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Assessing Alternatives to California's Electric Vehicle Registration Fee

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Assessing Alternatives to California's Electric Vehicle Registration Fee

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16. Abstract

After the Road Repair and Accountability Act of 2017 (Senate Bill 1) was passed, transportation revenue funding in California was bolstered by numerous fees including gasoline and diesel taxes, as well as an annual registration fee exclusively for zero-emission vehicles (ZEVs). We assess the ability of the ZEV registration fee to provide adequate funding in the future, how the registration fees affect the sales of ZEVs in California, and alternative funding mechanisms instead of the registration fee. We find that the registration fee is not a sustainable mechanism to provide adequate funding as California transitions towards ZEVs. Additionally, the fee detracts from the market adoption of ZEV technologies by as much as a 20% decrease in new ZEV sales. Lastly, we examine alternative funding mechanisms include a fuel tax for hydrogen and electricity, as well as a road user charge (RUC). We find that a ZEV exclusive RUC is the most promising alternative to the ZEV registration fee.

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Assessing Alternatives to California's Electric Vehicle Registration Fee

UNIVERSITY OF CALIFORNIA INSTITUTE OF TRANSPORTATION STUDIES

December 2018

Alan Jenn, Research Scientist, Institute of Transportation Studies, University of California, Davis

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Executive Summary

The Road Repair and Accountability Act of 2017 (SB1) imposed additional gasoline and diesel taxes to fund road infrastructure. Because zero-emission vehicles do not use gasoline, an annual registration fee was also imposed for new zero-emission vehicles (ZEVs), taking effect in July 2020. This study was requested in Section 48 of SB1, which asks the Institute of Transportation Studies at the University of California, Davis to evaluate the ZEV registration fee as a funding mechanism, understand its impact on the adoption of ZEVs, and propose and assess alternative funding mechanisms.

A number of other states have also introduced registration fees for electric vehicles in lieu of a fuel tax. However, only California's transportation funding system is significantly affected, due to the relatively high adoption of ZEVs in the state —and policies and incentives aimed at achieving Governor Brown's goals of 5 million ZEVS by 2030. We find that the annual registration fee for ZEVs in SB1 suffers from several major drawbacks related to funding and equity:

1. Infrastructure will become drastically underfunded with the current registration fee, given the long-term shift towards ZEVs. Assuming 5 million EVs on the road in 2030, the current registration fee and gasoline tax would together lead to a decrease in infrastructure funding by over $500 million annually.
2. The fee penalizes plug-in hybrid electric vehicles, which must pay both the registration fee and the current gasoline tax (for any gasoline consumed).
3. Owners of ZEVs would pay more under the registration fee compared to what they would equivalently pay with a gasoline tax (if electricity/hydrogen were converted to gasoline on an energy basis).
4. A flat $100 fee is disconnected from usage and the "user pays" principle; a ZEV owner would pay the same amount no matter how much they drive—directly in contrast with a gasoline tax which is based on usage.

Also, while ZEV registration fees do align with transportation infrastructure goals, they hamper attainment of California's clean air and climate goals as they relate to the adoption of the new vehicle technologies. Through a large-scale survey administered to electric vehicle owners, as well as an econometric analysis across different states with various registration fees for electric vehicles, we found that the fees would reduce ZEV sales by 10-20% in the short run. While ZEV registration fees do align with transportation infrastructure goals, these effects on ZEV sales should be kept in mind when designing vehicle fees.

In response to the drawbacks listed above, this study considers two alternative funding mechanisms: an analogous fuel tax for alternative fuels and a road user charge (RUC). A summary of the mechanisms for funding road infrastructure and an assessment of their ability to meet funding requirements, responsiveness to inflation, revenue stability, administrative cost, ability to meet the user pays principle, and ability to meet equity concerns are provided in Table 1.

Table 1. Impact of transportation infrastructure funding mechanisms

= Very Poor = Poor = Fair = Good = Very Good

	Traditional gasoline tax	Annual ZEV registration fee	ZEV fuel tax	Road User Charge
Revenue meets funding requirements?	SB1 has improved sustainability of funding.	Aligns neither with the gas tax nor with funding requirements.	Would address funding deficits from ZEV adoption.	Creates a long-term solution for efficiency improvements and ZEV adoption.
Responsiveness to inflation?	Automatically adjusts with inflation	Automatically adjusted with inflation.	Can be designed to be adjusted to inflation.	Can be designed to be adjusted to inflation.
Revenue stability?	Stability hindered by improvements in fuel efficiency and shifts towards ZEVs	$100 annual fee is significantly lower than the average CA vehicle, this will exacerbate with more ZEVs.	ZEV adoption solved. Fuel efficiency gains will continue to be problematic.	Robust to changes in efficiency and to adoption of ZEVs. Long-term VMT* shifts could be problematic.
Administrative cost?	Administrative costs are only 1% of revenue	Coupling this fee to the existing registration fees results in little added costs.	Metering usage of electricity to charge PEVs is likely prohibitively expensive.	Higher costs due to hardware and fee collection. Potential to lower costs exists (e.g., telematics).
User pays?	Efficiency benefits address some externalities but detract from stable funding.	Decouples fees from usage of roads.	Identical to gasoline taxes for all alternative fuel vehicles.	Similar to gasoline taxes without variation in fuel efficiency.
Equitable?	Gas tax is relatively neutral as it closely aligns with "user pays" principle.	ZEV users would pay more than they would with the gas tax (based on energy content).	Identical to gasoline taxes for all alternative fuel vehicles.	Less regressive than the gasoline tax: lower income users tend to pay slightly less

* Vehicle miles traveled

The alternative fuel tax for electricity and hydrogen, referred to in Table 1, could be constructed based on a user-pay principle using one of the following methods:

- Revenue neutral relative to the average vehicle in California with taxes of $0.072/kWh (electricity) and $1.35/kg ($H_2$)
- Revenue neutral with the $100 SB1 registration fee: $0.028/kWh (electricity) and $0.52/kg ($H_2$)

- Equivalent tax on an energy equivalent basis to the gasoline tax: \$0.018/kWh (electricity) and \$0.55/kg (H_2)

Unfortunately, all of these alternative fuel tax methods are difficult to implement for electric vehicles because of the high cost of measuring and tracking electricity use by electric vehicles. Separate metering for electric vehicles would likely be prohibitively expensive and detract from the ability of the state to raise revenue from these vehicles. Hydrogen is less problematic, with fee collection points at the station level.

A road user charge (RUC) program, the other major alternative funding mechanism, has been investigated in California through SB1077. The California Department of Transportation identified several general challenges, based on the pilot program (California State Transportation Agency, 2017). One challenge is the relatively high administrative cost. This cost burden could be alleviated by imposing the RUC only on ZEVs, with the gasoline tax staying in place with other vehicles. The benefit of this approach is to eliminate the prospect of double tax payments for gasoline (traditional vehicles would pay both the RUC fees and gasoline taxes during the long transition period, requiring a costly fix). Another benefit of imposing the RUC only on ZEVs is that it allows gasoline cars to avoid the extra hardware costs and compatibility issues of pairing telematics (or other advanced technologies) needed to monitor vehicle miles travelled with existing technologies (e.g. on-board diagnostic [OBD] devices). This dual path approach would result in a slow transition to RUCs, but at much less cost.

In considering the transition to either an RUC or alternative fuel tax, there are a number of synergistic opportunities to mitigate their downsides. The Low Carbon Fuel Standards program could serve as a partner program to implement either the fuel tax or RUC, possibly even using the existing LCFS credit mechanism to manage payments. In addition, leveraging a telematics system to implement an RUC program can assist in the development of other pricing mechanisms such as congestion or occupancy pricing/discounting. As the transportation system transitions towards RUC or alternative fuel taxes, it is important to consider how they might synergistically interact with current or future financial and policy mechanisms.

With increasing fuel efficiency in gasoline vehicles and increasing sales of zero emission vehicles, funding our transportation infrastructure with gasoline taxes becomes outdated. The annual ZEV registration fee under SB1 seemed like a good fix, but has major shortcomings. Our analysis suggests that the best solution for creating a sustainable, robust funding system is a RUC program applied only to ZEVs (allowing the parallel gasoline tax to gradually atrophy and eventually disappear).

1. Introduction

On April 28, 2017, Senate Bill 1 (SB1) was signed into law by Governor Edmund (Jerry) Brown Jr. The bill enacted several changes to the funding of road infrastructure, including an increased tax of $0.12 per gallon of gasoline with an annual inflation adjustment, a $0.20 per gallon of diesel tax increase with a similar inflation adjustment, a transportation improvement fee as part of the Vehicle License Fee Law (ranging from $25 to $175), and a $100 annual vehicle registration fee applicable to zero emission vehicles (ZEVs) of model year 2020 and later.

The $100 annual fee is levied because current ZEVs (plug-in hybrid electric vehicles [PHEVs], full battery electric vehicles [BEVs], and hydrogen fuel cell vehicles [FCVs]) operate partially or entirely on alternative fuels (electricity/hydrogen) and thus do not pay at least a portion of the gasoline tax. This report is written to comply with Section 48 of SB1, which directs the Institute of Transportation Studies at the University of California, Davis, to assess the annual ZEV registration fee.

In this study, we provide a brief overview of infrastructure funding, an analysis of the ZEV registration fee, and potential alternative methods to raise revenue from zero-emission and low-emission vehicles.

2. An Overview of Zero Emission Vehicles

Zero emission vehicles are so called because at least some portion of their operation produces no tailpipe emissions. ZEVs include PHEVs (which operate on both gasoline and electricity), as well as BEVs and FCVs. Plug-in vehicles (PEVs) encompass all forms of electric vehicles, both PHEVs and BEVs. The PHEV is a partial ZEV, as it has both a battery-powered motor and a gasoline-powered engine and can thus operate using either electricity or gasoline. Studies have found that the proportion of time that PHEV owners operate using the engine compared to the motor is closely related with the battery range of the vehicle (Tal, et al., 2014). A summary of different vehicle technology types and their corresponding operation can be found in Table 2.

Table 2. Comparison of vehicle technology types

	Conventional Gasoline Vehicle	Hybrid Electric Vehicle (HEV)	Plug-in Hybrid Electric Vehicle (PHEV)	Battery Electric Vehicle (BEV)	Fuel Cell Vehicle (FCV)
Drive	Engine	Engine	Engine & Motor	Motor	Motor
Fuel	Gas	Gas	Gas & Electricity	Electricity	Hydrogen
ZEV	No	No	Yes	Yes	Yes

The adoption of ZEVs in California has been promoted by regulatory supply signals such as the Zero Emission Vehicle program[1] administered by the California Air Resources Board (CARB), as well as supporting demand-side incentives such as the Clean Vehicle Rebate Program[2] and Clean Air Vehicle decals[3] (Jenn, et al., 2018; DeShazo, 2016). This has led to a steady growth in the adoption of these vehicles, particularly BEVs and PHEVs, as seen in Figure 1. As of June 2018, there were 45 models of BEVs and PHEVs commercially available on the California market, with additional upcoming models announced by a number of automakers. BEVs and PHEVs have been adopted in roughly equal proportions since the introduction of the technologies, though sales in 2018 have been trending toward BEVs due to the increasing availability of the Tesla Model 3. The sales of FCVs are lower due to less development in the technology, lack of fueling infrastructure, and relatively high fuel prices (Park, et al., 2011). As a result, only three FCV models are currently available for lease (but not for purchase): the Toyota Mirai, Honda Clarity, and Hyundai Tucson.

