Task 8: Final Report on Parameterized RUC Formulas

Prepared for:
Western Road Usage Charge Consortium (RUC West)

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EXECUTIVE SUMMARY

This project further explores the feasibility and appropriateness of a mileage-based user fee as an alternative to the gas tax. The specific purpose of the project is to evaluate factors that could be considered when setting a usage charge—to account for the complex makeup of statewide motor fleets and the diversity of driving behaviors and experiences for households—and investigate the feasibility of expanding the use of road usage charge architecture, infrastructure, and technologies into congestion pricing.

The researchers considered thirteen potential parameters for testing in the financial analysis work before choosing to focus on considerations of fuel type and fuel efficiency. These parameters were tested in a variety of formula structures including mileage exemptions, rate adjustments, and formulas combining these two strategies. In total, six formulas were tested in comparison to the current fuel excise tax and a flat per-mile charge. The six formulas are:

1. An initial mileage allowance of 2,000 miles per year for all vehicles;
2. An allowance of 2,000 miles per year for electric vehicles (EVs) and 1,000 miles per year for other non-gasoline vehicles including hybrids;
3. A 10 percent lower rate for non-gasoline vehicles including hybrids;
4. An allowance of 2,000 miles per year for the top 25 percent most fuel-efficient vehicles;
5. A 20 percent lower rate for the 33 percent most efficient vehicles and a 20 percent higher rate for the 33 percent least efficient vehicles; and
6. A combination of the allowances in Formula 2 and the rate adjustments from Formula 5.

Financial impacts were assessed for urban, mixed, and rural household categories. Results show that almost universally, under the seven formulas tested, households in urban tracts pay slightly more and households in mixed and rural tracts pay less when transitioning from an excise-based gas tax to a mileage-based road usage charge (RUC). However, the changes in either direction are small when computed in terms of the amounts of money involved. Nevertheless, the study identifies significant heterogeneity between census tracts within the types of geographic classifications examined (urban, mixed, and rural) as well as differences in impacts between states.

Formula impacts were also assessed based on changes experienced by owners of vehicles of different fuel types. Research found that adjusting for fuel efficiency through introduction of parameters reduces the difference between impacts in urban, mixed, and rural census tracts. Fuel efficiency allowances also reduce the differences in tax payments for any vehicle fuel type group compared with the fuel excise tax. More important, if based on annually adjusted efficiency quantiles, a parameterized RUC does not lead to revenue erosion over time. For now, fuel type parameters have relatively small impacts on RUC-based revenue systems because of low alternative fuel penetration in most states. This may or may not change rapidly over the coming years depending on the rate of integration of non-gas fueled vehicles into the passenger car fleet in each state.

For California, Oregon, and Utah, scenarios for providing a sustainable level of revenue were tested. Results showed that if the transition to a RUC includes collection of new revenue to support sustainable funding levels, the disparate impacts on households from different geographic areas may be increased.

This may depend more on the mix of vehicle fuel types than on household travel characteristics. However, the formulas have largely the same effects at the higher level of revenue and can help narrow the differences between costs of transition for urban and rural households if appropriate parameters are selected that account for characteristics of the vehicle mix and household travel patterns.

Another major objective of the research was to understand attitudes towards congestion pricing proposals that might be combined with road usage charges and the technological feasibility of combining these revenue mechanisms. Results showed that the majority of the public is not yet aware of RUC or other alternatives to the fuel excise tax but that they also lack knowledge about transportation funding more broadly. There is no evidence that the public conflates mileage-based fees with congestion pricing, in part because these two mechanisms are still foreign concepts to most people. Concerns surrounding RUC and congestion pricing tend to focus on issues of privacy, equity, and efficient administration. The existing literature indicates that familiarity, built over time through education, messaging, and direct participation, may increase public support and overcome concerns. Overall it is very important that pricing proposals be accompanied by clear explanations of the need for a change and expected benefits to the community. People also need to contextualize fees in a meaningful way. Therefore, comparisons to existing and familiar fees, such as gas tax costs, can improve understanding.

In terms of technological feasibility, we found that there are several different packages of technologies that could enable integration of congestion charging and road usage charging. However, those technologies that would facilitate congestion charging do not include some of the mileage reporting methods being offered to pilot and permanent program participants in order satisfy privacy concerns. Future congestion pricing implementation requires systems be designed to include technology in the near term even if it is not used immediately. Adding technology required for congestion pricing will be much more difficult in the future if it is not designed side-by-side with RUC systems now.

INTRODUCTION

This project explores the feasibility and appropriateness of a mileage-based user fee as an alternative to the gas tax. It goes beyond examination of a flat charge per mile traveled across all vehicle types to consider other characteristics of the statewide motor fleets and the diversity of driving behaviors and experiences for households. It especially considers how vehicles of different fuel types and fuel efficiencies might be addressed by a road usage charge as well as whether it is technologically or politically feasible to integrate tolling and congestion charging capability into a road usage charge.

A road usage charge could be collected to address two types of costs: those borne by the agency to construct, maintain, and operate transportation facilities; and those borne by society that are not internalized by road users. The simplest formulation of a road usage charge is a constant mileage-based fee, under which each covered vehicle is charged a fixed rate for each mile of travel. However, both agency and external costs of road use vary based on other underlying factors meaning that approaches beyond flat rates merit consideration. It is these factors that are captured by the parameters considered in this study.

This report begins with an assessment of the potential parameters that a road usage charge (RUC) might consider and the selection of two first-level parameters. Methods are discussed for parameterizing RUC rate formulas. The selected formulas for testing and the methods for analysis are briefly presented.

As part of the analysis for this study, the impacts of the simple fee as well as fees with additional parameters will be considered at two levels: 1) revenue-neutral relative to the current fuel tax and 2) sustainable relative to each state’s transportation needs. The analysis will focus on impacts at the time of implementation. To address long-term sustainability issues, a constant fee and any variations of it could be indexed to an inflation measure so that their purchasing power is not eroded over time by price changes. The study is also focused only on private household vehicles. Revenue-neutral applications of the formulas are also tabulated for different vehicle fuel types in each state.

The formulas tested in the financial analysis do not include parameters for addressing tolls or congestion. Data availability and compatibility with the modeling framework are considerably more limited, thereby limiting the appropriateness of addressing this topic through the financial analysis tasks. While this modeling is based on household behavior, it does not identify specific travel patterns, which would likely be necessary to track household spending on tolls. Tolling data does not exist in a consistent manner across states, a major consideration for choosing data sources for this analysis. Instead this report provides a summary of attitudinal research on road usage charges and congestion fees and a high-level technical assessment of the available technologies for implementing related policies.

SELECTION OF PARAMETERS

This section reviews 13 types of parameters that might be considered when calculating RUC rates. The 13 parameter types are assigned to two levels: first-level parameters and second-level parameters. These lists were reviewed with the Project Advisory Committee to determine which parameters would be tested in the later stages of the project. The types of parameters can be further grouped into four categories of parameters based on vehicle characteristics, owner characteristics, travel location, and vehicle use levels.

First-level parameters include those that may be considered, in conjunction with a mileage-based charge, to address perceived fairness and equity concerns related to social costs (externalities of vehicular travel). These first-level parameters cover factors that rate design could relatively easily address while still encouraging vehicle operating efficiencies that a simple per-mile charge would not. These factors are the most feasible, both technologically and politically.

Second-level parameters provide specific policy, equity, or externality adjustment opportunities. However, issues of technological feasibility, political or legal barriers, privacy concerns, and administrative or implementation complexity have been raised with these second-level parameters.

FIRST-LEVEL PARAMETERS

First-level parameters have a higher likelihood of being incorporated into a formula. These are the factors which are most feasible, both technologically and politically, and which are likely to affect aspects of a RUC rate that influence perceptions of fairness and equity.

The first-level list focuses on vehicle-related parameters. These parameters minimize the need to collect additional household or travel behavior information about the driver. Readily-available parameters maximize the technical and political feasibility of a rate structure by relying on data that may already be collected for registration purposes.

These parameters will likely lead to consensus among the states participating in the RUC West consortium. To address cross-border traffic between states, it may be important to consider implementing mileage-based formulas that have similar structures, data needs, and parameters across neighboring states.

VEHICLE: FUEL EFFICIENCY

One of the major motivations for replacing the gasoline tax with a RUC is that increasing fuel efficiency is slowly eroding revenue receipts from the gas tax. The average efficiency of the in-use vehicle fleet is increasing, largely because newer vehicles are more efficient than previous models. In addition, there is also a wider range of fuel efficiencies available within the new vehicle market. Under the current tax structure, the fuel taxes paid by one vehicle could be several times those of another vehicle. Some observers consider this payment disparity unfair. However, apart from the effect on agency revenues, increasing average fuel efficiency is probably beneficial to society. Still, some agencies might consider it desirable to provide an explicit incentive to high-efficiency vehicle ownership, while eliminating the possibility of very large disparities between tax payments when owners' use patterns are similar.

Incentivizing fuel efficiency could be desirable for some agencies because environmental externalities associated with fuel consumption make up a meaningful portion of the external cost of travel. There are additional long-term benefits of a more fuel-efficient vehicle fleet, including increased energy independence and reduced household operating costs. Greenhouse gas emissions are the environmental externality most closely tied with fuel efficiency. However, local pollutants that cause smog, acid rain, and other impacts on public health and the environment are also produced in greater quantities by inefficient vehicles. These pollutants raise health care costs and impose other burdens on public and private actors, and consequently might be worth addressing through the RUC rate structure.

On the other hand, some may argue that fuel economy is already strongly incentivized by the inherent need for fuel-inefficient vehicle owners to purchase more gasoline. These people may view fairness through the lens of ensuring that everyone pays the same amount of road tax per mile driven since passenger vehicles of all efficiencies contribute equally to road maintenance and capacity needs.

Providing a price signal in the RUC could internalize the cost of emissions for households and may also provide an incentive to vehicle manufacturers to continue to improve efficiency for all classes of vehicles. Households could still pick the vehicle most suitable for their travel requirements and preferences, but rates would be adjusted to capture the per-mile external costs. The gas tax is not explicitly designed to address external costs of fuel consumption, but the net result of the current gas tax system more closely serves this purpose than its original conception as a use tax proxy (which has been eroded due to efficiency gains, as described above).

A RUC rate incorporating measures of fuel efficiency could eliminate revenue erosion, while still incentivizing the purchase of efficient vehicles by setting variable rates based on relative efficiency. For example, the most efficient third of vehicles could be charged 0.9 cents per mile, the next third could pay 1.0 cents per mile, and the least efficient vehicles could pay 1.1 cents per mile. All vehicles could be categorized each year, to adjust for new registrations filed during the previous year.

VEHICLE: FUEL TYPE

States might wish to consider alternative fuels in their RUC rate structures to better address electric cars and others not captured by the gasoline tax. When alternative fuel use is not captured in a state's fuel tax structures, it provides an implicit subsidy for those fuels. Some states may also choose to provide an explicit subsidy through differential RUC rates. Some states currently incentivize alternative fuel vehicle purchases through tax credits at the time of purchase. These policies could be maintained or subsumed within a RUC rate structure.

Policymakers might consider a diverse mix of fuels across the fleet desirable or undesirable for several reasons. Alternative fuels and alternative engine types have different emissions profiles associated with them than gasoline vehicles, both in terms of toxic pollutants and greenhouse gases. Alternative fuel penetration in the vehicle fleet also might be desirable to provide resiliency against price fluctuations in the petroleum markets, or to support domestic energy markets or other automotive industries. Subsidizing alternative fuel technology could also be seen simply as an incentive for additional innovation and competition. A fuel type parameter could also account for lower noise levels from certain engine types, another reasonably significant external cost of travel.

In cases where alternate-fueled vehicles are typically preferable to gasoline vehicles they can be incentivized with a RUC rate structure that is lower than the standard RUC rate; and where they are less efficient their rates could be marginally more under a RUC. A fuel type parameter would be much easier to forecast, track, and adjust in a RUC rate structure than currently under the gasoline tax or other fuel taxes.

Second-Level Parameters

These parameters have been considered but may not be feasible to include in a RUC-based formula. Although many of these second-level parameters may provide tools to address equity or fairness perceptions, they typically require more complex measurement, data collection, or policy considerations.

The major limiting factors for second-level parameters are: 1) limited marginal ability to affect the equity issue they are perceived to address, 2) high probability of privacy concerns, and/or 3) data management and advanced technology requirements. These second-level parameters add complexity to rate formulation and management and could decrease the ability to predict long-term revenue potential even as they may help to address socioeconomic, technological, and geographic changes. Parameters should provide recognizable benefits to be worth implementing, even if they address high-level policy goals.

Second level parameters are organized by four different dimensions: owner, tied to characteristics of the vehicle owner such as place of residence and household income; vehicle, tied to the characteristics of the vehicle such as emissions, age, and weight; location, tied to where the vehicle is operated such as on tolled highways, in congested areas, or on a specific class of highway; and use, tied to the intensity of vehicle use.

Owner: Place of Residence

One of the most common concerns among the public regarding road usage charges continues to be the idea that rural households will be adversely impacted. Previous research (including the *RUC West Financial Impacts Study*) found that rural drivers do indeed take longer trips. However, this tendency is balanced by findings that rural households travel less frequently and have older and less fuel-efficient vehicles. Thus, the average rural driver sees slight benefits from shifting to a RUC. In a revenue-neutral implementation relative to the current fuel tax, urban drivers would see relatively small increases in payments compared to expenditures under the current gas tax system (less than one percent increase) because there are more urban drivers amongst which to spread the increase.

Including a place of residence parameter to eliminate any shift in payments does not provide enough value for the complexity it would add. The average difference between urban and rural areas is quite small, and in many cases the variation within locations, whether census tracts, counties, or some other geographic entity, is larger than the variation between location types.

Tracking place of residence, rather than solely vehicle and use characteristics, also raises a potential privacy concern that would need to be addressed by policymakers. Although registrations already require mailing address information, explicitly tying specific addresses to vehicle use taxes could call attention to how registration data is used. Additionally, registration addresses may be given as a P.O. box or an alternative address not tied to residential location, which would have to be addressed by any system implementing this parameter, possibly by charging those choosing to register at P.O. boxes the highest rate among residential location classifications.

Owner: Household Income

Lower-income households tend to spend a greater percentage of income on transportation, and hence gasoline taxes and road usage charges can be regressive relative to income. This could be addressed by structuring rates such that lower-income households either pay less per mile or receive a rebate or other financial offset (e.g., tax credit) that could have income equity benefits.

Parameters addressing income as part of a road usage charge are likely to be a relatively inefficient mechanism for addressing income equity since transportation fees that are proportional to the current gas tax are a relatively small portion of the total costs of transportation born by individual users. Including a progressive rate structure could be politically sensitive in many states, and the additional information requirements increase the data needed to implement the RUC. Very few state departments of transportation or departments of motor vehicles today maintain accurate income records of vehicle owners. Maintaining this information would likely require integration with state tax administration departments and may receive pushback from members of the public that don't want their income data shared with additional government agencies.

Vehicle: Weight

Recent studies by McMullen et al (2008), Merriss (2004), and Johnson (2005) conclude that the difference in pavement damage from passenger vehicles with different weights is inconsequential. Most design standards at the state or municipal level do not even consider light vehicles (typically those less than 10,000 pounds) when planning facilities (Moser 2011; Johnson 2005). States that conduct highway cost allocation studies have treated all passenger vehicles as a single increment with limited pavement damage being considered (ECONorthwest 2016).

This is because both the large SUV and the midsized car cause negligible pavement damage compared with heavier commercial vehicles. The Equivalent Single Axle Load (ESAL) system developed by AASHTO is standardized to a 18,000-pound axle-load – typical of a semi-tractor-trailer combo.[1] This configuration usually has five axles each resulting in 9,000 to 10,000 times the damage compared to each of a midsized car's two axles. For a road with ten percent heavy-commercial truck traffic, passenger cars cause less than one percent of pavement damage.

The largest SUVs typically have curb weights below 6,000 pounds. Even trucks such as the Ford F-350, which would more commonly be used for commercial purposes, do not exceed 7,000 pounds unloaded. Although the amount of pavement damage caused by these light trucks and SUVs is 10-15 times greater than an average midsize car (with a curb weight of about 3,500 pounds), pavement damage produced by either of these vehicle types are negligible based on the fourth-power rule-of-thumb for ESAL calculations. Although their relative values may be different by an order of magnitude, the actual effect on pavement damage is quite small.

Based on this information, the portion of highway costs based on passenger vehicle use that is attributable to pavement damage is very small. It would not be meaningful to adjust a small percentage of a usage fee by a multiple of 15, and would add administrative complexity, could confuse drivers, and could decrease

[1] 1993 AASHTO Design Guide, Part III, Chapter 5, Paragraph 5.2.3

public acceptance of a RUC. Large pick-up trucks that are being loaded to their gross vehicle weight rating levels are either being used infrequently in this manner or may be otherwise covered by commercial vehicle fee structures that are not being examined for this research.

Vehicle: Age

Older vehicles typically produce more environmental impact (through higher emissions) than comparable newer vehicles. Vehicle model year data that is already collected through the registration process could provide a relatively efficient instrument for adjusting a RUC rate to account for this externality. Older vehicles likely also impose more noise costs on average than newer vehicles. However, both factors are very indirect measurements, which are unlikely to be judged sufficient to overcome the negative factors related to an age parameter. The main concern with including an age parameter in RUC rates is that rural and low-income households have been shown to own older vehicles on average, hence possibly creating a significant equity concern for a slight benefit.

Vehicle: Emissions

Emissions of toxic air pollutants are among the most agreed upon negative effects of vehicle travel and are slightly less location dependent than noise or congestion externalities. Vehicles could be charged variable rates based on their emissions rating as issued at time of manufacture, or emissions could be directly measured each year at emissions testing sites. Emissions levels for cars are highly correlated with vehicle age, both because older vehicles were manufactured when emission standards were less restrictive and because as a vehicle ages its emissions production tends to increase. As discussed above, vehicle-age-based measures are likely to decrease equity more than they increase fairness. However, states that currently provide incentives for low-emission vehicles could consider delivering those incentives through a RUC rate structure.

Location: Tolled Facilities

Some states considering road usage charges may have facilities that are tolled at a rate sufficient to cover the construction, and/or operation and maintenance of those toll facilities. If these tolled facilities are completely self-supporting at present, with no gas tax revenue being used, a future RUC rate could consider excluding any miles traveled on them from RUC charges. Under the current gas tax structure, travelers on tolled facilities may be paying more than the true agency cost of their travel on the tolled facility. Rebating tolls (under annual or period payment methods) or excluding those miles from consideration (under GPS-based collection of a RUC) may make travelers more amenable to future toll projects that provide dedicated revenue for facility financing using public-private partnerships by eliminating the “double taxation” argument.

However, a RUC rate that offsets toll fees raises a privacy and data management barrier that would have to be overcome. Requiring all mileage recording to be GPS-based to directly account for tolled miles, so that the RUC administrator could determine what travel was tolled, would likely be politically untenable in many locations. Non-location-based payment and rebate methods would likely need to be developed, especially for those who cannot provide proof of the distances and frequency of their tolled travel, thereby forfeiting the rebate. If states have a single toll collector, or a clearinghouse for multiple collectors, this entity could report toll payments annually or periodically to the administrator of a RUC.

This would probably only be an option for toll authorities that are all cashless, or that record vehicle information even when payments are made with cash.

Location: HOT/HOV Lanes

Travel in HOT lanes, HOV lanes, and on similar facilities would probably not make sense as an exclusion or rebate parameter for a road usage charge because those travelers are paying mostly for travel time and reliability savings and not for the existence of the facility itself either in terms of construction, maintenance, or operations (even if the revenue is used for these purposes). While HOV lanes may address a congestion externality, HOT lanes largely shift that externality to the non-tolled lanes. If a RUC was designed to address congestion externalities, that might be a reason to rebate HOV travel. There is limited justification for using a RUC to return HOT revenue to travelers.

Identifying travel in dedicated lanes would likely require high-resolution GPS and time-of-day data to be collected about travelers. Privacy concerns arise in these situations. If a central toll authority clearinghouse collects standard tolls and HOT fees, privacy safeguards may need to be developed to limit how vehicle information is reported to the RUC collector.

Location: Other

There are several additional situations in which varying rates based on location of travel could improve some aspect of fairness or equity. For example, charging differential rates based on the type of facility could make sense if the costs of maintenance and, optionally, the costs of future replacement were judged to differ meaningfully across functional classes of roads or locations.

Costs could be adjusted based on the urban and rural locations (as defined by the location of the facility rather than a households' place of residence discussed above), differential construction costs, as an adjustment for higher external costs, or for different pavement types (e.g. paved or unpaved). Ricardo-AEA (2011) finds all major external costs are higher in urban areas, including crashes, noise, congestion, air pollution, climate change, and vehicle lifecycle cost externalities. Because of the greater portion of urban traffic traveling under stop-and-go conditions, fuel and engine efficiency are lower, increasing emissions of greenhouse gasses and local pollutants.

Rather than just differentiating by facility type, RUC rates could be structured to account for travel conditions on a facility. The cost of congestion is often higher than the other external costs of travel, and in some cases, may be greater than the infrastructure costs of a facility. Capturing travel in congested conditions could be done in-vehicle, through communication between the vehicle and local infrastructure, or at a central processing center.

Facility information, or general location within an area, could be combined with variable rates by time of day for a slightly less accurate and up-to-date fee for travel on facilities or in areas that are highly congested.

As with many of the previously discussed parameters, tracking information on facility type, location of driving, and time of day could raise very significant privacy concerns from travelers who do not wish to have their trip-making behavior examined. Collecting this type of information would be difficult without GPS location data being communicated to central servers that record travel totals for later billing. Doing all billing calculations in-vehicle could require a significant amount of technology to be installed. Either of these solutions have the potential to significantly increase the agency's administrative complexity and costs. Agencies could elect to offer drivers who opt into GPS-based systems some lower cost options while allowing those with privacy concerns to pay a higher constant rate. However, this would also increase administrative complexity and could be seen as inequitable by drivers.

USE: INITIAL MILEAGE ALLOWANCE

Allowing all drivers to travel a fixed number of miles before they start paying a road usage fee could be considered. Annual vehicle mileage traveled is loosely correlated with household income and consequently allowing the first 3,000 miles to be free could make a RUC slightly more progressive. Prior studies have estimated that high income households that live on the urban fringe travel the most per year (Economic Development Research Group, Inc. (2017) and Weatherford (2017)). Mileage allowance could also be administered as a monthly quantity, depending on the collection mechanisms used, to smooth transportation costs.

A minimum mileage allowance would be technically and administratively feasible and should not raise privacy concerns any more than the base RUC structure. However, it seems likely to raise questions about the relevant definitions of fairness and equity for a road usage charge program. Providing a right to some level of travel may be strongly supported by some groups, while others may feel like it is a divergence from a "user pays" principle. It is difficult to establish the threshold for the allowance before RUC payments begin.

USE: MILEAGE BRACKETS

Graduated payment rates, which rise as certain thresholds are crossed, could be an alternative to a single mileage allowance cut-off. For example, the first 5,000 miles could cost 0.8 cents per mile, the second 5,000 could cost one cent per mile, and all miles over 10,000 could cost 1.2 cents per mile. This should be relatively feasible to implement and is a familiar structure when compared to other progressive tax and fee regimes.

USE: MAXIMUM MILEAGE BILLING

Another proposal has been to not charge for mileage over a certain threshold, such as 25,000 miles per year, to prevent placing a very high burden on travelers that may not have flexibility to travel less per year. This proposal does not appear to have a strong enough fairness or equity justification, especially if travel is for work purposes (e.g., sales persons), which should be tax-deductible as business expenses. If travel is for personal or commuting purposes, there also does not seem to be any reason why high mileage travelers should not have to pay for each mile like others. Additionally, this structure could add year-to-year data tracking complexity, especially under collection strategies that rely on odometer readings and in the cases of mid-year car sales.

PARAMETERIZING RUC RATE FORMULAS

The development of parameterized formulas for RUC rates builds on the analysis of potential parameters presented in the previous section. The goal of adding parameters is to assess the effects of alternate RUC factors for agencies that want to incentivize certain behaviors by manipulating what would otherwise be a flat RUC rate replacement of the per gallon fuel tax. The subsequent financial analysis sections of this report present results from analyses of formulas that add these parameters on top of the computation of the flat RUC rate.

The first-level parameters recommended in the previous chapter were vehicle fuel efficiency and vehicle fuel type. The prior section discusses why these first-tier parameters were considered, and how they affect perceptions of fairness. The previous section also explained why second-tier parameters that were initially considered were not considered further.

Adjustments to rate formulas included to affect perceptions of fairness must be weighed against the increasing complexity of operating a system to monitor and administer these more complex formulas. Selected parameters and any other adjustments to a RUC must maintain an acceptable level of complexity, in terms of both data needs and administrative burden. Adding complexity makes a RUC more difficult to explain to the public – which even the limited attitudinal research currently available shows is one of the greatest barriers to acceptance.

One way to address complexity is to apply parameters based on limited, yet easy to explain rules. For fuel types, this will require determining a manageable level of detail and differentiation between different energy sources. For fuel efficiency, or parameters with many potential values like weight, this means splitting the fleet into a limited number of discrete groups, perhaps as few as two or three. An additional benefit of this “rules-based” approach is that it is much more resistant to deterioration in revenue generation as the fleet changes over time (sometimes in unexpected ways). Deterioration of the gas tax due to changing fuel efficiency is one of the largest motivations for a transition to a RUC. RUC formulas should be based on parameters that follow easily interpreted rules whenever possible.

The most basic RUC applies a fixed rate to the total annual miles traveled by a vehicle. For example, this can be expressed for a constant 1.5 cent per mile rate and a vehicle driven 10,000 miles per year as shown in Formula Structure 1.

Formula Structure 1

*Total RUC Payment = Annual Miles * RUC Rate*
*= 10,000 miles * 1.5 cents per mile*
= $150

There are two major mechanisms to apply parameters for a RUC: mileage adjustments and rate adjustments. An example of how a mileage adjustment could be applied is shown in Formula Structure 2. Mileage adjustments will most likely take the form of exemptions for a certain number of miles annually.

Formula Structure 2

*Total RUC Payment = (Annual Miles + Parameter Adjustments) * RUC Rate*
*= (10,000 – 2,000) miles * 1.5 cents per mile*
= $120

Mileage adjustments can provide incentives to drivers for meeting a parameter threshold. They will reduce the RUC equally for a vehicle that is driven 8,000 miles per year and one that is driven 15,000 miles per year. The value of a 2,000-mile exemption to a 1.5 cent RUC rate is $30 dollars for both vehicles. This makes the revenue effects of a mileage adjustment predictable for the agency and simplifies calculation of the base rate necessary to achieve a certain level of revenue. On the other hand, when and how exemptions are applied could affect agency cash flow and administrative costs. If all vehicles' adjustments are applied during the same period of the year, revenue streams could be highly irregular throughout the year, but the administrative burden of tracking which vehicles have had their mileage adjustments fully applied would be reduced. Possible solutions include releasing adjustment credits as smaller numbers of miles per month or providing them as rebates rather than exemptions.

Because a RUC is tracked by vehicle rather than by vehicle owner, there are a few other possible concerns with mileage adjustments. Depending on how and when adjustments are applied, new car purchases and changes in vehicle ownership could create administrative complexity. Additionally, drivers that own two vehicles would receive twice the level of mileage adjustment as a driver that owns a single vehicle, even if the total miles driven by these individuals was the same. Mileage adjustments could include penalties as well as exemptions, but this would raise a further issue about how to administer the charge. If payments are made based on a single annual odometer reading, there would be no issue. If mileage is billed electronically and more frequently, policies and procedures would need to be developed for applying penalties as well as adjustments.

The second mechanism for implementation of a RUC parameter is a rate adjustment. In the following example, a vehicle that traveled 10,000 miles per year is charged a base rate of 1.5 cents per mile but receives a 20 percent reduction, resulting in an effective rate of 1.2 cents per mile.

