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**Abstract**

Currently, the US federal government sets fuel economy and greenhouse gas standards for passenger vehicles and promotes innovation for alternative fuel vehicles. Many states are considering their own transportation policies that would reduce the environmental, health, and time costs of driving. In principle, federal and state policies may interact in important ways, either positively or negatively. We find that state policies targeting only emissions of new vehicles and particularly alternative fuel vehicles are unlikely to decrease national greenhouse gas emissions in the short run, primarily due to interactions with federal regulations. We then examine the conditions under which state and federal policies can have positive long-run social benefits. Carefully constructed state policies can complement the federal policies and achieve states' objectives.

**Key Words:** new vehicle Corporate Average Fuel Economy Standards, carbon tax, feebate, congestion charge, electric vehicles, registration tax, policy interactions

**JEL Codes:** Q5, Q4, L62

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## 1. Introduction

Motivated by concerns about energy security and climate change, the current US passenger vehicle fuel economy and greenhouse gas (GHG) emissions standards are projected to roughly double new vehicle fuel economy between 2011 and 2025 (EPA 2016a). The Environmental Protection Agency (EPA) administers the greenhouse gas standards, and the National Highway Traffic Safety Administration (NHTSA) administers the fuel economy standards. Because a vehicle's fuel economy is closely linked to its GHG emissions, the two agencies attempt to harmonize their standards. In addition, several current federal policies directly support innovation and adoption of new technologies such as plug-in vehicles.

New vehicle standards affect the rate of fuel consumption (gallons per mile) and the emissions rate (grams of carbon dioxide [$CO_2$] per mile) of new vehicles. Because total fuel consumption and emissions also depend on miles traveled and the carbon content of the fuel, the standards target only one component of total fuel consumption and emissions. Thus there is an opportunity for other policies to complement the federal standards.

Many states have adopted or are considering their own policies to reduce their passenger vehicle fuel consumption and emissions. Several environmental and economic considerations motivate these policies. First, many states have climate, air quality, and sustainability goals that include reducing air pollution, traffic accidents, and traffic congestion. Second, states promote alternative fuel vehicles, such as through California's Zero Emission Vehicle (ZEV) program, to support new technology and reduce pollution in the long run (we use the terms alternative fuel vehicle and plug-in vehicle interchangeably). Finally, states may want to tax driving or vehicles to raise revenue; such taxes reduce the external costs of driving and could improve the overall efficiency of the tax system (Goulder et al. 1997).[1] States choose from among a range of policy options to meet these objectives, such as subsidies or mandates for alternative fuel vehicles or taxing GHG emissions, miles traveled, or vehicle use.

Often, when multiple levels of government enact policies that have the same objective, the overlapping policies interfere with one another and reduce social welfare compared with a situation in which the federal government alone implements the policy. For example, Goulder et al. (2012) analyze the inefficiencies caused by overlapping federal and state fuel economy standards. However, there is little research on whether states can design policies that complement rather than interfere with federal policies.

This paper analyzes the interactions between state and federal passenger vehicle policies. Taking the current structure (if not the stringency) of the federal policies as given, we argue that carefully constructed state policies can complement the federal vehicle policies and reduce GHG emissions, air pollution, and congestion. We focus on passenger vehicles because they cause most transportation sector emissions and congestion.

In Section 2 of the paper, we note that new vehicle standards can address some but not all of the market failures associated with new vehicles. If consumers do not account for carbon and energy security externalities in their choice of vehicle fuel economy, new

[1] A substantial literature has investigated this double-dividend hypothesis, that environmental taxes could simulateneously improve the environment and reduce the welfare costs of the tax system (Parry and Bento 2000). Under some but not all conditions, such a double dividend may exist (Fullerton and Metcalf 1997).

vehicle standards are one way to raise fuel economy to the socially optimal level.[2] In addition, if some buyers do not fully value fuel savings when purchasing a new vehicle, standards could be more economically efficient at achieving fuel consumption and GHG objectives than a carbon price (Allcott and Greenstone 2012). However, GHG emissions depend on the emissions rates of all vehicles on the road, the miles those vehicles travel, and the carbon content of the fuel. Because vehicle standards cover only new vehicle emissions rates, there are opportunities for reducing emissions from the entire on-road vehicle fleet. The standards may even exacerbate external costs that scale with miles traveled because of the rebound effect—the fact that standards reduce per-mile fuel costs and increase driving (Gillingham et al. 2016). In principle, state policies could counteract this effect.

In addition, new vehicle standards do not address market failures associated with innovation. As we discuss in Section 2, learning spillovers and other factors may cause firms to invest below socially optimal levels in developing and commercializing new technologies. Standards encourage technology adoption, but because of the innovation and adoption market failures, complementary innovation and adoption policies are more efficient than standards alone (Fischer and Newell 2008; Acemoglu et al. 2012). Current federal subsidy policies support innovation in alternative fuel vehicles, but if the federal policies are below the social optimum, states could improve social welfare by further supporting innovation and adoption. Thus, state passenger vehicle policies can improve welfare by complementing rather than interfering with the federal policies.

Notwithstanding the opportunities for state vehicle policies to increase social welfare, there is a risk that they will cause emissions leakage. Leakage refers to a situation in which one state enacts a policy that reduces emissions in that state, but the policy also induces an increase in emissions outside the state. Federal GHG and fuel economy standards can interact with state policies to cause leakage in two ways. First, the federal standards determine the overall level of fuel economy of vehicles sold in the United States. Because national standards are binding, any state policy that increases the average fuel economy of new vehicles in the state will be counteracted by a decrease in average fuel economy of vehicles sold in other states. The second source of leakage arises from the fact that, to promote sales of alternative fuel vehicles, the current federal standards intentionally underestimate the emissions from those vehicles. The underestimation implies that any state policy, such as California's ZEV program, which increases sales of such vehicles in some states, can actually increase total national emissions. This is a short-run effect because the federal provisions that allow for underestimating emissions are temporary. The broader goal of promoting alternative fuel vehicles, whether at the federal or state level, is premised on the notion that increasing short-run sales will reduce costs to vehicle consumers or manufacturers of adopting the technologies in the long run, enabling stricter emissions standards and lower emissions in the long run. State policymakers considering policies that promote innovation and new technology adoption should be aware of the trade-off between higher emissions in the short run and the potential for lower costs and lower emissions in the long run.

[2] Several studies, such as Jacobsen (2013), conclude that fuel taxes are more efficient than standards at achieving this objective.

A broader caveat to the implementation of state innovation policies is that they are justified only if federal innovation policies are insufficient. The California ZEV program is the most significant state effort that is designed to promote alternative fuel vehicles. It is different from the federal policies in that it sets sales targets for alternative fuel vehicles, rather than providing subsidies or compliance incentives. However, the goals of the federal and state policies are the same—to increase sales of those vehicles in the short run, as a way to attain the long-term goals of lower vehicle cost and higher penetration. But are additional state incentives such as the ZEV mandate on top of the federal incentives warranted? As we discuss in Section 2, we can think of ZEV as providing an implicit subsidy to alternative fuel vehicles because ZEV causes manufacturers to reduce prices of alternative fuel vehicles and encourage sales. This conceptualization allows us to compare the hypothetical optimal level of subsidy for alternative fuel vehicles with existing subsidies, including both direct and implicit subsidies. State subsidies can be justified if existing federal subsidies are below the optimum.

Given the emissions reduction and innovation opportunities, as well as the potential leakage, from state policies, we compare several policies that are available to states: taxing carbon, congestion, or miles traveled; subsidizing alternative fuel vehicle technologies; and subsidizing public transportation. We conclude that a carbon tax addresses, if imperfectly, the external costs of driving. A congestion tax is more efficient at reducing congestion than other taxes. Therefore, combining carbon and congestion taxes is more efficient than using only one tax or a combination of the other taxes. Nonetheless, other taxes can increase social welfare by addressing behaviors that federal policies do not address or by reducing the inefficiencies of the federal policies.

Direct subsidies to alternative fuel vehicle technologies, such as tax credits for vehicle purchase or charging stations, could be justified if federal subsidies are below the socially optimal levels. Implicit subsidies created by vehicle mandates such as ZEV or other policies could be justified as well. However, at the current time, research provides little information about the magnitude of that optimal subsidy, and it is unclear whether federal policies exceed or fall short of the optimal. The policy analysis below focuses on effectiveness and total costs; we do not consider the important and complex issues of fiscal revenue and distributional effects of the policies.