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[1] The Zero Emissions Vehicle program is a regulation that was passed and is enforced by the California Air Resources Board. The regulation requires manufacturers to produce a certain percentage of ZEVs based on the manufacturers' overall sales of vehicles. Compliance is fulfilled through a credit system where credits are awarded based on the type of ZEV sold. https://www.arb.ca.gov/msprog/zevprog/zevprog.htm

[2] The Clean Vehicle Rebate Program provides rebates to purchasers of ZEVs. FCVs receive $5,000, BEVs receive $2,500, and PHEVs receive $1,500, subject to income requirements. https://cleanvehiclerebate.org/eng

[3] Clean Air Vehicle decals permit vehicles to drive in High Occupancy Vehicle (HOV) lanes regardless of the number of people in the car. https://www.dmv.ca.gov/portal/dmv/detail/vr/decal

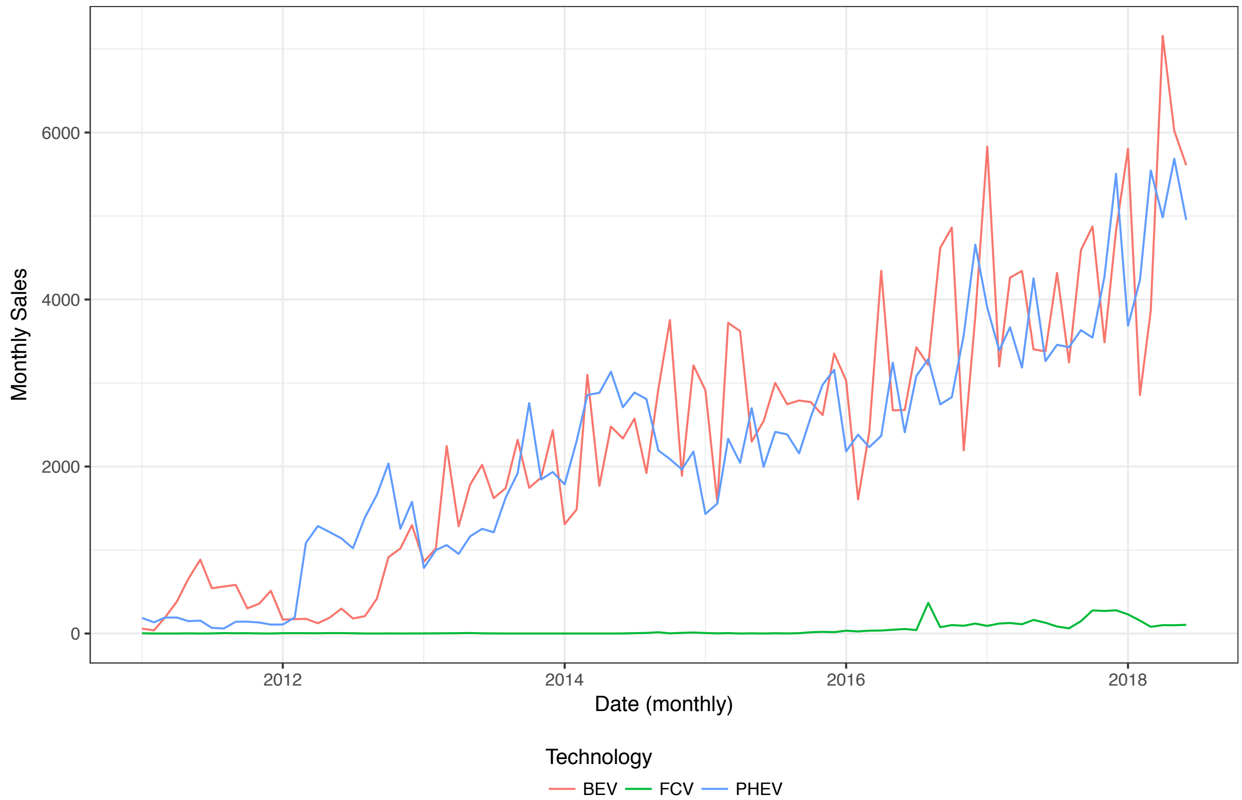

Figure 1. Monthly sales of ZEV technologies in California from 2011 to 2018

3. Road Infrastructure Funding

Revenue for road infrastructure funding has traditionally been collected primarily from fuel taxes. In California, the components of revenue can be seen in Figure 2. The funding from fuel taxes are a combination of the federal tax on gasoline[4] (currently set at 18.4¢ per gallon) and state taxes on gasoline (47.3¢ per gallon after SB1) and diesel (36¢ per gallon). The federal gasoline tax is collected by the federal government and disbursed to each U.S. state based on the relative amount paid by each state.

[4] H.R.2264 – Omnibus Budget Reconciliation Act of 1993. https://www.congress.gov/bill/103rd-congress/house-bill/2264

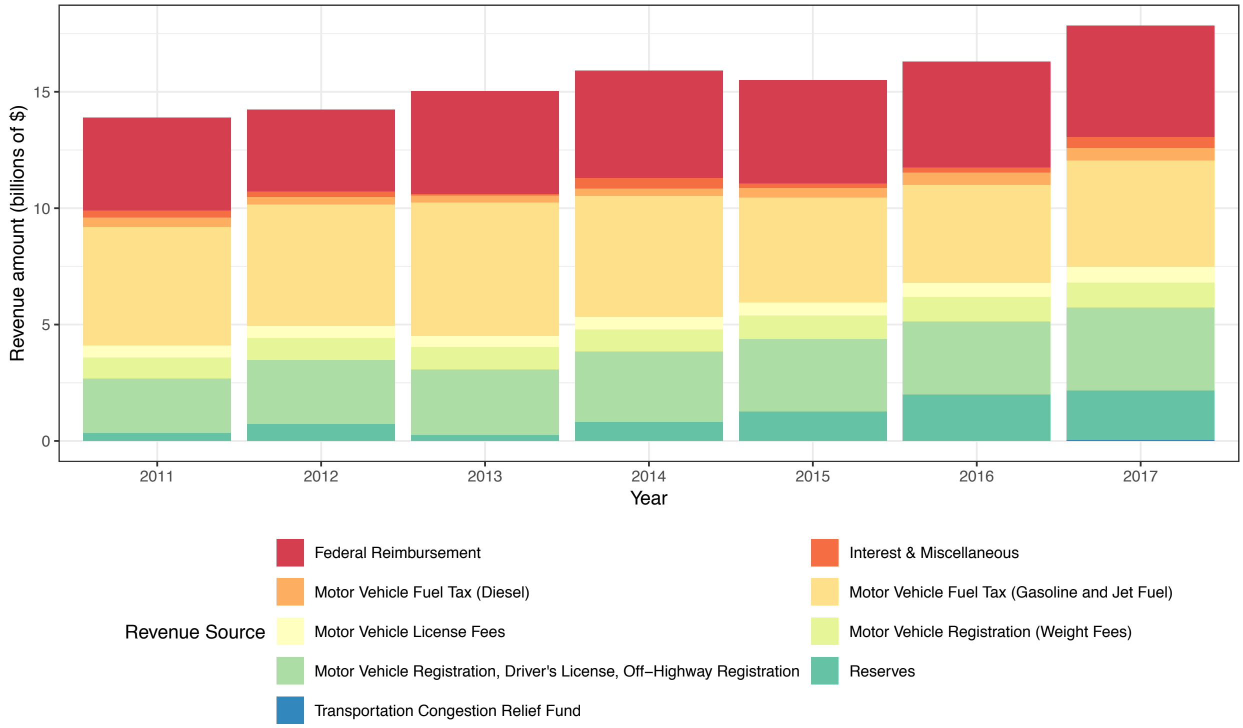

Figure 2. California revenue for funding its transportation system[5]

It is important to note that revenues raised from fuel consumption are subject to several sources of variation and uncertainty from year to year. Fuel consumption, and hence the amount paid in taxes, changes if the total miles traveled fluctuates (either through growth/shrinking of the fleet size or changes in travel behavior) or if the fuel economy of vehicles in the fleet changes. California's current tax is a flat per gallon excise tax, as opposed to a sales tax which would produce revenue based on the price of gasoline. Prior to 2010, California had a sales tax on gasoline but this was eliminated by the "Gas Tax Swap" enacted in 2010 by the California Legislature (Madowitz & Novan, 2013; Brown, et al., 2017). The swap divided the excise tax into two components: a fixed tax and a variable tax which was supposed to remain revenue-neutral with a 6% sales tax. Unfortunately, the variable tax unexpectedly created an extra layer of variability because of constant changes in gas prices: unexpected shifts in the price of oil could lead to sudden shortfalls or windfalls in revenue from the gasoline sales tax. These sources of uncertainty led to large fluctuations in the total annual revenue and varied substantially from year to year. The passage of SB1 removed the variable tax component of the excise tax, thus removing a large source of variability in road infrastructure funding.

Other sources of revenue include licensing and registration fees, interest on state payments to local agencies, and reserves from several state accounts[6]. The annual ZEV fee is part of the

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[5] California Transportation Financing Summary for Fiscal Years 2011 through 2017

[6] There are several reserves associated with state transportation accounts. From the Transportation Tax Fund (TTF): the motor vehicle fuel account, highway users tax account, and motor vehicle license fee account. From the

registration fee. An additional revenue source from SB1 is the Transportation Improvement Fee, which specifically provides funding for the State Transit Assistance Program for transit services (not shown in Figure 2).

4. Assessing the Electric Vehicle Registration Fee

California joined 18 other states (as of October 2018) that assess fees on either BEVs or both BEVs and PHEVs (see Figure 3). Minnesota assesses fees for only BEVs but not PHEVs; Vermont, New Hampshire, Illinois, Kentucky, and Alabama currently are considering proposed bills to introduce electric vehicle registration fees; and Montana, Kansas, Oklahoma, Arkansas, and Maine have all failed to implement fees (which were overturned, withdrawn, or failed to pass). The remaining states in red in Figure 3 have fees ranging from $50 to $200 annually for electric vehicles. Washington has already increased its registration fees from $100 for only BEVs to $150 for both BEVs and PHEVs. Similarly, North Carolina has increased its fees from $100 to $130 annually for both BEVs and PHEVs. Utah's current fee is scheduled to increase annually over three years from $60 to $120 for BEVs and from $26 to $52 over the same period for PHEVs.

State Transportation Fund (STF): major accounts are the state highway account, motor vehicle account, and public transportation account (though there are twelve other smaller accounts that have contributing reserve funds).