Formula Structure 3

*Total RUC Payment = Annual Miles * (Base Rate + Parameter Adjustments)*
*= 10,000 miles * (1.5 – (Base Rate * 20%)) cents per mile*
*= 10,000 miles * (1.5 – 0.3) cents per mile*
= $120

Rate adjustments could also be used to assess a premium that adds to the base rate. Rate adjustments avoid some of the administrative challenges of mileage exemptions, since every marginal mile is affected. However, revenue streams may be slightly more difficult to predict than with a fixed value of a mileage adjustment. Depending on the level of the base and effective charges, driver behavior could change and affect revenue collection.

Rate adjustments affect perceptions of fairness on a mileage basis rather than on a vehicle basis. Depending on the parameter, it may be unclear which basis for adjustment is a preferable means to implement parameters. The savings from a 10 percent discount for a vehicle used 15,000 miles per year are twice that of a vehicle used 7,500 miles per year. Because of their consistency, rate adjustments may have more effect on driver behavior.

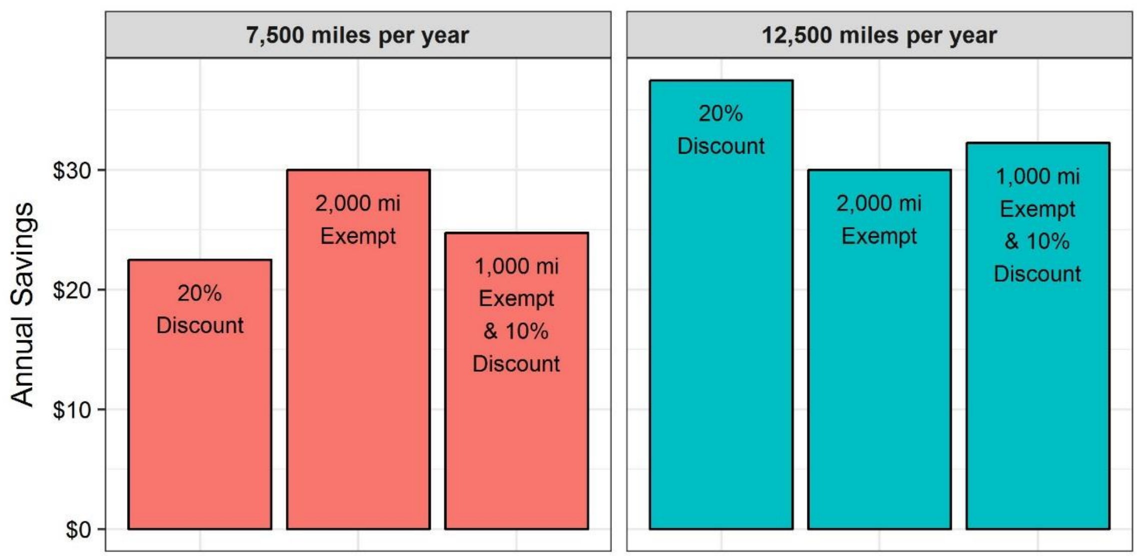
Additionally, mileage adjustments and rate adjustments could be combined in a single rate formula, an example of which is given in Formula Structure 4. Use of both adjustment types may best capture different parameters from a fairness perspective, but it introduces the challenges of both structures to administration of the formula and increases in calculation complexity.

Formula Structure 4

*Total RUC Payment = (Annual Miles + Parameter Adjustments) * (Base Rate + Parameter Adjustments)*
*= (10,000 – 1,000) miles * (1.5 - 0.1) cents per mile*
= $126

Figure 1 shows the impact of a parameter adjustment for vehicles driving different annual distances if it is implemented as an exemption or a rate adjustment. For a 1.5-cent charge, the mileage exemption is worth $30 to the users of both vehicles, but this represents a very different portion of their total annual payment. The 20 percent discount on the other hand has different monetary values. Figure 1 further shows how a formula that applies parameters using mileage and rate adjustments could be evaluated compared to formulas using a single adjustment type. For these two example vehicles to save money, other vehicles would have to pay a greater charge for the state to collect the same amount of revenue.

Figure 1. Comparing Savings from Different Formula Structures and Annual Mileages.



Overview of the Financial Analysis Process

This section briefly describes the various components of the financial analysis process. The analysis builds on the work described in the Final Report for the RUC West Project *Financial Impacts of Road Usage Charges on Urban and Rural Households* (Economic Development Research Group, Inc. (2010)). The detailed methodology for that project can be found in Appendix A (data preparation) and Appendix B (formula analysis).

The financial analysis brings together data from several sources to provide insight into how households in different parts of a state are likely to be affected by transitioning from the current fuel excise tax regime to a RUC regime. Analyses of diesel-fueled and commercial vehicles were not included in this study.

Households were chosen as the unit of analysis for this work because they are the entity that has a financial interest in how much they pay in transportation fees. Other studies utilize vehicles as the unit of analysis because of the direct relationship to vehicle characteristics and the availability of mileage information at the vehicle level. However, vehicles may have varying relationships to drivers and households. By focusing on household travel behavior, we do not rely on mileage information for every single vehicle in a state.

Formulas Tested

In collaboration with the Project Advisory Committee, a total of six parameterized formulas were chosen for evaluation to understand the effects of different definitions of mileage-based user fee formulas and the effects of different sets of parameters. The goal of this evaluation is to test the sensitivity of financial impacts to the selected parameters and formula structure.

The six parameter formulas are:

1. An initial mileage allowance of 2,000 miles per year for all vehicles;
2. An allowance of 2,000 miles per year for EVs and 1,000 miles per year for other non-gasoline vehicles including hybrids;
3. A 10 percent lower rate for non-gasoline vehicles including hybrids;
4. An allowance of 2,000 miles per year for the top 25 percent most fuel-efficient vehicles;
5. A 20 percent lower rate for the 33 percent most efficient vehicles and a 20 percent higher rate for the 33 percent least efficient vehicle; and
6. A combination of the allowances in Formula 2 and the rate adjustments from Formula 5.

The first alternative formula does not use the first-tier parameters identified in previous sections. It is meant to be the most general formulation to help understand the effects of tiered mileage rates and mileage adjustments generally.

The main analysis is constructed so that the RUC will collect an annual level of revenue equal to that currently received from households under the fuel excise taxes charged in each participating state. In addition to identification of impacts on the three geographic classifications of households (urban, rural, and mixed), impacts of replacing the fuel excise tax with each of the revenue-neutral parameterized RUC formulas are tabulated and discussed in terms of their impacts on vehicles of different fuel types. Three states also requested an assessment of a second, higher level of RUC-generated revenue with the objective of providing a more sustainable level of funding than available from their current gas tax. All formulas to be tested will be compared to a revenue-neutral flat RUC rate.

Household Classification

The first key analysis component is classification of census tracts as urban, mixed, or rural. These classifications form the basis for many of the key tabulations of results for the financial analysis. The census tract geography was chosen after observing that within a single county there can be wide variation in travel behavior. Classification is based on the Rural Urban Commuting Area codes from the US Department of Agriculture's Economic Research Service.[2] Households in urban tracts primarily commute within dense urban areas. Households in mixed tracts travel to dense urban areas. And rural tracts are those without tight employment ties to urban areas.

Household Travel Estimates

The next key step in the analysis is estimating how much households in each of these tracts travel. Work done by the Bureau of Transportation Statistics using the National Household Transportation Survey informs this step. Based on the 2009 NHTS, regression coefficients were estimated for the urban, suburban, and rural tracts of each census division. More recent socioeconomic data from the American Community Survey[3] was used along with these equations to estimate daily travel for the average household in each census tract.

Vehicle Fleet Characteristics

Data from each state's vehicle registration database is used to determine the fuel types present in each census tract and the average fuel efficiency for vehicles of each type by census tract.[4] This process usually involves decoding VINs using the National Highway Traffic Safety Administration's (NHTSA) vPIC decoding API and matching them with Environmental Protection Agency fuel economy data based on make, model, year, and other vehicle characteristics. Based on the type of geographic information provided by the states, vehicle fleet information is assigned directly to census tracts, down-allocated from ZIP codes to census tracts, or when details were not available, down-allocated based on county-level information. In each case, the share of each fuel type and the mean and distribution of fuel efficiency was assigned to the same unit of analysis (census tracts) for which mileage estimates were made.

Rate Estimation

Combining the fuel type and average fuel efficiency information with the mean daily miles of travel for each household allows estimation of current fuel consumption for different fuel types. Fuel excise tax rates, as shown in Table 1, are applied to these fuel consumption estimates to identify the amount of fuel excise tax revenue that the RUC would need to replace for household non-diesel vehicles. Hybrid vehicles use gasoline but have much higher fuel efficiency. Electric and fuel cell cars are modeled as paying no fuel taxes. Other fossil fuels include liquefied natural gas, liquefied petroleum gas, compressed natural gas,

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[2] RUCA codes are generated after each decennial census when large samples of commuting patterns are collected.
[3] At the time the analysis was completed the 2011-2015 ACS 5-year samples were the most recent available.
[4] Data was provided in early 2017 for Hawaii and Colorado and early 2016 for the other states.

and other non-traditional fuels. Biofuels are mainly ethanol, with some biodiesel included (most biodiesel-fueled vehicles are excluded with diesel vehicles). We assume that only 20 percent of fuel purchases for flex fuel vehicles are biofuels (with the balance being standard gasoline). Of the 20 percent biofuels, we assumed that 10 percent come from non-retail sources and avoid biofuel taxes.[5]

Table 1. Fuel Tax Rates Used for the Analysis by State (dollars per gallon)

State	Gasoline	Other Fossil	Biofuel
Arizona	0.180	0.000	0.180
California	0.297	0.090	0.090
Colorado	0.220	0.100	0.205
Hawaii	0.160	0.040	0.032
Oregon	0.300	0.300	0.300
Utah	0.294	0.145	0.294
Washington	0.494	0.000	0.494

The estimated revenue based on fuel excise tax rates is the total amount that would need to be collected under the RUC program to replace current revenue. Current revenue is divided by the number of miles traveled statewide to which a RUC rate would be applicable to estimate a statewide RUC rate. For each formula, this mileage number is different depending on whether some miles are not chargeable due to allowances (Formulas 1, 2, 4, and 6). If rate adjustments are used to implement parameters (Formulas 3, 5, and 6), an equivalent mileage measure is calculated. For simplicity, all adjustments from the mileage chargeable under the flat rate RUC are referred to as equivalent mileage estimates.

Equivalent miles are first calculated as tract level means. For Formula 1, if a tract containing 100 vehicles of all fuel types each travels 10,000 miles a year on average (for a total of 1,000,000 miles), only 800,000 equivalent miles would be used for calculating the revenue neutral rate. If 20 of these 100 vehicles were electric, under Formula 3, they would pay 10 percent less for every mile traveled. Paying 10 percent less for 10,000 miles is equivalent to only traveling 9,000 miles at the base rate for that formula, and total equivalent miles would be 980,000.

The equivalent mileage of each tract across the state is added together to get a statewide value. This statewide value is used to estimate a single base rate for all vehicles in the state. Equation 1 and Equation 2 provide examples of the calculation for two more of the formulas.

Equation 1. Calculation of Equivalent Miles for Formula 2

$$F2\ Equivalent\ Miles = \sum_{tracts} \begin{matrix} ((AnnHHMiles_{tract} - 1{,}000) * Vehs_{tract}^{hyb,flex,other} + \\ (AnnHHMiles_{tract} - 2{,}000) * Vehs_{tract}^{elec} + \\ AnnHHMiles_{tract} * Vehs_{tract}^{gas}) \end{matrix}$$

[5] In the *Financial Impacts of Road Usage Charges on Urban and Rural Households* project, we used a less refined estimate of biofuel vs gasoline purchases of 50 percent and 50 percent. Additionally, we included the biofuel portion of vehicles not paying any taxes.

Equation 2. Calculation of Equivalent Miles for Formula 5

$$F5\ Equivalent\ Miles = \sum_{tracts} \begin{gathered}(1.2 * AnnHHMiles_{tract} * \%VehsBottom3rd_{tract} + \\ AnnHHMiles_{tract} * \%VehsMid3rd_{tract} + \\ 0.8 * AnnHHMiles_{tract} * \%VehsTop3rd_{tract})\end{gathered}$$

By estimating the equivalent mileage based on each of the parameters used in the formulae and using the total revenue estimates computed initially from current travel and fuel mix information, parameter-specific base RUC rates can be estimated for each of the formulas tested. Base rates can then be adjusted for fuel type (in Formulas 3, 5 and 6) and used to estimate revenue from each tract using the equivalent mileage. The financial impact of these rates can be compared with the current fuel excise tax and the flat rate RUC.

Financial Impacts

Each formula's base rate and parameter adjustments are applied to each census tract based on the mileage, fuel type, and fuel efficiency information associated with that tract. Household daily VMT is annualized and scaled up by the number of households in each census tract to estimate fuel tax payments by that census tract. Then RUC payments under each formula are calculated for each census tract. The RUC formula payments can then be compared to the fuel tax and to each other to estimate financial impacts. Urban, mixed, and rural tracts are grouped and analyzed to see how, on average, effects vary across these types of census tracts. Results are presented in the next section of the report.

Urban, Mixed, and Rural Analysis of Revenue-Neutral Formulas

This section presents results of the financial analysis of the flat rate RUC and six parameterized formulas in the seven participating states. Household financial impacts resulting from each formula are compared to the current fuel tax and the flat rate RUC. The key goal of this analysis is to understand how each parameterization affects the RUC system and financial impacts on households in urban, mixed, and rural census tracts. Each revenue-neutral formula's distributional effects are presented in a subsection[6].

Before looking at the details, Table 2 provides one way to compare the different formulas at a statewide level. Differences between states are mostly due to the variations in current fuel tax regimes (see Table 1) and how much revenue these excise taxes provide. The RUC rates presented in Table 2 replace the current fuel excise tax to achieve revenue-neutrality. A smaller portion of the inter-state differences is due to variation in average fuel economy across states, since states with high average fuel economy require lower rates per mile to be equivalent to the existing fuel excise tax.

Table 2. Base RUC Rates for Equivalent Revenue to the Current Fuel Tax Regime (cents per mile)

State	Flat Rate	Formula 1	Formula 2	Formula 3	Formula 4	Formula 5	Formula 6
Arizona	0.81	1.07	0.82	0.82	0.86	0.81	0.81
California	1.09	1.44	1.10	1.10	1.16	1.10	1.10
Colorado	1.04	1.36	1.05	1.05	1.10	1.04	1.06
Hawaii	0.71	0.90	0.71	0.71	0.75	0.71	0.71
Oregon	1.45	1.93	1.45	1.46	1.50	1.42	1.43
Utah	1.31	1.70	1.33	1.33	1.40	1.32	1.33
Washington	2.21	2.94	2.23	2.22	2.36	2.22	2.23

For any single state, the base rates under different formulas are almost identical except for Formula 1. Formula 1 exempts 2,000 miles for every single vehicle from the road usage tax, leading to a large reduction to the mileage base on which alternative revenue is collected. Formula 2 reduces the amount of applicable mileage but has a much smaller impact on the RUC rate because the full 2,000-mile allowance is limited to only certain types of non-gas-powered vehicles. Because all states in the study still have a relatively low penetration of non-diesel, non-gasoline vehicles (never exceeding 10 percent), mileage allowances for these vehicles have smaller effects. Formula 4 also reduces eligible mileage – affecting 25 percent of vehicles and reducing their mileage obligation by 2,000. The rate effect is larger because it adjusts mileage for a higher percentage of vehicles.

Formula 3 only gives a small rate adjustment to non-gasoline vehicles and has a negligible effect on base rates because of the low penetration of non-gas vehicles. If alternative fuels continue to gain in popularity, Formulas 2 and 3 could start to affect revenue based on the current gas tax, and hence the RUC rate, to a greater degree.

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[6] Additional detail on Hawaii is presented in Appendix D since the complete coverage of county fuel taxes made this additional analysis convenient.

Formulas 5 and 6 have a negligible effect on the base rate because the major parameter adjustment includes lower rates for high-efficiency vehicles and higher rates for low efficiency vehicles – two effects that balance out in terms of the revenue base. Because Formulas 4 and 5 are targeted based on annually adjusted efficiency percentiles, there is little to no risk of erosion of the RUC-based revenue over time. Formula 6, however, has the same revenue risk (linked to non-gas vehicle penetration) as Formula 2.

The following sections focus on the impacts on households in different geographic regions of the state as defined by physical form, density, and commuting patterns. Policymakers and the public have often expressed concern that rural households will be made worse off by a road usage charge system compared to the current fuel tax regime. This is the major motivation for taking this perspective in the financial analysis. Households are a common unit for financial analysis and were chosen for this work.

Flat Rate Formula

Analysis of the financial impacts of replacing the gasoline tax with a revenue-neutral RUC show that households in rural and mixed census tracts will pay less on average than they are currently paying in fuel excise taxes. Households in urban areas see a slight increase in payments, but this increase is of a smaller magnitude than savings of rural households (except in Hawaii) because a greater portion of total fuel excise taxes already comes from urban tracts and because there are so many more urban households across which an increase can be spread. Table 3 shows the percent changes in payments for each of the geographic classifications. Because average household gas tax payments are between $200 and $300 per year depending on the state, the average changes range from an increase of $3.50 for urban tracts in Washington to a $17 decrease for rural tracts in Utah.

Table 3. Change in Average Annual Payments Compared to Current Fuel Excise Taxes

State	Urban	Mixed	Rural	Urban-Rural Range
Arizona	0.8%	-2.0%	-7.7%	8.5%
California	0.3%	-2.6%	-6.7%	7.0%
Colorado	1.5%	-4.5%	-7.3%	8.8%
Hawaii	0.9%	-2.0%	-5.8%	6.7%
Oregon	1.3%	-3.7%	-5.8%	7.1%
Utah	0.8%	-4.4%	-7.4%	8.2%
Washington	1.1%	-3.9%	-5.3%	6.4%
All States	0.7%	-3.3%	-6.4%	7.0%

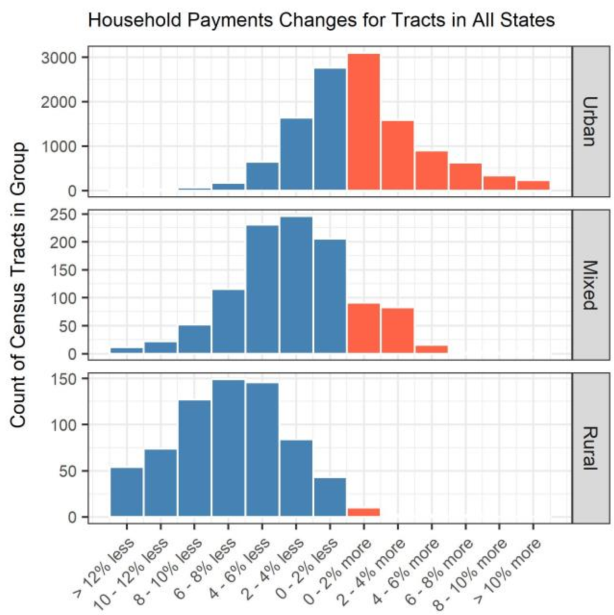
The final column is a simple way to think of the relative effect of the flat rate RUC comparing urban and rural areas, since changes are consistently positive or negative for urban and rural tracts for each state. This range is used as a reference to discuss how some of the other formulas differ from the flat rate. The percentages shown in Table 3 are derived based on the dollar value of payment shifts that are shown in Table 4. In many states, a few million dollars of additional revenue would be expected to come from urbanized portions of the state. This provides another lens to understand the magnitude of effects but requires the reader to remember that in 2016 most of these states collected hundreds of millions of dollars, or in the case of California almost $3 billion, of motor vehicle fuel excise tax.

Table 4. Dollar Value Change Compared to Current Fuel Excise Taxes

State	Urban	Mixed	Rural
Arizona	1,884,568	-689,108	-1,195,460
California	6,005,947	-2,872,382	-3,133,565
Colorado	3,919,459	-1,588,599	-2,330,860
Hawaii	375,694	-178,240	-197,453
Oregon	2,977,273	-1,653,213	-1,324,060
Utah	1,464,371	-398,572	-1,065,800
Washington	7,538,494	-4,809,056	-2,729,438

In addition to the average change for urban, mixed, and rural areas, there is substantial variation between tracts in each of these areas. There is further heterogeneity within these tracts as well that we do not examine in detail. For example, despite urban tracts on average paying slightly more, Figure 2 shows that there are also many tracts where the average household saves money. Overall, there are a very small number of rural tracts (15 or ~2 percent) that are expected to pay more under the flat rate RUC – mostly due to very high alternative fuel penetration and relatively high fuel efficiency. Figure 2 is based on all seven of the states in this study. Appendix C shows the distributions for each state.

Figure 2. Payment Changes from Fuel Excise Tax to Flat Rate RUC



Formula 1 - Universal Mileage Allowance

Formula 1 does not add any new parameters to the rate equation but does adjust the mileage to which the RUC is applied. This first formula is illustrative of one of the main mechanisms to parameterize RUC rates and can be used to understand how mileage allowances related to other parameters might also affect a RUC system. Allowing the first 2,000 miles traveled per vehicle to be exempt from mileage charges is likely to reduce total chargeable miles by 20-25 percent depending on the state. This reduced mileage base is reflected in the higher rates seen for Formula 1 in Table 2. These higher rates still allow the RUC system to collect the same amount of revenue as the existing fuel excise tax (the revenue-neutral assumption) but the combination of higher rates and mileage allowances affect RUC payments in individual tracts and produce different results for urban, mixed, and rural census tract classifications.

The impact on average household payments follows a similar pattern to the flat rate impacts, with households in urban tracts paying more on average and those in rural tracts paying less. For some states, the range between these two changes is larger, while for others it has decreased. These shifts largely depend on how significant the difference in average household VMT is between the three geographic classifications, as well as differences in vehicle ownership averages. The variation in urban-rural RUC range is partly driven by both their relative fuel efficiencies and VMT compared to mixed areas.

In Arizona, urban tracts pay less relative to a flat rate RUC with mixed tracts switching to paying slightly more on average, rather than saving as they did under the flat formula (comparisons to the results for a flat rate shown in Table 3). In Colorado and Utah, mixed tracts pay slightly more, and RUC payments decrease for both urban and rural tracts on average. This is because the share of total chargeable miles in mixed tracts rises when the allowance is a fixed number of miles. In California, Hawaii, Oregon, and Washington, where annual urban mileage is similar to or higher than in rural tracts, savings for both mixed and rural drivers increase even more than under the flat rate system. A further reason for these differences in Washington and Oregon is that these are the two states where rural tract vehicle ownership rates are greatest relative to urban tracts. They also have very high mixed tract ownership – more than 25 percent higher than urban tracts.

Table 5. Formula 1 – Change in Average Payments Compared to Current Fuel Excise Taxes

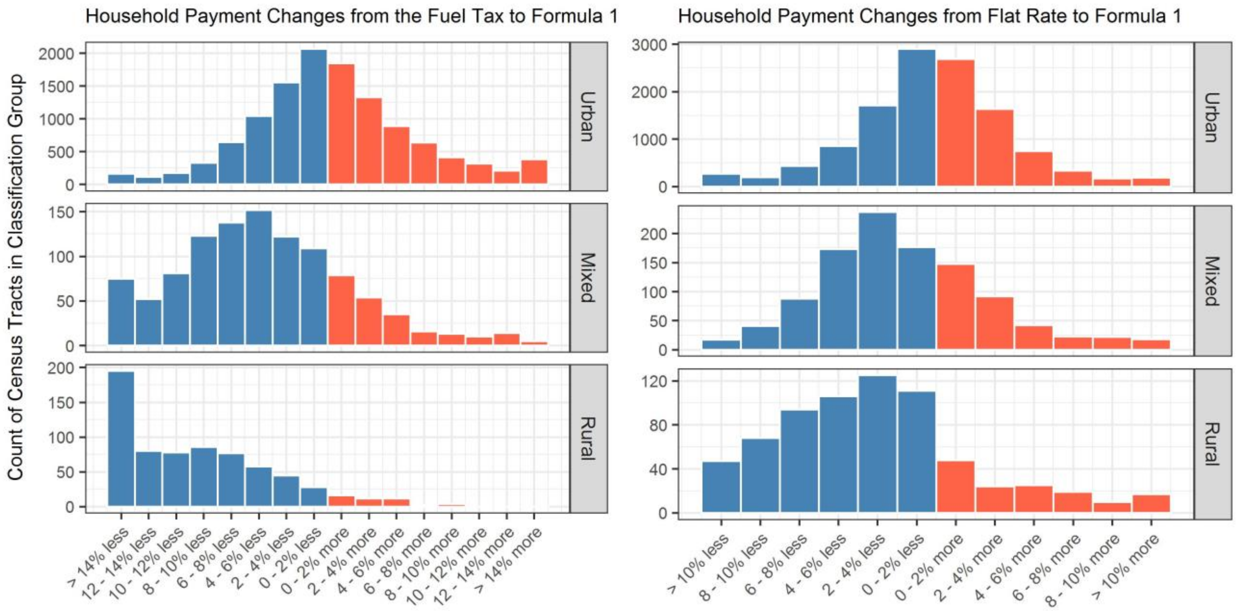
State	Urban	Mixed	Rural	Urban-Rural Range	Flat Rate Range[7]
Arizona	0.5%	0.2%	-6.9%	7.3%	8.5%
California	0.5%	-4.6%	-11.0%	11.5%	7.0%
Colorado	1.3%	-2.6%	-7.9%	9.2%	8.8%
Hawaii	1.5%	-3.8%	-7.8%	9.3%	6.7%
Oregon	2.4%	-7.4%	-10.4%	12.8%	7.1%
Utah	0.7%	-2.0%	-7.6%	8.3%	8.2%
Washington	1.9%	-6.7%	-10.1%	12.0%	6.4%
All States	1.0%	-4.9%	-9.4%	10.3%	7.0%

The distribution of impacts when comparing a fuel excise tax to Formula 1 is much more varied (see Figure 3) than it was for the flat rate. This is perhaps unsurprising with state impacts moving in different directions compared with the flat rate. Additionally, variation within the states has also increased. Whereas with a flat rate, the number of rural tracts facing more than a 2 percent increase was negligible (see Figure 2), we now estimate households may pay more on average in around 7 percent of rural tracts. Although the average shift of the rural distribution is only 3 percent, there are many more tracts where households are estimated to save more than 14 percent.[8] Impacts have spread out in both directions because removing a portion of mileage for all vehicles makes the differences between annual VMT more pronounced relative to the average equivalent mileage.

[7] From Table 3.

[8] An artificial limit to the graph's scale to keep it readable. A few of these tracts save as much as 20 percent or more.

Figure 3. Payment Changes from Fuel Excise Tax and Flat Rate RUC to Formula 1



The impacts on urban and mixed tracts are similarly much less concentrated. The increase in variation is much greater than the shift in the mean values for these categories. The right panel of Figure 3 shows that while many tracts are affected only marginally by Formula 1 compared to the flat rate, some tracts show much greater differences in financial impact. The tracts that show the largest difference were already more extreme cases under the flat rate – with very high or low household mileage relative to others in their class. Their distinctive characteristics are accentuated by reducing all vehicles' eligible mileage by the allowance amount. These tracts could have substantially higher or lower vehicle ownership than others in their class – something that would affect Formula 1 more than the flat rate.

FORMULA 2 - FUEL TYPE MILEAGE ALLOWANCE

Formula 2 provides two different levels of mileage allowances to vehicle owners. EVs receive a 2,000-mile allowance and hybrid, flex fuel, and alternative fossil fuel vehicles receive a 1,000-mile allowance. These vehicles range from between 3.8 percent of non-commercial vehicles registered in California to 9.6 percent of vehicles registered in Colorado. When states have large shares of vehicles that are not traditional gasoline or diesel vehicles, this is usually due to higher prevalence of flex fuel vehicles – which may be using standard fuels for some or most of their travel.[9] California has the highest prevalence of EVs with just under four-tenths of a percent, followed by Hawaii.