## 2. Overview of Current Federal Policies for New Passenger Vehicles

This section provides a brief overview of the federal fuel economy and GHG standards for new passenger vehicles, summarizes the economic arguments for policies that promote innovation and adoption of new technologies, and describes current federal policies for alternative fuel vehicles.

### *2.1. Fuel Economy and GHG Standards*

Beginning with the 2012 model year, EPA and NHTSA have jointly regulated vehicle emissions and fuel economy. The EPA standards require that each manufacturer attain a specific overall average rate of GHG emissions per mile across all its vehicles. The NHTSA standards set minimum fuel economy requirements.

Two important features of the standards are (a) the standards depend on the vehicle's size as well as its class (car or light truck); and (b) manufacturers can trade compliance credits across their car and truck fleets as well as with one another. The standards are more stringent for cars than for light trucks and for smaller than for larger vehicles within a class. Therefore, a manufacturer selling more trucks or larger vehicles than another manufacturer is subject to lower fuel economy and higher GHG emissions rate requirements. The fact that manufacturers can buy and sell credits reduces compliance costs.

The post-2011 standards differ fundamentally from the previous fuel economy standards set by NHTSA. The new standards tighten by roughly 3 percent per year, whereas the previous standards had been largely unchanged for two decades. The preceding NHTSA standards depended on class and not footprint, and they placed greater restrictions on credit trading.[3]

## *2.2. Federal Policies Promoting Alternative Fuel Vehicles*

The federal GHG regulations include provisions that grant special status to vehicles with electric drive trains, such as electric vehicles (EVs) and fuel cell vehicles. The federal government also provides tax credits for purchasing such vehicles and subsidizes charging infrastructure. In addition, EPA and DOE fund research and development on alternative fuel vehicles. This subsection discusses the economic rationale for these policies and compares optimal and actual levels of the subsidies.

### 2.2.1. Economic Rationale for Policies Targeting Innovation and New Technology Adoption

Economic theory suggests that firms have sufficient incentive to innovate if they fully and exclusively benefit from investments in research and development of new technologies. However, in certain situations, firms do not fully benefit from these investments. For example, suppose a firm invests in battery research that reduces the cost of producing batteries. Other firms may observe the innovation and adopt similar techniques (that is, without violating patents). In that case, knowledge gained by one firm reduces production costs for all firms, reducing the original firm's return on its innovation investment. Because firms cannot capture all the returns to investment in innovation, they underinvest in research and development compared with the socially optimal investment level.

The literature has identified learning spillovers and incomplete capital markets as two market failures that may cause too little innovation. As in the preceding example, a learning spillover refers to a situation in which a firm can improve its vehicles (for example, by reducing production costs or improving quality) based on another firm's learning. In the highly competitive automobile industry, firms do not publicize their strategies and new products before bringing them to the market. However, companies pay a lot of attention to what other companies do, and once a new vehicle enters the market, the competing firms can purchase the vehicle, take it apart, and observe the innovations that the new vehicle includes. There may also be learning spillovers in battery production. Innovation that reduces production costs or improves battery performance may spill over to other battery-producing firms.

Incomplete capital markets may also reduce innovation. The transition to an entirely new fuel and a new vehicle—for example, from the internal combustion engine to electric drive vehicles fueled by electricity or hydrogen—requires automakers to make risky investments in new technologies. Firms may not be willing to accept the risk at market borrowing rates because of information

[3] Starting with the 2007 model year, light trucks were subject to a size-based standard, but cars continued to be subject to a uniform standard. In 2011, NHTSA set footprint-based standards for cars and light trucks, after which both EPA and NHTSA set footprint-based standards.

asymmetries, agency problems, or other market failures between automakers and potential lenders and investors. Consequently, it may be socially beneficial if the government accepts some of the risk by subsidizing investments in research and development and spreading the risk across taxpayers (Levi 2013).

These market failures are distinct from economies of scale and within-firm learning. Increasing production volumes can induce greater efficiencies and reduce the average production costs for batteries or vehicles. Large-scale battery production may reduce costs, although scale economies for battery production may be limited (Sakti et al. 2015).[4] In addition, there could be learning within a firm, in which a firm accumulates knowledge about designs or production techniques over time, leading to better products and greater efficiency. As long as there are no capital market failures or learning spillovers among firms, any single firm should be able to achieve scale and invest in learning that results in the efficient level of innovation. In other words, only in the case that there are learning spillovers or capital market failures would there be suboptimal investments in innovation.

Thus far we have focused on innovation market failures, but there may also be market failures for the commercialization and adoption of new technologies. For example, vehicle consumers may have incomplete information about the quality or other attributes of EVs because they have had so little experience with them. If early adopters provide valuable information to potential buyers of vehicles sold by other firms, firms would underprovide such vehicles because some of the information gains would accrue to other firms. In addition, for consumers, vehicle charging infrastructure is a complementary good to EVs. If firms do not realize the full benefit of investing in charging infrastructure, there could be insufficient investment in it (Li 2016; Springel 2016). Such market failures in adoption could justify incentives for purchasing EVs or for the charging infrastructure.

In general, new vehicle fuel economy and GHG standards will increase the returns to innovation and marketing new technologies, and they will cause more innovation and marketing than would occur in the absence of the standards. However, if the standards are technology neutral, meaning that they credit vehicles according to their fuel economy and emissions but not the underlying technology, the standards would not address the emerging technology market failures discussed above. Additional policies directed at electric drive vehicles would be called for; Fischer and Newell (2008) and Acemoglu et al. (2013) show that it is more efficient to combine a policy that targets carbon emissions with a policy that targets new technology. Nemet and Baker (2009) compare subsidies and R&D policies for a low-carbon energy technology.

### 2.2.2. Innovation Policies: Vehicle Subsidies and Mandates and Their Interaction

In the following discussion, we consider the optimal subsidy for addressing the potential market failures associated with emerging technology vehicles and compare that with the existing subsidies for these vehicles. In considering existing policies, it is important to differentiate between policies that are price-based and those that are quantity-based. Quantity-based policies, such as ZEV, set particular sales volumes for alternative fuel vehicles or set fleetwide emissions standards (such as the EPA program). Price-based policies include everything else, and generally

[4] Tesla Motors argues that the battery “gigafactory” opening in Nevada is key to lowering the costs of its EV, the Model 3.

speaking, they either directly reduce the cost to manufacturers of manufacturing and selling alternative fuel vehicles or raise the benefit to consumers of owning such vehicles. For example, the federal vehicle purchase tax credits are a price-based policy, as are subsidies to electric charging infrastructure, because public charging stations reduce the cost of recharging away from home.

Conceptually, the combined effect of price-based policies equals the sum of the subsidies, measured appropriately. For example, if there is a federal vehicle purchase tax credit of $7,500 per vehicle and a state vehicle purchase tax credit of $2,000 per vehicle, the combined subsidy would be $9,500. In principle, these tax credits can be added to other types of subsidies, such as charging infrastructure subsidies, although those subsidies would have to be converted to a per-vehicle basis, which may be challenging. Nonetheless, if one knew the value of all the price-based subsidies, one could simply add them together to determine the total subsidy.

The combined effect of price- and quantity-based policies is more complex. To consider the combined effect, it is instructive to consider a hypothetical world that contains a set of price-based policies, and then consider the incremental effect of adding a quantity-based policy, such as the ZEV mandate. If the price-based policies cause aggregate sales to exceed the ZEV requirements, then ZEV has no effect. If this is not the case, we define the implicit subsidy of ZEV as the hypothetical vehicle price subsidy that would be needed for aggregate sales to exactly equal the ZEV requirements, given the other subsidies that are in place. In this way, one can add price- and quantity-based policies.

In the following discussion, where we compare optimal innovation subsidies with existing subsidies, we use the term *subsidy* to include price-based subsidies as well as implicit subsidies caused by quantity-based policies. For example, hypothetically speaking, if the only policies affecting alternative fuel vehicles were a federal $7,500 tax credit and an implicit subsidy from ZEV of $5,000, we would describe the combined subsidy as being equal to $12,500.

### 2.2.3. How Large Should Innovation and Adoption Subsidies Be?

It is difficult to determine the appropriate magnitude of subsidies for new technologies, such as for electric drive vehicles. The magnitudes of the socially optimal government subsidies for innovation and adoption depend on the magnitudes of the corresponding market failures, but existing research has not been able to determine these magnitudes because of the complexities of evolving markets and limited available data.