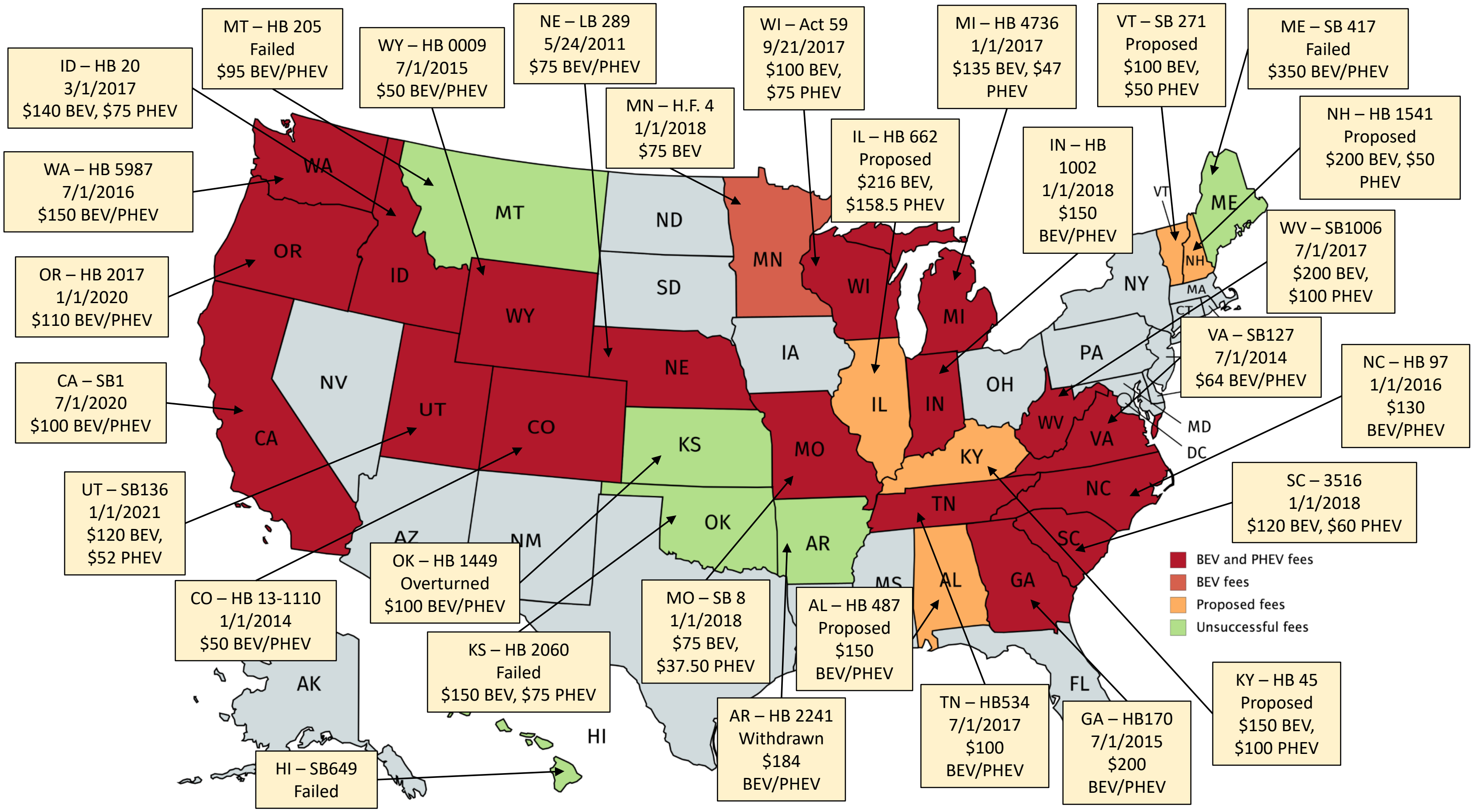

Figure 3. An overview of electric vehicle registration fees assessed at the state level in the United States (as of Fall 2018). States in grey have not introduced registration fees for electric vehicles.

Similar to California, states that have proposed a unique electric vehicle registration fee have done so under the premise that electric vehicles (and FCVs) must pay their fair share to help fund road infrastructure because they do not pay a fuel tax. Unfortunately, the registration fees being enacted around the country depart from the principle of “user pays”. That is, whereas the traditional gasoline tax is indirectly linked with the usage of roads (the more a user drives, the more that is paid in gas taxes), the registration fee does not take this into account—a ZEV driver pays the same per year no matter how may miles he/she drives. While the structure of these fees may respond to political realities and avoid the implementation challenges of alternative mechanisms, they are inconsistent with use-based fees for funding road infrastructure.

Section 4.1 assesses the ZEV registration fee in comparison to revenue produced by conventional gasoline vehicles and the ability of registration fees to sustain funding for road infrastructure in the future. Section 4.2 assesses the impacts of shared vehicles (such as ride-hailing programs like Uber and Lyft), autonomous vehicles, and electric vehicles (the “three revolutions” (Sperling, 2018)). And Section 4.3 assesses the effect of the registration fee on the adoption of ZEV technologies.

4.1 Revenue from an annual ZEV registration fee

A forecast of electric vehicle adoption was conducted to assess the revenue resulting from the enacted ZEV fee. A relatively simple time-series analysis, based on historical sales, generated a range of possible outcomes for both BEV and PHEV adoption in the future (Figure 4). The baseline scenario is based on the mean outcome of the time-series analysis model. However, there is considerable uncertainty in the vehicle sales projections, which is characterized as the error in the time-series analysis. In the baseline case (dashed line), adoption slightly overshoots CARB’s target of 1.2 million ZEVs in 2025 with 1.4 million ZEVs, but falls short of Governor Brown’s target of 5 million ZEVs in 2030 with 4.6 million ZEVs. On an annual basis, BEVs and PHEVs will each account for approximately 300,000 vehicle sales in California in 2030. At these volumes, ZEVs will constitute nearly 20% of on-road passenger vehicles in California in 2030. It is therefore critical to understand the impact of the ZEV registration fee on the funding of road infrastructure.

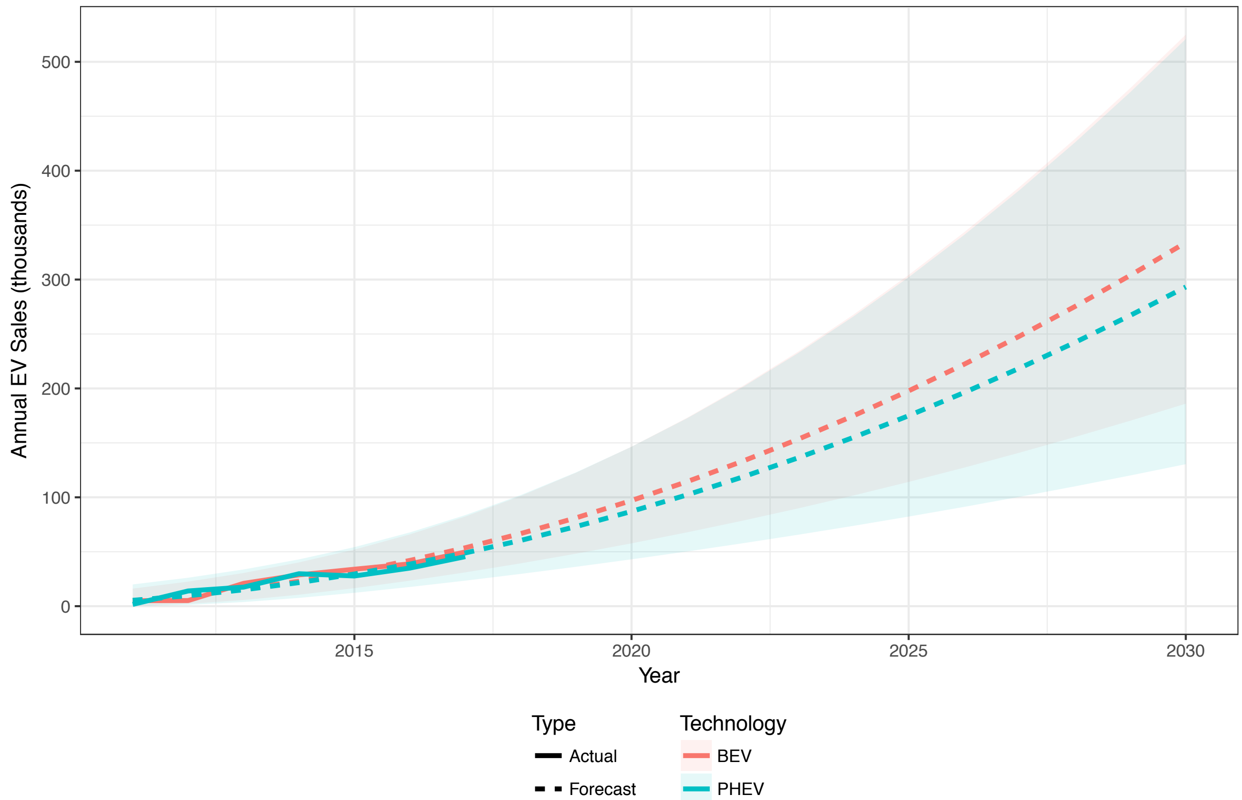

Figure 4. Electric vehicle annual sales forecast in California from 2011 through 2030

With a tax of 47.3¢ per gallon of gasoline, the average Californian driving 12,000 miles per year in a new vehicle achieving 32 miles per gallon (an estimated sales-weighted average fuel efficiency, given CAFE rules in the 2018 to 2025 time frame) will pay approximately $180 per year in gas taxes (in addition to registration fees). Under the current SB1 rules, BEVs will pay an annual $100 fee and PHEVs will pay both the annual fee of $100 and any gasoline tax for gasoline used. The electric vehicle miles traveled (eVMT) versus gasoline miles can be calculated for PHEVs (with different battery sizes) and then applied to the fleet of existing PHEVs in California to estimate the sales-weighted eVMT. Based on the estimate of average gasoline consumption by PHEVs in California (see Appendix, Section A2), drivers of these technologies are expected to pay approximately $150 per year consisting of $50 in gasoline taxes and $100 in ZEV registration fees.

One question raised by the legislature is how ZEVs compare "to the average annual state fuel excise tax assessed on gasoline or diesel vehicles with equivalent fuel economy." Using the sales-weighted mile-per-gallon equivalent[7] (MPGe) by the EPA, the average BEV would pay $64

[7] Miles per gallon equivalence (MPGe) equates fuel efficiencies across alternative fuel vehicles. Neither electric vehicles nor hydrogen fuel cell vehicles consume gasoline, but both electricity and hydrogen can be converted to a "gasoline equivalent" based on the energy content of the fuels. This allows for a common efficiency metric across

per year while the average PHEV would pay $93 per year (using MPGe for its electric operation). For both technologies, the vehicles would be paying approximately 50% more under the current annual ZEV registration fee compared to a gasoline tax on the equivalent fuel economy of those vehicles. The ZEV registration fees in SB1 would be charging owners of ZEVs more money compared to gasoline vehicles, potentially creating a disincentive for adopting these new vehicle technologies. However, it should be noted that the MPGe is not necessarily the ideal comparison. First, MPGe converts to gasoline equivalence on an energy basis, but the difference in prices of electricity, hydrogen, and gasoline would mean that MPGe does not accurately reflect what a driver would pay. Second, from a well-to-wheels system perspective, MPGe typically overstates efficiency—while the drivetrain in an FCV or PEV is very efficient, MPGe does not reflect the losses in efficiency in the production of electricity or hydrogen.

Figure 5 shows the expected annual revenue under three different funding schemes across different numbers of vehicles. These three funding schemes include what the average vehicle in California pays in gasoline taxes (red line), what the average BEV/PHEV would pay under the current SB1 ZEV annual registration fee plus gasoline taxes (green line), and what the average BEV/PHEV would pay under the current gasoline tax if the energy consumption associated with electricity/hydrogen use were converted to gasoline (blue line).

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different fuels (e.g., if the electricity for a PEV were converted to gasoline on the basis of energy content, MPGe would be the fuel efficiency corresponding to the PEV).