Because of the low levels of alternative fuel penetration and most of the alternative fuel vehicles qualifying for the 1,000-mile allowance (rather than the 2,000-mile EV allowance), this formula has a relatively negligible effect compared to the flat rate RUC (Table 6). Like the flat rate RUC, households in

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[9] No information on the share of alternative fuels used in flex fuel vehicles is available for non-commercial vehicles. The US EIA reports the total amount of alternative fuel consumed by commercial fleets (see: https://www.eia.gov/renewable/afv/index.php), but even for commercial fleets, there are no estimates of the share of total fuel consumed this represents.

urban census tracts may pay a few dollars more per year while households in mixed and rural census tracts pay less.

Table 6. Formula 2 – Change in Average Payments Compared to Current Fuel Excise Taxes

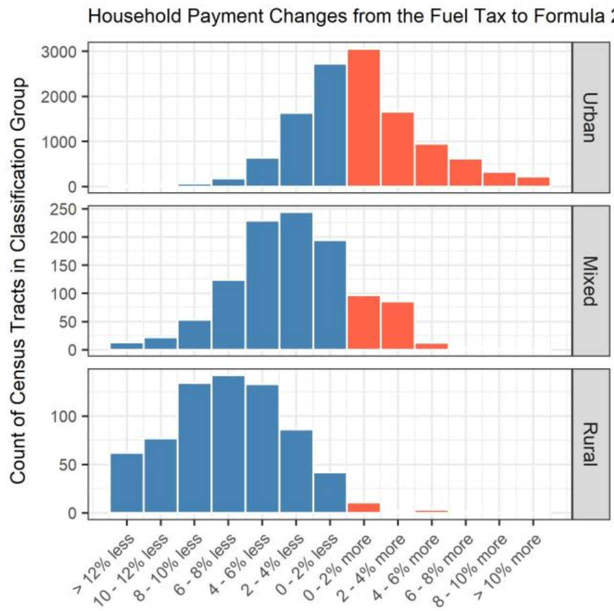
State	Urban	Mixed	Rural	Urban-Rural Range	Flat Rate Range
Arizona	0.8%	-2.0%	-7.7%	8.6%	8.5%
California	0.3%	-2.6%	-6.7%	7.0%	7.0%
Colorado	1.5%	-4.5%	-7.6%	9.1%	8.8%
Hawaii	0.9%	-2.0%	-5.7%	6.6%	6.7%
Oregon	1.3%	-3.8%	-5.9%	7.2%	7.1%
Utah	0.8%	-4.4%	-7.6%	8.4%	8.2%
Washington	1.1%	-4.0%	-5.4%	6.5%	6.4%
All States	0.7%	-3.4%	-6.5%	7.2%	7.0%

Compared to the flat rate RUC (as shown in Table 3), the analysis of results from applying Formula 2 produces very modest increases for urban tracts (less than one-tenth of a percentage point) and similarly modest savings for mixed and rural tracts. This is because these areas often have slightly more alternative fuel vehicle registrations than urban areas. The exception is Arizona, where households in urban census tracts pay less, although still only slightly less when compared to the flat rate RUC. Comparing Table 3 and Table 6, Arizona households in mixed tracts pay more on average and the difference between their mileage and other areas is large enough that households in urban tracts save relative to a flat rate RUC. In Arizona, it is again due to average estimated mileage in mixed tracts being much higher than in urban or rural tracts, so that any mileage allowances increase the proportion of total mileage attributable to mixed tracts faster than occurs in other states. As with Formula 1, vehicle ownership rates could also play a role, but it is far less apparent because of the low penetration.

The limited differences from the flat rate RUC at a state level also lead to a distribution across tracts that is very similar to the flat rate outcomes shown in Figure 2. Figure 4 again exhibits limited dispersion around each classification of census tracts' statewide average change. A few tracts in each group have unique characteristics that result in higher changes.

Less than one percent of rural tracts experience a change of more than one percent between the flat rate and Formula 2. This makes a graphical comparison of the flat rate and Formula 2 less insightful. Just as alternative fuel vehicles do not have very high penetration in any state, they do not dominate any census tracts sufficiently to cause large swings in financial impacts.

Figure 4. Payment Changes from Fuel Excise Tax to Formula 2



Formula 3 - Fuel Type Rate Adjustment

Formula 3 is the first parameter adjustment tested that changes the RUC rate rather than the mileage to which it is applied. Under Formula 3, households are less affected by the differences in mileage between the different geographic classifications and the number of vehicles owned – two of the major factors for the first two formulas. Instead, only the number or portion of alternative fuel vehicles influences the outcome. Additionally, the parameter is applied as a 10 percent reduction in the RUC rate for non-gas-powered vehicles – with no additional discount for EVs, as provided in Formula 2.

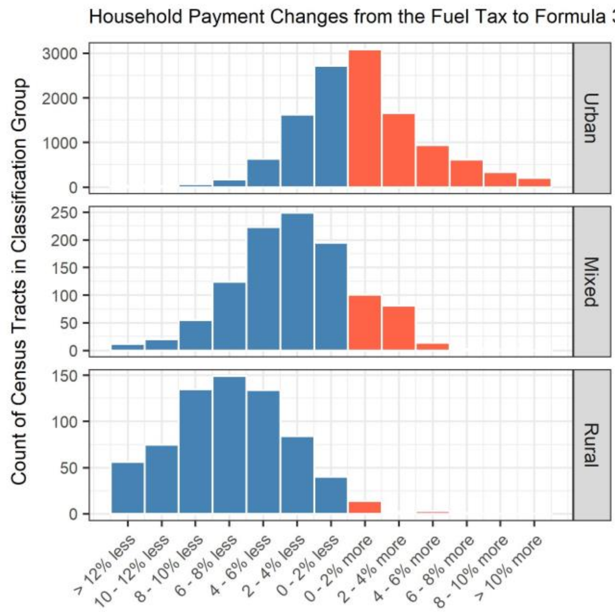
Just as with Formula 2, overall impacts are very small because alternative fuel vehicles still represent a significant minority of total household registrations in all states. This could certainly change in the future if there is widespread electrification of cars or other developments in fleet fuel mix. At some point, most vehicles could be paying the discounted rate. Depending where adoption of alternative fuels is the fastest, changing composition of the vehicle fleet could modify the distribution of impacts across urban, mixed, and rural portions of the state.

Table 7. Formula 3 – Change in Average Payments Compared to Current Fuel Excise Taxes

State	Urban	Mixed	Rural	Urban-Rural Range	Flat Rate Range
Arizona	0.9%	-2.0%	-7.8%	8.6%	8.5%
California	0.3%	-2.6%	-6.7%	7.0%	7.0%
Colorado	1.5%	-4.6%	-7.5%	9.0%	8.8%
Hawaii	0.9%	-2.0%	-5.7%	6.6%	6.7%
Oregon	1.3%	-3.7%	-5.8%	7.1%	7.1%
Utah	0.8%	-4.5%	-7.6%	8.4%	8.2%
Washington	1.1%	-3.9%	-5.3%	6.4%	6.4%
All States	0.7%	-3.3%	-6.4%	7.1%	7.0%

The urban-rural range differs from the flat rate range only slightly (see Table 7). Arizona, Colorado, and Utah see very minor increases due to higher alternative fuel penetration in the mixed and rural areas – mostly flex fuel vehicles. California, Oregon, and Washington show very negligible changes because the distribution of flex fuel vehicles is reasonably consistent across the three areas. If rate adjustments applied to only some alternative fuel types, different fuels had different rates, or the rate adjustment was larger, it could lead to different patterns of effects.

Figure 5. Payment Changes from Fuel Excise Tax to Formula 3



The distribution of payments across tracts for Formula 3, as shown in Figure 5, is very similar to the distribution from Figure 2 or Figure 4. Like Formula 2, there are almost no changes between the flat rate and Formula 3 of more than one percent. The differences could grow over time and, depending where uptake of alternative fuels is concentrated, there could be more differences within areas.

Formula 4 - Fuel Efficiency Mileage Allowance

This is the first formula using a fuel efficiency parameter that allows owners of high efficiency vehicles to drive them 2,000 miles per year before paying a RUC. If the data upon which designation of the top 25 percent of vehicles that qualify for this mileage allowance is updated each year, there is no risk of revenue erosion over time due to increasing alternative fuel penetration in the fleet like there is with Formulas 2 and 3. This is because the mileage allowance is offered relative to the fleet of registered vehicles rather than independently based on each vehicle’s characteristics. If the allowance was offered for all vehicles that are rated at greater than 40 miles per gallon, for example, then agency revenue could be at risk as more and more vehicles cross that threshold.

Because 25 percent of vehicles have some of their mileage exempt, base rates must be slightly higher than under a flat rate to maintain revenue neutrality (see Table 2). However, this base rate should be relatively stable over time, unlike what it would be if the parameter was not relative.

Formula 4 has a noticeable effect on the urban-rural range statistic. Providing a 2,000-mile allowance for the 25 percent of vehicles ranked as the most efficient in each state’s registration databases means that households in urban, mixed, and rural census tracts all pay closer to what they paid under the excise tax. The overall reduction in the range is greatest in Arizona, Utah and Colorado, where, in Colorado, the urban-rural range is 2.7 percent closer (the difference between the Formula 4 urban-rural range and the flat rate urban-rural range). The narrower urban-rural range means that while the flat rate formula caused urban and rural household payments to be about fifteen dollars closer together in Colorado, Formula 4 only results in household payments ten dollars closer together, leaving them more like the effect of the gas tax. The effect is less than seven dollars per year in all states.

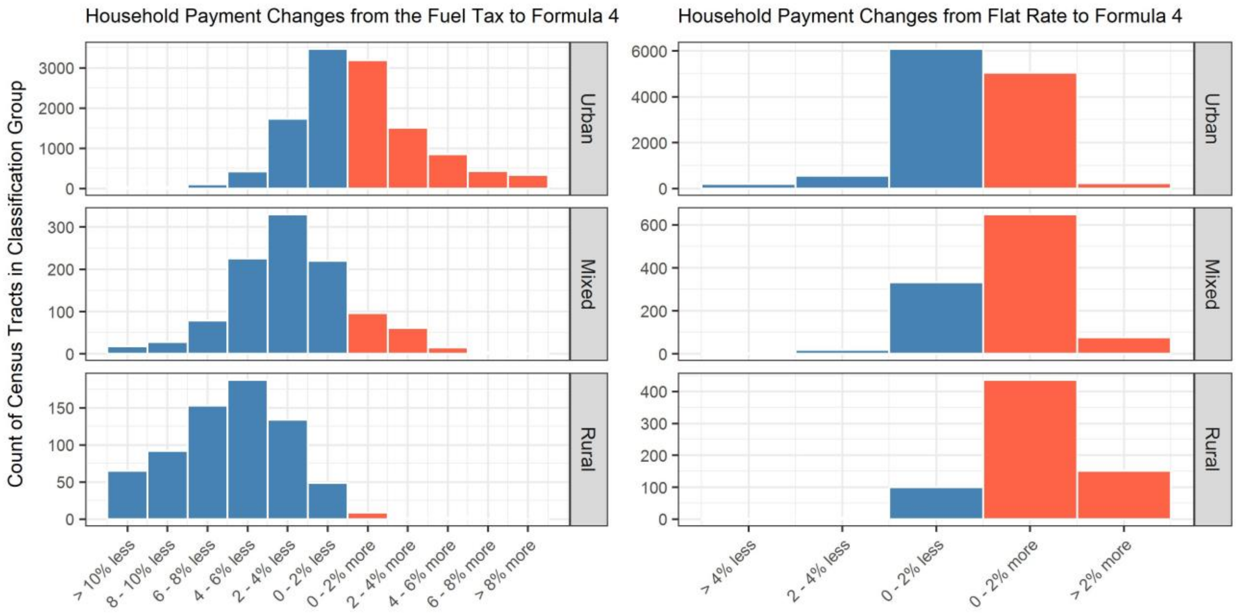
Table 8. Formula 4 – Change in Average Payments Compared to Current Fuel Excise Taxes

State	Urban	Mixed	Rural	Urban-Rural Range	Flat Rate Range
Arizona	0.6%	-1.3%	-6.1%	6.8%	8.5%
California	0.3%	-2.4%	-6.0%	6.3%	7.0%
Colorado	1.0%	-2.7%	-5.1%	6.1%	8.8%
Hawaii	0.8%	-1.8%	-4.9%	5.8%	6.7%
Oregon	1.1%	-3.4%	-5.1%	6.2%	7.1%
Utah	0.6%	-2.8%	-5.6%	6.2%	8.2%
Washington	1.0%	-3.7%	-5.1%	6.1%	6.4%
All States	0.6%	-2.9%	-5.4%	6.0%	7.0%

In states where households in mixed tracts travel much more than rural tracts, the increase for mixed tract households is also noticeable. It is 1.8 percent higher in Colorado and 1.5 percent in Utah when subtracting the mixed changes in Table 3 from those in Table 8. This is despite mixed tracts having better fuel efficiency on average than rural tracts. What this shows is that when mileage averages are very high for some tracts, fixed allowances are not as beneficial as a rate adjustment to those households.

Since the highest efficiency vehicles, including hybrids and EVs, are disproportionately registered in urban tracts, average payments under Formula 4 are slightly closer to those under the fuel excise tax in urban tracts. Hybrids and EVs are still paying more than under the fuel excise tax, but along with high efficiency vehicles using other fuels, they don't pick up quite as much of the revenue burden as they would with a flat rate RUC. In general, under this type of a RUC system, high efficiency vehicles pay more than they would if taxed based on their fuel consumption and older, lower efficiency vehicles also pay more. Because of the allowance for high efficiency vehicles, the tracts with the lowest fuel efficiency no longer benefit as much from revenue contributions by owners of higher efficiency vehicles.

Figure 6. Payment Changes from Fuel Excise Tax and Flat Rate RUC to Formula 4



The distribution of tract-level impacts in Figure 6 is less spread out than under the flat rate. This result is expected because the RUC rate for high efficiency vehicles has been partially compensated for under Formula 4. Tracts with lots of high efficiency vehicles see less increase than under other formulas. From the right panel, however, it's clear that the changes in average costs are incremental at a census tract level – almost all changes are within positive and negative 2 percent. Although savings relative to the flat rate are slightly skewed towards households in urban tracts, many of these households pay more on average and a meaningful number of households in mixed and rural tracts pay less.

Formula 5 - Fuel Efficiency Rate Adjustment

Formula 5 adds another dimension to the rate adjustment parameterization by providing both an incentive for high efficiency vehicles and a disincentive for inefficient vehicles. The top third of registered vehicles in a state pay 20 percent less than the base rate (which is not significantly different from the revenue neutral rate), while the bottom third pay 20 percent more. Like Formula 4, these relative parameters prevent any revenue erosion as the efficiency of the fleet changes over time. Unlike Formula 4, where the revenue equivalent to the 2,000-mile allowance was compensated for by the other 75 percent of vehicles, most of the savings for the top third of vehicles are instead paid by the bottom third. Because the mileage base stays the same, base rates in our model are largely unaffected by Formula 5 (see Table 2). This modeling considers driving behavior by vehicle to be static. However, if differential rates cause households to shift miles from lower efficiency vehicles to higher efficiency vehicles it may be necessary to adjust base rates to account for this change. The shift is likely to be small because the cost difference due to parameters remains small compared to the total operating cost per mile of a vehicle.

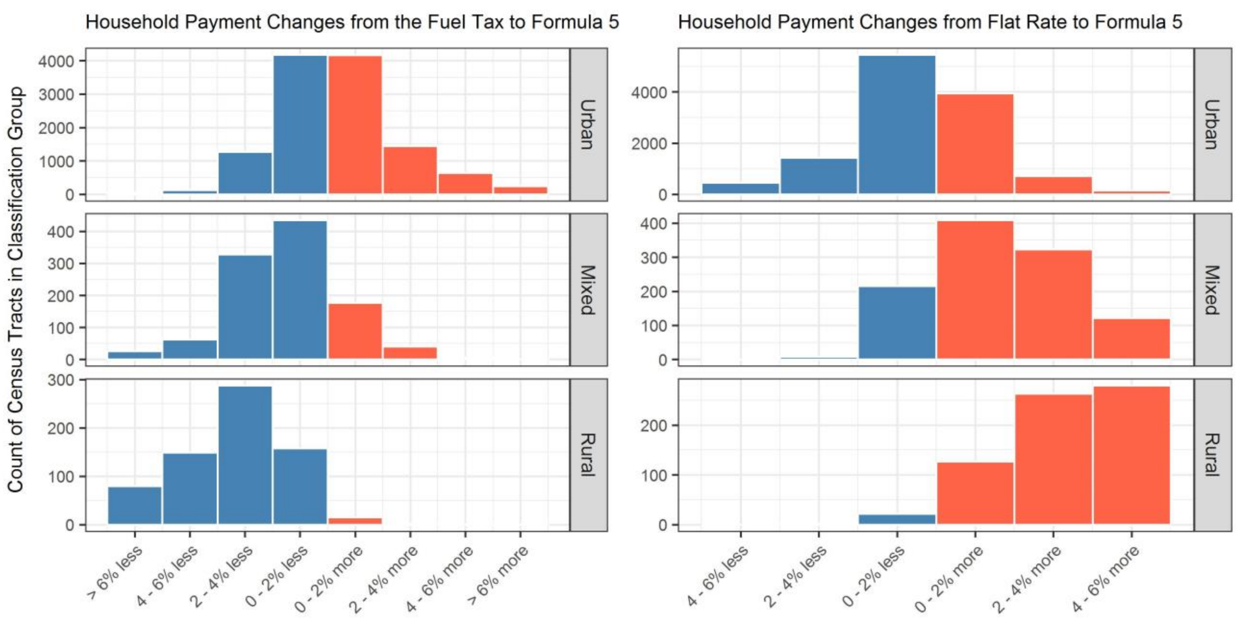
This structure achieves average household payments in each geographic region very similar to the fuel excise tax. As shown in Table 9, the reduction in the range between urban and rural impacts is more than twice as much as with Formula 4. Across all states, the average range is 50 percent smaller compared to the range under a flat rate, 3.4 percent instead of 7 percent. At a state level, no urban populations have an average increase more than half a percentage point. However, all states' rural and mixed census tracts still show savings on average.

Table 9. Formula 5 – Change in Average Payments Compared to Current Fuel Excise Taxes

State	Urban	Mixed	Rural	Urban-Rural Range	Flat Rate Range
Arizona	0.5%	-1.3%	-4.5%	5.0%	8.5%
California	0.2%	-1.5%	-3.9%	4.1%	7.0%
Colorado	0.5%	-1.4%	-2.5%	3.0%	8.8%
Hawaii	0.2%	-0.4%	-1.8%	2.0%	6.7%
Oregon	0.5%	-1.5%	-2.4%	3.0%	7.1%
Utah	0.4%	-2.1%	-3.7%	4.1%	8.2%
Washington	0.5%	-1.7%	-2.4%	2.9%	6.4%
All States	0.3%	-1.5%	-3.1%	3.4%	7.0%

Although the right panel of Figure 7 suggests that rural tracts pay a lot more compared to the flat rate RUC option, the increases are almost entirely among those tracts whose households averaged the greatest savings under a flat rate RUC. Households in rural tracts almost universally see decreased payments (relative to fuel taxes) under Formula 5. All geographic areas show more concentrated distributions when transitioning from a fuel excise tax to a road usage charge with this fuel efficiency parameterization. Most of the upper tail of the urban tracts has also shifted towards the center, with many urban tracts (where the bottom third of vehicles outnumber the top third of vehicles) also paying slightly more.

Figure 7. Payment Changes from Fuel Excise Tax and Flat Rate RUC to Formula 5



Formula 6 - Fuel Type and Fuel Efficiency Parameters

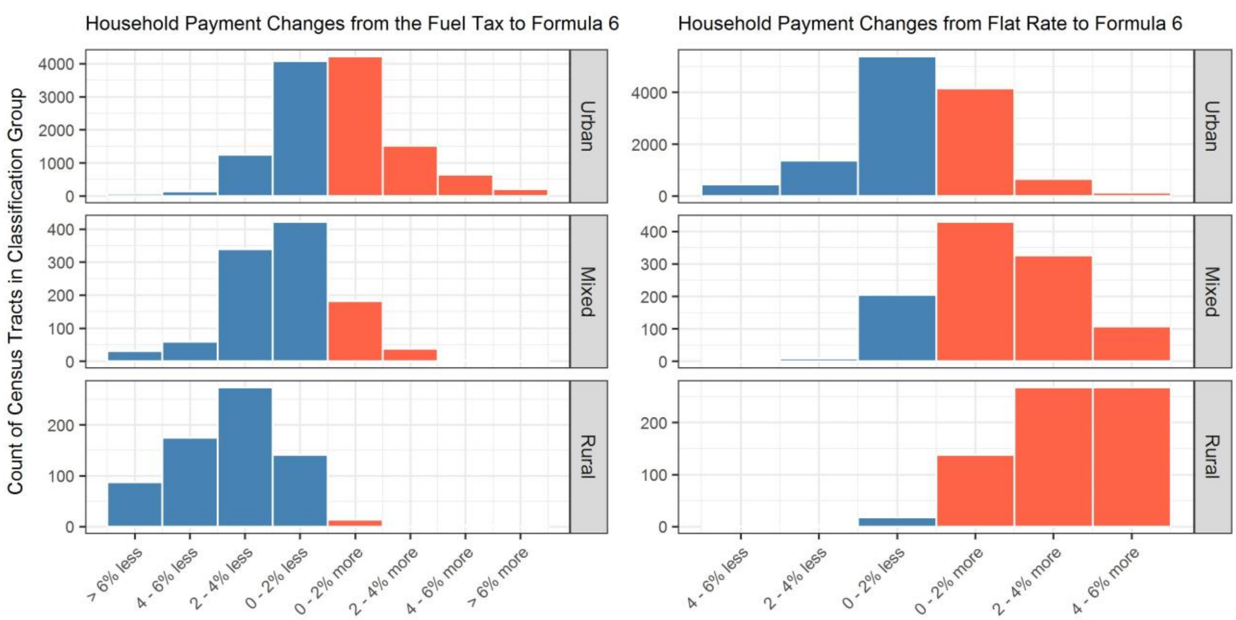
Formula 6 combines the fuel efficiency rate adjustment from Formula 5 with a 2,000-mile allowance for EVs and a 1,000-mile allowance for other alternative fueled vehicles. The addition of these parameters has a small impact relative to Formula 5. Formula 6 outputs closely follow Formula 5, although there are slight differences because some high efficiency alternative fuel vehicles, like EVs and hybrids, apply their differential rate to a smaller base after using the mileage allowance.

Table 10. Formula 6 – Change in Average Payments Compared to Current Fuel Excise Taxes

State	Urban	Mixed	Rural	Urban-Rural Range	Flat Rate Range
Arizona	0.5%	-1.2%	-4.5%	5.0%	8.5%
California	0.2%	-1.5%	-3.9%	4.1%	7.0%
Colorado	0.5%	-1.4%	-2.8%	3.4%	8.8%
Hawaii	0.2%	-0.4%	-1.7%	1.9%	6.7%
Oregon	0.6%	-1.6%	-2.6%	3.1%	7.1%
Utah	0.4%	-2.1%	-3.8%	4.2%	8.2%
Washington	0.5%	-1.8%	-2.6%	3.1%	6.4%
All States	0.3%	-1.6%	-3.2%	3.5%	7.0%

The urban-rural range statistic suggests that payments under Formula 6 would be much more like the fuel tax for these geographic groups on average than under the flat rate formula (Formula 6 and Flat Rate ranges can be seen in Table 10). There is also a risk of slowly eroding the mileage base as the prevalence of alternative fuel vehicles grows – one of the trends transitioning to a road usage charge aims to address. This risk arises because, as more alternative fuel vehicles enter the fleet, the mileage base will decrease due to more vehicles qualifying for the allowance. Comparing Figure 7 and Figure 8 shows some slight differences between formula effects.

Figure 8. Payment Changes from Fuel Excise Tax and Flat Rate RUC to Formula 6



Formula Impacts by Fuel Type

The preceding section focused on how the households in urban, mixed, and rural geographic areas would be impacted by replacing the fuel excise tax with a flat rate RUC or one of the six parameterized formulas. This section covers the impacts on vehicles by fuel type as this is an important dimension for most of the formulas and for RUC policy generally. A RUC increases the revenue contribution of using an EV (from zero) and increases payments by hybrid vehicles across all formulas. Only a very limited number of hybrids have fuel consumption rates that would result in them paying less under a RUC.

The change in payments from the current fuel excise tax to a flat rate RUC for vehicle fuel types in each state is presented in Table 11. Hybrids under a flat rate RUC pay between 70 percent and 115 percent more than under the fuel excise tax. Along with the new revenue from EVs, this contributes to decreased payments by gasoline and flex fuel vehicles. Although some biofuel vehicle users were previously paying lower or no fuel tax, flex fuel vehicles on average have lower fuel efficiency and consequently benefit from the transition to a RUC. In most states, vehicles powered by other fossil fuels pay more after the transition. For other fossil fuel vehicles such as CNG or LNG, only those in Oregon pay less, because they face a tax equal to gasoline vehicles under current policy.

Because standard gasoline vehicles make up the clear majority of registered non-commercial vehicles in every state, their percentage change in payments is small. The greatest impacts are California gas vehicles – averaging $1.55 less under a flat rate RUC. Utah is the only state where, on average, gasoline vehicles contribute more revenue by changing to a flat rate RUC. This is due to Utah's high percentage of flex fuel vehicles, which average considerably lower fuel efficiency than other vehicles.

Table 11. Annual Payment Changes Per Vehicle from Fuel Excise Tax to Flat Rate RUC

State	Gasoline	Hybrid	Flex fuel	Other Fossil	Electric
Arizona	$ (0.09)	$ 28.28	$ (6.61)	$ 56.60	$ 62.69
California	$ (1.55)	$ 51.41	$ (1.76)	$ 64.82	$ 102.60
Colorado	$ (0.34)	$ 47.53	$ (5.44)	$ 26.48	$ 95.17
Hawaii	$ (1.09)	$ 30.06	$ 4.75	$ 36.76	$ 59.17
Oregon	$ (0.18)	$ 72.04	$ (34.96)	$ (46.24)	$ 160.08
Utah	$ 0.38	$ 44.31	$ (16.60)	$ 61.21	$ 108.45
Washington	$ (1.39)	$ 101.60	$ (37.79)	$ 205.45	$ 227.04

Table 12 shows that there are very minor differences in the impacts of the universal mileage allowance modeled under Formula 1 compared to those under a flat rate RUC when assessing impacts based on vehicle fuel type. These small changes are based on where these vehicle types are predominately registered in each state and the differences in travel patterns between those areas. However, the differences in concentration of fuel types are not substantial enough to produce interesting differences in fuel type impacts between the flat rate and Formula 1.

Table 12. Annual Payment Changes Per Vehicle from Fuel Excise Tax to Formula 1

State	Gasoline	Hybrid	Flex fuel	Other Fossil	Electric
Arizona	$ (0.13)	$ 28.48	$ (6.16)	$ 56.93	$ 63.81
California	$ (1.57)	$ 52.08	$ (2.04)	$ 64.74	$ 103.76
Colorado	$ (0.35)	$ 48.29	$ (5.40)	$ 25.64	$ 97.17
Hawaii	$ (1.09)	$ 30.15	$ 4.86	$ 36.52	$ 59.31
Oregon	$ (0.20)	$ 73.71	$ (35.47)	$ (47.19)	$ 165.50
Utah	$ 0.34	$ 44.46	$ (16.27)	$ 61.65	$ 108.65
Washington	$ (1.43)	$ 104.45	$ (38.75)	$ 203.57	$ 232.68

Formula 2 introduces the 2,000-mile electric and 1,000-mile alternative fuel mileage allowances and Table 13 shows how this affects the vehicles of different fuel types when compared to current fuel excise taxes. Payment increases for hybrid, electric, and other fossil fuel vehicles are lower on average (by about $10). Hybrid increases now range from 55 percent to 90 percent more than under a flat rate RUC – a noticeably lower dollar amount in states such as Washington. Flex fuel vehicle savings are even larger – with Oregon vehicles paying almost $50 less than they are estimated to pay under the excise tax (more than a 30 percent decrease). This revenue is made up for by reducing or reversing the savings the average gasoline vehicle received under the flat rate RUC. The impact on standard gasoline vehicles is still small – less than or equal to one dollar in all but one state (Utah).