In this subsection, we outline a simple framework for determining the optimal innovation subsidy, and we use plausible parameter assumptions to attempt to bound the optimal subsidies. Specifically, we compare the immediate cost of the subsidy with the long-run benefit that arises from improving technology. For reasons of data availability, we focus on the new vehicles market observed in 2015, when there were federal fuel economy and GHG standards, as well as a federal tax credit of up to $7,500 for purchasing plug-in vehicles.

To simplify the analysis, we consider a marginal change in the federal subsidy that is perfectly targeted at consumers. Specifically, suppose that the government could identify a consumer who is exactly indifferent between purchasing a plug-in vehicle, given current policies and market conditions, and not purchasing the plug-in vehicle. The government offers a small additional subsidy to that consumer, which causes the number of plug-in vehicles sold to increase by one compared with the observed level.[5]

We determine the percentage change in sales caused by this additional purchase, which, combined with the spillover elasticity (the percentage reduction in future vehicle production costs caused by a 1 percent increase in current sales), yields an estimate of the proportionate reduction in vehicle cost. If we assume a spillover elasticity, initial vehicle cost, and future plug-in sales, we can calculate the total cost reduction across all future EVs due to the addition of this one vehicle to the fleet. That is, we multiply the elasticity by the initial cost to obtain the future cost reduction, which we multiply by the expected number of plug-in vehicles sold. This cost reduction represents the marginal benefit of slightly increasing current sales; the marginal cost of slightly increasing sales is the increase in tax expenditure. The optimal innovation subsidy is such that the marginal cost equals the marginal benefit.

We make two assumptions to simplify the calculations: (a) the reduction in future costs does not affect equilibrium plug-in sales at any point in the future; and (b) the tax credit is perfectly targeted to the marginal consumer. The first assumption causes us to understate the optimal innovation subsidy.

Although there are estimates of volume-based learning rates for battery production (e.g., Nykvist and Nilsson 2015), we are aware of no research that estimates the spillover elasticity specifically for alternative fuel passenger vehicles, such as electric or fuel cell vehicles. However, there is some evidence from other emerging technology markets. Van Benthem et al. (2008) argue that the optimal solar photovoltaic subsidies depend on knowledge spillovers among producers, which can be quite large. Bollinger and Gillingham (2014) estimate a spillover elasticity for the solar industry of 0.003. In contrast, Nemet (2006) finds that spillovers have only weak explanatory power for the recent reductions in the costs of producing photovoltaic panels. However, Nemet (2012) and McDowell (2015) find more evidence of learning spillovers in the emerging wind power industry, but with diminishing returns over time. Thus there is some evidence of learning spillovers in these emerging energy industries, but there is no consensus on the spillover elasticity as distinct from learning that the company can appropriate fully.

Aside from the spillover elasticity, other factors affecting the optimal subsidy include the number of vehicles in the future whose costs would be lowered, the discount rate, and the magnitude of the tax credit needed to increase current sales by one unit.

The optimal innovation subsidy is the net present value of future cost reductions from selling one more vehicle. Figure 1 reports the optimal innovation subsidy under a range of scenarios. The base case takes the spillover elasticity from the photovoltaics literature and uses 2015 sales of EVs, a 3 percent discount rate, and a forecast 22 percent annual growth rate of EV sales through the 2025 model

[5] The federal tax credits for a particular manufacturer's vehicles phase out after the manufacturer exceeds a cumulative sales threshold. We assume that this phase-out condition is not binding for the particular manufacturer selling the vehicle in the hypothetical subsidy that raises sales by one unit.

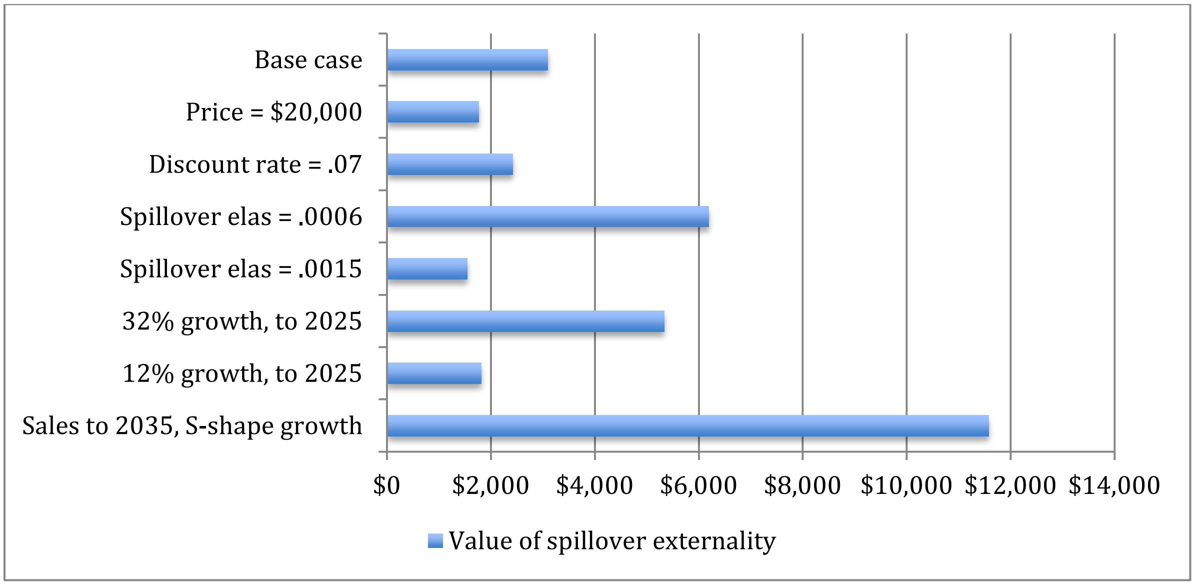
year.[6] The sales forecast is consistent with the EPA forecast for plug-in vehicles to 2025 (EPA 2016a). Note that because we consider a hypothetical marginal change in subsidies from current policies, we use sales forecasts that include the effects of existing policies such as ZEV. Under these assumptions, the optimal innovation subsidy is $3,095 per EV.

Figure 1 illustrates several sources of uncertainty over the optimal innovation subsidy. Our initial elasticity estimate of 0.003 is based on limited evidence from another industry that may not have bearing on the extent of spillovers for alternative fuel vehicles. Figure 1 shows the effect of halving or doubling the elasticity, which causes the optimal innovation subsidy to vary from $1,548 to $6,191 per vehicle. The figure also shows that a higher discount rate (7 percent rather than the 3 percent used in the baseline) implies a lower optimal innovation subsidy, of $2,422 per vehicle. The growth rate of plug-in sales is highly uncertain because the market is so young. Existing forecasts of sales in the United States by the 2025 model year, which include assumptions about future policy, imply annual growth between 12 and 32 percent. These different growth rates imply subsidies that range from $1,818 to $5,338 per vehicle. The above estimates account only for sales of vehicles through the 2025 model year. Sales of EVs will continue beyond 2025, and assumptions about sales in the later years substantially affect the estimated optimal innovation subsidy, as shown in the last bar of Figure 1. Uncertainties about federal fuel economy and emissions programs, and the ZEV program, amplify the uncertainty over the optimal subsidy indicated by the range of estimates in Figure 1.

The estimates of the optimal innovation subsidy in Figure 1 are, for the most part, lower than the current $7,500 federal subsidy for EVs. This suggests that the federal subsidy—as well as other direct and implicit subsidies—would have to be justified based on market failures besides innovation. But there is substantial uncertainty about the optimal innovation subsidy, because that subsidy depends on numerous highly uncertain parameters. Moreover, accounting for other market failures, such as insufficient provision of electric charging stations, could cause the optimal subsidy to exceed the optimal innovation subsidy, and perhaps by a large amount. We next examine the magnitudes of current subsidies.

[6] The baseline elasticity is 0.003. At current sales, and an average vehicle price of $35,000, this elasticity implies doubling sales will reduce costs to $34,000 (for simplicity, we assume that the price equals the cost; in practice, the price could be greater or lower than the cost, depending on the extent to which the manufacturer subsidizes plug-ins). This cost reduction due to the learning spillover is therefore 2.8 percent, or if the learning spillover is attributed only to battery improvement, the battery cost reduction would be about 10 percent (assuming battery costs are about one-third of the cost of the vehicle).