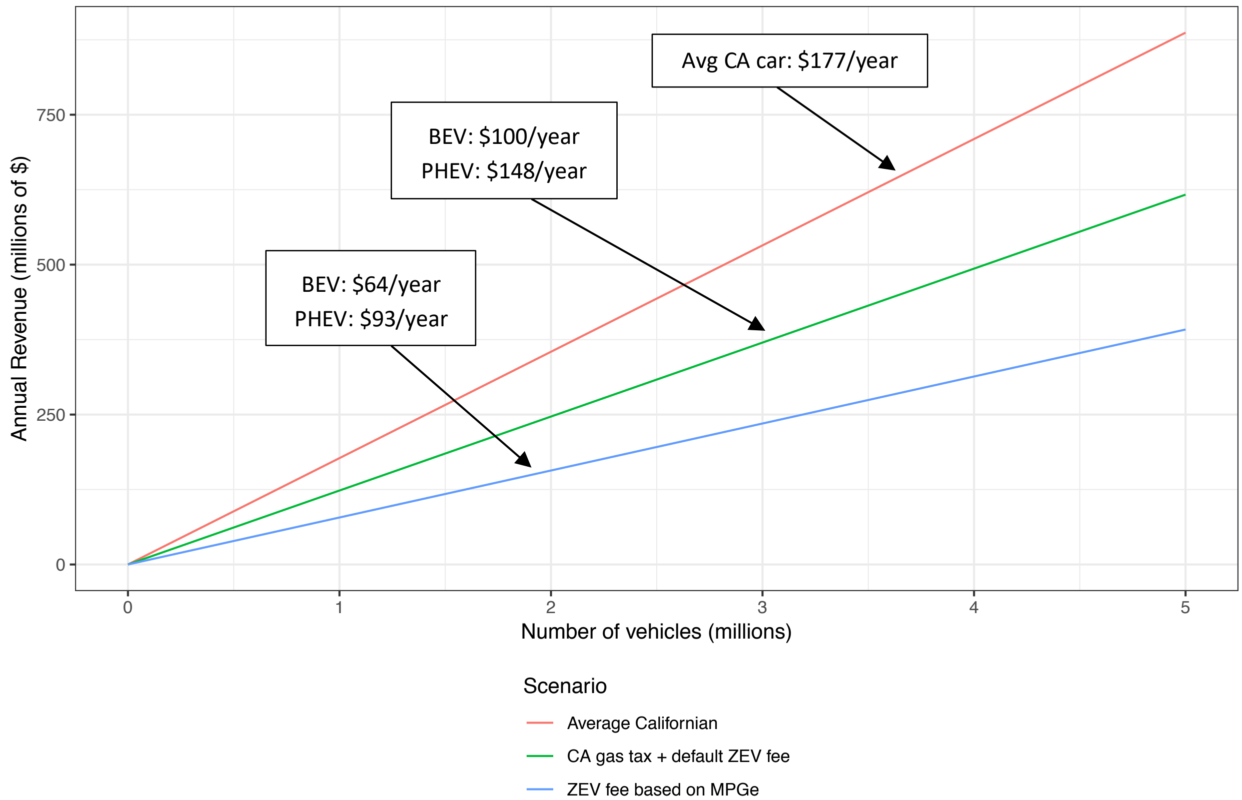

Figure 5. Relative revenue generated from three different schemes for comparison: gasoline taxes from the average vehicle in California (red), the currently implemented annual ZEV fees as levied by SB1 plus gasoline taxes (green), and a gasoline tax equivalent fee for electric vehicles based on MPG equivalence in 2020 (blue). With the current registration fees, BEVs and PHEVs would pay less than the average vehicle in California but would pay more than what they would under the gasoline tax based on their MPGe ratings.

The ZEV registration fee will help to alleviate shortfalls in revenue resulting from electric vehicles and FCVs not paying gasoline taxes, relative to if those vehicles were conventional gasoline vehicles that paid fuel taxes. In Figure 6, this cost-recovery mechanism is displayed in comparison to the existing gasoline tax (dashed line) relative to the revenue from the gasoline tax alone (solid line). At 4.6 million electric vehicles in 2030, this yields about $550 million in annual revenue (combined $100 registration fee plus the gasoline tax from PHEV gasoline operation), though with uncertainty this ranges from $290 million to over $900 million. These annual revenues are generated from the forecasts of adoption seen in Figure 4, similarly incorporating uncertainty in both the adoption levels and the driving behavior (see Appendix, Section A2 for methods and assumptions).

It is critical to note that the ZEV registration fee mechanism is only a partial stopgap against decreases in revenue due to the adoption of increasingly fuel-efficient vehicles. The analysis indicates that improvements in fuel economy for new vehicles will likely lead to a decrease of approximately $1.75 billion annually over the next decade, but only about 30% of this decrease will be recovered by the registration fee for ZEVs. While the slopes of both the solid and dashed lines are negative, the divergence with the base revenue continues to grow despite the rapid growth of ZEVs. This indicates that the revenue stream coming from registration fees is not sustainable—as the share of the California fleet continues to become electrified, revenue shortfalls will be an ongoing problem with the registration fee mechanism proposed under SB1. This issue is particularly salient when considering the average Californian gasoline-vehicle currently pays about $177 a year while an electric vehicle owner would pay between $100 to $150 per year.

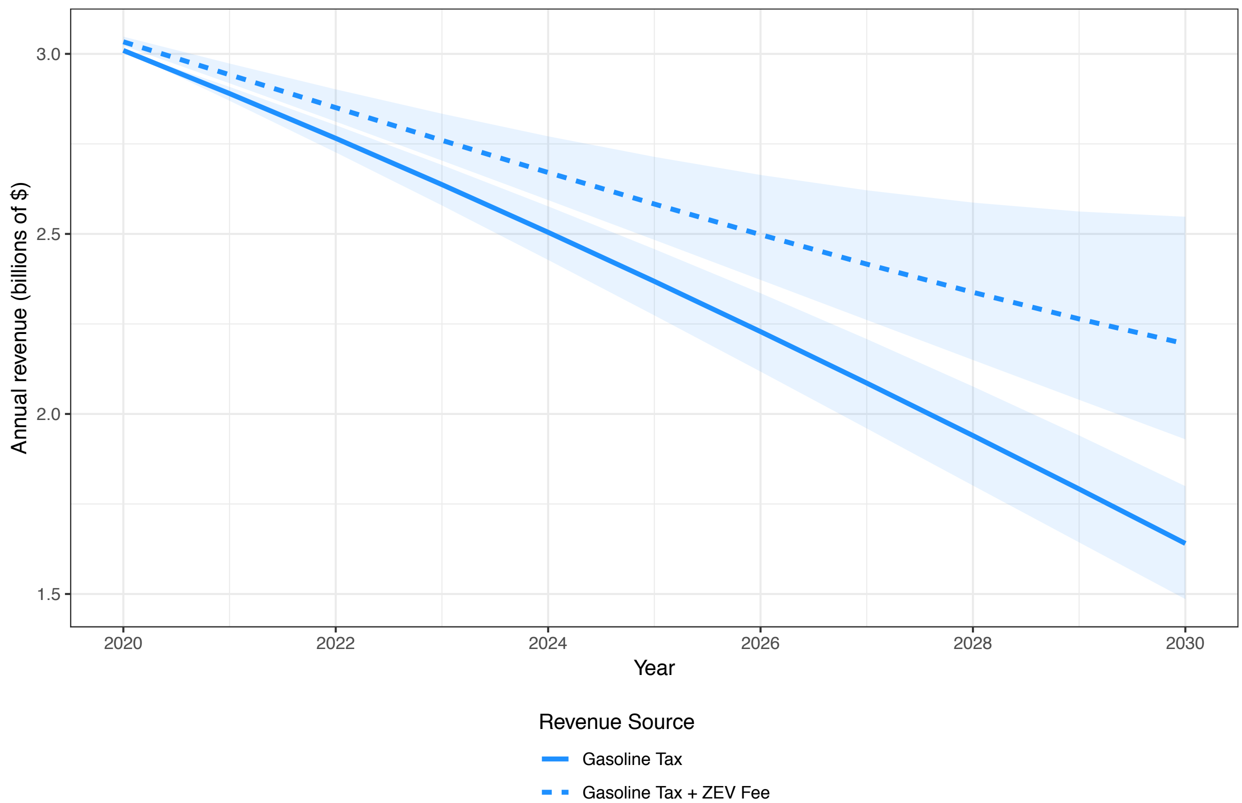

Figure 6. Revenue forecasts from the gasoline tax and current ZEV registration fees through 2030

As California continues to meet its long-term goals of higher ZEV adoption, the ability of the fee to help meet infrastructure funding revenue requirements will be strained. While the relatively low volume of ZEVs in other states currently produces a small fraction of overall revenues from fuel and registration fees, the number of ZEVs in California will produce approximately $50 to $80 million toward the replacement of annual lost revenue from gasoline taxes. The uncertainty in this revenue calculation depends on what conventional vehicles would have been driven had ZEVs not been available.

4.2 Three revolutions and shifting revenues

The assumptions in Section 4.1 are based on continuing trends without large shifts in travel behavior and vehicle ownership. However, recent developments in automation technology and the sharing economy may lead to a shift in transportation known as the "three revolutions" (referring to automation, electrification, and shared services), which in turn may lead to large changes in ownership and travel behavior models. The widespread adoption of these transportation changes will significantly impact funding road infrastructure in the future because the number of vehicles on the road as well as the total miles traveled could vary significantly (Wadud, et al., 2016; Greenblatt & Saxena, 2015). Specifically, integration of automated vehicles in shared economies can lower the cost of operation (since a large portion of costs are to pay the driver), leading to higher rates of carpooling (Alonso-Mora, et al., 2017) and lower rates of car ownership (Menon, et al., 2018; Zhang, et al., 2018; Becker, et al., 2018).

Drawing from a report published by UC Davis (Fulton, et al., 2017), Figure 7 shows the hypothetical requirements for the gas tax and ZEV registration fee to approximately maintain in 2030 and 2050 the same revenues expected from these sources in 2020, under different scenarios of the three revolutions (3Rs). In other words, the analysis measures the required increases in fees if all vehicles were subject to the energy equivalent gasoline tax (based on MPGe) or new vehicles were subject to an increased annual registration fee. With a scenario of 25% automation (1R) (without significant electrification or sharing), by 2030 the gasoline tax would not need to shift very much from the $0.47 per gallon charge (with a $100 ZEV registration fee as well). Under a "2 revolution" (2R) scenario with the same 25% level of automation plus 50% electrification by 2030, the gasoline tax would need to be increased to $0.52 per gallon and the annual registration fee would need to be increased to $114. Under the full "3 revolutions" (3R) scenario, with a 50% adoption of travel fulfilled by shared mobility services, the gasoline tax would need to be further increased to $0.68 per gallon with a corresponding $148 annual registration fee for ZEVs (refer to Appendix, Section A4 for details on assumptions and methods). The 2050 levels are based on full saturation, i.e., 100% of each revolution indicated. Thus, under 100% automation (1R) in 2050, as in 2030, nearly no change in the current gas tax and registration fee would be needed to maintain revenue. However, 100% of 2Rs (automation plus electrification) will require an increase in the gasoline tax to $0.57 per gallon and registration fee to $144. Finally, 100% of 3Rs (automation, electrification, and sharing) would hypothetically require a $1.96 per gallon tax and $640 annual registration fee to maintain current revenue levels.