Table 13. Annual Payment Changes Per Vehicle from Fuel Excise Tax to Formula 2

State	Gasoline	Hybrid	Flex fuel	Other Fossil	Electric
Arizona	$ 0.49	$ 21.57	$ (12.32)	$ 50.30	$ 56.01
California	$ (1.09)	$ 39.61	$ (13.62)	$ 53.23	$ 91.21
Colorado	$ 0.64	$ 38.13	$ (14.40)	$ 17.32	$ 85.66
Hawaii	$ (0.69)	$ 24.12	$ (0.33)	$ 30.97	$ 53.17
Oregon	$ 1.01	$ 56.04	$ (49.66)	$ (61.30)	$ 143.25
Utah	$ 1.51	$ 33.26	$ (27.36)	$ 50.45	$ 97.19
Washington	$ 0.10	$ 76.78	$ (62.48)	$ 180.56	$ 202.46

When using a rate adjustment instead of a mileage allowance to incentivize alternative fuels, as in Formula 3, there are more moderate shifts in the impacts of a parameterized RUC by vehicle fuel type (see Table 14) when compared to the current excise taxes for each state. Because electric and hybrid vehicles are more likely to be driven fewer miles per year, the relative rate adjustment is slightly less effective at moderating their payment increases than the fixed mileage allowance. Electric and hybrid vehicles pick up more of the revenue burden compared to Formula 2, while still paying less than under the flat rate. Flex fuel vehicle savings are also reduced, but other fossil fuel vehicles, which tend to be driven longer average distances, see slightly increased payments. As under Formula 2, the gasoline group still makes up for shifts in revenues from non-gas vehicles – reducing or reversing the savings the average gasoline vehicle received under the flat rate RUC. Gasoline powered vehicles in four of the seven states pay more under Formula 3 than under the gas tax.

Table 14. Annual Payment Changes Per Vehicle from Fuel Excise Tax to Formula 3

State	Gasoline	Hybrid	Flex fuel	Other Fossil	Electric
Arizona	$ 0.40	$ 22.76	$ (11.40)	$ 51.37	$ 56.90
California	$ (1.16)	$ 41.33	$ (11.60)	$ 55.14	$ 92.70
Colorado	$ 0.49	$ 39.35	$ (13.02)	$ 19.03	$ 86.49
Hawaii	$ (0.72)	$ 24.56	$ 0.04	$ 31.52	$ 53.60
Oregon	$ 0.76	$ 58.91	$ (46.41)	$ (57.85)	$ 145.17
Utah	$ 1.38	$ 34.61	$ (26.11)	$ 51.66	$ 98.55
Washington	$ (0.18)	$ 80.73	$ (57.39)	$ 185.97	$ 205.52

As shown in Table 15, Formula 4 no longer explicitly treats fuel types differently because this formula is based on fuel efficiency rather than fuel type. It is more successful than the previous RUC formulations at lessening the impact of the transition from a fuel excise tax to a RUC on each fuel type group. Hybrids pay between $15 and $65 more – averaging 65 percent more across all states. Savings for flex fuel vehicles are two-thirds as large with a fuel efficiency parameter as under the flat rate. Most states' gasoline powered vehicles now save money relative to what they would pay under a flat rate RUC, as high efficiency gasoline vehicles are also captured in the formula. These savings come mostly from less preferential treatment of flex fuel vehicles rather than from hybrid or electric groups. Hybrid and electric powered vehicles pay less on average under Formula 4 than under the flat rate RUC, with the lowered payments (excluding Hawaii) averaging just under $20 per year for hybrid vehicles and just over $20 for EVs. In Hawaii, these savings are in the range of $10.

Table 15. Annual Payment Changes Per Vehicle from Fuel Excise Tax to Formula 4

State	Gasoline	Hybrid	Flex fuel	Other Fossil	Electric
Arizona	$ (0.07)	$ 17.18	$ (4.03)	$ 56.73	$ 51.15
California	$ (1.21)	$ 37.54	$ 1.12	$ 59.57	$ 84.95
Colorado	$ (0.40)	$ 34.12	$ (3.25)	$ 29.42	$ 79.00
Hawaii	$ (0.97)	$ 21.07	$ 5.22	$ 38.75	$ 49.05
Oregon	$ 0.24	$ 45.06	$ (28.69)	$ (41.91)	$ 131.67
Utah	$ 0.17	$ 30.20	$ (10.61)	$ 49.28	$ 89.19
Washington	$ (0.84)	$ 65.03	$ (27.30)	$ 211.37	$ 187.44

Formula 5 has similar impacts by fuel type to Formula 4. Table 16 shows how introducing a rate penalty for the least efficient vehicles affects the shift in sources of program revenue. Hybrid payments under Formula 5 are slightly lower when compared with Formula 4, with the maximum increase still in Washington. Net payments in all states are lower for gasoline powered vehicles than under the fuel excise tax and are lower under Formula 5 than under Formula 4 (California is unchanged). Flex fuel vehicles still save money in states where biofuel taxes are equivalent to gasoline taxes under current policy but pay more where they have no tax preference. Other fossil fuel vehicles, which are disproportionately low efficiency and have tax preferences in more states, typically pay more than under the fuel tax or other RUC formulas.

Table 16. Annual Payment Changes Per Vehicle from Fuel Excise Tax to Formula 5

State	Gasoline	Hybrid	Flex fuel	Other Fossil	Electric
Arizona	$ (0.16)	$ 16.36	$ (2.56)	$ 58.55	$ 49.99
California	$ (1.21)	$ 33.25	$ 7.65	$ 63.78	$ 83.56
Colorado	$ (0.79)	$ 32.57	$ 0.56	$ 37.44	$ 76.40
Hawaii	$ (1.10)	$ 19.70	$ 7.56	$ 43.93	$ 47.44
Oregon	$ (0.21)	$ 42.51	$ (18.61)	$ (33.82)	$ 126.08
Utah	$ (0.06)	$ 24.76	$ (6.56)	$ 48.87	$ 87.01
Washington	$ (1.12)	$ 58.67	$ (14.81)	$ 174.96	$ 183.66

The final formula tested shifts some revenue burden from alternative fuel vehicles to gasoline vehicles as well as accounting for fuel efficiency. These shifts are shown in Table 17. All state average hybrid increases are less than under a flat rate and are only about 40 percent more than under the gas excise tax. In all states except Hawaii, flex fuel vehicles pay less. Utah gas vehicles face the largest increase at just over one dollar. EVs still contribute significant new revenue but due to both the efficiency and fuel type adjustments it is smaller for all states, on average, than under any of the previously considered formulas.

Table 17. Annual Payment Changes Per Vehicle from Fuel Excise Tax to Formula 6

State	Gasoline	Hybrid	Flex fuel	Other Fossil	Electric
Arizona	$ 0.43	$ 10.99	$ (8.70)	$ 52.04	$ 44.66
California	$ (0.78)	$ 23.47	$ (5.35)	$ 52.24	$ 74.25
Colorado	$ 0.23	$ 24.79	$ (8.99)	$ 27.12	$ 68.80
Hawaii	$ (0.70)	$ 14.82	$ 2.19	$ 37.39	$ 42.64
Oregon	$ 0.99	$ 29.86	$ (35.26)	$ (50.40)	$ 112.83
Utah	$ 1.12	$ 15.78	$ (18.30)	$ 39.39	$ 78.00
Washington	$ 0.35	$ 38.68	$ (42.29)	$ 153.76	$ 163.75

Increased Revenue for Sustainable Infrastructure Funding

In this section, a second level of revenue from the RUC program is tested. The RUC rate is recomputed to collect additional revenue compared to the current excise tax regime and consequently would no longer be revenue neutral. The additional revenue targets, provided by the states, estimate the total revenue necessary to sustainably fund transportation infrastructure investments. Three states asked for an analysis from this perspective: California, Oregon, and Utah.

California

In the summer of 2017, California passed Senate Bill 1, which increased the fuel excise tax from the previous 29.7 cents (as used in the revenue neutral analysis) to 47.3 cents. This is a 59.3 percent increase starting fall of 2017. Table 18 shows how this revenue level would impact households in the three geographic categories under the flat rate RUC and each of the formulas tested when compared to the current fuel excise tax (i.e., before Senate Bill 1 took effect).

Looking only at the household non-commercial vehicles for which we analyzed registrations in California, roughly a 1.74 cent per mile RUC would be needed to provide the same revenue as this higher, sustainable gas tax, compared to a rate of 1.09 cents per mile under the former rate (see Table 2). Rates are slightly higher for Formula 4 (1.85 cents per mile compared to 1.16 cents per mile under the former rate) when 25 percent of higher-efficiency vehicles are provided 2,000-mile allowances, and quite a bit higher when all vehicles receive mileage allowances, as under Formula 1 (2.29 cents per mile versus 1.44 cents per mile). Consistent with the revenue-neutral analysis, urban households are expected to pay more relative to their payments under current excise tax laws when compared with households in mixed and rural tracts.

Table 18 also shows the percentage increase in RUC rates for sustainable revenues in California for urban, mixed, and rural census tracts compared to the previous fuel excise tax rates assessed in earlier sections of this report. Households in urban areas would pay 59.7 percent more under a sustainable flat RUC rate than under the previous gas tax. Households in mixed census tracts would pay 55.1 percent more and households in rural census tracts would pay 48.6 percent more when compared to their payments under current policy. Currently all gas-tax-paying households are paying 59.3 percent more in excise taxes than they were under the old gas tax rate, irrespective of where they live.

Table 18. Formula Impacts for a Sustainable Revenue Program in California

RUC Type	Equiv. Rate (cents per mile)	Urban	Mixed	Rural	U-R Range
Flat Rate	1.74	59.7%	55.1%	48.6%	11.1%
Formula 1	2.29	60.1%	52.0%	41.8%	18.3%
Formula 2	1.75	59.7%	55.1%	48.6%	11.2%
Formula 3	1.75	59.7%	55.1%	48.6%	11.1%
Formula 4	1.85	59.7%	55.4%	49.7%	10.0%
Formula 5	1.75	59.5%	56.9%	53.1%	6.5%
Formula 6	1.75	59.5%	56.8%	53.0%	6.5%

Mixed and rural payments are minimized by Formula 1. This is due to the same reasons that these areas save under the revenue-neutral Formula 1 analysis – household mileage estimates are not significantly different between urban and rural areas, but higher vehicle ownership increases the benefit per household. Lower fuel efficiency in these areas means they benefit from full transition to a RUC and this is accentuated when the mileage base is decreased. This is also the formula that results in the greatest range in the difference between the costs per household (18.3 percent).

Formulas 5 and 6 minimize the urban-rural range in payment shifts from transitioning from the 29.7 cent gas excise tax to the sustainable-level RUC. The less efficient vehicles in rural and mixed tracts still pay less than if all vehicles experienced the increase uniformly – which is the case when implementing the excise tax increase.

Oregon

For this study, Oregon identified a need for 176 million dollars of additional revenue; excluding the amount needed to provide additional highway capacity. The fuel excise tax or RUC would need to account for 78.1 million dollars of this revenue with the remainder coming from DMV sources or motor carrier revenues (mostly the weight-mile tax). All vehicles in excess of 26,000 pounds GVWR pay the weight-mile tax rather than a fuel excise tax. Although there is still considerable fuel excise tax paid by light commercial vehicles and other non-household vehicles, these 78.1 million dollars are included in addition to the estimated household component of current fuel tax revenue.

In Oregon, the RUC rate for a sustainable level of revenue is estimated to be 1.82 cents per mile compared to an estimate of 1.45 cents per mile for a revenue neutral flat RUC rate. The RUC rates required for sustainable revenues under the flat rate and for each of the six formulas are shown in Table 19. Since the formulas applied to Oregon are the same as those applied to California, the underlying patterns of costs for households living in urban, mixed, and rural census tracts are similar. Differences arise because of the distribution of vehicle types and mileage driven in these areas. In Oregon, under the flat rate RUC, households in urban areas would pay 27.5% more under a sustainable RUC rate than under current fuel excise taxes. Households in mixed census tracts would pay 21.3% more and households in rural census tracts would pay 18.6% more.

Table 19. Formula Impacts for a Sustainable Revenue Program in Oregon

RUC Type	Equiv. Rate (cents per mile)	Urban	Mixed	Rural	U-R Range
Flat Rate	1.82	27.5%	21.3%	18.6%	8.9%
Formula 1	2.44	29.0%	16.6%	12.9%	16.1%
Formula 2	1.84	27.6%	21.1%	18.5%	9.1%
Formula 3	1.84	27.5%	21.3%	18.6%	8.9%
Formula 4	1.94	27.4%	21.6%	19.5%	7.9%
Formula 5	1.79	26.6%	24.1%	22.9%	3.7%
Formula 6	1.81	26.6%	23.9%	22.7%	4.0%

As in California, the urban-rural range in costs paid per household is the greatest under Formula 1 and lowest under Formulas 5 and 6. Transitioning from current fuel excise policies to a sustainable RUC rate would increase transportation revenue contributions from households in urban tracts by about 9 percent more than for households in rural tracts. In Table 19, a universal mileage allowance under Formula 1 would cause even less increase in rural and mixed tracts contributions, with urban households picking up the difference. Formula 5 narrows the disparity between the tract classifications to 3.7 percent, again driven by the differences in where high efficiency and low efficiency vehicles are located.

Utah

Based on the Utah Unified Transportation Plan, the state estimates its transportation needs at roughly 2.24 billion dollars per year. Revenues are currently about 1.17 billion dollars per year. Assuming all other revenue sources would also increase proportionally, a sustainable RUC would need to collect 91.2 percent more revenue than the revenue-neutral formulas. To achieve this sustainable level of revenue the charge per mile in Utah would be 2.51 cents per mile (see Table 20) compared to the estimate of 1.31 cents per mile for a revenue neutral RUC rate.

Table 20. Summary of Formula Impacts for a Sustainable Revenue Program in Utah

RUC Type	Equiv. Rate (cents per mile)	Urban	Mixed	Rural	U-R Range
Flat Rate	2.51	92.7%	82.8%	77.0%	15.7%
Formula 1	3.26	92.5%	87.4%	76.7%	15.9%
Formula 2	2.54	92.8%	82.8%	76.7%	16.1%
Formula 3	2.54	92.8%	82.6%	76.7%	16.0%
Formula 4	2.67	92.3%	85.8%	80.4%	11.9%
Formula 5	2.52	91.9%	87.2%	84.2%	7.8%
Formula 6	2.55	92.0%	87.2%	83.9%	8.1%

The RUC rates required for sustainable revenues for each of the six formulas are also shown in Table 20. Since the formulas applied to Utah are the same as those applied to California and Oregon, the equivalent RUC rates for the six formulas follow a similar pattern. Formula 1 produces the highest RUC rate, due to the universal mileage allowance. In Utah, most transportation funding is drawn from households in the urbanized areas of the state. Urban households contribute 1.5 percent more (based on a flat rate) than the statewide average of 91.2 percent. Mixed and rural tract household increases are less than the average increase under all formulas tested.

Apart from Formula 1, the differences between what urban households would pay and what households in mixed and rural households would pay are much greater than in either Oregon or California. This is evident from the urban-rural ranges for Formulas 2 through 6 shown in Table 20 when compared to similar ranges shown for California (Table 18) and Oregon (Table 19). Formulas 2, 3, and 4 that provide adjustments for fuel-efficient vehicles result in greater spreads in the increase in what households pay than in either California or Oregon. In Formulas 5 and 6, where rate adjustments include increases for less fuel-efficient vehicles, the spread between what households in urban and rural census tracts pay, on average, is greater than either California or Oregon, reflecting the differences in the mix of mileage and vehicle types in Utah compared to these other states.

FINDINGS OF THE FINANCIAL ANALYSIS

Almost universally, under the seven formulas tested, households in urban tracts pay slightly more and households in mixed and rural tracts pay less when transitioning from an excise-based gas tax to a mileage-based road usage charge (RUC). However, the changes in either direction are small when computed in terms of the amounts of money involved. This study identifies significant heterogeneity between census tracts within the types of geographic classifications examined (urban, mixed, and rural) as well as differences in impacts between states. There is also significant heterogeneity within census tracts that is beyond the level of detail available in this study but has been assessed for a flat rate RUC in previous studies for RUC West.

When replacing a gasoline excise tax policy with a RUC policy, adding a fuel efficiency parameter results in a smaller change in payments between urban, mixed, and rural census tracts. A fuel efficiency parameter also reduces the change for any fuel type. It provides a way to explicitly influence how much convergence there is in payments between the most and least fuel-efficient vehicles. If based on annually adjusted efficiency quantiles, a parameterized RUC would not lead to revenue erosion over time.

When considering a fuel type parameter, deciding how to address the portion of non-gasoline fuels used by flex fuel vehicles is very important and deserving of more research. Better information is needed on the use of biofuels by flex fuel vehicle owners and their benefits to the transportation system and society. Flex fuel vehicle owners may be some of the greatest beneficiaries of a transition to a RUC, but this finding is based on the assumptions unique to this report regarding the mix of gasoline and biofuel purchased by private vehicle operators.

For now, fuel type parameters have relatively small impacts on RUC-based revenue systems because of low alternative fuel penetration in most states. This may or may not change rapidly over the coming years. However, to the extent that non-gasoline and alternative fueled vehicles continue to increase their market share – irrespective of their distribution in urban, mixed, or rural areas – the risk of erosion of the revenue base will become greater. Some indication of the effects of the composition of vehicle fuel type can be assessed by comparing the ways that households in urban, rural, and mixed census tracts in each of the states in this study vary. However, some caution is needed in interpreting state-by-state comparisons, given the differences in travel characteristics between states.

Geographic impacts (differential effects on households in urban, mixed, and rural areas) were also relatively minor for the parameters tested. However, there was a consistent trend in reducing the spread between urban and rural households when both high- and low-efficiency vehicles were accounted for in the formulas, and when mileage allowances were incorporated.

If fixed mileage allowances are applied across significant portions of the population, a reduced mileage base can accentuate differences in the level of RUC payments for households at the census tract level because of differences in travel patterns between geographic areas and tracts within them. Because mileage allowances would be applied at a vehicle level instead of a household's "marginal mile", they also are more beneficial to households that own multiple vehicles.

If the transition to a RUC includes collection of new revenue to support sustainable funding levels, the disparate impacts on households from different geographic areas may be increased. This may depend more on the mix of vehicle fuel types than on household travel characteristics. However, the formulas have largely the same effects at the higher level of revenue and can help narrow the differences between costs of transition for urban and rural households if parameters are selected to account for characteristics of the vehicle mix and household travel patterns.

The formulations used in this study reflect initial levels of mileage allowances and discounts/surcharges developed to test the general effects of certain parameters from a multistate perspective. Additional sensitivity analysis of parameters in each formula and more detailed assessments of the effects of urban, mixed, and rural areas as part of a state-specific sensitivity analysis are warranted. It is clear, from the perspective of geographic impacts as developed for this analysis, that individual states should identify the parameters of relevance to their situations and that these parameters should be evaluated against policy directions relevant to each state.

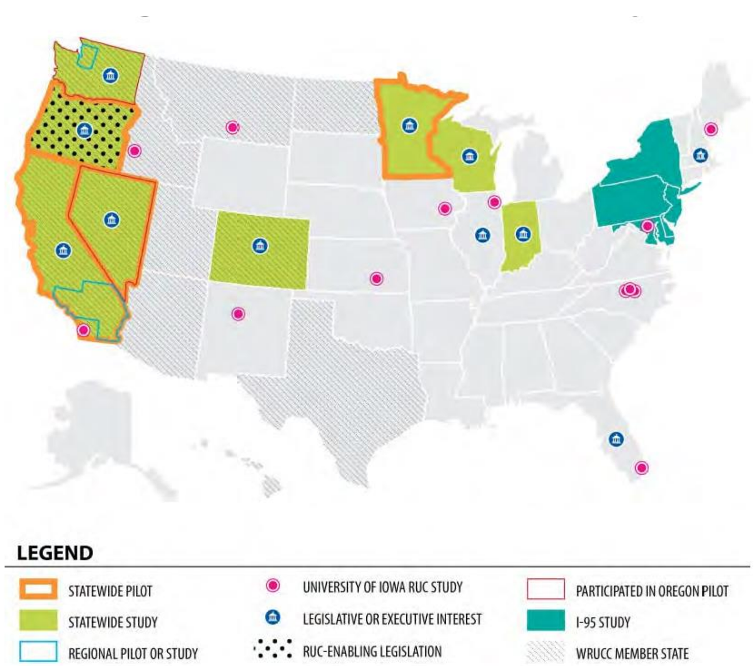
Feasibility of Combining Congestion Charges with a Road Usage Charge

In addition to financial analysis of parameterized RUC formulas, this project reviews the technologies and methods being used in the member states' pilot programs as well as other RUC and congestion pricing strategies nationally and internationally. This review provides a basis for discussing the feasibility of integrating technologies used in RUC systems with congestion pricing charge collections.

Public perceptions are a key component of the viability of expanding RUC systems and including other components of transportation management and funding schemes within them. Public visibility of RUC began growing after about 2012 following a national study run by the University of Iowa and a pilot in Minnesota. Since then, interest in RUC has spread across the country.

Oregon created a permanent program, following two pilots (the first in 2006 and the second in 2012). California and Colorado recently finished pilot programs, and Washington is launching a pilot program in early 2018. In the West, California's next pilot and Hawaii's system should both start up shortly afterwards. A group of Northeastern states are also developing a pilot program through the I-95 Corridor Coalition (participating states included Delaware, Maryland, New Jersey, New York, and Pennsylvania). Arizona, Indiana, Idaho, Missouri, Montana, North Dakota, Nevada, New Mexico, Oklahoma, Texas, Utah, and Wisconsin are pursuing research related to RUC. The Washington State Transportation Commission (2016) summarizes much of this progress in Figure 9.

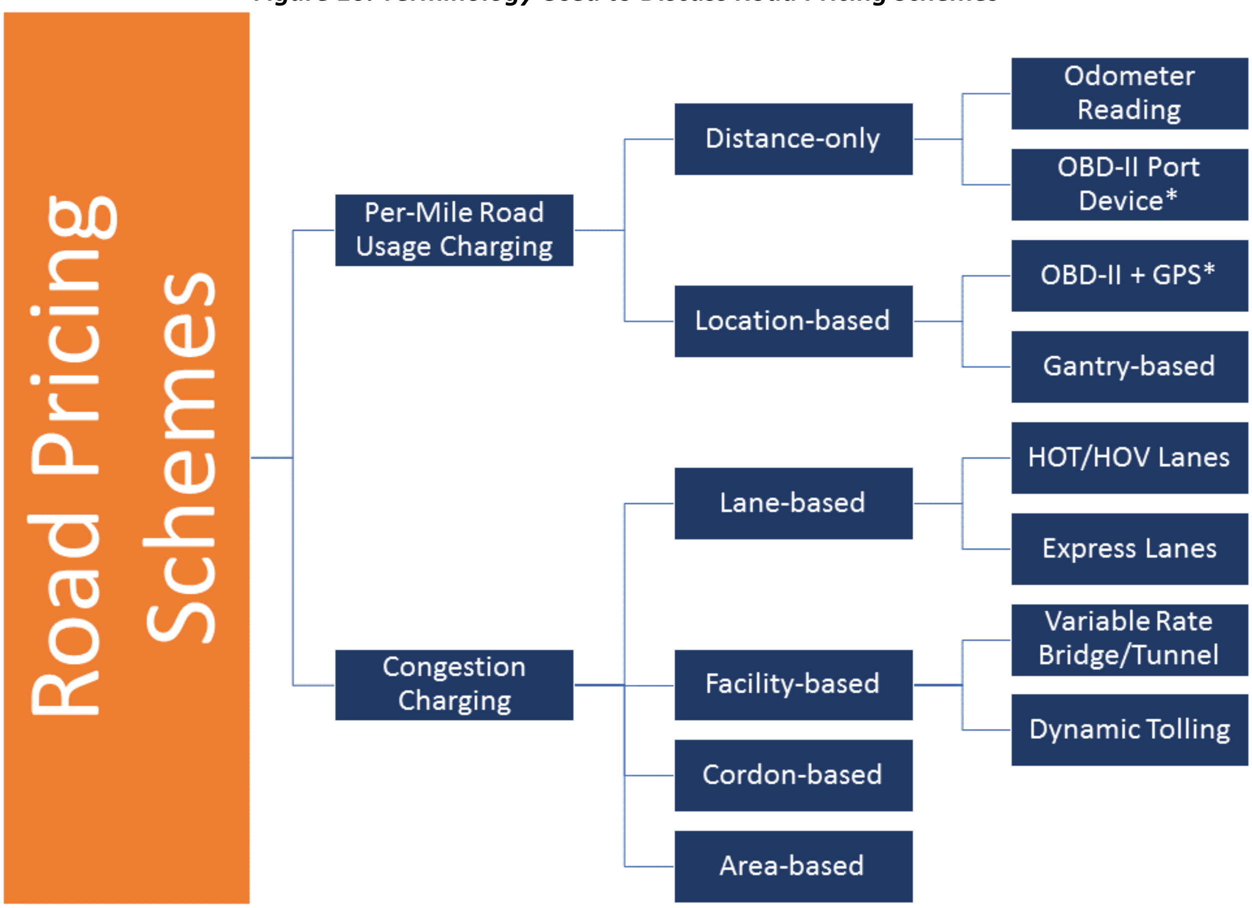
Figure 9. States with RUC Activity as of 2016 (WSTC 2016)



A key objective of this analysis is to understand how the public might respond to proposals to combine congestion charges with a RUC system. The literature that simultaneously assesses attitudes towards congestion-pricing *and* mileage-based fees discovered during our review is quite limited. Because of this, it remains largely unclear how closely aligned these mechanisms are in the public's mind. However, looking at literature covering these topics independently gives a great deal of insight into concerns that should be addressed to build public acceptance and the types of technologies that might be considered.

There are a variety of different terms used to discuss both congestion-based pricing and RUC. Some of the primary terms from the domestic literature are highlighted in Figure 10. Road usage charges have also been referred to as mileage-based user fees (MBUF) and vehicle miles travelled (VMT) fees; and both congestion pricing and RUC systems are related to facility-based tolling as a broader topic. Several pilots and proposals have also looked at how a pay-at-the-pump RUC collections framework could provide better continuity between the current fuel tax regime and a RUC system. Reviewing the current understanding of these different systems is important to understanding how we can expect the public to support their introduction in the future.

Figure 10. Terminology Used to Discuss Road Pricing Schemes

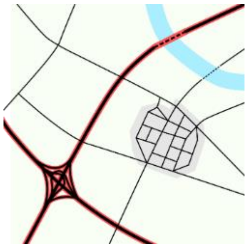
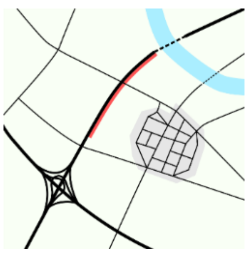
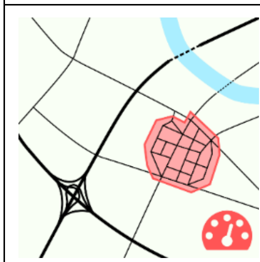


* Mileage and/or location measurement technology is independent of reporting technology used (e.g. pay-at-the-pump or cellular data transmission)

For the more technical components of the feasibility assessment, we analyze the types of congestion charging presented in Figure 11. The various types of congestion charging have different requirements regarding the (implied) accuracy of the location information that is needed to distinguish chargeable from non-chargeable use of infrastructure.

To understand both the technical and policy components of the tested RUC frameworks and the systems currently or soon to be in place, Appendix E provides a chronology and additional detail received from an information request for technical descriptions from states participating in this study. The assessment builds from an understanding of what a RUC system includes in the context of this study and the available technologies.