**FIGURE 1. OPTIMAL INNOVATION SUBSIDIES DUE TO LEARNING SPILLOVER, UNDER ALTERNATIVE ASSUMPTIONS**




*Base case assumptions*: Sales of EVs are assumed to grow at an annual rate of 22 percent through model year 2025 (sales in the 2025 model year are 850,000); vehicle cost = $35,000; discount rate = 3 percent; spillover elasticity = 0.003.
*Notes*: Base sales are actual EV sales in 2015 of 116,099. The Sales to 2035 scenario is assumed to follow an S-shaped growth curve, with about 1.8 million in new EV sales by 2035.

### 2.2.4. How Large are Federal Subsidies for Alternative Fuel Vehicles?

The preceding analysis demonstrates the considerable uncertainty regarding the magnitude of the optimal innovation subsidy. In this subsection, we quantify the value of current federal subsidies.

The federal government subsidizes innovation and adoption of EVs in several ways. First, there are subsidies to battery research managed by the Department of Energy (DOE). Between 2009 and 2016, the Advanced Projects Research Agency–Energy provided over $500 million for battery research in vehicle applications (NRC, 2015).

Second, there are subsidies and logistical support for local and state governments to invest in charging infrastructure. DOE has provided over $230 million for deployment of charging infrastructure (NRC 2015). In addition, the federal government initiated a public-private partnership in 2016 that would provide more than $4.5 billion in loan guarantees for commercial scale deployment of innovative vehicle charging facilities.

Third, the federal government provides a tax credit of up to $7,500 to households for the purchase of a plug-in vehicle. The subsidy increases plug-in vehicle sales, which raises the returns to innovating and marketing such vehicles.

Fourth, the federal GHG emissions standards implicitly favor plug-in electric and fuel cell vehicles over vehicles powered by internal combustion engines. When evaluating a manufacturer's compliance, EPA includes the emissions associated with liquid fuel consumption but not the emissions associated with charging the vehicle's battery. Electric vehicles, such as the Nissan Leaf, are therefore assumed to emit zero GHGs according to the standards. For hybrid electric vehicles, EPA assumes that a fraction of miles are driven in all-electric mode, and those miles are counted as emissions-free when evaluating a manufacturer's compliance.

This approach is accurate if the vehicle is charged in a region in which electricity sector GHG emissions are capped, because the increase in emissions from charging the vehicle would be precisely offset by a reduction in emissions elsewhere in the electricity system.[7] However, such emissions caps cover just a portion of the United States (currently, California and the Northeast); for other states, charging a vehicle's battery would increase GHG emissions from the electricity sector (Graff Zivin et al. 2014).

Omitting electricity sector emissions constitutes an implicit subsidy for EVs. This provision reduces the average emissions rate for a manufacturer that sells plug-ins compared with a situation in which electricity emissions are counted. If electricity sector emissions were counted, the manufacturer would have to further reduce the emissions of its vehicles to meet the standards, raising the cost of achieving the standards. The forgone costs from omitting electricity emissions represent the value to manufacturers of the implicit subsidy.

We estimate the magnitude of the subsidy using two examples (see Jenn et al. 2016 for a more extensive and rigorous analysis of alternative fuel vehicle crediting). The blue columns of Figure 2 show the value of this subsidy for the Chevrolet Volt and the Nissan Leaf. To calculate the subsidy, we first estimate the electricity sector emissions caused by the two vehicles, allowing for the possibility that emissions vary across regions because of differences in the generation mix and other factors.[8] Using vehicle sales data from the 2015 model year (the most recent year for which we have data), we compare the manufacturer's average emissions rate, across all its vehicles, between two cases: the first in which the emissions are counted, and the second in which emissions are not counted (the latter is consistent with provisions in the current standards).[9]

The manufacturer's emissions rate is higher in the first case than in the second, which implies that if the electricity sector emissions were included for compliance, the

[7] This is because charging an EV does not affect emissions if emissions are capped and electricity consumption in the region with the emissions cap does not affect emissions in regions that are not subject to the cap. For example, an increase in electricity consumption in California, which has an emissions cap, could affect generation and emissions outside of California because of transmission connections between California and other states. California attempts to address this situation but may do so imperfectly (Fowlie 2009).

[8] More specifically, we compute the vehicles' emissions rates as the product of the electricity consumption rate (kilowatt hours per miles traveled), the share of miles driven in all-electric mode, and the rate of emissions per kilowatt hour of electricity consumed. We obtain consumption rates and miles shares from the EPA website http://www.fueleconomy.gov (the miles share equals 0.46 for the Volt and 1 for the Leaf). We follow Graff Zivin et al. (2014) to estimate rates of emissions per electricity consumption. We estimate these emissions rates using hourly emissions data from EPA for 2010–15 and dividing the country into three regions that correspond to the three major interconnections: East, Texas (Electricity Reliability Council of Texas), and West. We estimate a separate emissions rate for each hour of the day and use the hourly charging pattern assumed in EPRI and NRDC (2007); the only difference between our methodology and Graff Zivin et al. (2014) is that we use more recent emisisons data.

[9] A model year begins in October of the preceding calendar year and ends in September of the current calendar year (Leard et al. 2017). We use 2015 sales data because that is the most recent year for which we have data. In 2015, the EPA emissions standards did not include electricity emissions, but the overcrediting of plug-ins started with the 2017 model year.

manufacturer would have to reduce the emissions rates of its other vehicles to attain the standards. For example, counting the electricity emissions, the average emissions rate across all GM vehicles was about 386 grams of carbon dioxide per mile (g $CO_2$/mile), whereas omitting these emissions reduces the average emissions rate to about 384.5 g $CO_2$/mile. Therefore, if the emissions were counted, GM would have to reduce the average emissions rates of its vehicles by an additional 1.5 g $CO_2$/mile. To calculate the cost of doing so, we assume that GM would add fuel-saving technology to its vehicles, as in Leard et al. (2017), and compute the total cost across all GM vehicles. Dividing the total avoided cost by the number of plug-ins sold during the 2015 model year yields the implicit subsidy per plug-in that arises from this zero emissions assumption. The first columns in Figure 2 show that it is equal to about $2,000 to $5,000 per vehicle. The subsidy is higher in the East than in the other regions because emissions per unit of electricity consumption are higher in that region. The subsidy is roughly half the value of the federal tax credit that was offered that year for the Volt, which was about $7,500.

In addition to ignoring the electricity emissions, the second way that the federal standards promote plug-in vehicles is by allowing them to be counted as more than one vehicle—in other words, overcrediting them. Plug-in electrics are overcredited by more than plug-in hybrid electrics. For example, starting in the 2017 model year, when EPA assesses compliance with its standards, each new plug-in hybrid vehicle sold is counted as 1.6 vehicles, and each new EV is counted as 2 vehicles. Partly because electricity sector emissions are not counted, plug-in vehicles have lower emissions than gasoline-powered vehicles. Therefore, overcrediting reduces the manufacturer's average emissions rate relative to counting each plug-in as one vehicle. The overcrediting provision therefore introduces an implicit subsidy in a similar manner to the provision that ignores electricity generation emissions. The magnitude of the subsidy depends on the difference between the plug-in's emissions rate and the fleetwide emissions rate that the manufacturer must attain.

To quantify the magnitude of the overcrediting subsidy, we compute the reduction in cost for GM and Nissan, assuming the overcrediting rules were in place in that year, as compared with a hypothetical in which the overcrediting rules were not in place (again, we use 2015 for reasons of data availability). We calculate the emissions reduction savings this provision allows for GM and Nissan, and multiply by the cost estimate of additional reductions, similarly to the calculations above.

The red bars in Figure 2 show the total dollar subsidy when both the zero electricity emissions and overcrediting provisions are included. The combined subsidy varies from about $8,000 to $11,000 per vehicle.

It is important to examine the short-run effects of the EV provisions on overall vehicle emissions rates. The provisions create a wedge between the actual average GHG emissions rate of a manufacturer's vehicles and the average GHG emissions rate EPA uses to assess compliance. The more EVs a manufacturer sells, the larger this wedge and the larger the emissions rates. Again, considering the examples of the Volt and the Leaf, Figure 3 compares emissions rates of GM and Nissan under different provisions. The blue bars show that the zero electricity generation provision raises GM's average emissions rate by about 1–2 g $CO_2$/mile (0.3 to 0.5 percent), depending on the region. The zero electricity generation provision raises Nissan's emissions rate by 4–8 g $CO_2$/mile (1.5–2.3 percent).