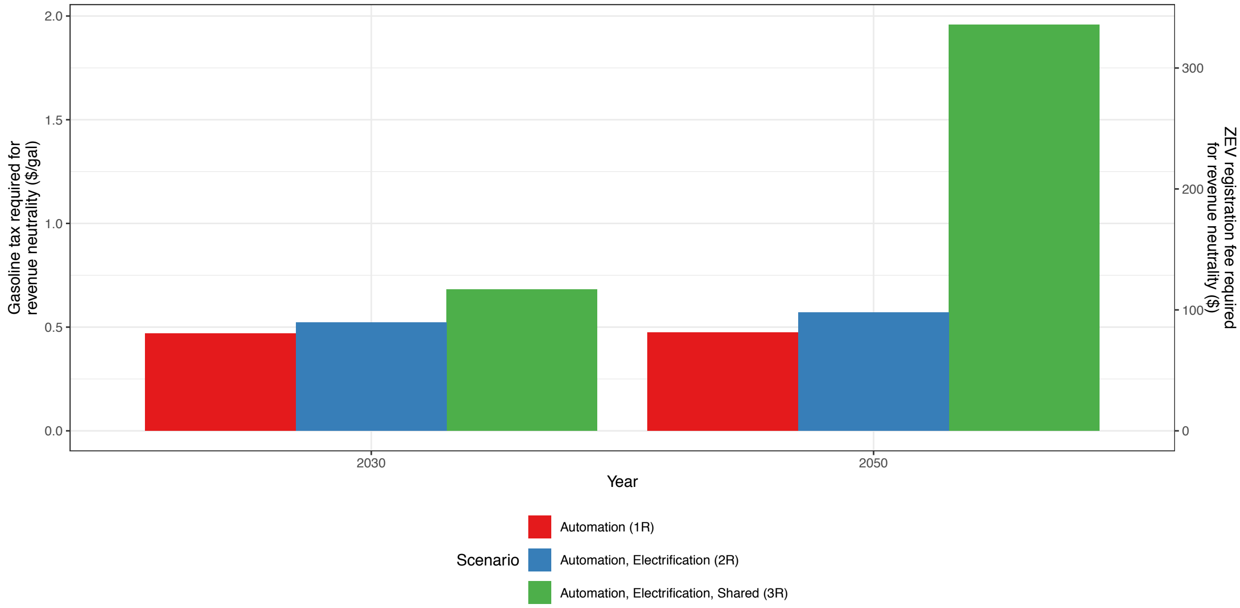

Figure 7. Gasoline tax and ZEV registration fee required to maintain revenue neutrality under different scenarios of electrification, automation, and shared mobility services through 2050. The combination of vehicle automation, electrification, and shared mobility may result in large shifts in travel behavior and vehicle ownership. The gasoline tax and ZEV registration are estimated such that they maintain revenue neutrality in 2030 and 2050. These estimates are based on projections of the 3 Revolutions from Fulton et al., (2017).

The projections used to forecast the required fees levied according to Figure 7 act as a bounding analysis, not as an accurate representation of the future. Rather, this analysis serves to demonstrate the necessity of considering longer term shifts in transportation systems that may alter future infrastructure funding. While no current action is required, alternative funding mechanisms may provide opportunities to automatically accommodate these shifts in transportation trends such that revenues are maintained. In other words, robustness to future changes should be one of the key factors when considering alternative funding mechanisms.

4.3 Impacts of fees on adoption of ZEVs

California surpassed 400,000 ZEVs on-road in 2018 and the adoption of PEVs and FCVs is expected to continue to increase in the future. Despite promising adoption figures, the market still faces steep challenges to meet both the ZEV program 2025 requirements and Governor Brown's executive order goals. CARB estimates that sales of ZEVs will need to be about 8% of the market for new vehicle sales to reach 1.2 million ZEVs on-road in 2025[8]. Furthermore,

[8] https://www.arb.ca.gov/msprog/zevprog/factsheets/zev_regulation_factsheet_082418.pdf

Governor Brown's signing of Executive Order B-48-14[9] increases California's ZEV goals by requiring 5 million on-road by 2030.

It is possible that the introduction of a registration fee specifically for ZEVs under SB1 may reduce the ability of the state to meet the target adoption requirements. This report investigates the potential impact on sales through two approaches: stated preference and revealed preference analysis. Stated preference relies on questioning respondents directly about their preferences (e.g., through surveys), while revealed preference uses data on previous buying behavior to measure consumers' responses to registration fees for ZEVs being passed in other states.

In the stated preference approach, a nationwide survey asked over 2,000 owners of electric vehicles if they would have changed their purchase decision had there been a $100 annual registration fee. The possible responses were: "I would still purchase my plug-in vehicle"; "would buy another plug-in vehicle"; "would buy a gas car"; or "won't buy a new car." For BEV owners, there was an 11% decrease in adoption while PHEV owners reported a 19% decrease in adoption had a registration fee been in place when purchasing the vehicle. A very small percentage of both BEV and PHEV purchasers stated they would switch to a different plug-in vehicle (<3%), though they would still be subject to the same fees.

[9] https://www.gov.ca.gov/2018/01/26/governor-brown-takes-action-to-increase-zero-emission-vehicles-fund-new-climate-investments/

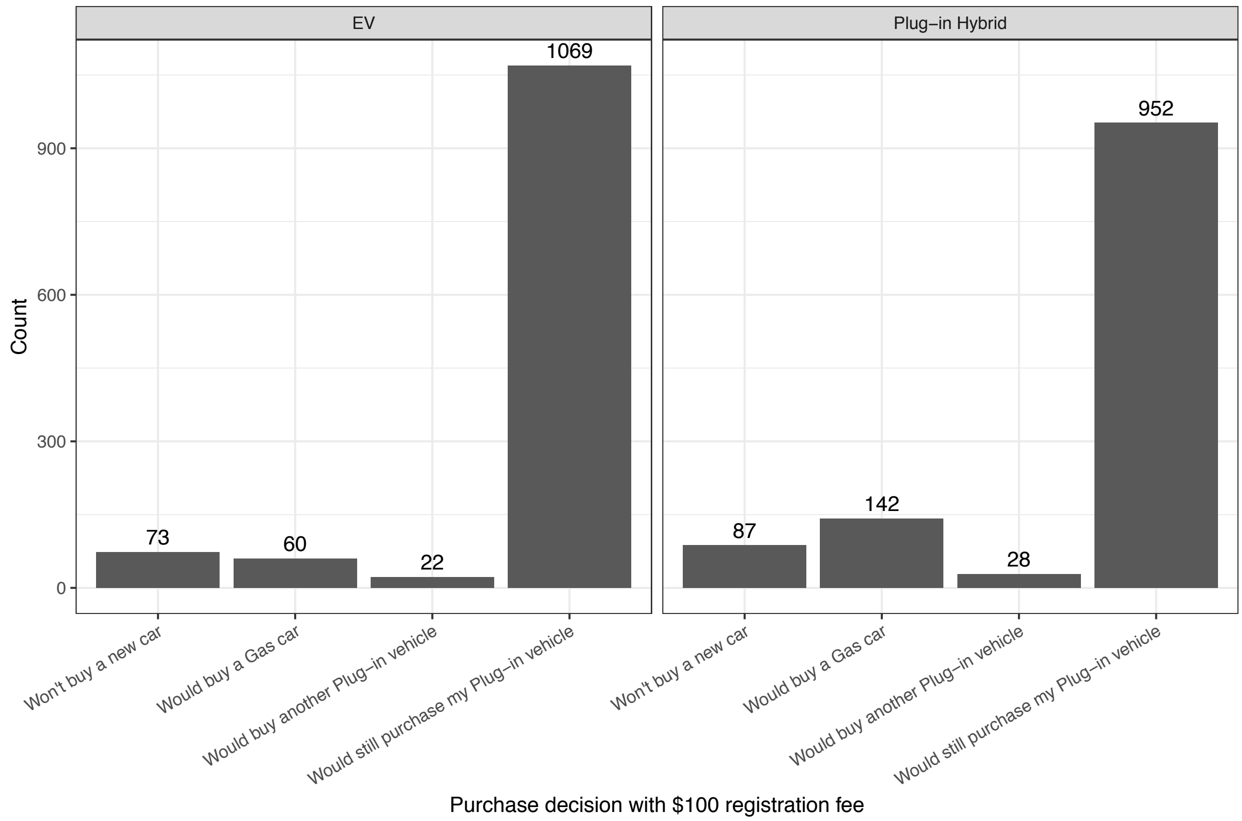

Figure 8. Survey response for changes in electric vehicle purchase decision had a $100 registration fee been in place.

There are a number of potential biases in stated preference approaches (such as sampling bias and response bias) and therefore a revealed preference method was also employed. We analyzed historical sales data along with the implementation of different registration fees in states across the U.S. at different periods of time and observed the change in sales as they were introduced. The modeling employed fixed effects regression, the details of which can be found in Appendix A3. After controlling for a number of variables including state-level fixed effects differences, the results indicate that the enactment of registration fees into law present a stronger effect on sales than the implementation of those fees. The reason for this is unclear, but it is possible that negative media coverage of bills regarding electric vehicle registration fees have a salient effect on the potential purchasing patterns of PEV buyers. The projected effect of the fees was measured using observations of changes in sales and we found, on average, a 0.24% decrease in electric vehicle sales per dollar of fee. In other words, a $100 fee would lead to a 24% decrease in sales on average, though there was variation from state to state. Since the regression results are primarily focused on the introduction of PEV fees, which have only started to occur in the last several years, many of the effects are likely short-run (on the order of 2–4 years) and may decrease in magnitude over the long run (>4 years). The findings from the regression model aligns relatively closely to the stated preference decrease as denoted from the survey results, lending more confidence to the findings that the registration fees have a measurable impact on sales of ZEVs.

While many other states have enacted fees for electric vehicles, California's registration fees stand somewhat at odds with the state's goals of adopting ZEVs. Exemption of plug-in electric vehicles and hydrogen vehicles from registration fees can be viewed as a form of an indirect subsidy for the new technology, particularly given the effect on sales. There is substantial debate as to the proper time that subsidies should be phased out to allow the market to take over growth of ZEVs. California is providing incentives to increase PEV sales through the Clean Vehicle Rebate Program, high occupancy vehicle lane decals, and Low Carbon Fuel Standard credits to promote the technology, while simultaneously creating a disincentive through an annual registration fee on the same vehicles. This may be justified by the need to satisfy disparate goals of infrastructure funding and alternative fuel vehicle adoption. One approach to balancing these conflicting goals would be a partial transfer of funds for ZEV incentives towards road infrastructure funding that would ramp down as incentives for ZEVs faded over time. This would be more efficient than both providing an incentive and charging a fee at the same time.

5. Alternative Funding Mechanisms

As shown in Figure 3, many states have defaulted to a registration fee for electric vehicles to supplement the lost revenue from gasoline taxes. These fees vary in magnitude and by vehicle technology type (BEVs versus PHEVs), but all of the states have consistently chosen a registration fee to recover lost gasoline tax revenue from electric vehicles. Though SB1 implements a similar annual registration fee for ZEVs, there are a number of shortcomings with this arrangement in California and in other states nationwide:

1. The registration fee will not provide sustainable funding for infrastructure; a long-term shift towards ZEV will leave infrastructure drastically underfunded in comparison to the gasoline tax as it exists today.
2. The fee penalizes owners of plug-in hybrid electric vehicles, who must pay both the registration fee and the current gasoline tax (for any gasoline fueled operation).
3. PEV owners would pay more under the registration fee compared to what they would equivalently pay with a gasoline tax (see Figure 5).
4. A flat fee is disconnected from usage and hence violates the "user pays" principle; a PEV owner will pay the same amount regardless of the miles driven, directly in contrast with a gasoline tax which is based on usage.

The state of California has a unique opportunity to consider alternative mechanisms for raising revenue and to lead a transition towards sustainable funding for road infrastructure. The use of registration fees for electric vehicles in other states provides a small fraction of their infrastructure funding, but California leads the nation with its rapid growth trajectory in plug-in hybrid, full battery electric, and fuel cell vehicles. SB1 has improved the stability of funding from the gasoline tax, both from inflation and fluctuations in the gasoline price, but the state will likely face similar challenges as alternative fuel vehicles become increasingly popular. Section 5.1 describes a fuel tax for both electricity and hydrogen, and Section 5.2 describes a per-mile fee or road charge.

5.1 Alternative fuel tax

Similar to the tax on gasoline, both electricity and hydrogen can be taxed as a fuel/energy source. This entails levying a fee based on the consumption of the energy, consistent with the "user pays" principle. However, this also poses unique challenges that are specific to the respective fuel sources. In Sections 5.1.1 and 5.1.2, the cost structure, comparisons to current prices, and implementation schemes are discussed for electricity and hydrogen respectively.