Figure 11. Types of Congestion Charges

Type	
	**Controlled access toll corridors** Vehicles are charged for using a defined segment of the road network, e.g. a stretch of highway. This type of congestion charge has relatively low requirements regarding spatial data accuracy. Charges can be levied per use of a toll corridor (e.g. for discouraging highway use for relatively short trips) or per distance travelled on the toll corridor.
	**Facility access toll** Vehicles are charged for using a specific facility, e.g. a bridge. This type of congestion charge has medium to low requirements regarding spatial data accuracy, depending on the type and extent of the facility at hand. Underground facilities such as tunnels might impose specific challenges (e.g. non-availability of Global Navigation Satellite System (GNSS, e.g. GPS, GLONASS or Galileo) information but these can typically be overcome.
	**Lane toll (on facility with general-purpose lanes)** Vehicles are charged for using a dedicated toll lane on a road segment featuring several travel options, including general purpose lanes. Vehicles on the toll lane will usually experience less congestion and faster mean travel times. This type of congestion charge has high requirements regarding spatial data accuracy.[10] Charges are typically levied per distance travelled on the toll lane.
	**Cordon charge** Vehicles are charged for crossing a defined line (cordon), e.g. around a city center. This type of congestion charge has relatively low requirements regarding spatial data accuracy.
	**Area charge** (similar to cordon charge) Vehicles are charged per distance travelled within a defined area, e.g. a city center. This type of congestion charge has relatively low requirements regarding spatial data accuracy.

[10] The system needs to be able to distinguish which lane a vehicle is using, positing spatial accuracy of a few feet. Alternatively, a system with high *implied* spatial accuracy can be employed that uses an in-vehicle unit communicating with roadside-infrastructure rather than high absolute positioning using e.g. GPS.

A Review of Attitudes Towards Road Usage and Congestion Charging in the Literature

Current discussions of RUC and congestion charging were reviewed to understand where these concepts fit in the public perception of transportation funding. Building support for both RUC systems and congestion charges is essential before technical implementation becomes a major issue. The key findings of this review are that:

- The majority of the public is not yet aware of RUC or other alternatives to the fuel excise tax. They also lack knowledge about transportation funding more broadly. Although they are open to the idea of RUC, they do not necessarily see a need to replace the fuel excise tax.
- There is no evidence that the public conflates mileage-based fees with congestion pricing, in part because these two mechanisms are still foreign concepts to most people.
- People are more likely to support a RUC program if administrators explain why RUC is necessary and how it benefits the community. It is essential to address concerns about privacy, impacts to people who must drive long distances or have low incomes, and the start-up cost of RUC systems.
- One approach to assuage privacy concerns is offering options for drivers to report their mileage, including self-reported odometer readings or flat-fee (non-mileage-based) plans.
- The public may consider RUC systems fairer if vehicles are separated into several user/vehicle categories (e.g. rural residents, low-income drivers, long-distance commuters, and hybrid/EVs). Generally, very little research has considered how the public views the fairness of a RUC for these categories of user/vehicle type relative to the fuel excise tax and if there are differences in how the public views issues related to questions of fairness and equity.
- Administrators should ensure the data on the types of chargeable miles included in a RUC can be verified by users to build confidence that the system is accurate.
- It is important for the costs to implement and maintain the RUC program to be transparent and for RUC administrators to share as much information as possible about how much revenue is raised and where this money is going.
- Public acceptance of RUC increases with familiarity, typically based on direct experience with a pilot program, but also possibly through education campaigns.

Detailed information on many of the studies cited in this report are available in the separate Annotated Bibliography.

In the most comprehensive review of attitudinal research on RUC to date, Agrawal, Nixon, and Hooper's (2016) meta-analysis of 38 public opinion surveys between 1995 and 2015 found that mean public support for RUC as a transportation funding mechanism averaged around 24 percent (with a substantial range of

8-50 percent).[11] These quantitative results are supported by the authors' review of an additional 12 qualitative studies since 1995. Duncan et al (2017) corroborate the Agrawal, Nixon, and Hooper review, finding that about a quarter of respondents support replacing the gas tax with a *general* mileage-based user fee.[12] When presented with an array of mileage-collection technologies, 21 percent support odometer-based tools, 15 percent support basic GPS technologies, and 13 percent support advanced GPS technologies.[13]

An expert panel convened by Dieringer Research Group (2007) argued that RUC should *supplement* the fuel tax, which panel members considered an efficient option for transportation funding. In their review, Agrawal, Nixon, and Hooper (2016) found only 23 percent of the public supports eliminating the gas tax to replace it with a different mechanism for collecting revenue (with a substantial range of 8-42 percent). Evidence from qualitative studies supported this finding, too. The public thinks primarily of higher gas taxes when asked about long-term solutions for transportation funding – they generally are not aware of structural problems with the fuel excise tax other than rates being unsustainably low (Dieringer Research Group 2007). Other important structural problems include generally increasing fuel efficiency, more vehicles using alternative fuels, the increasing dispersion of fuel efficiency available in new vehicles, and the equity concerns of lower income earners' higher propensity to own old, fuel-inefficient vehicles.

Popular opinion may be swayed over time. Studies found that most people are at least amenable to the idea of RUC as an alternate means of generating transportation funding (D'Artagnan Consulting 2013; Dieringer Research Group 2007; Duncan et al 2016; Hanley & Kuhl 2011; Harrington 1997; WSTC & WSDOT 2017), and their attitudes become increasingly positive with experience (Agrawal, Nixon, and Hooper 2016; D'Artagnan Consulting 2013; Hanley and Kuhl 2011; WSTC and WSDOT 2017). This has also been found to be true for congestion charge systems (EnviroIssues 2007; Golob 1999; Greene and Smith 2009; Li et al 2002).

Education may alter the negative perception of RUC-based programs. Participants in the Minnesota RUC pilot at first believed that RUC would be more expensive than the gas tax for high-mileage drivers; they did not realize that these drivers pay relatively more than low-mileage drivers in gas taxes already (Rephlo 2013). Putting RUC fees in comparison with familiar expenses, such as monthly gas tax, helps improve people's understanding of the system (Rephlo 2013).

Further, Agrawal, Nixon, and Hooper (2016) found that in almost all the studies in their review, people had little knowledge about RUCs to inform their responses, particularly when taking surveys with little background information.

Harrington (1997) gauged public opinion for a hypothetical scheme in which a per-mile fee that varies based on congestion levels is levied for freeway travel during rush hour. He found the main reason for opposition is the perception of charges as a new tax. Greene and Smith (2009) found that people favor congestion pricing over raising undifferentiated toll fees to manage traffic levels in part because they have

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11 See Appendix F for summaries of studies included in Agrawal, Nixon, and Hooper's (2016) study.

12 The authors use the term "general" to mean that study administrators did not specify *how* the fee would be administered (e.g. self-reported odometer reading, GPS-enabled devices, etc.)

13 Here, the term "advanced" refers to devices that can differentiate between taxable and non-taxable miles.

a choice about whether to pay to use the highway during peak hours. It is possible that this finding could also apply to inclusion of congestion components in a RUC rather than just a higher base RUC.

Several of the international-based studies look at multiple schemes simultaneously. Generally, they apply to different cities where the schemes have been implemented rather than public perception of specific mechanisms, much less the extent to which the various mechanisms are aligned in the public's mind (Currier 2008; Department for Transport 2004; Hamilton et al 2014; Institution of Engineering and Technology 2010).

PSRC (2008) provides the most topical example from the U.S. of a system with characteristics of both a RUC and congestion charge. The studied system used a GPS-enabled OBD-II device to charge a per-mile fee that varied by time of day and location and covered not only the primary freeway network but most of the secondary facilities (arterials). This study suggested such a system was fiscally and technically feasible.

Privacy Concerns

Privacy tops the list of concerns. When asked about privacy concerns related to RUC, about 50 percent of people agree that they are concerned. Technologies that collect data on location or time of travel alarm people – even odometer-based systems (Agrawal, Nixon, and Hooper 2016). Beyond data tracking concerns, people want to make sure that data is stored securely and cannot be accessed for non-RUC purposes. They do not, for example, want insurance companies to use the information to set rates without their permission. There is a general suspicion that devices will track people's movements, despite assurances from RUC administrators. Focus group participants expressed the view that recording miles is a "slippery slope" to "Big Brother" and "social engineering" (Dieringer Research Group 2007). Concerns about "surveillance" and a generalized distrust in government are present in international studies on RUC as well (Institution of Engineering and Technology 2010; Hamilton et al 2014).

Privacy concerns are independent of age, but there are other contributing factors. Privacy issues tend to be sensationalized by the media. RUC technologies seem overly complicated and intrusive while people perceive the problem (charge people based on how many miles they drive) as straightforward. Survey participants respond that low-tech solutions, such as higher fuel taxes, annual odometer reporting, or higher registration fees, would achieve the same goal (Dieringer Research Group 2007).

Oregon's experience may hold lessons for future RUC programs. Oregon has been on the leading edge of transportation funding mechanisms. It was the first state to introduce a gasoline tax (1919), a weight-mile tax (1925), and now a RUC scheme for passenger vehicles (2015). The first RUC pilot, from 2006 to 2007, failed politically even though it was technically sound. The "pay at the pump" model relied on in-vehicle devices equipped with GPS capabilities to record mileage information. These devices sent mileage information electronically through systems located at gas stations so that drivers saw their mileage fees and fuel tax credits along with their gas receipt. Participants raised privacy concerns about being "tracked." The second pilot was successful on the technical and political front because the system was based on user choice, open systems, and commercial account management. It also removed the GPS mandate, offering drivers three different reporting options to choose from, one of which was not GPS-based.

The PSRC (2008) study observed that experience with a congestion charging program with itemized charges provided to the participants resulted in polarization of opinions regarding privacy concerns. Many participants became much more comfortable with the concept, while many others became much more worried about privacy. The report recommended strict privacy protections and involvement of "trusted third parties."

Equity Concerns

The issue of fairness comes up frequently when debating the costs and benefits of RUC. Although most people tend to view RUC as fair to them on an individual basis (D'Artagnan Consulting 2013; Rephlo 2013), they worry about how the policy affects other classes of drivers, such as commuters, rural residents, hybrid or EV owners, and out-of-state travelers. Some research finds that RUC is seen as *fair* because people understand mileage-based fees as another usage-based utility bill, similar to payments they make for electricity and water (Dieringer Research Group 2007). Other research, such as recent surveys in Oregon, suggest that people feel they have much less discretion over their driving activity than their use of electricity or water and do not agree with presenting RUC as a utility-type charge (based on correspondence with ODOT).

Some respondents see RUC as a way to ensure that all drivers are paying their fair share, in contrast to the fuel excise tax in which drivers of fuel-efficient, hybrid, or EVs pay less tax or avoid paying tax altogether even though they benefit from well-maintained roads as much as those who pay a higher share of taxes (Agrawal, Nixon, and Hooper 2016; D'Artagnan Consulting 2013; Duncan et al 2017; WSTC 2016; ODOT 2017). This was reported as a cause of political failure for ODOT's initial pay-at-the-pump pilot, which did not offer a clear solution to including alternative fuel vehicles in the scheme. Oregon's current (ongoing) demonstration program addresses these concerns by exempting EVs from the newly passed registration surcharge on EVs. Bringing EVs and other alternatives into the transportation funding mechanism is often viewed as a key reason that a RUC would be fairer than the fuel excise tax.

Respondents in other studies express the opposite opinion – thinking that changing from the fuel excise tax to a RUC would be unfair to fuel-efficient, hybrid, and electric vehicles, who would pay more under a RUC system than they currently pay. These surveys find an interest in incentivizing eco-friendly modes of travel (Agrawal, Nixon, and Hooper 2016; Dieringer Research Group 2007; Duncan et al 2017).

RUC is perceived by some people as *unfair* to low-income drivers, who may have to commute long distances for work, but have less wherewithal to pay for those miles, and to individuals who might have no choice but to drive long distances, such as commuters and rural drivers (Duncan et al 2017). However, it's important to note that people forget that the gas tax is also more burdensome to the poor and those that drive long distances (Rephlo 2013), and those types of people may benefit from transitioning away from the gas tax to a RUC system. This contradiction highlights the importance of educating the public as well as the current lack of knowledge many people have about transportation funding, excise taxes, and RUC.

Congestion pricing is seen as unfair, possibility more than a RUC, for similar reasons. People respond that it penalizes those who need to commute to and from work during standard times (e.g. "rush hours"). They worry that it excessively impacts lower-income individuals who might not have flexible schedules and are less able to afford increased charges. The public is also resistant to congestion-based pricing because of concerns about social engineering and safety. People believe that congestion fees would only be applied to freeways and would displace traffic to local roads. Traffic increases on these roads could be dangerous because local roads are not designed for heavy commuter traffic and are often residential (Dieringer Research Group 2007). International studies support these findings (see Institution of Engineering and Technology 2010). The public is unfamiliar with how RUC technology might allow area charges that could mitigate this outcome.

There is a worry that it is easier to cheat the system with RUC, depending on the technology used to record miles. People are skeptical that a RUC system could be properly enforced and that consequently the burden of transportation funding would fall disproportionately on law-abiding motorists (Agrawal, Nixon, and Hooper 2016; Dieringer Research Group 2007; Duncan et al 2017). International studies support these findings (see Hamilton et al 2014).

Administrative Concerns

Under a RUC scheme, the public wants ways to verify that the information collected during their trips is accurate. Specifically, they want to confirm that charges are correct and to identify when their recording device has a glitch (e.g. a GPS malfunction or failure) (Agrawal, Nixon, and Hooper 2016; D'Artagnan Consulting 2013; Dieringer Research Group 2007; Duncan et al 2017; Hanley & Kuhl 2011). Younger drivers accept more readily that technology would work as described. Older drivers are less certain, have more questions, and are more skeptical of the system in general (Dieringer Research Group 2007). Experience with the technologies seems to ameliorate these concerns.

The public believes that RUC technology is complex and expensive to implement and maintain, which raises support for lower-tech solutions such as the fuel excise tax, annual odometer reporting, and registration fees (Agrawal, Nixon, and Hooper 2016; Dieringer Research Group 2007). The complications that arise from interstate travel raise doubts in many people's minds about how RUC can be administered fairly and enforced properly. They want to prevent charges when residents cross state lines, and they feel it is important to make provisions to charge out-of-state vehicles (Agrawal, Nixon, and Hooper 2016; D'Artagnan Consulting 2013; WSTC and WSDOT 2017). These two concepts would seem to be in conflict if all states simultaneously implemented RUC systems, but as long as neighbor states have fuel taxes, people are concerned about contributing to other states' tax revenue but no longer having a mechanism to collect the same type of tax revenue when others travel within their borders.

The public believes that enforcement would be challenging and costly for a RUC scheme because its reliance on technology opens the door for ways to cheat the system. They want to ensure that drivers cannot evade payment and are penalized if they do (Agrawal, Nixon, and Hooper 2016; Dieringer Research Group 2007; Duncan et al 2017).

Moreover, there is a more general concern with funding (mis)management. People are willing to pay their "fair share" based on how much they use the roads, but they are not convinced that transportation needs additional funding. They worry that existing funding levels are sufficient and that administrators mismanage the funds (Dieringer Research Group 2007). However, survey participants in a study by Dieringer Research Group (2007) did not know how much transportation projects cost on an annual basis, where that funding comes from, or how much they personally pay towards the funding reserves. This lack of understanding about transportation funding is seen widely across studies (Agrawal, Nixon, and Hooper 2016; WSTC and WSDOT 2017).

Helpful Guidelines to Boost Public Acceptance

The existing literature indicates that familiarity with RUC, built over time through education, messaging, and direct participation in pilot programs, may increase public support for RUC systems. Support for replacing the gas tax has increased slightly over time (Agrawal, Nixon, and Hooper 2016). Media coverage is important in shaping public opinion and has become more positive over time for RUC. Message repetition is critical in changing opinions and attitudes (Agrawal, Nixon, and Hooper 2016). RUC pilot post-participation research shows relatively strong support, indicating that personal experience with RUC may ease concerns people have about the system (Agrawal, Nixon, and Hooper 2016; WSTC and WSDOT 2017). D'Artagnan Consulting (2013) found that attitudes towards RUC improved or remained neutral after participating in a pilot program. Direct experience with RUC may be the most effective way to shift public opinion on the topic, as demonstrated by Oregon's second pilot program (ODOT 2017).

The strongest evidence for the power of direct experience comes from the congestion pricing literature. Public opinion towards managed lanes is typically negative before implementation, but after familiarity increases, people generally support managed lane tolls (EnviroIssues 2007; Golob 1999; Greene and Smith 2009; Li et al 2002). Greene and Smith (2009) note that drivers' familiarity with managed lanes is the key determinant of their opinion of the system. The international literature also finds that experience with congestion pricing substantially increases public support (Hamilton et al 2014).

The first step in public education and messaging is to identify the objectives of RUC and clearly communicate them to the public. This communication should be direct and carefully worded to accommodate different levels of technology skills and awareness. It must also explain the reason for changing from a fuel excise tax to a RUC scheme and why a mileage-based system is preferable to fuel tax. Participants are receptive to raising the fuel tax or switching to a new system entirely (e.g. RUC) when they know how the transition will unfold and why it needs to happen. People need to contextualize RUC fees in a meaningful way. Therefore, comparisons to existing and familiar fees, such as gas tax costs, would help people better understand how RUC will impact them (Rephlo 2013).

Communication should provide details about how the revenue collected through RUC goes towards transportation funding and how that funding is split among different projects and government levels (e.g. local, county, and state levels). It is critical to demonstrate why projects are needed and how they benefit residents (Dieringer Research Group 2007; WSTC and WSDOT 2017). A study of pricing acceptance for managed lanes drew similar conclusions (EnviroIssues 2007).

As part of their education efforts, RUC advocates and administrators should explain how privacy concerns, technology costs, and enforcement will be addressed. They should demonstrate how the system will be convenient, accurate, and fair (Duncan et al. 2017). Having multiple ways for drivers to measure mileage helps them feel like their concerns are being addressed (Duncan et al 2017; ODOT 2017; WSTC and WSDOT

2017). Keeping technology and pricing as simple as possible also builds confidence in the system (Zmud and Arce 2008).

The literature reveals the following pitfalls when implementing and messaging about a RUC or congestion charge:

- A common reason for opposing congestion pricing is that the public views the fees as a new tax (and people dislike taxes more than tolls) (Zmud and Arce 2008).
- People are resistant when they do not think the time-cost tradeoff benefits them. Time savings is the main benefit that travelers are expecting to receive from congestion charges, and they often feel the savings are not worth the fee they pay (Harrington, 1997). It may be beneficial to include messaging about other benefits besides time savings to build support.
- A key communications angle is declining fuel excise tax revenue and clearly connecting RUC revenue to infrastructure projects that directly benefit drivers (WSTC & WSDOT 2017).
- Opponents of mileage-based fees are more interested in acting to prevent their implementation than supporters are in defending the system (Duncan et al 2017).
- Finally, people respond strongly and negatively to the language of "tracking" because it conveys social engineering and "Big Brother" (see Dieringer Research Group 2007).

Gaps in the Attitudinal Research

Agrawal, Nixon, and Hooper (2016) identify these gaps in the domestic literature on perceptions of RUC:

- How does opinion vary based on geography, demographics, travel behavior, vehicle type, or other factors? What are the most important factors?
- How do subgroups within the population (low-income drivers, minority groups, rural residents) perceive the fairness of RUC? (Mostly participants external to these groups have expressed concern on their behalf.)
- How does familiarity with transportation funding processes affect support for RUC?
- Does support for RUC charges depend on how revenue raised will be used?
- What role does the media (specifically social media) play in influencing attitudes towards RUC?
- Does education about transportation issues or RUC specifically change levels of support for RUC? Does direct program experience? (There is room for more pre-/post-implementation studies and message testing because the data to date are not quite sufficient to confirm this.)

Some other gaps identified during this review include:

- Very few research efforts have presented participants with specific rate structures to compare their acceptability.
- More research is needed on the relative perception of different revenue mechanisms rather than simply the absolute acceptability of each. Why is a fuel excise tax preferable to a RUC or to a congestion toll? Does this change depend on the information available about each system?
- What are the most effective means for communicating the benefits of congestion charges without raising concerns of social engineering?
- Are there specific concerns about congestion charges that could be alleviated by combining them with a RUC?

Assessment of Proposed RUC Technologies for Congestion Pricing

Understanding the public's perspective on simplicity, privacy, and transparency is important to selecting RUC technologies for widespread deployment. However, if there is an interest in being able to include congestion charges in a RUC scheme now or in the future, planning for education and implementation should make sure to cover the technologies that can meet those needs. This section presents analysis of five technologies and how they could support variable charging in congested locations. It begins with several observations on the systems being used today.

Location privacy. All currently tested or envisaged systems have a focus on location privacy. This is clearly in response to the findings about public attitudes towards privacy. In many cases, users can opt for technologies that do not record location data. When location data is recorded it is usually transmitted to a RUC system vendor and solely used for distinguishing chargeable from non-chargeable (e.g. out of state, off-road, private) road use. The location data is not sent to the state and must be deleted within a given timeframe (usually 30 days after account settlement/payment, to allow time for the driver to contest the charges). Congestion charges will require accurate location information and implementation may reduce the flexibility of users to choose from many different reporting technologies.

Prevalence of vehicle-only systems. Most systems that are being tested in pilot programs use vehicle-only components and do not rely on external (e.g. road-side or pump-side) infrastructure other than cellular communication services. Exceptions are California's (upcoming) pay-at-the-pump pilot, which envisages pump-side infrastructure with which in-vehicle components will communicate (likely over DSRC) and transponder- or Automatic Number Plate Recognition (ANPR)-based express lane tolling (Colorado, California, Utah, and Washington). In contrast, some international systems use transponder-based systems for relatively accurate RUC collection. On the other hand, all current congestion charging frameworks we know of utilize roadside infrastructure. These two perspectives will need to be reconciled if the systems are integrated.

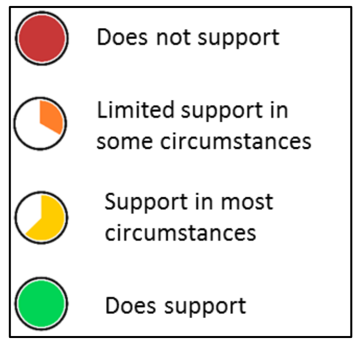
OBD-II systems and charge evasion. OBD-II systems can be evaded by disconnecting the device. Newer OBD-II-based systems with limited energy autonomy enable automatic transmission of an alert upon being disconnected from the vehicle. These devices are now available from manufacturers. However, no enforcement policies have been tested yet based on this technology. One feasible policy would charge a flat fee per day that the device is disconnected. Setting the level of the flat charge, preventing false positives, and adjudicating contested fees could still pose enforcement challenges. Congestion charges and other modifications or increases to the RUC rate could make evasion more attractive at certain times or locations. Other enforcement measures to address removal of OBD-II could be more invasive.

SUMMARY: APPLICABILITY OF TECHNOLOGY TYPES

Congestion charges can be levied using a time-variable rate (TVR) or fixed rate (FR). The information on *when* a vehicle has travelled on a specific corridor, lane, facility, or within a specific area is important for time-variable rate congestion charging. If fixed rate congestion charging is applied, *when* a usage occurred is not relevant, but *if/how often* is relevant. Both require accurate location information as they would be required at a finer resolution than a standard RUC.

Figure 12 provides a key to the rest of this section. It uses intuitive symbols to show where the best and worst compatibility exists between different frameworks and technologies. Figure 13 summarizes the findings of the review in a single graphic, which facilitates comparison between technologies, while Figure 14, Figure 15, Figure 16, Figure 17, and Figure 18 provide more detailed discussion of how technologies could work with different congestion charge frameworks. The subsection with detailed descriptions of the technologies gives more specific descriptions of the specific technology packages being analyzed and refers to Figure 11 for information on the types of congestion charges.

Figure 12. Pricing Tech Key



Generally, without location information from GPS or roadside infrastructure, location-based charge variation will not be feasible. From the perspective of including congestion charges, both cellular-equipped OBD-II devices and annual odometer readings are equally lacking in detail. OBD-II is likely to remain an important component of RUC systems because it does not suffer from the urban canyon effect. GPS alone – even without OBD-II – could support cordon charging and combined with OBD-II is the most viable solution to distance-based variable charges within designated areas. However, commercially-available GPS might struggle to provide enough resolution to identify travel in specific lanes without the augmentation infrastructure.

Figure 13. Compatibility Between Technologies and Congestion Pricing Types

	Priced Corridor	Bridge/ Tunnel	HOT Lane	Cordon	Area
Odometer Reading	● (red)	● (red)	● (red)	● (red)	● (red)
OBD-II without GPS	● (red)	● (red)	● (red)	● (red)	● (red)
OBD-II with GPS	● (green)	◔ (yellow)	◔ (orange)	● (green)	● (green)
License Plate Recog	● (green)	● (green)	● (green)	● (green)	◔ (orange)
DSRC Transponder	● (green)	● (green)	● (green)	● (green)	◔ (orange)

Roadside infrastructure for license plate reading or dedicated short range communications (DSRC) systems can best integrate HOT lanes and a RUC system. Along with OBD-II, they provide a means to administer area charges, but are not necessarily more attractive than GPS-enabled OBD-II devices.

Depending on the goals of future systems, multiple technologies may continue to be necessary for the most accurate and dependable system. The technology source of mileage and location information is also independent of the reporting technology, as manual period reporting, cellular-enabled reporting, and schemes like pay-at-the-pump are all equally capable of transmitting charges for different numbers of miles at different rates if designed with that objective.

Detailed Tables: Measurement Technology

Periodic mileage reporting encompasses odometer reading, typically carried out by official representatives or by the driver or owner of the vehicle, using a web interface, smartphone app, or other IT solution for entering the data.

Figure 14. Periodic Odometer Reporting

Types of Congestion Charge				
Controlled Access Toll Corridors	**Facility Access Toll**	**Lane Toll**	**Cordon Charge**	**Area Charge**
Periodic mileage reporting **does not support** controlled access toll corridor congestion charging. Operators cannot infer if/when/how often a vehicle has travelled on chargeable corridors and for what proportion of the measured overall distance.	Periodic mileage reporting **does not support** facility access tolling. Operators cannot infer if/when/how often a vehicle has used a facility.	Periodic mileage reporting **does not support** lane tolling. Operators cannot infer if/when/how often a vehicle has travelled on chargeable lanes and for what proportion of the measured overall distance.	Periodic mileage reporting **does not support** cordon charging. Operators cannot infer if/when/how often a vehicle has passed the chargeable cordon.	Periodic mileage reporting **does not support** area charging. Operators cannot infer if/when a vehicle is inside the chargeable area nor what proportion of the measured overall distance has been travelled within the area.

Figure 15. OBD-II On-Board Unit without Access to GNSS[14] Information

Types of Congestion Charge				
Controlled Access Toll Corridors	**Facility Access Toll**	**Lane Toll**	**Cordon Charge**	**Area Charge**
OBD-II on-board units without access to GNSS **do not support** controlled access toll corridor congestion charging. Operators cannot infer if/when/how often a vehicle has travelled on chargeable corridors and for what proportion of the measured overall distance.	OBD-II on-board units without access to GNSS **do not support** facility access tolling. Operators cannot infer if/when/how often a vehicle has used a facility.	OBD-II on-board units without access to GNSS **do not support** lane tolling. Operators cannot infer if/when/how often a vehicle has travelled on chargeable lanes and for what proportion of the measured overall distance.	OBD-II on-board units without access to GNSS **do not support** cordon charging. Operators cannot infer if/when/how often a vehicle has passed the chargeable cordon.	OBD-II on-board units without access to GNSS **do not support** area charging. Operators cannot infer if/when a vehicle is inside the chargeable area nor what proportion of the measured overall distance has been travelled within the area. (An exception could occur if there are means to ensure a vehicle is *only* driven within a chargeable area, e.g. because it is only licensed to travel there and not outside.)