The red bars in Figure 3 show the emissions rate increases, including both the electricity generation and overcrediting provisions. The emissions increase for Nissan is about 4.5 percent of its emissions rate without either provision, and the increase for GM is about 1 percent. The effect of the provisions is larger for Nissan than for GM because the Leaf (all electric) receives a greater subsidy than the Volt (hybrid electric), and because the Leaf accounts for a larger share of Nissan's sales than the Volt does for GM.

In summary, the combined implicit subsidies from these two EV provisions of the EPA rules range from $8,000 to $12,000 per vehicle. Because of the complex dynamics of the alternative fuel vehicle market, the total subsidy from the federal tax credit and implicit subsidy is not necessarily equal to the sum of the credit and implicit subsidy; however, the tax credit and implicit subsidy jointly increase sales. Nonetheless, given the range of uncertainty over the optimal innovation subsidy that we discussed in the previous subsection, these calculations suggest that the existing federal subsidies may be of the same general magnitude as the optimal innovation subsidy.

Also recall that the optimal total subsidy is greater than the optimal innovation subsidy because the total subsidy includes other market failures, such as incomplete information of consumers about the quality of the vehicles. Unfortunately, existing research sheds little light on the magnitude of either the optimal innovation subsidy or the optimal total subsidy. Existing research also has not yielded precise estimates of the implicit subsidy under ZEV and other policies such as subsidizing public charging stations. Thus it is unclear whether the federal policies go too far or not far enough in attempting to address market failures specific to the innovation and adoption of new technology. More analysis of these magnitudes will be important for policy decisions in the future.

**FIGURE 2. IMPLICIT FEDERAL PER VEHICLE SUBSIDY OF ELECTRIC VEHICLES: THE VOLT AND THE LEAF**

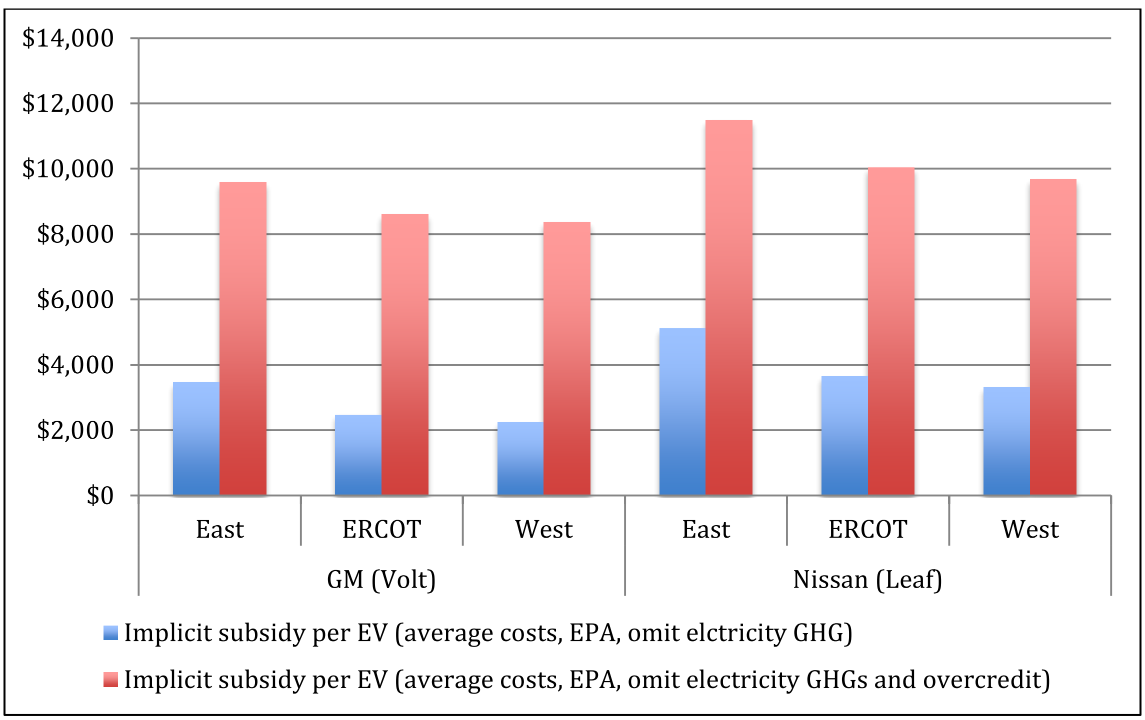
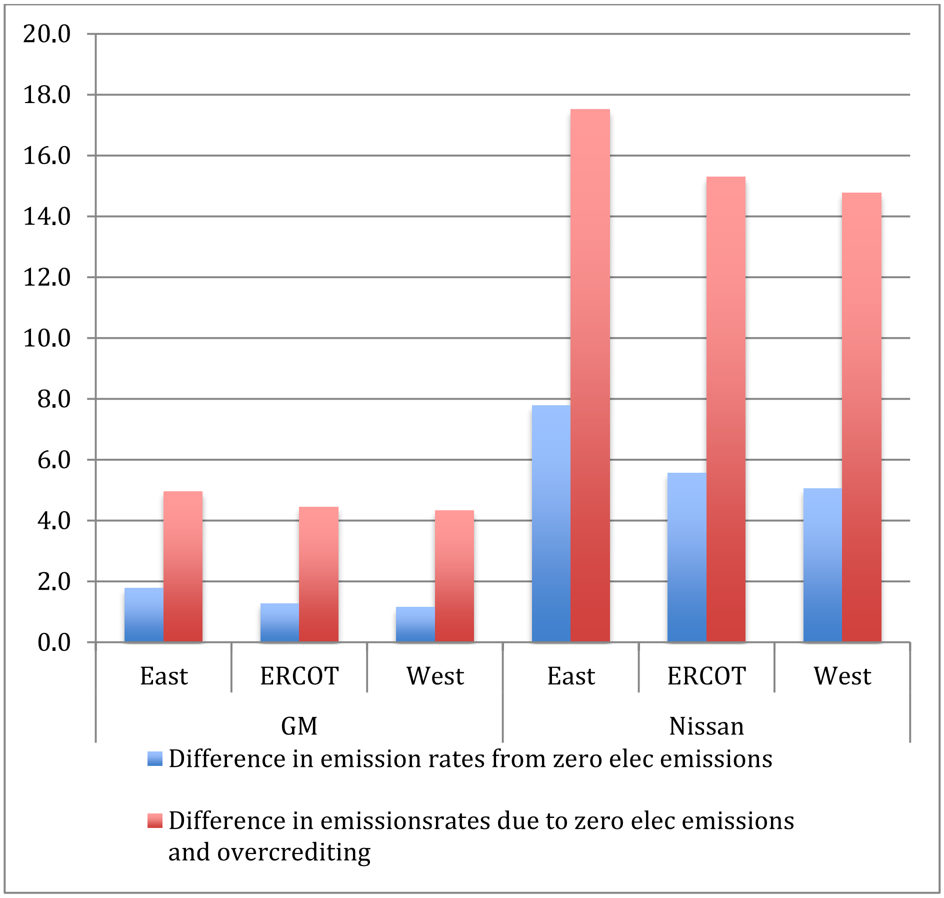


**FIGURE 3. INCREASES IN AVERAGE EMISSIONS RATES DUE TO EPA PROVISIONS FOR ELECTRIC VEHICLES, GM AND NISSAN, 2015 MODEL YEAR**




## 3. Opportunities for and Potential Leakage of State Policies

In this section, we first discuss the limitations of the federal standards and technology policies, which create opportunities for states to complement federal policy and increase social welfare. Second, we discuss the potential for emissions leakage of state policies caused by their interactions with the federal standards.

### *3.1. Limitations of the New Vehicle Standards*

The limitations of the federal standards include the fact that they regulate *emissions rates* rather than *emissions*; exacerbate external costs of driving that increase with miles traveled; and regulate new but not existing vehicles. Each of these limitations creates an opportunity for state policy, as we explain.