5.1.1 Electricity fee

Rate Structure

An electricity fee can be levied on electric vehicles based on the electricity used, commonly measured in kilowatt-hours (kWh). To provide a frame of reference for electricity pricing, Table 3 provides an overview of residential electricity prices for four of the largest utilities in California. The most common rate structures are tiered rates which charge a certain price up to a threshold level of electricity usage and then higher prices at higher levels of usage. These rates are consistent across single family and multi-unit dwelling types. As a result of the relatively large electricity draw from electric vehicles that would push owners into higher tiered rates (producing a disincentive for their usage), all four of the major utilities have exclusive time of use rates that PEV owners can opt in to. The EV Time of Use (TOU) rates in Table 3 are not rates exclusive to the electricity for charging the vehicle, but are rates offered to PEV owners for their household consumption of electricity.

Table 3. Residential electricity rates across four California utilities

	Pacific Gas & Electric	Sacramento Municipal Utility District	Southern California Edison	San Diego Gas & Electric
Tiered Rates (per kWh)	\$0.215 (100%) \$0.285 (101%-400%) \$0.44 (>400%)	\$0.131 (summer) \$0.1145 (fall, winter, spring)	\$0.17 (100%) \$0.25 (101%-400%) \$0.35 (>400%)	\$0.23-\$0.27 (130%) \$0.40-\$0.47 (101%-399%) \$0.46-\$0.55 (>400%)
EV Time of Use Rates (per kWh)	\$0.34-\$0.48 (peak) \$0.21-\$0.26 (partial-peak) \$0.13 (off-peak)	\$0.3704 (super peak) \$0.1481 (peak) \$0.0703 (off-peak)	\$0.16, \$0.36 (peak) \$0.17, \$0.14 (mid-peak) \$0.09, \$0.10 (off-peak)	\$0.24 (peak) \$0.09 (super off-peak) \$0.23 (off-peak)

The rate structure for a special electricity fee can be set at several different rates depending on the desired outcome. These include structuring the fee to be equivalent to: (1) the annual gasoline taxes paid for the average vehicle in California; (2) the SB1 \$100 annual registration fee; and (3) the gasoline tax that would be paid for a ZEV if it were using gasoline on an energy equivalence basis. For (1), cost parity with the average vehicle in California based on the average fuel efficiency in the state would result in a fee of about \$0.058/kWh. This pricing scheme sets a baseline for the average electric vehicle fee that would match the average gasoline vehicle fee, therefore creating a sustainable funding pool as more electric vehicles are adopted. However, more fuel-efficient gas vehicles pay less in gasoline taxes, but this benefit would not apply for electric vehicles despite their higher efficiency compared to conventional gasoline vehicles.

For (2), an alternative fee would be to match on average the fees paid with the existing SB1 $100 annual fee for electric vehicles, which would result in fees of about $0.028/kWh (though PHEVs would end up paying approximately $116 per year on average in California). This rate structure would be revenue neutral with the existing $100 annual registration fee but unfortunately would not achieve sustainable road infrastructure funding and would diminish the benefits of owning a vehicle that is more fuel efficient than a gasoline vehicle. The final option (3) could be set equal to the gasoline tax on the basis of energy equivalence (in other words, the same as gasoline would be charged on a miles per gallon equivalent basis). The rate is the lowest among the rate structure options at $0.015/kWh. This rate preserves the individual vehicle benefits of improved fuel efficiency relative to gasoline vehicles but does not address sustainability of funding options and in fact would be lower than the $100 annual registration fee in SB1 for ZEVs.

One final note of significance on any pricing scheme for electricity is the dichotomy between contributing to the funding of road infrastructure and the promotion of the technology and its adoption. PEV users enjoy a relatively lower operational cost because electricity prices (see Table 3) are typically lower than gasoline prices on a per mile basis. This gap is slightly diminished when adding additional fees. For perspective on relative costs per mile, assuming gasoline prices of $3.50/gallon, a Toyota Prius owner would pay the equivalent of $0.21/kWh, owners of popular sedans such as the Honda Civic or Toyota Camry would pay approximately $0.33/kWh, and the average California gasoline vehicle would pay about $0.43/kWh.

Implementation

The implementation of a different electricity price for a specific end-use is inherently difficult for a number of reasons. To levy a fee on electricity specifically being used to charge electric vehicles, an accurate accounting of this electricity would need to be conducted. This can either be measured from on-the-ground infrastructure or via instrumentation on the vehicle. Measurement of electricity usage for PEVs from charging infrastructure, or electric vehicle supply equipment (EVSE), could be conducted by having EVSEs each have separate meters Unfortunately, the cost of metering all EVSEs would far surpass the revenue that would be raised (smart meters cost on the order of several hundred dollars), not to mention the logistical costs associated with metering all home-based charging for PEV owners. Additionally, there is no way to avoid leakage: PEV owners could choose to plug-in their vehicles into an unmetered outlet which would not be measured, even if all homes and EVSE public services were separately metered.

On-vehicle measurement of electricity consumption is an alternative option for ascertaining the electricity consumption by the PEV. Electric vehicles are typically equipped with advanced telematics, often capable of cellular communication as well as GPS capabilities. It is possible to not only measure the amount of electricity used to charge the vehicle but to transmit the information to a party that would administer the fee. There is already a precedent for using telematics in order to integrate with the electric grid, as in the Open Vehicle Grid Integration Program (OVGIP) (a collaborative effort between the Electric Power Research Institute, major utilities, and automakers)[10] and in standardizing the output of on-board diagnostics (OBD)[11]. However, any plan to leverage these technologies should seriously consider issues of privacy, particularly with regard to location information (Iqbal & Lim, 2010; Karim, 2004; Hubaux, et al., 2004) and hacking the telematics systems (M.M-Saleh, 2016). The success of using telematics to assess fees will rely on whether the system can adequately protect the privacy of drivers.

The Low Carbon Fuel Standard (LCFS)[12] in California awards credits based on usage for different types of fuels. For electricity, the LCFS program has the same data requirements for electricity usage that would be necessary to levy a PEV-specific electricity charging fee. However, the LCFS program currently credits both electric vehicles that are and are not separately metered. While the electricity associated with separately metered charging events are captured with a relatively high degree of accuracy (as reported by utilities), non-separately metered residential charging is estimated by the California Air Resources Board rather than empirically obtained[13]. This method of measurement is sensible in the aggregate (as in the LCFS program) but would be problematic for assessing fees for individuals. This is particularly problematic for PEV owners who are assessed fees based on estimated driving that could include miles not driven. Nevertheless, leveraging LCFS for measurement leads to a compelling possibility of combining programs where fees for road infrastructure could be subtracted from LCFS credits rather than being charged to PEV owners. This eliminates the negative consequences of fees on adoption and instead decreases the credit awards from LCFS. Further study is warranted to understand whether this option would negatively affect PEV sales because the current credits from LCFS are used to promote adoption of PEVs.

5.1.2 Hydrogen fee

Rate Structure

Currently, hydrogen (H_2) can be purchased for $12 to $16 per kg, with most retail distribution in California at $14 per kg. At about 50 miles per kg of H_2, the cost per mile is approximately $0.27 (in comparison with gasoline vehicles at approximately $0.10 per mile on average). Similar to electricity, the fee can be set to meet several goals. If the fee were set to (1) match the average vehicle in California, this would amount to approximately $1.09 per kg of H_2. This pricing would create a sustainable fee to fund infrastructure but would be a higher fee than if the FCVs paid a gasoline tax based on equating the energy of hydrogen to gasoline. Alternatively, (2) a price of $0.52 per kg of H_2 would reflect, on average, fees equivalent to the annual $100 ZEV fee. Lastly,

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[10] https://www.epri.com/#/pages/product/3002008705/?lang=en-US
[11] https://www.arb.ca.gov/regact/2015/obdii2015/finalregorder2.pdf
[12] The Low Carbon Fuel Standard is a program administered by the California Air Resources Board with the purpose of reducing the carbon intensity of transportation fuels. The program works by awarding credits of a certain monetary worth for users that use transportation fuels with lower carbon intensity to conventional petroleum fuels such as gasoline or diesel. https://www.arb.ca.gov/fuels/lcfs/lcfs.htm
[13] https://www.arb.ca.gov/fuels/lcfs/lcfs_meetings/12022016discussionpaper_electricity.pdf

(3) a similar price of $0.45 per kg of H_2 would equal the fees that the average FCV would pay with the existing gasoline tax if hydrogen were equated to gasoline on an energy basis. Like the electricity-specific fueling fee, option 3 would confer benefits on the owner comparable to fuel efficiency savings with the gasoline tax but would not provide sustainable revenue for future infrastructure because the average FCV would pay substantially less than the average gasoline vehicle.

Implementation

Hydrogen fuel is similar to gasoline in some respects—use as a transportation fuel would likely dictate a stand-alone infrastructure for distribution purposes. One of the benefits of this is that hydrogen fuel fees could be collected within its distribution system, as is done with gasoline, but without the difficulties of assessing an electricity fee. Hydrogen is primarily produced from natural gas steam reformation, though electrolysis can be employed for cleaner generation of the fuel. Unfortunately, due to the early stage of the market for FCVs, it is currently unclear whether the future hydrogen economy will be centralized production (fuel is produced at a central facility and then transferred to stations via pipelines or trucking) or distributed production (fuel is produced on-site where FCVs fill their tanks). Expert elicitation has suggested that assessing the fee at the station level, as opposed to the production centers, will provide the most flexibility for accommodating different hydrogen infrastructure futures. If fees were designed to be administered at centralized production centers but production ended up being distributed, then the fees would need to be redesigned.

Fewer than 4,000 hydrogen fuel cell vehicles had been sold in California as of the end of June 2018, in comparison to over 400,000 PHEVs and BEVs. While the debate continues over the balance between incentivizing alternative fuel vehicles during the transition period versus charging their owners to fund road infrastructure, the current early-stage of market penetration for FCVs may warrant exemption from the SB1 ZEV annual registration fee (and other alternative fee mechanisms). At a minimum, FCVs should receive the same benefits that PEVs have enjoyed; then hydrogen fees could be implemented once FCVs have reached similar volumes to the current stock of PEVs in California.

Regarding alternative fuel fees in general, one of the drawbacks of this system is that a separate fee system would be required for every type of fuel. Even if the fee structure were similar in principle, the distribution system of the fuel/energy would require different revenue collection methods. For example, electricity is generated at a power plant and reaches its end destination through transmission and distribution grid infrastructure, whereas hydrogen is generated through steam reformation or electrolysis and then transferred to its end destination via pipeline or trucking. The only way to avoid a different system for each fuel would be to transfer administration of the fee to the vehicle level, which also offers many challenges.

5.2 Mileage fee (road charge)

A mileage fee, also commonly referred to as a road usage charge (RUC), is a fee assessed on the amount of travel rather than fuel consumption. This system already exists within the United

States: the Oregon Road Usage Charge Program[14] was launched on July 1, 2015 (Jones & Bock, 2017) and remains in place on a voluntary basis for drivers in the state. California initiated a pilot program[15] in compliance with SB1077[16] and Caltrans is continuing to explore pilot programs under the guidance of the RUC Technical Advisory Committee as specified in SB1328[17]. Additionally, the Western Road Usage Charge Consortium, also called the RUC West[18], is a coalition of 14 states that have either implemented (Oregon), are testing through pilot programs (California, Colorado, Hawaii, Washington, and Utah), or are conducting research on RUC programs (Arizona, Idaho, Montana, Nevada, New Mexico, North Dakota, Oklahoma, and Texas).