14 Global Navigation Satellite Systems (typically GPS in the United States, possibly additionally Galileo, GLONASS); GPS can achieve horizontal accuracy of 3 meters and vertical accuracy of 5 meters 95% of the time (this is based on 4 meters root mean square error (95% confidence interval at 7.8 meters) for satellite-to-receiver distance (http://www.gps.gov/technical/ps/2008-SPS-performance-standard.pdf). Systems integrating various GNSSs (e.g. GPS, Galileo, GLONASS) (available in smartphones) should theoretically achieve better accuracy. GNSS accuracy (http://www.gps.gov/systems/gps/performance/accuracy) generally depends on factors such as satellite-receiver geometry, signal blockage and ("multipath") signal reflection (e.g. in urban 'canyons', in forests, around bridges and other tall structures), atmospheric conditions (cf. ionospheric delay effect), solar conditions, (non-)use of augmentation systems such as WAAS or CORS (http://www.gps.gov/systems/augmentations), and receiver quality.

Figure 16. OBD-II On-Board Unit with Access to GNSS Information

Types of Congestion Charge				
Controlled Access Toll Corridors	**Facility Access Toll**	**Lane Toll**	**Cordon Charge**	**Area Charge**
GNSS-enabled OBD-II on-board units **support controlled access toll corridors**. Distance travelled, date, and time are typically obtained via OBD-II port (OBD-II-based distance being more precise than GNSS-based). GNSS location information is used to determine chargeability (vehicle on or off controlled access toll corridor).	GNSS-enabled OBD-II on-board units **support facility access tolling for most types of facilities**, considering typical GPS accuracies of several meters and typical facility scales of dozens to hundreds of meters. Underground facilities (facilities without GNSS reception) and facilities that induce major GNSS errors will need special processing on part of the system operator for detecting entering and exiting of the facility. Location within/on such facilities can to some degree be inferred using auxiliary systems such as dead reckoning or inertial measurement units.	GNSS-enabled OBD-II on-board units **do not support lane tolling for all environments and conditions**. In good conditions, GPS accuracy combined with a dedicated, vendor-operated, sufficiently-dense D-GPS-like (differential GPS) augmentation system (similar to WAAS and CORS) should achieve high enough (sub-lane scale) accuracy. However, despite U.S. patent application US20120215594[15], industry news[16], and an EU research program[17], we are not aware of a successful operational system. Even with an augmented-GNSS solution, situations like urban canyon may still pose accuracy problems.	GNSS-enabled OBD-II on-board units **support cordon charging** as typical spatial separation between “gates” through a cordon is considerably larger than expected GNSS accuracy even in urban contexts. Note: OBD-II readout is not required for cordon charging as only crossing the cordon is critical for chargeability, not distance travelled.	GNSS-enabled OBD-II on-board units **support area charging** as typical extent of chargeable areas is considerably larger than expected GNSS accuracy even in urban contexts. Distance travelled, date, and time are typically obtained via OBD-II port. GNSS location information is used to determine chargeability (vehicle within or outside of chargeable area).

15 https://www.google.com/patents/US20120215594
16 E.g. http://www.traffictechnologytoday.com/news.php?NewsID=34192
17 https://www.gsa.europa.eu/gnss-innovative-road-applications-0

ANPR is one of the most common methods of collecting standard and congestion-based tolls, although it is most often employed as a backup system now, with transponder systems (discussed next) being more common. Installation of ANPR hardware for a cordon provides very high location accuracy and has been a proven method in other markets. A physical cordon also allows time of day information to be associated with travel across it and likely provides a logical location for displaying the fees/rates associated with a congestion charge – something GPS systems struggle to communicate.

Figure 17. Automatic Number Plate Recognition

Types of Congestion Charge				
Controlled Access Toll Corridors	**Facility Access Toll**	**Lane Toll**	**Cordon Charge**	**Area Charge**
ANPR **supports controlled access toll corridors**, both in the case where charges are levied per use of a toll corridor and per unit of distance travelled on the toll corridor. In the first case, ANPR facilities need to be in place on all ramps onto the corridor. In the second case, on all on- and off-ramps.	ANPR **supports facility access tolling**.	ANPR **supports lane tolling**. For minimum roadside infrastructure, the tolled lane is physically separated from the non-tolled lanes. In such a configuration, the required number of ANPR facilities is lower than in a configuration where vehicles could float more freely between tolled and non-tolled lanes.	ANPR **supports cordon charging**.	ANPR **supports area charging only to a limited degree under certain circumstances**. To be able to charge for the distance travelled within the chargeable area, the network of ANPR facilities would need to be very dense or partly rely on estimates (which could partly be gamed by drivers). Alternatively, the system would need to be complemented with a time-stamped method to measure travelled distance (e.g. an OBD-II device recording odometer readings in defined intervals of time and/or distance).

The advantages and weaknesses of a transponder-based gantry system are very similar to an ANPR system.

Figure 18. Transponder System (e.g. Gantry System with In-Vehicle RFID Tags)

Types of Congestion Charge				
Controlled Access Toll Corridors	**Facility Access Toll**	**Lane Toll**	**Cordon Charge**	**Area Charge**
Transponder Systems **support controlled access toll corridors**, both in the case where charges are levied per use of a toll corridor and per distance travelled on the toll corridor. In the first case, transponder system facilities need to be in place on all ramps onto the corridor. In the second case, on all on- and off-ramps.	Transponder Systems **support facility access tolling**.	Transponder Systems **support lane tolling**. For minimum roadside infrastructure, the tolled lane is physically separated from the non-tolled lanes. In such a configuration, the required number of transponder system facilities is lower than in a configuration where vehicles could float more freely between tolled and non-tolled lanes.	Transponder Systems **support cordon charging**.	Transponder Systems **support area charging only to a limited degree under certain circumstances**. To be able to charge for the distance travelled within the chargeable area, the transponder system network would need to be very dense or partly rely on estimates (which could partly be gamed by drivers). Alternatively, the system would need to be complemented with a time-stamped method to measure travelled distance (e.g. an OBD-II device recording odometer readings in defined intervals of time and/or distance).

CONCLUSIONS

This study has provided initial insights into the importance of the types of parameters tested and the potential effects of introducing both a flat rate RUC and RUCs based on policy considerations related to the distances households travel, the fuel types typically encountered in registered passenger vehicles and light duty commercial vehicles, and location of households. In most cases, the average differences in costs for households when transitioning from an excise-based fuel tax to a mileage-based fee structure are comparatively low.

However, as can be seen in assessments of the distribution of costs, there are a range of distributional effects both within and between the types of geographic areas at the census tract level that could be accounted for in formulating policy and implementing RUCs. It is important to consider these differences and account for the driving characteristics and policy preferences of each state. As was discussed in this report and shown in Appendix C, the distribution of household costs associated with transition to a RUC within census tracts classified as urban, mixed, and rural can extend across a broad range.

The importance of a multistate study such as this is that by using consistent methods of analysis and definitions to test geographic distribution of household costs and ways of formulating potential RUC systems, similarities and differences between states involved in the study can be identified, discussed, and addressed as RUC implementation proceeds through the next stages of planning. The multistate study identified both technical considerations (e.g., detail and reliability of registration data needed to estimate and differentiate mileage by geographic area) and policy considerations (e.g., differences in fleet composition and household travel patterns between states, and how these might affect implementation). Also, a better appreciation of the issues faced by all participating states can be developed, especially since a consistent methodology is used.

There are several different packages of technologies that could enable integration of congestion charging and RUC. However, due to privacy concerns, some of the mileage reporting methods being offered to RUC pilot program participants are not technologically capable of facilitating congestion charging. Future congestion pricing implementation would be made easier by designing RUC systems to include technology in the near term even if that technology is not used immediately, as it will be much more difficult to add technical capabilities in the future.

Some states have made progress with addressing privacy concerns through third-party account managers, but this will continue to be a concern as more pilot studies are implemented and program participation grows. There is a good chance that familiarity with the programs will increase the acceptability over time, but this could be a slow process. Because congestion charging would increase the complexity of a RUC program, this could also challenge support both from the public and from policy makers. Additional complexity further increases the importance of user experience design and planning, and provision of high quality interfaces for transparent reporting and billing.

Congestion charging addresses one of the most important transportation challenges of urban areas. Experience with implementation of managed lanes and other programs shows that support is typically robust once past the implementation phase. However, congestion charging could potentially be considered at odds with a narrative of RUC increasing revenue fairness and equity. Drivers in some areas may already be more familiar with congestion charging technology and the concept of congestion charges than with RUC generally. For others, education will be important for both concepts.

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Appendix A - Data Preparation

Introduction

This appendix presents the approach to collection, preparation, and processing of data in a framework for road usage charge estimation using publicly available data and vehicle registration records. It provides additional detail on the analysis methods for which an overview was given in the Overview of the Financial Analysis Process section of this report. It does not provide new information on the implications of transitioning from a gasoline excise tax to a road usage charge but should provide sufficient information for agency analysts to understand the data used and process undertaken such that they could extend or reproduce the analysis if desired. The focus is on methods and concepts, not specific calculations or data structures, since there are many ways that it would be possible to execute this analysis.

This project used the following data sources to test the financial impacts of parameterized RUC rates:

1) American Community Survey (ACS) data (this study used the 2011-2015 5-year sample)
2) State vehicle registration data including vehicle identification numbers (VINs) and location information,
3) The Product Information Catalog and Vehicle Listing (vPIC) tools from the National Highway Traffic Safety Administration (NHTSA),
4) The Environmental Protection Agency (EPA)'s records of vehicle fuel economy ratings,
5) Spatial boundary files for Census Bureau urban areas and census tracts,
6) The sets of equation coefficients for household daily vehicle miles traveled (VMT) from the Bureau of Transportation Statistics (BTS) 2009 National Household Transportation Survey (NHTS) Transferability Statistics report,[18]
7) State fuel excise tax rates, and
8) The 2010 Rural-Urban Commuting Area (RUCA) classifications from the U.S. Department of Agriculture's (USDA) Economic Research Service (ERS)[19].

Data Preparation

There are two major classes of data that need to be prepared for this analysis: tract level demographic and socioeconomic characteristics from U.S. Census Bureau sources and vehicle registration data from state motor vehicle divisions. These two major classes are discussed in the following subsection on data preparation. Data preparation includes data acquisition and processing into the format and variables needed for analysis.

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[18] See https://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/subject_areas/national_household_travel_survey/methodology for the Transferability Statistics report. There are 18 total equations - one equation for each of six geographies based on census divisions and regions, which are divided into urban, suburban, and rural components.

[19] This file can be downloaded here: http://www.ers.usda.gov/data-products/rural-urban-commuting-area-codes.aspx

In addition to the two major classes of data, tract-level geography files and some existing geographic classification data is necessary. This includes geometry files (e.g. shapefiles) for the census tract boundaries in each state and the urbanized areas of each state. Another key data source utilized is the Rural-Urban Commuting Area (RUCA) codes files from the UDSA Economic Research Service (ERS).

This work requires two different classifications of census tracts within a state. These tract attributes are static and based on 2010 census data. Following the 2020 census, urbanized area boundaries will be updated and updating this information would clearly be justified using new density information. One classification is used during Tract VMT Estimation, while the other is used for Comparisons and Result Tabulations.

Demographics and Socioeconomic Variables for VMT Estimation

Each tract must be associated with 10 demographic and socioeconomic variables drawn from decennial census or ACS data products from the Census Bureau. These variables were identified as valuable in estimating household daily VMT generation by BTS when calculating the 2009 NHTS Transferability Statistics equations in the paper Local Area Transportation Characteristics for Households.[20] For each tract, depending on its geographic location and characteristics, 5 to 8 of the variables are used in the regression equations. The 10 variables (census table and line numbers in parentheses) are as follows:

1) Count of Households (B11005 line 1)
2) Median Income (B19013 line 1)
3) Count of Household Vehicles (B25046 line 1)
4) Total Population in Households (B11002 line 1)
5) Owner-occupied Homes (B25009 line 2)
6) Number of Workers (B08137 line 1)
7) Households with at least 1 child under 18 (B11005 line 2)
8) One-person households, under 65 years old (B11007 line 8)
9) Multi-person households, no members over 65 years old (B11007 line 9)
10) Multi-person households, at least 1 member over 65 years old (B11007 line 4)

These data can be acquired via table searches on American Factfinder or from Census' Summary Files available from their FTP site.[21] The report analysis is based on 2011-2015 ACS summary files processed with an R script. For use in the Transferability Statistics, variables 3 through 10 should be normalized by

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[20] See http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/subject_areas/national_household_travel_survey/about for a brief description or http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/subject_areas/national_household_travel_survey/methodology to access the final technical documentation from the project.

[21] The site can be accessed at http://www2.census.gov/. The reports for the eight states included in the study utilized the most current 5yr data available at the time, downloaded from the acs2013_5yr folder on the FTP site.

variable 1. This converts raw counts in vehicles, persons and workers per household (for 3, 4, and 6) and percent of households in the category (for 5, 6, 8, 9, and 10). The natural logarithm of median income (2) is also a necessary variable.

In some cases, the Census Bureau may suppress some of these variables or have not collected enough information to impute them. An analyst using the tool can independently impute these values or allow them to drop out of the analysis. Removing tracts with missing values prevents invalid tract-level calculations from affecting state-level results. In the researchers' experience, most tracts with missing values have very low household counts and should not significantly impact analysis whether included or not. We have imputed missing tract means for household income and the number of vehicles based on areas of that state with the same Urban-Suburban-Rural classification.[22]

Some states have tracts with IDs that were changed or corrected since the 2010 Census.[23] If any tracts have been corrected, they will need to be renamed to match across data sources to prevent dropping from the analysis.

Processing Vehicle Registrations

This study used individual vehicle records for the full population of vehicles in each participating state. This level of detail provides significantly better analysis at small geographic scales then utilizing vehicle samples from NHTS or state travel surveys. The data collected during the registration process and stored by the agency in charge of vehicle registration rarely contains the full set of variables required by this analysis. To fill these gaps several data preparation steps are required, including:

Step 1: Allocation of vehicle registration data to census tracts:

1) removing out of scope vehicles,
2) identifying vehicle fuel type and vehicle characteristics for linking with EPA data,
3) matching to fuel efficiency information,
4) allocating vehicles to the geographic units of analysis (census tracts) and
5) calculating tract-level vehicle characteristics.

Step 2: Identification of five main fuel type groups:

1) Gasoline,
2) Hybrid,[24]
3) Electric or Hydrogen,

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[22] For the eight states, Vehicle ownership was imputed for 243 tracts and income was imputed for 25 tracts.

[23] Boundary changes or name changes can be found at https://www.census.gov/geo/reference/boundary-changes.html. For the eight-state analysis, names had to be reconciled for 7 CA tracts and 1 AZ tract.

[24] Because hybrid vehicles are classified separately from gasoline vehicles in registration databases, vPIC and EPA fueleconomy.com, the analysis tracked them separately through most stages. From a perspective of fuel tax payments these two fuel types are equivalent, but we have considered parameter formulas that address hybrids separately in the later steps.

4) Flex-fuel or Biofuel, and
5) Other Fossil Fuel (CNG, LNG, LPG, etc.).

These groups provide for treatment of different fuel tax types and coverage under different RUC parameterizations.

Finally, the fuel consumption characteristics of vehicle registered in each census tract need to be determined.

Step 3: Determine fuel consumption characteristics by census tract:

1) the percent of tract vehicles which belong to each fuel category,
2) the average fuel efficiency of tract vehicles in each category,
3) percent of tract vehicles of that fuel category above these fuel-efficiency thresholds:
    a. more efficient than 33% of vehicles statewide
    b. more efficient than 66% of vehicles statewide
    c. more efficient than 75% of vehicles statewide.

Details of the more involved components of each step are described below.

Removing Out-of-Scope vehicles

This analysis process was only interested in household non-commercial vehicles. Vehicles like trailers, golf carts, medium- and heavy-duty trucks, are covered under different tax and fee structures than passenger vehicles and will need to be studied under other research frameworks. Out-of-scope vehicles should be explicitly removed from the dataset. If information about vehicle type is available in registration information, it would be resource efficient to remove out-of-scope vehicles before using a VIN decoding tool.

Additionally, RUC West specified that diesel vehicles were out-of-scope for this effort. Some state registration databases include fuel type information that can be used to eliminate these vehicles to save processing time during the VIN decoding process as well.

Identifying Fuel Type and Vehicle Characteristics for Matching

Often fuel type is available in the registration data. When it is not, decoding VIN records provides this information. Usually VIN decoding is necessary for fuel efficiency matching, so registration reported fuel types can be compared with decoded fuel types for consistency. Most state registration databases had relatively incomplete or truncated information on vehicle make and model information. VIN decoding provided additional trim and engine characteristics as well to allow better matching to the EPA fueleconomy.com databases.

To match a vehicle’s fuel economy with the EPA database, generally at least make, model, model year, and fuel type are needed. Additional information such as number of cylinders, engine displacement, and transmission type may be useful. Depending on the information collected by the state agency in charge of vehicle registrations, some of the information required for determining fuel economy may be available immediately. Several of the states included in the initial study could provide fuel type and usable make, model, and year information. Other states were only able to provide VINs.

When working with only VINs, or VINs and less detailed make, model, and year information, it will be necessary to use a VIN decoding application. There are several commercially available services, but the NHTSA Product Information Catalog and Vehicle Listing (vPIC) products provide a robust publicly available service for VIN decoding.[25] There are several different tools available through an API collection for batch processing VINs.[26] When decoders fail to provide information on a vehicle, it can be assumed to be out-of-scope as decoders should cover most household vehicles from the last 30 years. Alternatively, available information for similar vehicles from the registration database can be used to make assumptions about fuel type and fuel efficiency.

After VIN decoding, it was necessary to eliminate additional out of scope vehicles that were not identified from original registration information. vPIC and most other VIN decoding tools provide information on vehicle type if desired. This output was used to remove vehicles such as golf carts and mopeds from the later analysis steps. In some cases, vehicle classifications from source data did not match with vehicle classifications in decoded data. Depending on time and resource constraints, it may be desirable to decode all registrations to see which type classification seems more dependable.

Matching to Fuel Economy

Fuel efficiency information comes from the EPA FuelEconomy.gov database for all model years. Few cars in regular use were produced before EPA began reporting fuel economy. The current databases have updated past fuel economy ratings to conform to current testing regimes, making EPA data comparable over time. For this study, we used the single overall fuel efficiency rating rather than the individual city and highway ratings provided by the EPA.

In some cases, decoded or source vehicle information will match perfectly with EPA records. In other cases, it will be necessary to use a process we refer to as “fuzzy lookups”. This process involves building linkages from the remaining problematic data to the EPA database entries using approximate matches rather than straight lookups. This is because of a few potential differences including:

1) The reporting and detail of the vehicle model (such as inclusion of number of doors, engine type) causing non-exact matches that cause a normal ‘lookup’ to fail.
2) Differences in abbreviations used in raw, decoded, and EPA data.
3) EPA not retesting vehicles which have no changes between model years, and consequently only including a record every few years.

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[25] See https://vpic.nhtsa.dot.gov/ all tools and descriptions and https://vpic.nhtsa.dot.gov/api/ for the API.

[26] For the eight-state study, API calls were made from an executable Visual Basic program with several options for interaction through a development environment console. All vehicles within the study were decoded from VIN information in order to apply a more consistent methodology across states.

There are several options to resolve imperfect matches, including the method we employed, which was to use a Jaccardian weighting tool to do our matching.[27] When making imperfect matches it is important to balance additional matched records with the risk of false positives. If too many records are matched to a fuel efficiency that is not close to the actual record, it could make statewide financial impact results less accurate than simply excluding those records.

If a relatively strict fuzzy lookup fails to produce additional matches between the data sets, it may be necessary to manually review records. Hopefully, at this point the majority of records have been successfully matched and there is some concentration of unmatched records. For example, in one state there were hundreds of Dodge RAM pickup trucks unmatched because EPA model names included whether vehicles are 2WD or 4WD. This alone could have been resolved by a fuzzy lookup, but other inconsistencies in model names meant these records came up for manual review and were a relatively easy fix. Manual review may also result in discovering that out-of-scope vehicles are the major issue.

Allocating to Census Tracts

It is necessary to process the vehicle data to align with the census tract demographic data that will support VMT estimates. All demographics inputs are readily available at for census tracts. However, vehicle inputs are likely available to agencies at a variety of geographic scales. Because of privacy concerns, different states were able to secure various levels of resolution for this research.

If address information is available, this can be geo-coded to specific locations and assigned a census tract in a bottom up approach. If only zip code or county of registration is available, down allocation from larger-scale geographies to census tracts will be necessary.

The researchers dealt with five different types of spatial assignment, which include most of the scenarios future analysts might face:

1) Census tract provided by source agency
2) Lat/long point provided by source agency → tract
3) Address → point → census tract
4) Zip code → census tract (results in fractional vehicles)
5) County → census tract (results in fractional vehicles)

Any point-based assignment to census tracts is preferable to a down allocation. Down allocation may require assigning fractions of less common fuel type vehicles to each tract within the larger geography. Geo-coding of addresses and assignment of points to tracts can be done using several products. Analysts used ESRI's Streetmap North America locators in ArcGIS. ArcGIS also has a default set of locators.

Even when working with data that provides full address information, some registrations are not located at a finer level of geography than the county. This could be due to spelling or typographical mistakes in

[27] If working in an Excel environment, the following site provides an explanation of the insufficiency of the built in functions and an add-in from Microsoft for fuzzy lookups similar to the ones used for the study: http://www.excel-university.com/perform-approximate-match-and-fuzzy-lookup-in-excel/.

the entries, inconsistencies between different levels of the address information (such as impossible zip code – county pairings), or simply a lack of sufficiently detailed information. In these cases, unassigned records are processed using a more aggregate assignment strategy.

Zip code assignment is more complicated because zip codes are based on line-based delivery routes that are imperfectly converted to polygons and not aligned with census tract boundaries. There are several data products available to establish a crosswalk between zip codes and census tracts.[28] Because each vehicle will be represented fractionally under this framework, a vehicle database will probably need to have duplicate entry and a field representing the fraction allocated to a tract. This will be necessary in the next step for calculating fuel type shares, average fuel efficiency by fuel type for a tract, and comparing the tract to state-wide efficiency percentiles.

County registrations were shared out by the number of households in each tract relative to the county-wide number of households. This can be done with the census tract household data discussed in the Demographics section, since tracts are subdivisions of counties and share borders. Fractional vehicles should be tracked similar to the zip code down allocation.

Records that cannot be spatially located or are outside the state's interest should be noted to understand differences in vehicle inputs at the beginning of the matching process and the set of vehicles used for analysis. There is no purpose in distributing unassigned vehicles across the state since the goal of the analysis is to examine within-state geographic differences.

Calculating Tract-level Vehicle Characteristics

Once all vehicles have been assigned fuel types, fuel efficiencies, and census tracts (or allocated among tracts), vehicles can be summarized to align characteristics with census tract demographic data. Until this point, vehicle data exists as a large database of records representing individual vehicles (or portions of vehicles), but after this step the data should have roughly the same number of entries as the demographic data.[29] **Error! Reference source not found.** shows roughly what vehicle data records might look like after processing to identify fuel type, fuel efficiency, and tract. **Error! Reference source not found.** shows roughly the format that census tract results were stored in for analysis in the next section.

Table A-1. Example Data Set After Prior Steps

Make	Model	Year	Fuel Type	Fuel Eff	Tract	Count
Ford	Focus	2014	Gas	25.2	06015100265	1
Ford	F150	2016	Gas	14.7	06015100265	.08333
Toyota	Prius	2015	Hybrid	57.2	06015100265	1

[28] The analysis for the reports utilized crosswalk files from the Census Bureau, available at https://www.census.gov/geo/maps-data/data/zcta_rel_download.html. This crosswalk uses Census' 2010 Zip Code Tabulation Areas, rather than using raw zip codes. The Department of Housing and Urban Development also publishes crosswalks between USPS ZIP codes and census tracts, which they update quarterly based on changes to ZIP Codes. See: https://www.huduser.gov/portal/datasets/usps_crosswalk.html.

[29] Some vehicles may be located in tracts that do not have population and few populated tracts will have no vehicles registered there, so there may be slight discrepancies.

For each tract, we summed vehicle counts to get the total tract vehicles. For each fuel type, we counted the number of vehicles in the tract and divided the result by the total tract count to get the percent of vehicles by fuel type. For each fuel type, average fuel efficiency was calculated (weighted to account for fractional down-allocated vehicles) for tracts.

For each state, we calculated the 33^{rd}, 66^{th}, and 75^{th} percentiles of fuel efficiency. For each fuel type, the number of vehicles over the statewide fuel efficiency percentile thresholds were counted and the percentage of vehicles of that fuel type in the tract was computed.

Table A-2. Example Final Outputs from Vehicle Processing for a Hypothetical Tract

Tract	Fuel	Percent	Fuel Eff	% Over 33rd	% Over 66rd	% Over 75rd
06015100265	Gasoline	0.92	24.11	.70	.32	.24
06015100265	Hybrid	.02	42.26	.98	.82	.62
06015100265	Flex/Bio	.05	18.66	.42	.26	.13
06015100265	Electric/H2	.0074	94.67	1.0	.95	.91
06015100265	Other Fossil	.0026	20.82	.48	.28	.11

The final data set should preserve the counts by fuel type as well as the calculated variables in **Error! Reference source not found.** in order to calculated weighted totals across fuel types for each tract in later analysis.

Appendix B - Formula Analysis Methodology

This appendix presents the steps required to calculate changes in transportation fee incidence among urban, mixed, and rural portions of a state and between vehicles of different fuel types. This analysis is presented in the Formula Impacts for by Fuel Type section and makes use of the data preparation described previously.

Tract VMT Estimation

This section covers application of the BTS Transferability Statistics for estimating VMT generated by residents of each tract in a state.

Step 1. Assign Urban-Suburban-Rural (USR) classification used by BTS for the Transferability Statistics. This classification must be assigned to match a tract with the appropriate VMT generation equation. The classification is based on whether a tract is within a Census-classified urbanized area or urban cluster[30] as well as the population density of the census tract. ***Table*** shows the classification rules and number of tracts in each group.

A tract is within an urban area if its geometric centroid is within the polygon area. This assignment was done by the researchers using ArcGIS for Desktop’s Select by Geography tool. The researchers used the population densities calculated by USDA in the RUCA code files from the 2010 Census. Updated information from the ACS was not used to be consistent with the classifications in place when the Transferability Statistics were estimated.

Step 2. Apply the Transferability Statistics equations to tract demographic information. For the states in this study, equations for three of the six census region groups were required. These equations were stored in a table with the same dimensions as the final tract demographic variables for easy application. The coefficients for these equations for each Census Division and Urban-Suburban-Rural class can be found in Tables A13 through A18 of BTS's technical report. The report also contains a full description of the functional form and derivation of these equations.[31]

Step 3. Annualize and scale the household daily VMT value. For this analysis, we used a full 365 days to scale from daily travel to the whole year. To scale from the average household to include all households, the value must simply be multiplied by the total household count contained in the census data.

[30] Urban areas are continuous groups of census tracts of blocks constructed from linking densely populated census tracts and blocks together by including some lower density tracts and non-residential areas. Urbanized areas and urban clusters are two types of urban areas, with a cluster defined by a population between 2,500 and 50,000 and an urbanized area with population greater than 50,000. Census tracts must have a density of 1,000 persons per square mile to initiate an urban area, after which census blocks with more than 500 persons per square mile can be added.

[31] See footnote 20 for information on the Transferability Statistics Report.

Table B-1. Urbanicity Index Categories used by BTS Transferability Statistics Analysis

Category	Census Tracts	With population density centile	Number of Tracts
Urban	In UAs	60 to 100	28,471
	In UCs	30 to 100	2,773
	Total (urban)		31,244
Suburban	In UAs	Greater than 0 and less than 60	18,464
	In UCs	Greater than 0 and less than 30	670
	Total (suburban)		19,134
Rural	Not in an UA or UC	N/A	22,153
	Total (rural)		22,153
No population (but land area)			208
Total			72,739

NOTES:

There are 318 Census tracts defined in the 2010 files with no land area. There are 208 tracts with land area but with no population in 2010.

Urbanized Areas (UAs) area areas with 50,000 or more people; Urban Region/divisions (UCs) are areas with at least 2,500 and less than 50,000 people. Census Tracts in UAs are defined as those with their centroid in an UA; Census Tracts in UCs are defined as those with their centroid in an UC.

