Extensions," *Ecological Economics*, 2008, *65* (3), 636–649.

Stoneman, Paul and Paul Diederen, "Technology Diffusion and Public Policy," *Eco-*

nomic Journal, 1994, *104* (425), 918–930.

Train, Kenneth, "Discount Rates in Consumers' Energy-Related Decisions: A Review of the Literature," *Energy*, 1985, *10* (12), 243–253.

Whitehead, Jake, Joel P. Franklin, and Simon Washington, "The impact of a congestion pricing exemption on the demand for new energy efficient vechicles in Stockholm," *Transportation Research Part A: Policy and Practice*, 2014, *70*, 24–40.

Table 1: History of Hybrid and Plug-in Electric Vehicles

Years	HEV market share	PEV market share	No. of HEV Models Offered	No. of PEV models offered
2000	0.05	0.00	2	0
2001	0.12	0.00	2	0
2002	0.21	0.00	3	0
2003	0.29	0.00	3	0
2004	0.49	0.00	4	0
2005	1.23	0.00	8	0
2006	1.52	0.00	10	0
2007	2.15	0.00	15	0
2008	2.37	0.00	17	0
2009	2.77	0.00	21	0
2010	2.37	0.00	30	2
2011	2.10	0.139	33	4
2012	3.01	0.367	44	11
2013	3.19	0.626	50	17
2014	2.75	0.723	50	22
2015	2.21	0.65	51	28

Data source:Hybridcars.com.

Table 2: Empirical Studies on the Sales Impact of AFV Subsidies

Study	AFV Type	Region	Method	Sales Impact[1]
Diamond (2009)	HEV	U.S.	reduced-from	14.9%
Gallagher and Muehlegger (2011)	HEV	U.S.	reduced-from	5%
Beresteanu and Li (2011)	HEV	U.S.	structural	6.7%
Chandra et al. (2010)	HEV	Canada	reduced-from	34% $\sim$ 42%
Congressional Budget Office (2012)	PEV	U.S.	data analysis	4%
DeShazo et al. (2014)	PEV	California	survey	2.8% $\sim$ 4.7%
Li et al. (2016)	PEV	U.S.	reduced-from	5.3%
Helveston et al. (2015)	PEV	U.S. & China	survey	2.5% $\sim$ 5.6%
Dimitropoulos et al. (2016)	PEV	Netherlands	survey	NA
Sierzchula et al. (2014)	PEV	30 countries	reduced-from	0.06%
Huse and Lucinda (2014)	FFV	Sweden	structural	1.7%

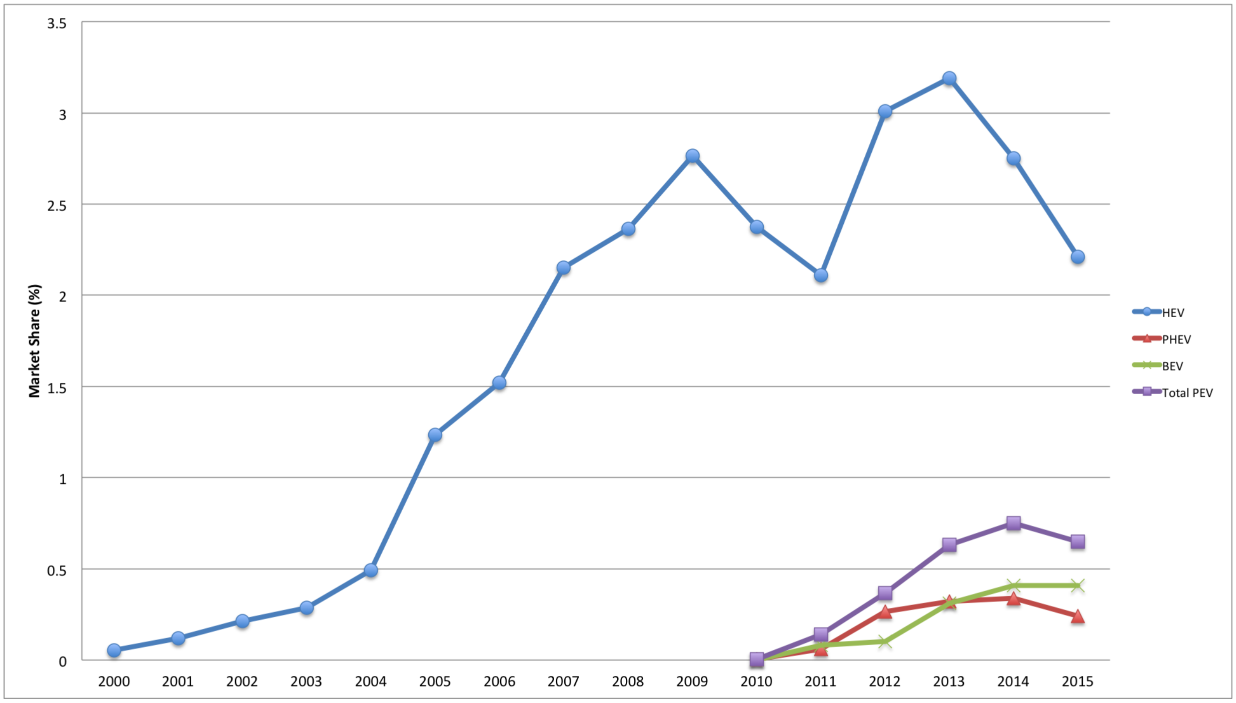
[1]The subsidy impact is the AFV sales increase due to subsidy estimated in each study, converted to the percentage increase due to a US$1,000 subsidy.

Table 3: Vehicle Emissions for 100 Miles (National Average Grid Mix)

Vehicles	GHG Emissions
Gasoline	87 lb CO2
HEV	57 lb CO2
PHEV	62 lb CO2
BEV	54 lb CO2

Data source:Alternative Fuel Data Center.

Figure 1: Annual Hybrid and Plug-in Electric Vehicle Market Shares in the U.S.



Data source: Hybridcars.com.