#### 3.1.1. Regulating Emissions Rates Rather than Emissions

The environmental costs of a vehicle depend on its emissions and not its emissions rate. If all vehicles were driven the same number of miles and used the same fuels, this distinction would not matter, and regulating emissions rates would yield exactly the same outcomes as regulating emissions. However, in practice, vehicles differ systematically in how much they are driven. For example, consider two vehicles that have roughly the same fuel economy: the 2009 Lincoln

Navigator and the Ford Expedition. Both are sport utility vehicles that achieve about 16 miles per gallon. According to the 2009 National Household Travel Survey, the Navigator was driven about 10,000 miles per year, and the Expedition was driven about 15,000 miles per year (the calculation includes vehicles that were obtained new in the preceding year). If Ford persuaded some of its consumers to purchase a Navigator instead of an Expedition, total emissions could decrease.[10] The fact that the standards treat the two vehicles equivalently represents an inefficiency that is not present in a hypothetical policy that targets total emissions rather than emissions rates.

Consequently, state policies that target emissions rather than emissions rates, such as an emissions tax, could decrease national emissions even if the average national emissions rate is not affected by the state policies (i.e., because of the interactions discussed below). We are not aware of research that quantifies the potential emissions reductions from such a policy.

#### 3.1.2. Exacerbating External Costs that Increase with Driving

A related issue to regulating emissions rates rather than emissions is the rebound effect. As noted above, the external costs of driving include energy security, climate, congestion, local air pollution, and traffic accidents. Given the level of fuel economy of vehicles on the road, each of these external costs increases with the amount people drive.

Because retail fuel prices do not account for the social costs of burning fuel, fuel costs (for a given level of fuel economy) are lower than their optimal level, causing consumers to drive more than is efficient (Parry and Small 2005). Tighter fuel economy and GHG standards exacerbate this problem because they cause fuel economy to increase (relative to weaker standards), further reducing fuel costs and increasing the wedge between the efficient level of fuel costs and the market level of fuel costs. EPA and NHTSA assume a 10 percent rebound effect, meaning that a 1 percent increase in fuel economy causes miles traveled to increase by 0.1 percent, but recent studies have yielded a range of estimates that are higher, typically falling between 10 and 30 percent (e.g., Gillingham et al. 2016; Linn 2013). Therefore, tighter standards increase miles traveled and the external costs that increase with miles traveled.

#### 3.1.3. Regulating New But Not Existing Vehicles

The federal standards regulate new but not existing vehicles, which increases the costs of obtaining a new vehicle relative to the costs of obtaining a used vehicle. This means that some consumers are likely to hold on to their older vehicles longer. The average age of vehicles increases, offsetting some of the emissions reduction gains of the new vehicle standards. The argument goes back to Gruenspecht (1982), and Jacobsen and van Benthem (2015) show that this effect undermines the fuel and GHG emissions savings of the standards by about the same magnitude as the rebound effect. Therefore, state policies that raise the costs of owning older and high-emissions vehicles reduce this inefficiency of the federal standards.

### *3.2. Potential Emissions Leakage of State Policies*

While the shortcomings of the federal new vehicle standards described above provide

[10] The effect of such a shift in market shares on total emissions would depend on whether consumers who purchase the Navigator instead of the Expedition change the amount they drive—in other words, the extent to which miles traveled depend on the vehicle rather than the household doing the driving (West et al. 2017).

opportunities for state policies to improve environmental outcomes, leakage is an important risk for state policy. The term *leakage* describes a situation in which a state's policy reduces its own fuel consumption or GHG emissions but raises fuel consumption or emissions elsewhere. Full leakage means that the reduction in a state's emissions is completely offset by an increase in emissions elsewhere.

The current federal standards are expected to be binding on all vehicle manufacturers at least into the mid-2020s, so that for each manufacturer, the mean GHG emissions rate of its vehicles equals the level required by the standards (allowing for potential annual fluctuations enabled by banking, averaging, and trading; EPA 2016a, b). The fact that the standards bind for all manufacturers contrasts with the CAFE standards from the 1980s through the 2000s, during which time some manufacturers overcomplied with the standards and others fell short and paid fines for noncompliance.[11] In the new regime, noncompliance fines by EPA are likely to be prohibitively expensive, and in fact, all manufacturers have complied since the new standards were implemented in 2012 (EPA 2016b).[12]

If all manufacturers meet the standards, and those standards are binding, then a state policy that reduces the average GHG emissions rate of new passenger vehicles sold in that state will cause an increase in the average emissions rate of vehicles sold in other states. For example, suppose a state increases its gasoline tax, which causes consumers to purchase vehicles with higher fuel economy and lower emissions in that state (Leard et al. 2017). The lower emissions rate relaxes the constraint imposed by the standards on manufacturers, which causes them to sell vehicles with higher emissions rates in other states (in the short run, by reducing relative prices on high-emissions vehicles, and in the long run, by reducing the adoption of fuel-saving technology). This implies that there would be full emissions leakage.[13]

[11] The fact that many manufacturers have overcomplied with the standards through 2015 might appear to imply that the standards have not binded so far. However, the most likely explanation for the overcompliance is that manufacturers are banking credits for later use, when the standards become more stringent. Consistent with the explanation is the observation that compliance credits have traded at prices well above zero (Leard and McConnell, forthcoming); if the standards were not binding, the credits would trade at a price close to or equal to zero.

[12] The EPA regulations are governed by the Clean Air Act (CAA), under which no fee in lieu of compliance is allowed. If a manufacturer is found to be out of compliance, a decision about whether that manufacturer may sell vehicles and under what penalty would have to be negotiated on a case-by-case basis. The penalty for CAA violations could be as high as $37,500 per vehicle. In contrast, fines for the NHTSA fuel economy regulations are about $140 per vehicle per mile per gallon by which the manufacturer falls short of the standards.

[13] More precisely, binding GHG standards imply that changes in emissions rates in one state are fully offset by changes in emissions rates in other states. Because of cross-state variation in miles traveled, this does not necessarily imply full emissions leakage. For example, suppose drivers in the state that increases its gas tax typically drive their vehicles more miles than drivers in other states, even following the gas tax increase. In that case, the state gasoline tax could reduce national emissions even if national emissions rates are unchanged.

We note that this discussion puts aside the provisions in the federal rules for plug-ins that allow manufacturers not to count EV electricity emissions and to overcredit sales. Accounting for those provisions would imply that if a state introduces a policy that increases plug-in sales in that state, then, because of the federal provisions, national GHG emissions would increase in the short run—that is, more than full leakage. As discussed above, the policy could reduce costs of EVs in the future, which a state would have to weigh against the short-run emissions increase.

## 4. State Policies

We have shown that federal standards create opportunities for states to adopt policies that complement the standards by targeting components of GHG emissions other than new passenger vehicle emissions rates. However, the structure of the federal standards implies that state policies that affect new vehicle sales will cause emissions leakage. Another opportunity for states is that if federal subsidies for innovation and adoption of new technology are less generous than the social optimum, states can increase social welfare by augmenting these policies.

Given the opportunities and potential pitfalls, this section discusses hypothetical state policies and analyzes the extent to which they complement federal standards and efficiently reduce GHG emissions and the extent to which they cause leakage. We assume that the federal fuel economy and emissions standards will remain, but we allow for the possibility that the Trump administration may weaken them or that Congress may reduce the EV tax credits. Here, we discuss the policies states may consider, whether or not the federal policies change. Because the welfare effects of any particular policy depend on the details of the policy, in this section, we focus on stylized examples of the policies and evaluate their welfare effects qualitatively. The conclusions are summarized in a table at the end of the section.

### *4.1. Carbon Prices*

We use the term *carbon price* to refer to an emissions tax or a cap-and-trade program. Under an emissions tax, a regulated entity (business or household) pays a tax per ton of emissions. Under an emissions cap, the regulator places a cap on aggregate emissions, and regulated entities must hold sufficient emissions credits to cover their emissions; the regulator can distribute the emissions credits for free or auction them.

Several states have adopted or are considering adopting a carbon price that would affect passenger vehicle fuel consumption, either as part of a policy that prices carbon across many sectors or as a transportation-only policy. For example, California's cap-and-trade program now covers about 85 percent of the state's emissions, including transportation fuels. The emissions price has been about $13 per metric ton of $CO_2$, which translates to about $0.13 per gallon of gasoline.[14] Other policies, particularly California's Low Carbon Fuel Standard, implicitly tax carbon emissions from transportation fuels, and the full tax on gasoline is higher than $0.13 per gallon.