Density centile was calculated by sorting Census Tracts with a population greater than 0 by their population density in ascending order and then assigning a score from 0 to 100 to each Census Tract according to this order. The Census tract with the smallest population density was assigned a score of 0 and the Census tract with the largest population density was assigned a score of 100.

Source: Figure 5 of the Transferability Statistics Report

Current Tax Payments

This section discusses the steps in estimating gas tax revenue from in-scope household passenger vehicles.

Step 4. Apply fuel type percentages to split tract VMT by the type of fuel consumed. This will give VMT by gasoline, VMT by electric, etc. This analysis assumes that on average vehicles are used the same regardless of fuel source. If the average annual VMT in a tract is 11,000 miles, both the average EV and the average natural gas vehicle are treated as traveling 11,000 miles per year. We are not aware of sufficiently conclusive evidence to treat vehicles of differing fuel types differently.

Step 5. Use each fuel type's mean fuel efficiency in a tract to estimate total fuel consumption for each fuel type. All EPA fuel efficiencies are available in gallons of gasoline equivalents. The results of this step are, therefore, total energy consumption for each fuel category in Gasoline gallon equivalents (GGEs).

Vehicles classified as gasoline, hybrid and flex-fuel are assumed to consume gasoline. The assumptions used by this analysis for flex- and bio-fuel vehicles are that 80 percent of vehicles use standard gasoline offerings, and 90 percent of bio-fuels are purchased from taxable retail outlets.

Step 6. Apply the state gas tax rate to the fuel consumption to estimate fuel tax paid. Almost all tax rates are provided in GGEs or were converted to line up with the data from the previous step. This step results in dollars for each fuel type which can be summed together to provide total estimated revenue from a tract. This value was adjusted to represent "sustainable" revenue levels for California, Oregon, and Utah.

California, Colorado and Hawaii tax biofuels at a lower rate than gasoline, while all states except Oregon tax other fossil fuels (like compressed natural gas) at lower rates. Arizona and Washington appear to still apply no tax to these fuels. The tax rates used in this project are recorded in Table 1 of the main report.

The gas tax payments in each census tract can be summed together to estimate total household passenger vehicle gas tax collections for a state, which will be needed later.

Alternative RUC Payments

This section discusses how we estimate payments under a variety of RUC formulas so that they can be compared with gas tax payments.

Step 7. Estimate equivalent miles eligible under a parameterized RUC formula. For the standard flat rate, this is simply the statewide sum of all tract VMT. For parameterized formulas, this is the key step in the analytic process. For mileage exemptions, total eligible VMT is reduced by subtracting the exemption from a tract's household average annual VMT based on the percent of vehicles qualifying and adjusting for household vehicle ownership levels in that tract.

For example, when testing a 2,000-mile exemption for EVs, if a tract has 1.2 percent EVs, average ownership of 2.1 vehicles, and average annual VMT of 16,000, 1.2 percent of households will only be counted as paying RUC on 11,800 miles. This adjustment is necessary given that households rather than vehicles are the unit of analysis. If there are 4,000 households in this tract, the total reduction in eligible miles is 201,600. This adjustment is repeated for all tracts in a state before summing to arrive at statewide VMT eligible for the RUC.

For rate adjustments, analysis is also done during this step rather than the next step, were you might expect it. This is done by calculating equivalent mileages. In this case, if a household travels 12,500 miles per year but must pay 20 percent more under Formula 5 due to the low efficiency of their vehicle, this will be recorded as 12,500 * 1.2 = 15,000 equivalent miles. The use of equivalent miles allows base rates to be accurately estimated in Step 8 and is otherwise analytically efficient. After calculating equivalent miles for each tract, they are again summed to a statewide total.

Payments are tracked for the VMT of each fuel type in a tract so that tabulations of payments and changes in payments by fuel type can also be provided.

Step 8. Calculate an equivalent RUC rate. After doing most of the analysis during the previous step, this is a straightforward division of total gas tax revenue collected (from Step 6) by RUC-equivalent/eligible VMT (from Step 7). Since "sustainable" revenue is calculated as a comparison value in Step 6, the same process can be used for calculating revenue-neutral and sustainable-revenue equivalent rates.

Step 9. Calculate total tract payments under a RUC. The equivalent rate calculated in the last step can be reapplied to the tract-level equivalent/eligible VMTs from Step 6 to estimate payments in each tract under the RUC.

Comparisons and Result Tabulations

This section documents how we calculated comparison metrics for financial impacts by different geographic classes and for different fuel types.

Step 10. Estimate tract-level changes in payments and percent differences. Payments under the gas tax can be subtracted from the payments under any RUC formula to estimate the change in payments. Dividing by gas tax payments provides a percent change metric.

Step 11. Assign Urban-Mixed-Rural (UMR) classification based on the RUCA codes. The primary codes designate 10 different categories of census tracts based on commuting patterns using 2006-2010 ACS

Journey-to-Work data and the urban area classifications developed from the 2010 decennial census. The primary codes can be seen in ***Table*** .

Table B-2. The 10 Primary RUCA Codes and Aggregation to Urban-Mixed-Rural Classes

Primary RUCA	Description of Primary RUCA	UMR Class
1	Metropolitan area core: *primary flow within an urbanized area (UA)*	Urban
2	Metropolitan area high commuting: *primary flow 30% or more to a UA*	Mixed
3	Metropolitan area low commuting: *primary flow 10% to 30% to a UA*	Mixed
4	Micropolitan area core: *primary flow within an Urban Cluster of 10,000 to 49,999 (large UC)*	Urban
5	Micropolitan high commuting: *primary flow 30% or more to a large UC*	Mixed
6	Micropolitan low commuting: *primary flow 10% to 30% to a large UC*	Rural
7	Small town core: *primary flow within an Urban Cluster of 2,500 to 9,999 (small UC)*	Rural
8	Small town high commuting: *primary flow 30% or more to a small UC*	Rural
9	Small town low commuting: *primary flow 10% to 30% to a small UC*	Rural
10	Rural areas: *primary flow to a tract outside a UA or UC*	Rural

The urban classification (RUCA codes 1 and 4) includes all census tracts were the primary commuting flow suggests that most of the tract residences and workplaces are within census-designated urban areas. This classification includes households who live in dense urbanized areas and those that live in smaller urban clusters but commute within the cluster's boundaries. Some census tracts on the urban fridge are also captured.

The mixed classification (RUCA Codes 2,3, and 5) captures census tracts that are not within urban areas but where significant portions of people commute to urban areas: at least 10 percent commute to areas with over 50,000 population or 30 percent commute to areas with over 10,000 residents. These tracts are much less dense and likely much more suburban, and in many cases even stretch out from population centers to include land with more rural settlement and land use patterns.

Rural areas (RUCA codes 6, 7, 8, 9, and 10) are classified as those tracts in which less than 30 percent of commuters go to areas with more than 10,000 residents and few people commute to larger urban areas. Residents of these tracts are likely to have to drive further to reach amenities than they drive for their daily commutes.

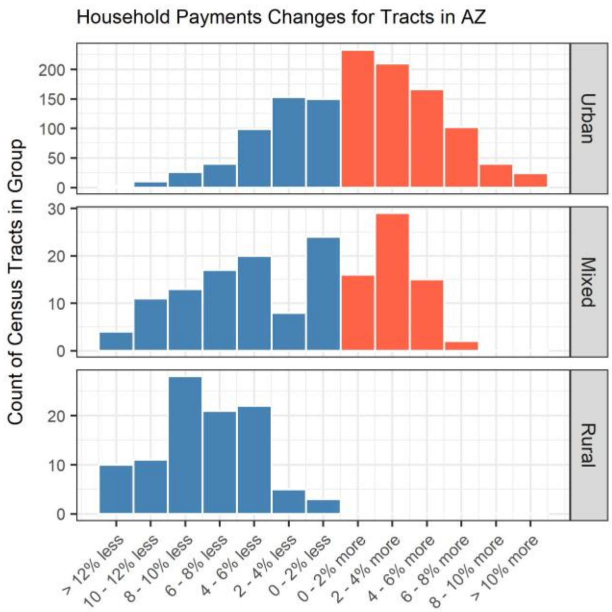
Step 12. Tabulate changes by UMR and fuel type. Several charts are provided in the body of the main report that count the number of urban, mixed, and rural tracts that experience different levels of change in payments. This requires adding up payments across fuel types for a tract.

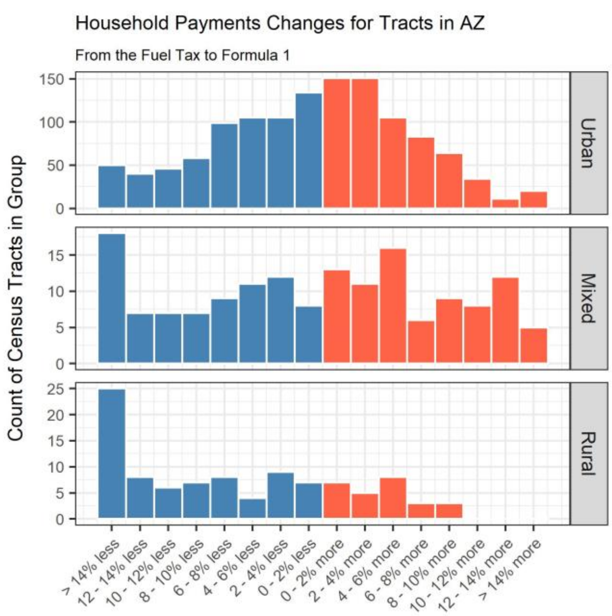
Tabular results aggregate the dollar value changes across all tracts of a geographic class in a state to get total changes in payments for a class before calculating the average percentage change by dividing by total statewide payments under the gas tax for that class of tracts.

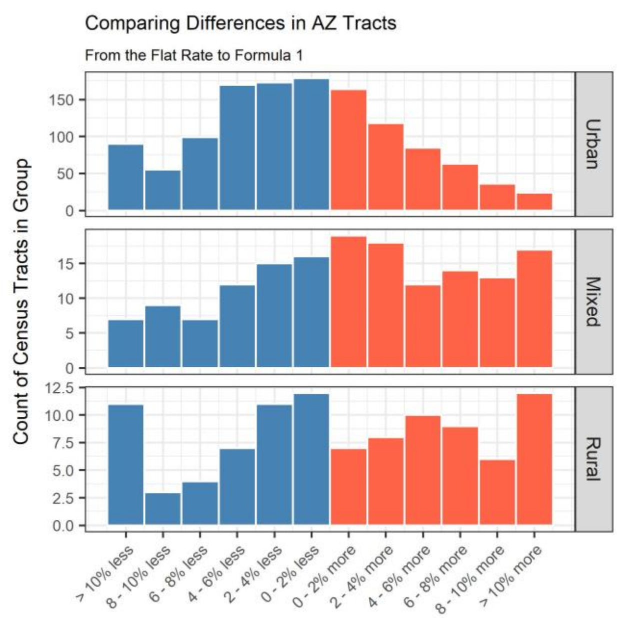
Changes in payments by fuel type are calculated by totaling across all tracts in a state while maintaining fuel type distinctions. Percentage changes are not presented because in cases such as EVs, they cannot be calculated since there is no gas tax payment for comparison.

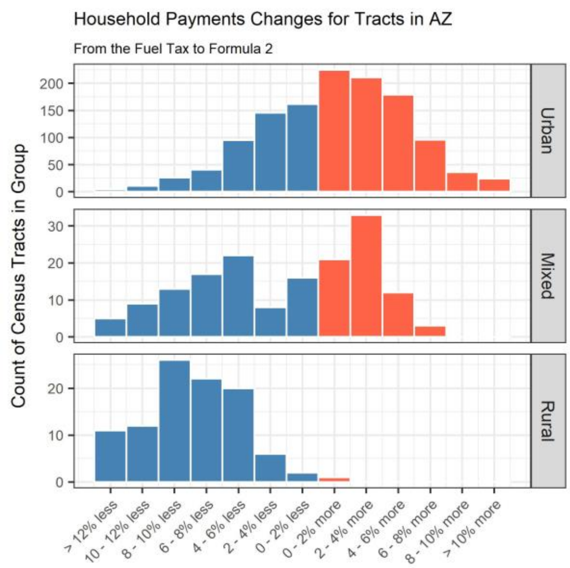
APPENDIX C - STATE REVENUE-NEUTRAL GRAPHICS

ARIZONA

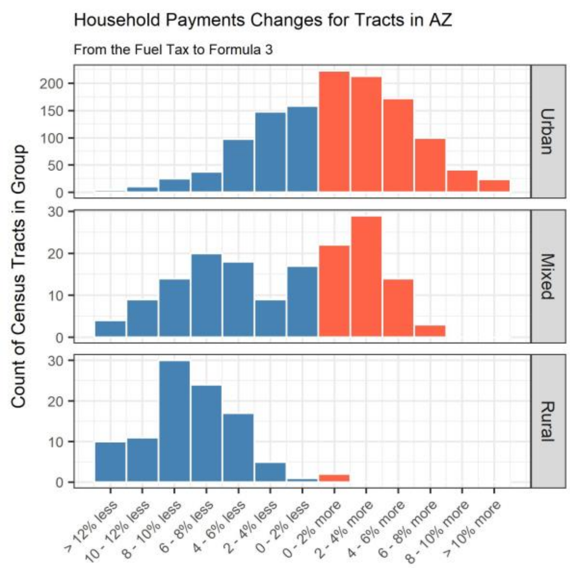




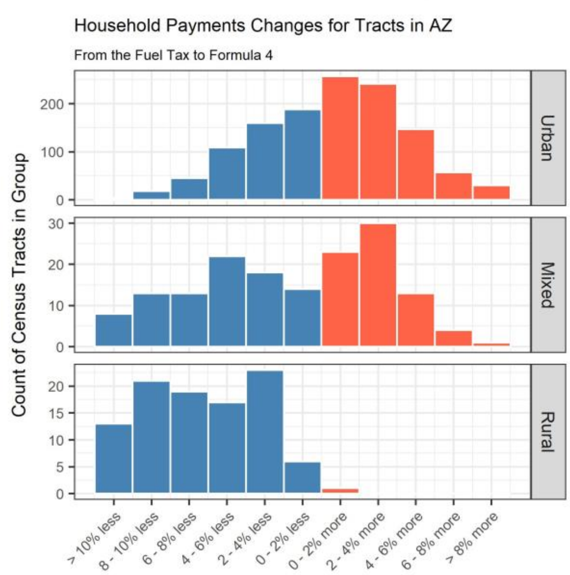


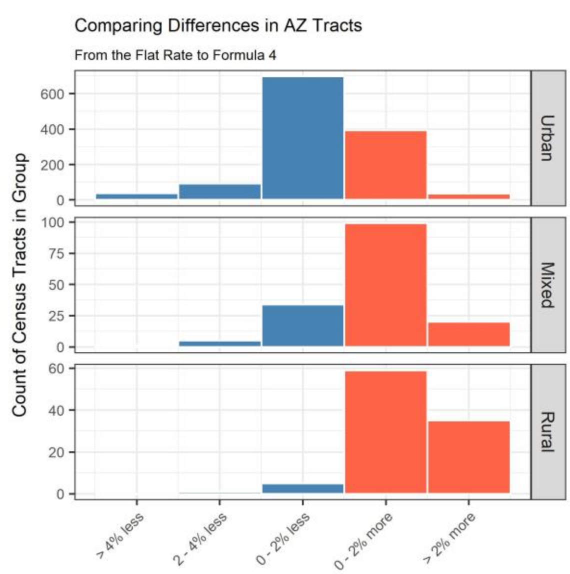


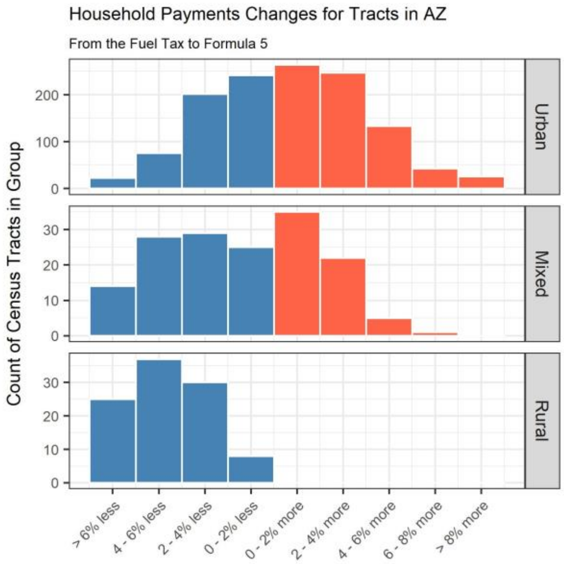
No changes relative to the flat rate are graphed, because shifts are almost all less than one percent



No changes relative to the flat rate are graphed, because shifts are almost all less than one percent



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Urban
Mixed
Rural
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2 - 4% less
0 - 2% less
0 - 2% more
2 - 4% more
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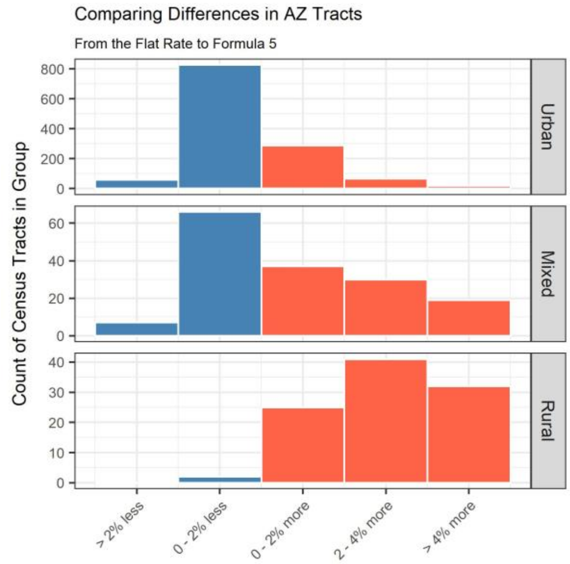
6 - 8% more
> 8% more


Comparing Differences in AZ Tracts
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Rural
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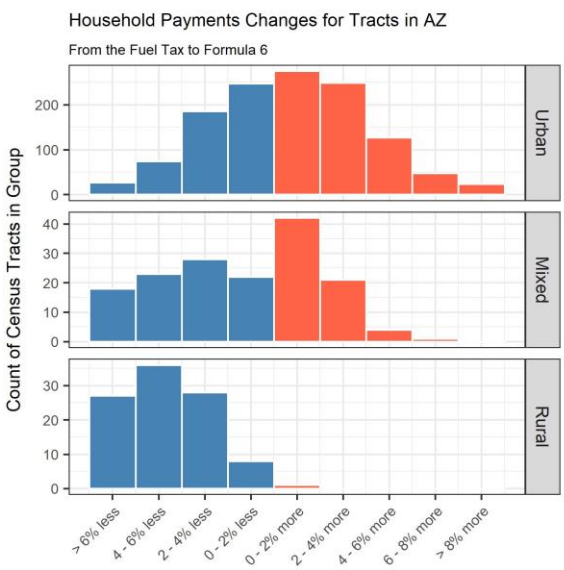
2 - 4% more
> 4% more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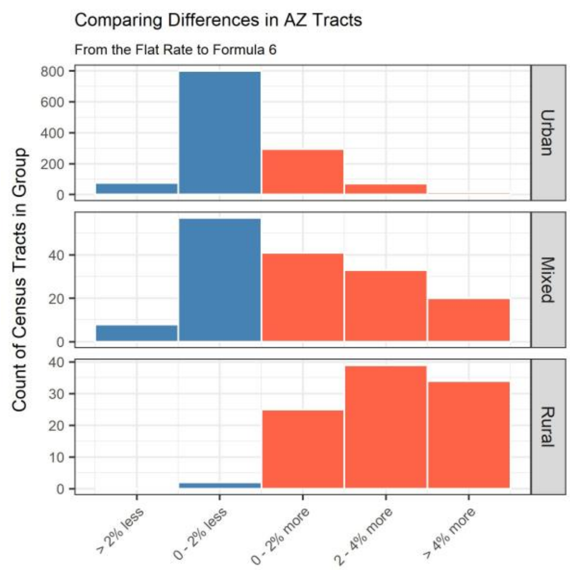
> 8% more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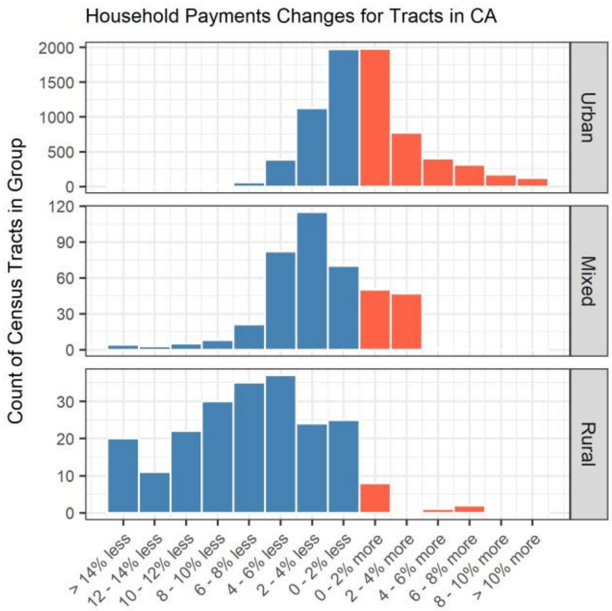
2 - 4% more
> 4% more

CALIFORNIA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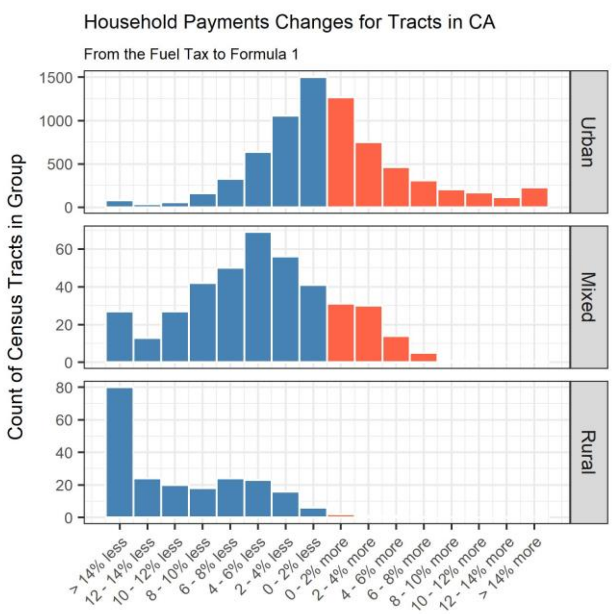
> 10% more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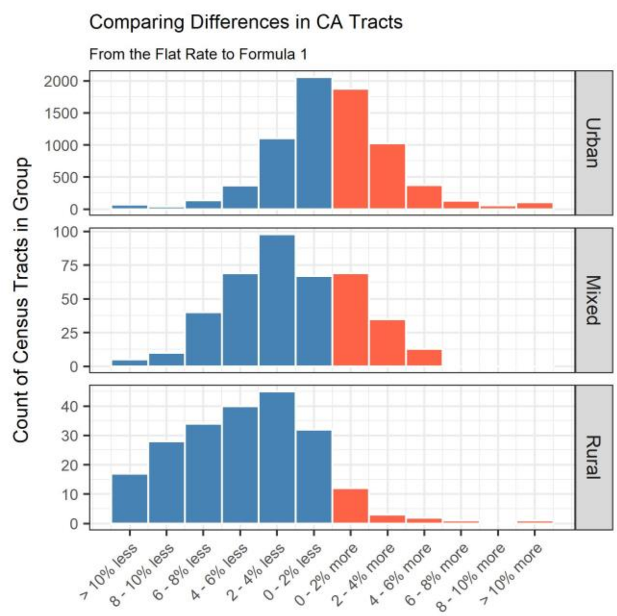
12 - 14% more
> 14% more


Comparing Differences in CA Tracts
From the Flat Rate to Formula 1
Count of Census Tracts in Group
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Mixed
Rural
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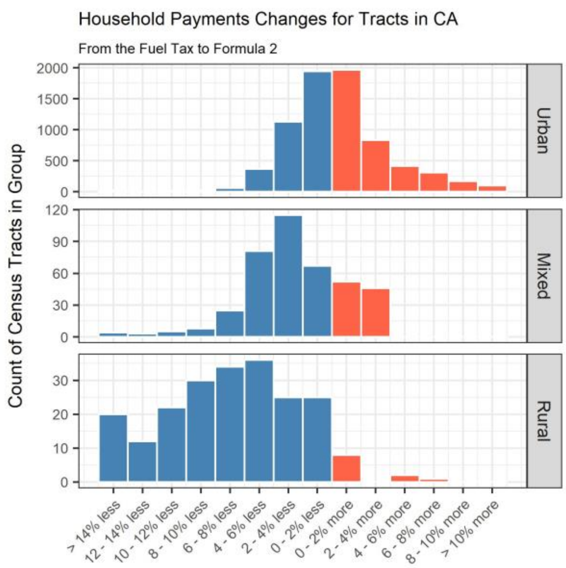
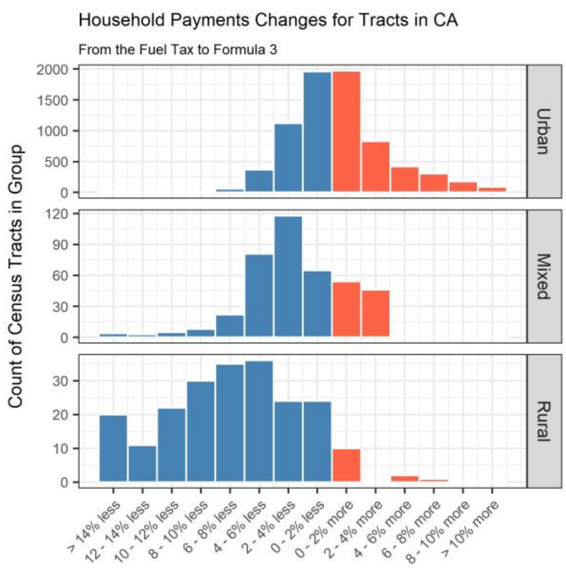
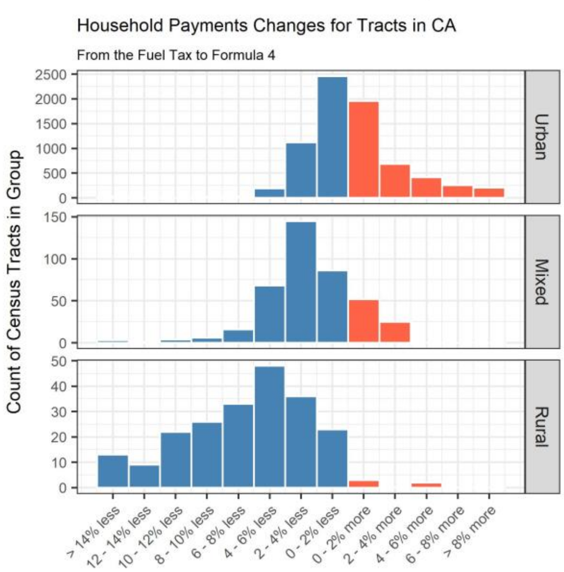
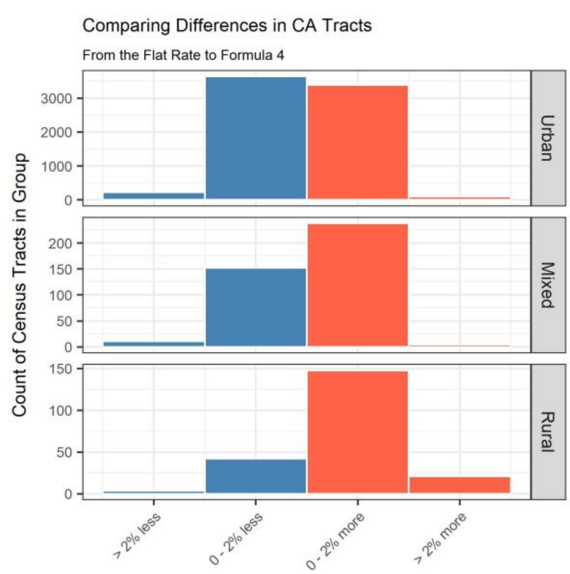