When the first gasoline tax was implemented in 1919, it acted primarily as a proxy for mileage fees since most vehicles had fairly similar fuel efficiencies (the fleet consisted mainly Cadillac Touring and Ford Model Ts). However, as a broader range of vehicles were introduced their fuel efficiency diversified, which meant that payment for the same travel distance would result in different fees for vehicles having different fuel efficiencies. This created a mechanism that aligned the gasoline tax to address externalities associated with vehicle efficiency (higher tax per mile for higher emissions rates). However, from the standpoint of infrastructure funding, the range of fuel efficiencies distorts the original intent of the tax because the cost of using the road is not closely correlated with the fuel efficiency of gasoline vehicles. Additionally, policies such as the national Corporate Average Fuel Economy standards and the California Clean Car Standards (AB 1493) require overall fleet efficiencies to improve, resulting in decreasing capacity of the gasoline tax to meet revenue targets (see Figure 6 for a projection in California).

Rate Structure

A rate structure to determine the necessary fee is relatively straightforward with a RUC because all drivers would pay the same rate. In order to structure a fee for a given revenue target, one would need to know the total travel demand in California (determining the optimal gasoline tax would also require knowledge of the overall fuel efficiency in the state). Revenue neutrality with the average California vehicle results in fees of approximately $0.015 per mile using a road charge mechanism (using identical assumptions as in Appendix, Section A2). This fee would apply uniformly across all miles, regardless of the efficiency of the vehicle. On average, more fuel-efficient vehicles would pay slightly more than what they would pay with a gasoline tax, while less efficient vehicles would pay lower fees on average compared with paying a gas tax, which has been demonstrated to be a generally less regressive policy than the current gasoline tax (as lower income drivers typically have less fuel efficient vehicles and have longer commutes) (Jones & Bock, 2017).

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[14] https://www.oregon.gov/ODOT/Programs/Pages/OReGO.aspx
[15] https://www.californiaroadchargepilot.com/
[16] https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201320140SB1077
[17] https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201720180SB1328
[18] https://www.rucwest.org/

Implementation

Implementation of a RUC program in California has already been pursued through pilot programs (as legislated in SB1077) and continues to be evaluated under the guidance of the RUC Technical Advisory Committee (as legislated by SB1328). Multi-state cooperative ventures in developing a road charge program is also being pursued through the RUC West program.

However, this report focused specifically on designing a road charge for ZEVs, which actually presents a unique opportunity for implementing a California RUC program. One of the drawbacks of the RUC program relative to the California gasoline tax is the relatively high cost of administration. In California, gas taxes are collected at the terminal when gasoline is removed at the central distribution hub[19]. Since the points of collection are few, the administrative costs associated with the gasoline tax are quite low, typically around 1% of the total revenue collected (Sorensen, et al., 2012). The cost of administering a road usage charge can be significantly higher. There are two potential sources of increased costs: it requires a system to facilitate the transition away from the gasoline tax (unless there is a total simultaneous switch to a RUC, program participants who drive petroleum powered vehicles will be paying both the gas tax and road user fee). For example, in Oregon's program the gasoline tax is assessed *in addition to* the voluntary RUC, and therefore users are credited at the gas station level (Jones & Bock, 2017). The other substantial contributor to cost is the hardware necessary for measuring vehicle miles traveled (VMT). The predominant device used in Oregon's current RUC program and California's pilot program is an on-board diagnostics (OBD) logging device with the ability to communicate information for assessing the user fees.

Rolling out a RUC program specific to ZEVs has a number of potential benefits that may ameliorate some of the issues outlined above. The RUC can be designed specifically to assess fees only on electric/hydrogen miles traveled, thus eliminating any crediting requirements needed to transition away from gasoline. This would simplify the program by avoiding double payments of both gasoline taxes and the RUC, since the fee would be assessed only for non-gasoline miles. The most difficult measurement would be from plug-in hybrid electric vehicles which run on both electricity and gasoline. Tracking miles operated on electricity for vehicles operating on blended mileage operation (where both electricity and gasoline are simultaneously used to drive the vehicle) cannot be tracked with traditional odometer readings but can be calculated based on the energy consumption of the battery.

The other potential for cost savings is to leverage advanced technologies being incorporated into new vehicles, particularly ZEVs, to replace some of the traditional hardware being used in RUC programs. Newer vehicles have telematic systems that are capable of both measuring mileage for the purposes of a RUC and communicating (through cellular connections) these measurements to the administrative entity of the RUC program. However, this would require efforts to standardize a protocol for measurement and communication for the RUC with automakers, which could likely be achieved through regulation/legislation. It should be noted,

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[19] CA Rev & Tax Code § 7362 (2016)

however, that other synergistic opportunities result from vehicle telematics for both implementation of the RUC and for other possible pricing mechanisms. Standardization and employment of vehicle telematics are currently being investigated, for example, in the Open Vehicle-Grid Integration Platform (OVGIP), a collaborative effort with the Electric Power Research Institute, utilities, and automakers (Chhaya, 2016). Also, as mentioned in Section 5.1.1, telematics might be employed by automakers to claim credits under the Low Carbon Fuel Standard, opening possibilities to leverage telematics for multiple programs.

The use of vehicle telematics enables a number of other pricing mechanisms. These include congestion, occupancy, and cordon pricing, to name a few. Developing an open-ended RUC program that would enable the rollout of other pricing mechanisms could facilitate their adoption. However, from a political standpoint, these pricing mechanisms may detract from the successful implementation of a RUC program.

6. Recommendations

The introduction of an annual registration fee exclusive for ZEVs, resulting from the passage of Senate Bill 1 in April 2017, follows attempts by nearly 20 other states to recover revenue from vehicles that do not pay a gasoline tax. However, it is our conclusion that these registration fees are flawed according to four key metrics:

1. Infrastructure will become drastically underfunded with the current registration fee combined with a long-term shift towards ZEVs. Specifically, assuming 5 million EVs in 2030, the current registration fee and gasoline tax would lead to a decrease in infrastructure funding by over $500 million annually.
2. The fee penalizes plug-in hybrid electric vehicles, which must pay both the registration fee and the current gasoline tax (for any gasoline consumed).
3. Owners of ZEVs would pay more under the registration fee compared to what they would equivalently pay with a gasoline tax (if electricity/hydrogen were converted to gasoline on an energy basis).
4. A flat $100 fee is disconnected from usage and the "user pays" principle; a ZEV owner would pay the same amount no matter how much they drive, directly in contrast with a gasoline tax which is based on usage.

The ZEV annual registration fee will adversely affect the adoption of the new vehicle technologies. Through both a survey and an econometric assessment of PEV sales, we found that there is an associated 10–20% decrease in sales attributable to the implementation of annual registration fees (though these are short-run estimates that may overestimate long-term effects). These effects should be considered in conjunction with California's goals of transitioning to ZEVs for the purposes of clean air and climate change mitigation.

We assessed several alternative funding mechanisms (see Section 5) that can be considered as replacements for the registration fee. Table 4 provides a summary of the gasoline tax, SB1 annual ZEV registration fee, and alternative mechanisms as judged by their ability meet funding requirements, responsiveness to inflation, revenue stability, administrative cost, ability to meet the "user pays" principle, and equity considerations. There are pros and cons to each of the alternative mechanisms, none are perfect, and each have a number of challenges.

Our analysis suggests that the best solution for creating a sustainable, robust funding system is a RUC program applied only to ZEVs (allowing the parallel gasoline tax to gradually atrophy and eventually disappear).

Table 4. Impact of transportation infrastructure funding mechanisms

= Very Poor = Poor = Fair = Good = Very Good

	Traditional gasoline tax	Annual ZEV registration fee	ZEV fuel tax	Road User Charge
Revenue meets funding requirements	SB1 has improved sustainability of funding.	Aligns neither with the gas tax nor with funding requirements.	Would address funding deficits from ZEV adoption.	Creates a long-term solution for efficiency improvements and ZEV adoption.
Responsiveness to inflation	Automatically adjusts with inflation	Automatically adjusted with inflation.	Can be designed to be adjusted to inflation.	Can be designed to be adjusted to inflation.
Revenue stability	Stability hindered by improvements in fuel efficiency and shifts towards ZEVs	$100 annual fee is significantly lower than the average CA vehicle, this will exacerbate with more ZEVs.	ZEV adoption solved. Fuel efficiency gains will continue to be problematic.	Robust to changes in efficiency and to adoption of ZEVs. Long-term VMT shifts could be problematic.
Administrative cost	Administrative costs are only 1% of revenue	Coupling this fee to the existing registration fees results in little added costs.	Metering usage of electricity to charge PEVs is likely prohibitively expensive.	Higher costs due to hardware and fee collection. Potential to lower costs exists (e.g., telematics).
User pays	Efficiency benefits address some externalities but detract from stable funding.	Decouples fees from usage of roads.	Identical to gasoline taxes for all alternative fuel vehicles.	Similar to gasoline taxes without variation in fuel efficiency.
Equity	Gas tax is relatively neutral as it closely aligns with "user pays" principle.	ZEV users would pay more than they would with the gas tax (based on energy content).	Identical to gasoline taxes for all alternative fuel vehicles.	Less regressive than the gasoline tax: lower income users tend to pay slightly less

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Appendix A: ZEV Fee Impacts

A1. ZEV Projections

Projections for future sales of ZEVs is based on a simple time-series regression-based model on the historical sale of BEVs and PHEVs in California[20,21]. The regression is specified as:

$$s_i = \alpha + \beta t_i + \varepsilon_i$$

Where *s* is the square-root of sales and *t* is the time index since PEVs were introduced to the market (*t*=1 for 2010). The structural form of the equation was chosen such that future predicted sales matched California's ZEV requirements and Governor Brown's goals as closely as possible. The 2025 prediction for cumulative PEVs sold was 1.64 million and the 2030 prediction for cumulative PEVs sold was 4.24 million.

Table A1. Regression on square-root of sales of PHEVs and BEVs in California from historical data

	PHEV Sales	BEV Sales
Time-Index	24.6**	26.6***
	(5.96)	(7.93)
Constant	48.7*	45.1*
	(2.635)	(3.00)
Adj R-square	0.852	0.912

t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

A2. Forecasting Revenue

Three scenarios of hypothetical per-vehicle revenue are calculated: How much the average Californian pays in gasoline taxes; how much the average BEV/PHEV would pay annually under SB1; and how much the average BEV/PHEV would pay if they operated on gasoline-energy equivalence (MPGe). The following calculations show the derivation of values seen in Figure 5.

[20] https://autoalliance.org/energy-environment/advanced-technology-vehicle-sales-dashboard/

[21] PEV sales are obtained from Clean Vehicle Rebate Program statistics at https://cleanvehiclerebate.org/eng/rebate-statistics

A2.1. California average per-vehicle revenue

The annual fees paid with the California gas tax for the average driver can be calculated as follows:

$$\left(\frac{v}{m^{\mathrm{MPG}}}\right)\cdot g$$

Where v represents the annual per-car vehicle miles traveled in California[22], m^{MPG} represents the average fuel efficiency in California[23], and g represents the nominal gasoline tax rate of $0.473/gallon in 2020.

A2.2. SB1 annual registration fee average per-vehicle revenue

The annual fees that would be paid by the average BEV and PHEV owners under SB1 can be calculated as follows:

$$R+\left(\frac{v\left(1-p_e\right)}{m^{\mathrm{MPG}}}\right)\cdot g$$

Where R represents the $100 annual registration fee, p_e represents the proportion of time that the vehicle spends in electric operation (for BEVs, p_e=1; for PHEVs, we approximate this value from empirical observations from studies at the Plug-in Hybrid & Electric Vehicle Center of the UC Davis Institute of Transportation Studies (Tal, et al., 2014): p_e=0.25 for PHEV10, p_e=0.5 for PHEV20, and p_e=0.75 for PHEV40), and m^{MPG} represents the sales-weighted fuel efficiency of the gasoline engine component of the PHEV[24]. In essence, BEVs would pay the $100 annual registration fee and PHEVs would pay this in addition to gas tax paid for any gasoline operation on the gasoline drivetrain of the vehicle.