In 2016, Washington State rejected a proposal to adopt a tax of $25 per ton of $CO_2$. However, Oregon is considering an economy-wide carbon price, and a group of northeastern states is considering a cap-and-trade program for carbon emissions from the transportation sector.

[14] We assume that the emissions price is passed through fully to retail fuel prices, which is consistent with evidence of fuel tax pass-through (Marion and Muehlegger 2011).

We first discuss the interactions of a carbon price with federal standards, and then discuss broader welfare effects. A state carbon price causes consumers to shift to smaller vehicles with higher fuel economy, but the magnitude of the effect is likely quite small. For example, Leard et al. (2017) suggest that a fuel price increase of $0.10 per gallon would induce substitution to smaller vehicles and raise the average fuel economy of vehicles sold in that state by 0.04 miles per gallon (mpg).

A state carbon price also creates leakage. The increase in new vehicle fuel economy in the state with the carbon tax is offset by a reduction in new vehicle fuel economy in other states. Also, the state carbon tax shifts compliance costs from manufacturers to consumers in the state with the tax.

On the other hand, because older vehicles tend to have lower fuel economy than newer vehicles, the carbon price reduces the inefficiencies of the standards caused by vintage differentiated regulation. That is, the carbon price increases the incentive to retire older vehicles with lower fuel economy, increasing total new vehicle sales and reducing emissions.

A carbon price addresses the external costs of driving that scale directly with emissions, such as climate costs. In 2015, the US government estimated the social cost of carbon to be $42 per metric ton, which translates to about $0.40 per gallon of gasoline. Estimates from Gillingham (2014) suggest that a carbon price of this magnitude would reduce miles traveled by 3 percent, reducing emissions, congestion, and traffic accidents. The carbon price would also raise average new vehicle fuel economy by 0.12 mpg, but the resulting emissions and fuel consumption rate decrease in the state would be offset by a corresponding increase in other states. However, these estimates suggest that the net emissions reduction from the carbon tax far exceeds the amount of emissions leakage.

Although a carbon price would reduce the external costs of driving, it would be an inefficient means of reducing the nonclimate external costs. The costs of driving a particular vehicle vary across times and locations. For example, congestion costs are higher during rush hour than in the early morning. However, a carbon price raises the cost of driving a particular vehicle by the same amount across times and locations, reducing driving too much when the external cost is low and too little when the external cost is too high, compared with a hypothetical efficient tax that varies across times and locations depending on the external costs of driving.

Thus a carbon price complements new vehicle standards by pricing emissions from all vehicles and internalizing climate externalities and by reducing inefficiencies of vintage differentiated regulation. The amount of emissions leakage is likely to be small compared with the overall emissions reduction. A carbon price also addresses the other external costs of driving, although inefficiently compared with the policies we discuss next.

### *4.2. Charges for Congestion or Miles Traveled*

A number of local and state governments use or are considering using congestion-based road charges. For example, Los Angeles charges drivers for accessing certain lanes on major freeways, with the fee increasing with the level of congestion. Effectively, people who drive during periods of high congestion have to either pay the fee to use the less congested lane or pay in terms of lost time by driving in the other, more congested lanes. Many other cities, such as Washington, DC, have similar systems.

State and local governments are also experimenting with vehicle miles traveled taxes. For example, California and Oregon have pilot programs in which drivers are charged a fee for each mile traveled and receive a rebate for gasoline taxes. Drivers can reduce the net amount they pay (or receive a higher net rebate) by driving less. Consequently, a miles traveled fee incentivizes drivers to reduce their miles traveled.

A variety of other state and federal policies affect miles traveled, such as subsidies to public transportation and other low-emissions transportation options. Many of these policies effectively reduce the cost of low-emissions transportation options. Policies that encourage land uses with higher density, greater public transit ridership, ride sharing, and nonautomobile travel also reduce miles traveled and carbon emissions.

Taxing congestion or miles traveled, as well as subsidizing low-emissions transportation options, reduces the external costs of driving. The congestion charge is more efficient at reducing the congestion costs than a miles traveled tax because it raises the cost of driving the most during periods of high congestion (Metcalf 2009). In contrast, the mileage tax increases driving costs equally in all time periods.

It would seem that taxing congestion or miles traveled would have similar effects as subsidizing low-emissions transportation options such as public transportation. However, an important difference between the two policy options is that the subsidies reduce the overall cost of travel, which can increase aggregate travel. That is, the subsidy induces two effects: (a) an increase in the share of trips made by the low-emissions mode and a corresponding decrease in the share of trips made by passenger vehicle; and (b) an increase in the total number of trips. The total amount of fuel consumption and GHG emissions is proportional to the total number of trips and the share of trips made by passenger vehicle. Because the total number of trips increases and the vehicle share decreases, subsidies to low-emissions travel options could either increase or decrease fuel consumption and GHG emissions. Even if the subsidy reduces fuel consumption and GHG emissions on balance, the increase in trips represents an inefficiency of subsidies that is not present with the congestion or miles driven tax. The inefficiency of subsidizing clean behavior rather than taxing dirty behavior shows up in a number of other contexts, such as low-carbon fuel standards (Hughes et al. 2009) and subsidies for renewable electricity generation technologies (Fell and Linn 2013).

The congestion tax, miles driven tax, and subsidies to low-emissions transportation options are inefficient at reducing carbon emissions because the taxes or subsidies depend only on travel and not on emissions. For example, a 2009 Toyota Tundra (16 mpg) would pay the same congestion charge as a 2009 Toyota Corolla (30 mpg), although the Tundra emits almost twice as much $CO_2$ per mile as the Corolla.

In summary, a state can use a carbon price to address the climate costs of driving all passenger vehicles, and it can use a congestion charge to address congestion costs. This approach would be more efficient than using a carbon price, a congestion tax, a mileage tax, or a low-emissions travel subsidy in isolation. Combining policies can increase social welfare by reducing inefficiencies of federal standards.

### *4.3. $CO_2$-Based Registration Taxes*

In the United States, states typically do not tax vehicle registration on the basis of attributes of the vehicle such as fuel economy or weight. Since the mid-2000s, many European countries have linked registration taxes to GHG emissions rates. The structure of the tax systems varies across countries. Some countries offer subsidies to low-emitting or alternative fuel vehicles, whereas other countries tax all vehicles by amounts that depend on emissions rates. For example, Germany imposes annual registration taxes that increase with a vehicle's $CO_2$ emissions rate and decrease with fuel economy. In 2010, the registration tax on the Volkswagen Golf (38 mpg for the gasoline version) was about 60 percent lower than the tax on the Volkswagen Passat (33 mpg). Several recent studies find that these taxes affect new vehicle purchases. For example, Klier and Linn (2015) estimate that in Germany, increasing a single vehicle's registration tax by 10 percent reduces new sales of the vehicle by about 3 percent.[15]

Taxing all vehicles on the basis of their emissions rates reduces the average emissions rate of new vehicles sold. But because of the binding federal new car emissions standards, if one state adopts a $CO_2$-based registration tax, the effect on average emissions rate of new vehicles in that state would be (roughly) offset by an increase in the average emissions rate of new vehicles sold in other states—in other words, full leakage. Another inefficiency of the vehicle taxes is that they do not address external costs that depend on when and how people drive, including congestion, local air pollution, and accidents. On the other hand, the tax would reduce the inefficiencies of vintage differentiated regulation by raising the cost of owning older vehicles with high $CO_2$ emissions rates. Consumers would more readily scrap older vehicles, and sales of new vehicles would increase. Consequently, despite causing some leakage, a $CO_2$-based vehicle tax could increase social welfare.

### *4.4. Policies that Promote Alternative Fuel Vehicles*

Like the federal government, many states have enacted policies to promote the sale of alternative fuel vehicles. California and a group of East Coast states have implemented a policy mandating that a certain number of ZEVs are sold each year, with the number increasing to about 15 percent of new car sales by the 2025 model year.[16] Many states also provide subsidies for EVs, adding to the federal subsidy of $7,500 per EV. Most current state subsidies range from $1,500 to $3,000 per vehicle. The objective of these vehicle mandates and subsidies is to increase the sales of such vehicles in the short run, resulting in lower costs over time and greater sales and reduced GHG emissions in the long run.

Other state policies lower the cost of EVs or raise their benefits. These include investing in charging infrastructure and allowing plug-ins or other alternative fuel vehicles to use high occupancy vehicle (HOV) lanes during congested time periods. These policies function as implicit subsidies to EVs by reducing the cost or increasing the benefit to drivers of using them, relative to conventional vehicles.

Any of these policies causes GHG emissions leakage in the short run. If the federal new passenger vehicle standards are binding on manufacturers, additional sales of

[15] Norway has recently implemented an extreme version of this policy. Conventional vehicles are very highly taxed, with some taxes equal to the sales price of the vehicle, whereas EVs are not taxed. Electric vehicles accounted for 35 percent of new vehicle sales in 2016 (Ciccone 2015; Springel 2016).

[16] Under the CAA, California can request EPA to allow it to set passenger vehicle standards or mandates such as ZEV that differ from federal policy. Other states are not allowed to have their own separate standards, but under the CAA, they can adopt the California standards. There are 15 of these states currently.

EVs in a state will not decrease average national GHG emissions rates. In fact, as we showed above, for every additional EV sold, the two federal provisions (omitting electricity emissions and overcounting sales) mean that state policies that promote EVs are likely to increase GHG emissions nationwide in the short run. In addition, Holland et al. (2016) show that even when local pollution effects, such as ozone and $NO_x$ levels, are taken into account, subsidies for EVs cause emissions leakage to other states. In fact, accounting for global and local air pollution, they find that cross-state differences in alternative fuel vehicle subsidies increase costs and reduce benefits nationwide.[17]

Notwithstanding the increase in short-run emissions, these policies could increase social welfare in the long run. As we have discussed above, the California ZEV program is expressly designed to reduce the costs of emerging vehicle technologies. Currently, the federal vehicle tax credit is $7,500 per vehicle, and as we showed above, the federal standards create implicit subsidies to manufacturers that are between $8,000 and $11,000 per vehicle (recall that the subsidies and tax credit are not necessarily additive). Are these federal subsidies higher or lower than an optimal innovation subsidy? We showed in Figure 1 that there is a great deal of uncertainty about the magnitude of the optimal subsidy. Our rough calculations suggest, however, that it is not greatly different from the sum of the explicit and implicit existing federal subsidies. And the optimal innovation subsidy does not include other potential market failures, such as incomplete consumer information. Accounting for those market failures could mean that the federal subsidies are insufficient to account for all the market failures and that additional state subsidies could increase social welfare in the long run.

To the extent that states elect to promote EV sales with the goal of reducing long-run costs, it is important to consider local variation in costs and benefits of particular policies. The costs and benefits of allowing alternative fuel vehicles to use HOV lanes will vary with local conditions, as will the costs and benefits of subsidizing infrastructure. These policies will depend on roadway conditions, the density of population, and the types and uses of vehicles in the state (e.g., it is more expensive and difficult to electrify trucks than smaller vehicles).

Another consideration for states is how to determine the stringency of their policies. States can mandate the sale of vehicles, as the California ZEV program does, or they can subsidize the vehicles or impose taxes on other higher-emitting vehicles. As we discussed in Section 2, we can think of ZEV as providing an implicit subsidy to alternative fuel vehicles. In addition, existing research has not quantified the value of existing subsidies, such as the implicit subsidy from ZEV. Estimating the value of this subsidy would require an assessment of the level of direct vehicle purchase subsidy needed to achieve the mandate, after accounting for the effects of other subsidies such as the federal tax credits. This lies outside the scope of this paper and is left for future research.

### *4.5. Summary*

Table 1 summarizes the extent to which each type of policy complements the federal policies or creates emissions leakage. The table indicates that a combination of policies, such as a carbon tax and congestion charge, can address many of the external costs of driving without causing substantial leakage.

[17] These are short-run results and are based on the electricity grid in the years 2010–12 and current gasoline vehicle technology.

**TABLE 1. SUMMARY OF WELFARE CONSEQUENCES OF STATE POLICIES**

| | Addresses climate and energy security costs? | Addresses congestion costs? | Addresses local air pollution costs? | Addresses vintage differentiated regulation? | Addresses innovation and adoption market failures? | Leakage risk? |
|---|---|---|---|---|---|---|
| Carbon price | Yes | Yes, inefficiently | Yes, inefficiently | Yes | Yes, partly | Yes, small |
| Congestion charge | Yes, inefficiently | Yes | Yes, inefficiently | No | No | No |
| Miles traveled charge | Yes, inefficiently | Yes, inefficiently | Yes, inefficiently | No | No | No |
| $CO_2$-linked vehicle registration tax | Yes, inefficiently | No | No | Yes | No | Yes, small |
| Subsidies to low-emissions travel modes | Yes, inefficiently | Yes, inefficiently | Yes, inefficiently | No | No | No |
| Alternative fuel vehicle subsidy or mandate | Possibly, in long run | No | No | No | Yes | Yes |

## 5. Conclusions

This paper has analyzed the interactions between federal and state policies that attempt to reduce the external costs of passenger vehicles. Federal standards are motivated by market failures caused by energy security and climate costs of consuming oil. Federal policies also incentivize alternative fuel vehicles such as plug-in electrics, both directly via tax incentives and indirectly via overcrediting for the GHG standards. These policies are motivated by potential market failures in innovation and adoption of new technologies. The federal direct and indirect subsidies on alternative fuel vehicles turn out to be similar to one another. We argue that there is vast uncertainty about the optimal level of subsidizing these vehicles that would account for the market failures, making it extremely difficult to determine how current federal subsidies compare with the optimal subsidies; this is an important area for future research.

The federal policies target emissions from new vehicles and therefore incompletely address all the external costs of driving. In particular, the standards exacerbate external costs that increase with the amount people drive. Moreover, the standards delay retirement of older vehicles because they apply to new and not existing vehicles, which increases demand for older vehicles and delays their retirement. Finally, federal policies, including the standards, may insufficiently address market failures associated with innovation and adoption of new technology.

Although the literature on overlapping policies suggests that it is inefficient for state and federal policies to target the same objective, these limitations of federal standards create an opportunity for state policies to complement the federal policies. We compared several classes of policies that states have adopted or may consider adopting. A carbon price addresses climate costs more efficiently than the other policies, but a carbon price is less efficient than a congestion charge at reducing traffic congestion. A mileage charge reduces external costs that scale with driving but inefficiently reduces the costs that depend on when and where the driving occurs, such as driving in congested areas. A carbon price and vehicle registration tax address the inefficiency of federal standards caused by vintage differentiated regulation. Therefore, any of these policies in isolation can increase social welfare in the presence of the federal policies, and the state policies can be used in combination with one another to target the multiple external costs of driving.

However, because federal standards are binding at the national level, state policies that increase the fuel economy of new vehicles purchased in that state will cause leakage. Leakage occurs when a state policy that reduces emissions rates of new vehicles sold in the state causes a corresponding increase in the emissions rate of new vehicles sold in other states, so that the national average emissions rate is unchanged.

State policies that increase sales of alternative fuel vehicles cause more than full leakage because of provisions of the federal regulations that favor alternative fuel vehicles over other vehicles. Therefore, state policies that increase the sale of alternative fuel vehicles increase emissions in the short run. On the other hand, if federal policy underincentivizes innovation and adoption of new technology, state policies that provide additional incentives for these vehicles could be efficient in the long run. This rationale for state policies includes both policies that reduce the costs or increase the benefits of alternative fuel vehicles, such as subsidizing vehicle purchase and charging infrastructure, and policies that implicitly subsidize alternative fuel vehicles, such as ZEV. State policymakers should be mindful of the tradeoffs that alternative fuel vehicle policies create between short-run emissions increases and long-run innovation.

We note that this paper has focused on the emissions reductions that particular policies achieve and has not considered the important issue of the distribution of the costs of reducing emissions. Each of the policies we discussed implies different costs in achieving higher alternative vehicle sales and differences in who pays the costs. The California ZEV raises prices of non-ZEVs, as manufacturers adjust vehicle prices to encourage consumers to purchase ZEVs. Assuming there is full compliance, ZEV determines the quantity of alternative vehicle sales, but the per-vehicle costs are uncertain. On the other hand, with subsidies, the per-vehicle fiscal cost is known, but the number of additional alternative vehicles sold is uncertain. Taxpayers incur the costs of subsidies, whereas vehicle manufacturers and consumers incur the costs of sales mandates. Although there is some research on the distributional effects of certain policies, such as fuel taxes (e.g., West 2004), the distributional effects of many policies are unknown.

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