A2.3. Energy equivalent (MPGe) average per-vehicle revenue

If electric vehicles were to pay the equivalent of gasoline vehicles under the current system as measured by the energy equivalent fuel efficiency, the average annual fees can be calculated as follows:

$$\left(\frac{vp_e}{m^{\mathrm{MPGe}}}+\frac{v\left(1-p_e\right)}{m^{\mathrm{MPG}}}\right)\cdot g$$

[22] https://www.fhwa.dot.gov/policyinformation/statistics/2016/vm1.cfm

[23] https://transweb.sjsu.edu/sites/default/files/1426-household-income-and-vehicle-fuel-economy-in-california.pdf

[24] Fuel efficiencies are obtained from www.fueleconomy.gov and PEV sales are obtained from Clean Vehicle Rebate Program statistics at https://cleanvehiclerebate.org/eng/rebate-statistics

Where m^{MPGe} is the sales-weighted miles-per gallon equivalent[25] when operating on an alternative fuel vehicle drivetrain, p_e represents the proportion of time that the vehicle spends in electric operation (see A2.2).

A2.4. Total revenue forecasts

The total revenue forecasts seen in Figure 6 are calculated based on scaling the equations in A2.1 and A2.2 by the projected sales of gasoline vehicles (based on current vehicle sales[26]) and the projected sales of zero-emission vehicles as projected in A1.

A3. Registration Fee Regression Approach

An econometric approach is used to estimate the effect of registration fees on the sales of plug-in electric vehicles (PEVs), both for BEVs and PHEVs. Sales are estimated as a function of registration fees, incentives for electric vehicles, and macroeconomic controls with fixed effects on vehicle type (BEV or PHEV), time periods (monthly), and region (by state). The form of the regression is as follows:

$$sales_{irt} = \beta R_{irt} + \delta I_{irt} + \pi M_{rt} + \alpha_i + \eta_r + \mu_t + \varepsilon_{irt}$$

Where i represents the set of fuel types, r represents the set of regions comprised of 50 states of the U.S., and t represents monthly time periods from January 2010 through June 2018. R represents registration fees for PHEVs and BEVs across all regions and time periods. Note that there are actually two different models: one examining the effect of registration fees when they are passed by the respective state legislature and one examining when they actually are implemented and take effect. I represents a vector of incentives associated with the purchase of a new BEV or PHEV including monetary incentives and carpool or high-occupancy vehicle (HOV) lane access, and M represents a vector of macroeconomic controls: gas prices, gross domestic product (GDP), and unemployment, which all vary by month and state. Lastly, α, η, and μ are fixed effects associated with technology type, regions, and time periods, respectively. The results of the model can be found below.

[25] https://www.fueleconomy.gov/

[26] https://www.cncda.org/wp-content/uploads/California-Covering-4Q-2017-1.pdf

Table A2: Regression on sales of PEVs as influenced by registration fees

	(1)	(2)
Registration Fee (passed, $)	-0.00238*	
	(-2.39)	
Registration Fee (implemented, $)		-0.00160
		(-1.20)
Tax credit ($)	0.0000377	0.0000431
	(1.08)	(1.18)
HOV Lane Access	0.253	0.252
	(0.65)	(0.63)
GDP (millions of $)	0.00000116	0.00000106
	(0.86)	(0.77)
Gas price ($/gal)	0.261***	0.258***
	(4.36)	(4.35)
Unemployment	-0.492***	-0.486***
	(-12.89)	(-12.65)
Constant	4.526***	4.515***
	(7.39)	(7.25)
Fixed Effects	Fuel Type, State, Month	Fuel Type, State, Month
Cluster	State	State
Adj R-square	0.457	0.455
N	8874	8874

t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

A4. Three Revolutions Forecast

The penetration of each of the three revolutions in Figure 7 are derived from a UC Davis report forecasting through scenario analysis the adoption of automated vehicles, electric vehicles, and shared mobility through 2050 (Fulton, et al., 2017). There are three scenarios under consideration: one revolution (1R), two revolutions (2R), and three revolutions (3R). The 1R scenario refers to automation alone; 2R, to automation plus electrification; and 3R, to a combination of automation, electrification, and shared mobility. Three potential solutions are investigated to alleviate the decrease in fuel taxes resulting from the 3Rs: a fuel tax plus EV registration fee, a RUC, and an energy equivalence fee. Regional data for the United States are extracted and scaled down to the California level based on the number of passenger vehicles in the state. Specifically, we use data on energy consumption of gas vehicles and electric vehicles, VMT of gas vehicles and electric vehicles, and the total number of electric vehicles.

The total revenue to maintain neutrality is determined as the sum of revenue from the fuel tax and EV registration fee. Each of the revolutions has significant impacts on revenues from the fuel tax and EV registration fee due to large shifts in VMT. For each of the scenarios in each year, a "Business as Usual (BAU) Equivalent Fuel Tax Rate" and a "BAU Equivalent EV Registration Fee Rate" are also calculated. The purpose is to examine how fuel tax rates and EV registration fees should be charged to keep the total revenues at the same level as in the base year. For equity, we assume fuel tax payers and EV registration payers make up the deficit of revenue due to revolution(s) according to their proportional contribution to the revenue if rates were the same as in the base year. For example, the "BAU Equivalent Fuel Tax Rate" and "BAU Equivalent EV Registration Fee Rate" of the 2R scenario for 2030 are calculated according to the following equations:

$$P_f = \frac{R_{f,0} + \frac{R_{f,0}}{R_{t,0}}\left(R_{t,b} - R_{t,0}\right)}{E}$$

Where P_f denotes the "BAU Equivalent Fuel Tax Rate" of this scenario, $R_{f,0}$ denotes the revenue from the fuel tax of scenario 2030 2R if rates were the same as in the base year, $R_{t,0}$ denotes the total revenue of scenario 2030 2R if rates were the same as in the base year, $R_{t,b}$ denotes total revenue in the base year, and E denotes total gallons of gasoline in scenario 2030 2R.

$$P_r = \frac{R_{r,0} + \frac{R_{f,0}}{R_{t,0}}\left(R_{t,b} - R_{t,0}\right)}{N}$$

Where P_r denotes the "BAU Equivalent EV Registration Fee" of scenario 2030 2R, $R_{r,0}$ denotes the revenue from the EV registration fee of scenario 2030 2R if rates were the same as in the base year, $R_{t,0}$ denotes total revenue of scenario 2030 2R if rates were the same as in the base year, $R_{t,b}$ denotes total revenue in the base year, and N denotes the total number of registered EV in scenario 2030 2R.

The 3 Revolutions will also have significant impacts on revenue from a RUC fee. For scenarios in each year, a "BAU Equivalent VMT Fee Rate" is also calculated. The purpose is to determine at what rate VMT fees should be charged to keep the total revenues at the same level as in the base year. For example, the "BAU Equivalent VMT Fee Rate" of 2R scenario for 2030 is calculated according to the following equation:

$$P_v = \frac{P_{v,b} R_b}{R_0}$$

Where P_v denotes the "BAU Equivalent VMT Fee Rate" of scenario 2030 2R, $P_{v,b}$ denotes the VMT fee rate in the base year, R_b denotes total revenue in the base year, and R_0 denotes total revenue of scenario 2030 2R if rates were the same as in the base year.

Energy-based fees charge motorists based on the amount of energy they consume by traveling based on an energy equivalence with gasoline. The energy content of each gallon of gasoline is assumed to be 1.32×10^8 J. The three revolutions will also have significant impacts on revenue from the energy-based fee for the same reasons that will cause shifts in overall VMT. For scenarios in each year, a "BAU Equivalent Energy-based Fee Rate" is calculated. The purpose is to determine what energy-based fee should be charged to keep the total revenues at the same level as in the base year. The "BAU Equivalent Energy-based Fee Rate" of the 2R scenario for 2030 is calculated according to the following equation:

$$P_e = \frac{P_{e,b} R_b}{R_0}$$

Where P_e denotes the "BAU Equivalent Energy-based Fee Rate" of scenario 2030 2R, $P_{e,b}$ denotes the energy-based fee rate in the base year, R_b denotes total revenue in the base year, and R_0 denotes total revenue of scenario 2030 2R if rates were the same as in the base year.

A5. Electricity Fee Calculations

The electricity fee rates are calculated in three different ways in Section 5.1.1: one to maintain revenue neutrality with the average California gas vehicle, one to maintain revenue neutrality with the current fee structure under SB1, and one to maintain neutrality with energy equivalence to current gasoline taxes. Revenue neutrality with the average California gas vehicle is estimated by converting the current gasoline tax to kWh using California's approximate average gasoline fuel efficiency and average electricity efficiency of PEVs:

$$\frac{\$0.473}{\text{gal}} \cdot \frac{1\ \text{gal}}{27\ \text{mi}} \cdot \frac{100\ \text{mi}}{30\ \text{kWh}} = \frac{\$0.058}{\text{kWh}}$$

Revenue neutrality with the SB1 annual registration fee is estimated by converting the fee to kWh by taking the approximate annual VMT and converting using the average electricity efficiency of PEVs:

$$\frac{\$100}{\text{yr}} \cdot \frac{1\ \text{yr}}{12000\ \text{mi}} \cdot \frac{100\ \text{mi}}{30\ \text{kWh}} = \frac{\$0.028}{\text{kWh}}$$

Revenue neutrality with the energy equivalence of gasoline is estimated by converting the current gasoline tax to kWh using the average miles per gallon equivalent of PEVs:

$$\frac{\$0.473}{\text{gal}} \cdot \frac{1\ \text{gal}}{108\ \text{mi}} \cdot \frac{100\ \text{mi}}{30\ \text{kWh}} = \frac{\$0.015}{\text{kWh}}$$

A6. Hydrogen fee calculations

The hydrogen fee rates are calculated in three different ways in Section 5.1.2: one to maintain revenue neutrality with the average California gasoline vehicle, one to maintain revenue neutrality with the current fee structure under SB1, and one to maintain neutrality with energy equivalence to current gasoline taxes. Revenue neutrality with the average California gasoline vehicle is estimated by converting the current gasoline tax to kg of H_2 using California's approximate average gasoline fuel efficiency and average efficiency of FCVs:

$$\frac{\$0.473}{\text{gal}} \cdot \frac{1\text{ gal}}{27\text{ mi}} \cdot \frac{312\text{ mi}}{5\text{ kg}} = \frac{\$1.09}{\text{kg}}$$

Revenue neutrality with the SB1 annual registration fee is estimated by converting the fee to kg of H_2 by taking the approximate annual VMT and converting using the average electricity efficiency of FCVs:

$$\frac{\$100}{\text{yr}} \cdot \frac{1\text{ yr}}{12000\text{ mi}} \cdot \frac{312\text{ mi}}{5\text{ kg}} = \frac{\$0.52}{\text{kg}}$$

Revenue neutrality with the energy equivalence of gasoline is estimated by converting the current gasoline tax to kg of H_2 using the average miles per gallon equivalent of FCVs:

$$\frac{\$0.473}{\text{gal}} \cdot \frac{1\text{ gal}}{66\text{ mi}} \cdot \frac{312\text{ mi}}{5\text{ kg}} = \frac{\$0.447}{\text{kg}}$$