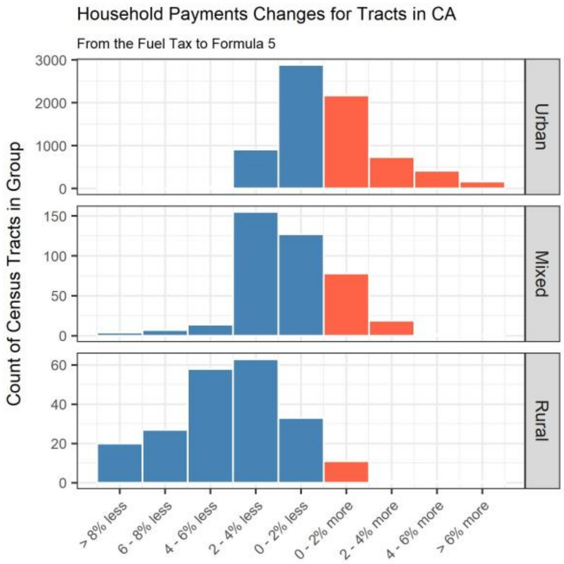
No changes relative to the flat rate are graphed, because shifts are almost all less than one percent

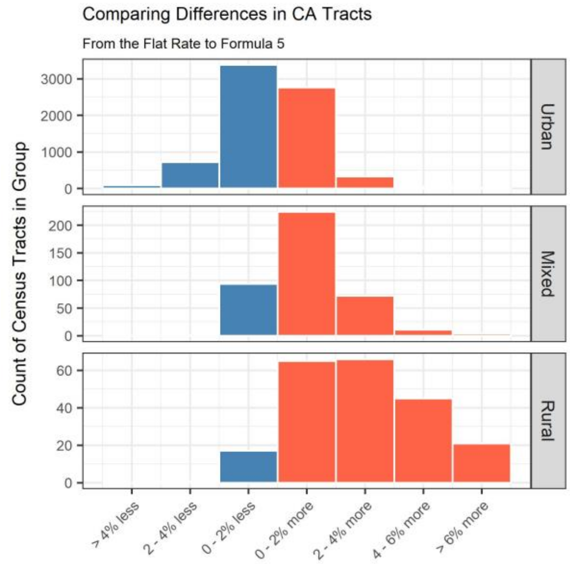


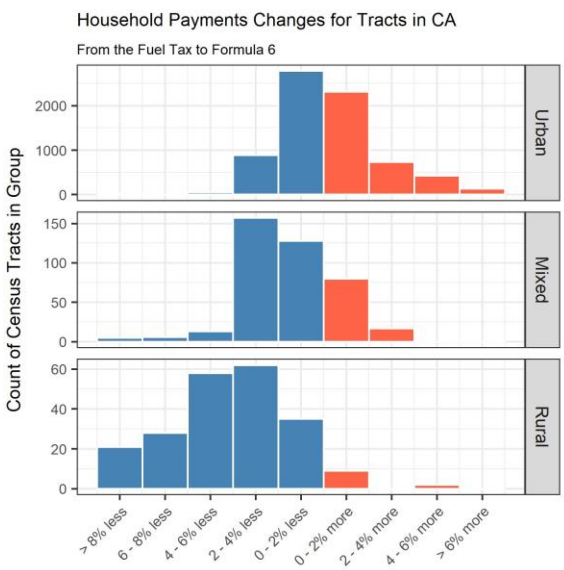
No changes relative to the flat rate are graphed, because shifts are almost all less than one percent

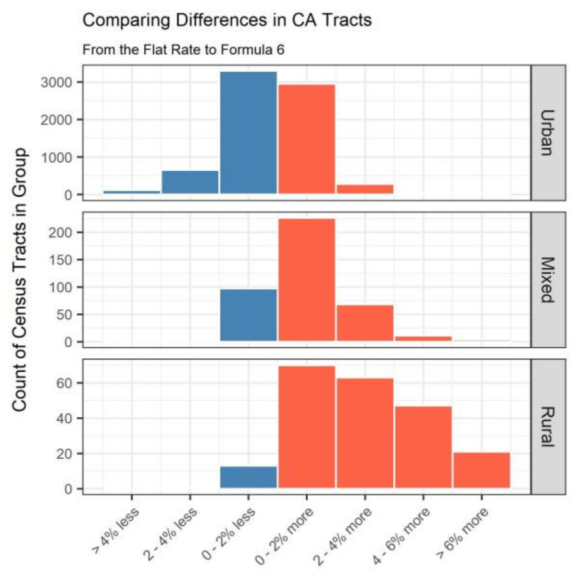




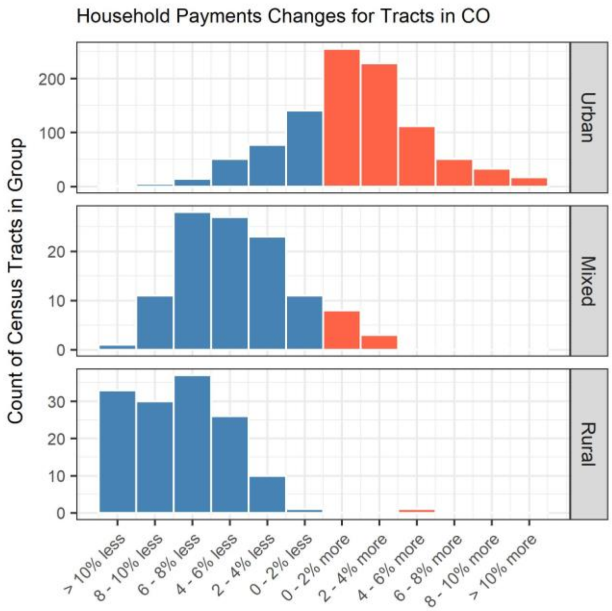

Household Payments Changes for Tracts in CA
From the Fuel Tax to Formula 5
Count of Census Tracts in Group
Urban
Mixed
Rural
> 8% less
6 - 8% less
4 - 6% less
2 - 4% less
0 - 2% less
0 - 2% more
2 - 4% more
4 - 6% more
> 6% more

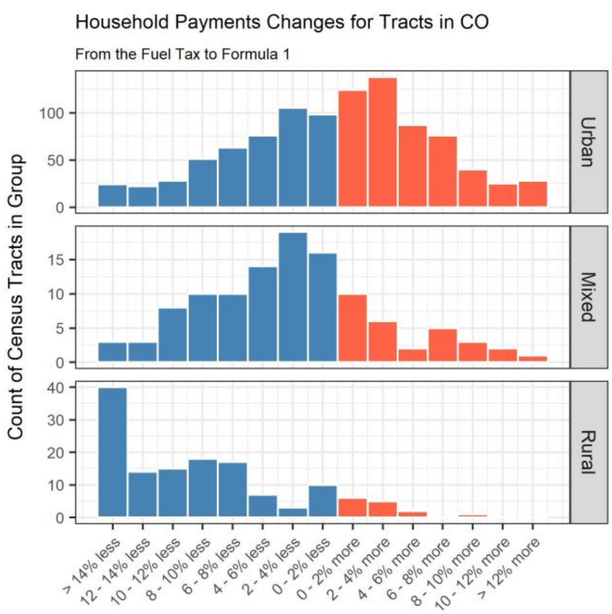

Comparing Differences in CA Tracts
From the Flat Rate to Formula 5
Count of Census Tracts in Group
Urban
Mixed
Rural
> 4% less
2 - 4% less
0 - 2% less
0 - 2% more
2 - 4% more
4 - 6% more
> 6% more

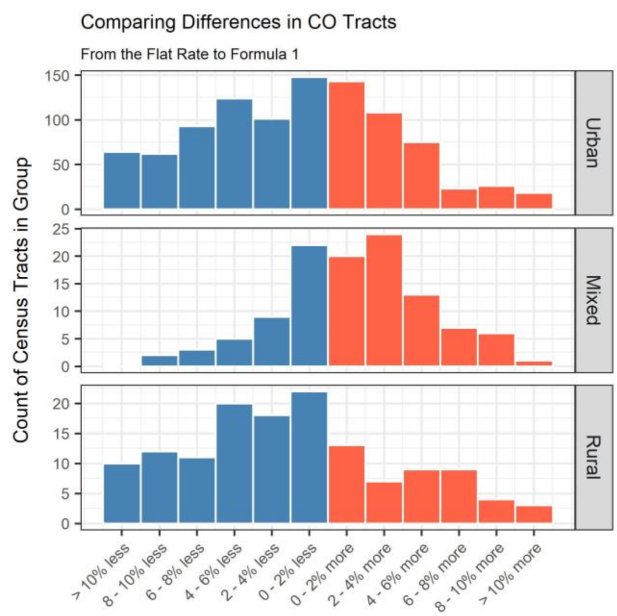

Household Payments Changes for Tracts in CA
From the Fuel Tax to Formula 6
Count of Census Tracts in Group
Urban
Mixed
Rural
> 8% less
6 - 8% less
4 - 6% less
2 - 4% less
0 - 2% less
0 - 2% more
2 - 4% more
4 - 6% more
> 6% more

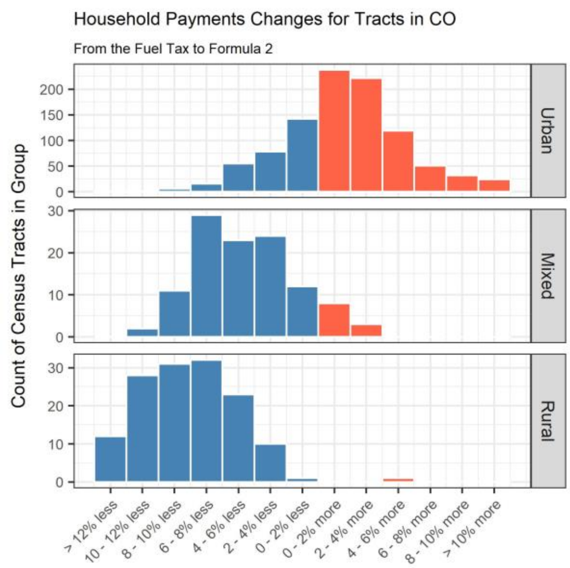

Comparing Differences in CA Tracts
From the Flat Rate to Formula 6
Count of Census Tracts in Group
Urban
Mixed
Rural
> 4% less
2 - 4% less
0 - 2% less
0 - 2% more
2 - 4% more
4 - 6% more
> 6% more

COLORADO

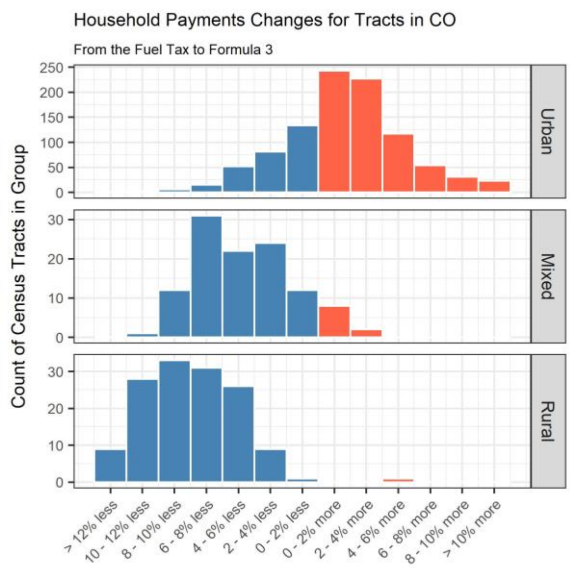

Household Payments Changes for Tracts in CO
Count of Census Tracts in Group
Urban
Mixed
Rural
> 10% less
8 - 10% less
6 - 8% less
4 - 6% less
2 - 4% less
0 - 2% less
0 - 2% more
2 - 4% more
4 - 6% more
6 - 8% more
8 - 10% more
> 10% more


Household Payments Changes for Tracts in CO
From the Fuel Tax to Formula 1
Count of Census Tracts in Group
Urban
Mixed
Rural
> 14% less
12 - 14% less
10 - 12% less
8 - 10% less
6 - 8% less
4 - 6% less
2 - 4% less
0 - 2% less
0 - 2% more
2 - 4% more
4 - 6% more
6 - 8% more
8 - 10% more
10 - 12% more
> 12% more

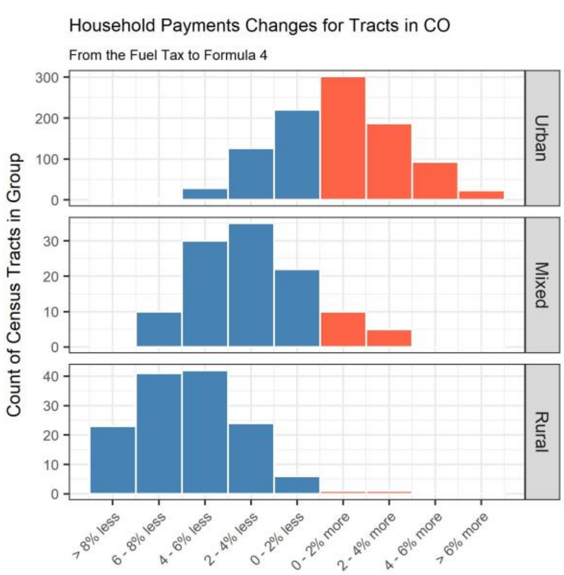

Comparing Differences in CO Tracts
From the Flat Rate to Formula 1
Count of Census Tracts in Group
Urban
Mixed
Rural
> 10% less
8 - 10% less
6 - 8% less
4 - 6% less
2 - 4% less
0 - 2% less
0 - 2% more
2 - 4% more
4 - 6% more
6 - 8% more
8 - 10% more
> 10% more

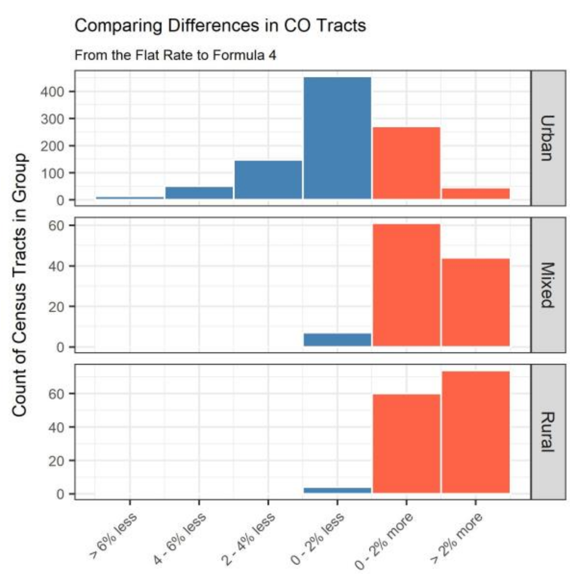


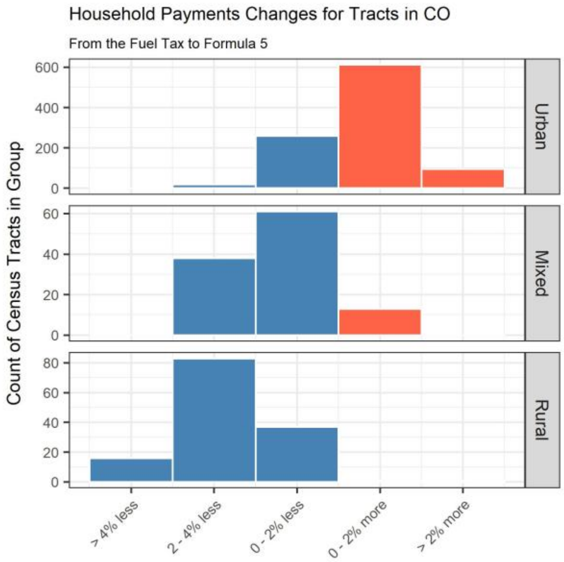
No changes relative to the flat rate are graphed, because shifts are almost all less than one percent

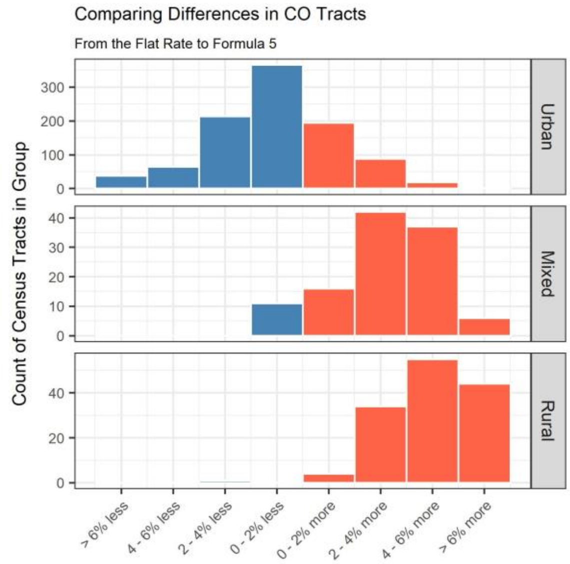


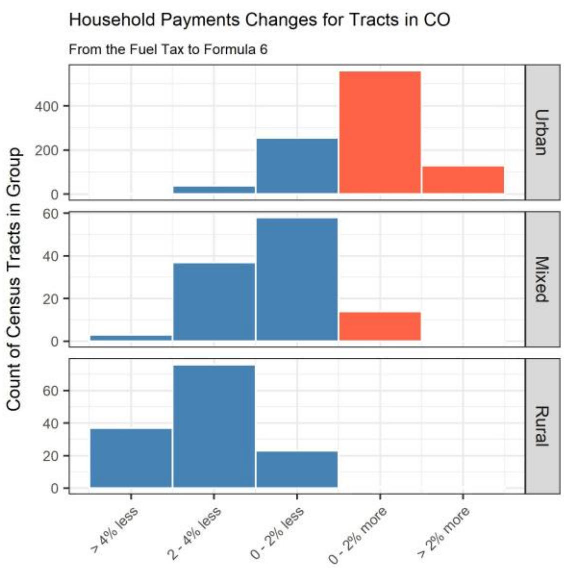
No changes relative to the flat rate are graphed, because shifts are almost all less than one percent

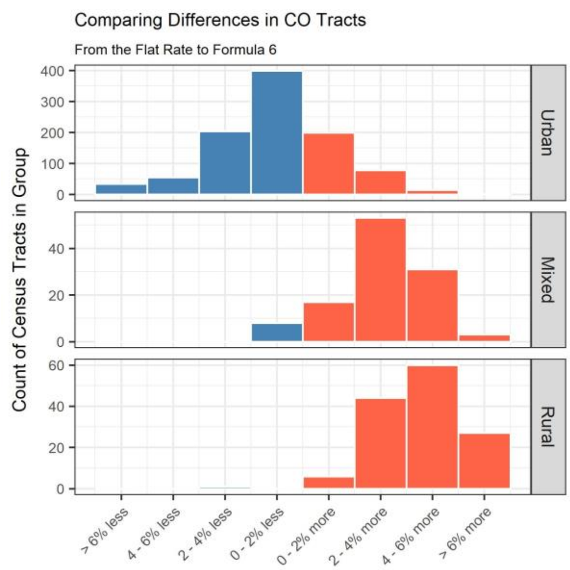




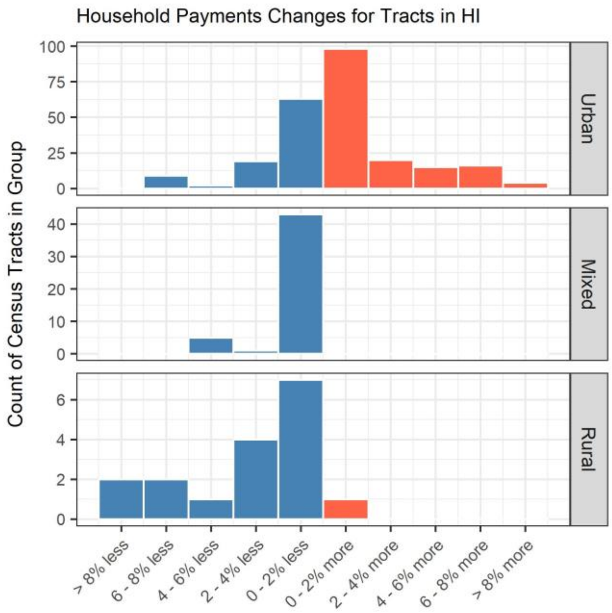

Household Payments Changes for Tracts in CO
From the Fuel Tax to Formula 5
Count of Census Tracts in Group
Urban
Mixed
Rural
> 4% less
2 - 4% less
0 - 2% less
0 - 2% more
> 2% more

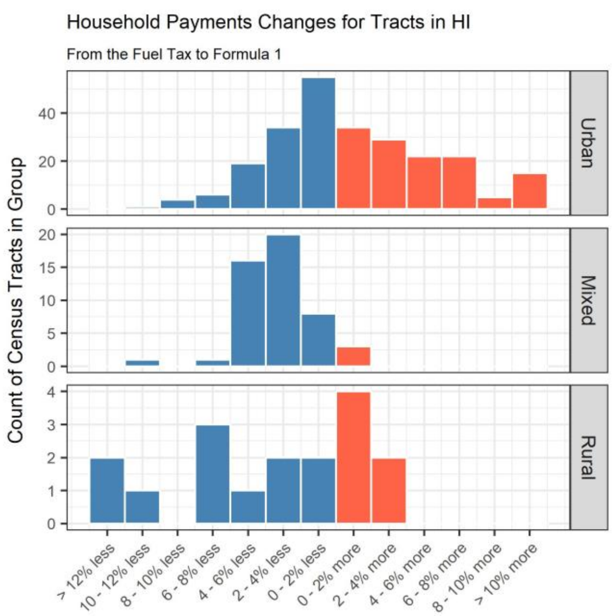

Comparing Differences in CO Tracts
From the Flat Rate to Formula 5
Count of Census Tracts in Group
Urban
Mixed
Rural
> 6% less
4 - 6% less
2 - 4% less
0 - 2% less
0 - 2% more
2 - 4% more
4 - 6% more
> 6% more

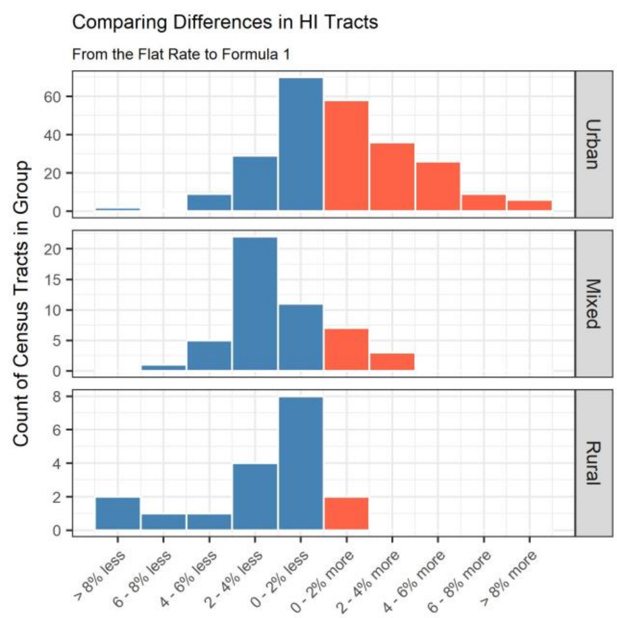

Household Payments Changes for Tracts in CO
From the Fuel Tax to Formula 6
Count of Census Tracts in Group
Urban
Mixed
Rural
> 4% less
2 - 4% less
0 - 2% less
0 - 2% more
> 2% more

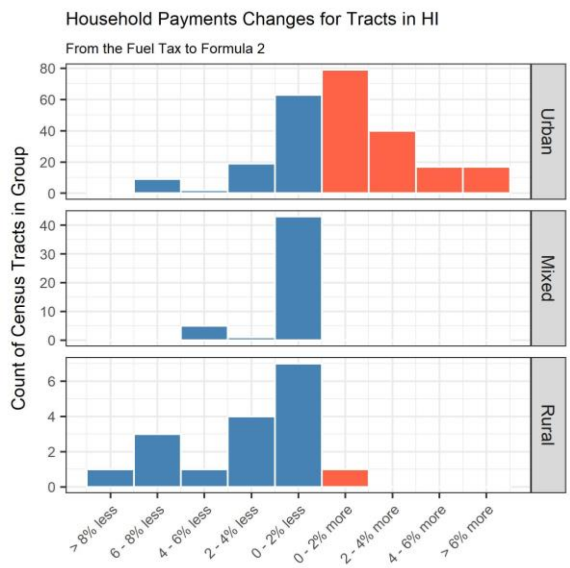

Comparing Differences in CO Tracts
From the Flat Rate to Formula 6
Count of Census Tracts in Group
Urban
Mixed
Rural
> 6% less
4 - 6% less
2 - 4% less
0 - 2% less
0 - 2% more
2 - 4% more
4 - 6% more
> 6% more

HAWAII

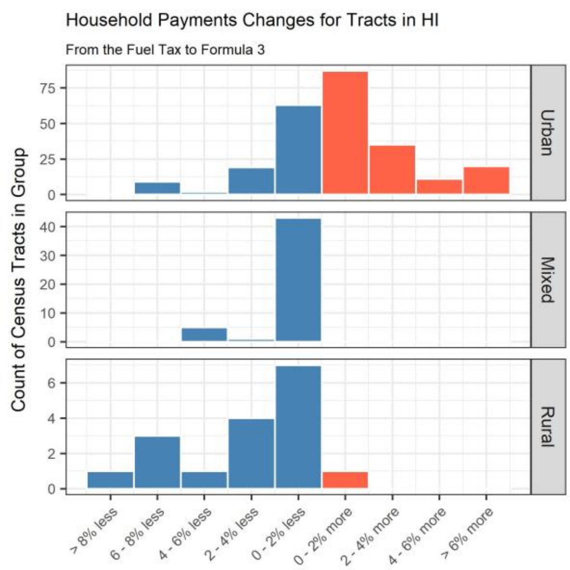

Household Payments Changes for Tracts in HI
Count of Census Tracts in Group
Urban
Mixed
Rural
> 8% less
6 - 8% less
4 - 6% less
2 - 4% less
0 - 2% less
0 - 2% more
2 - 4% more
4 - 6% more
6 - 8% more
> 8% more


Household Payments Changes for Tracts in HI
From the Fuel Tax to Formula 1
Count of Census Tracts in Group
Urban
Mixed
Rural
> 12% less
10 - 12% less
8 - 10% less
6 - 8% less
4 - 6% less
2 - 4% less
0 - 2% less
0 - 2% more
2 - 4% more
4 - 6% more
6 - 8% more
8 - 10% more
> 10% more

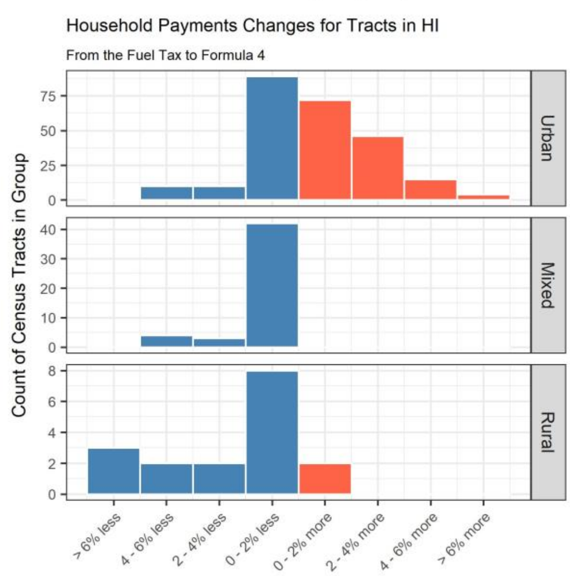

Comparing Differences in HI Tracts
From the Flat Rate to Formula 1
Count of Census Tracts in Group
Urban
Mixed
Rural
> 8% less
6 - 8% less
4 - 6% less
2 - 4% less
0 - 2% less
0 - 2% more
2 - 4% more
4 - 6% more
6 - 8% more
> 8% more

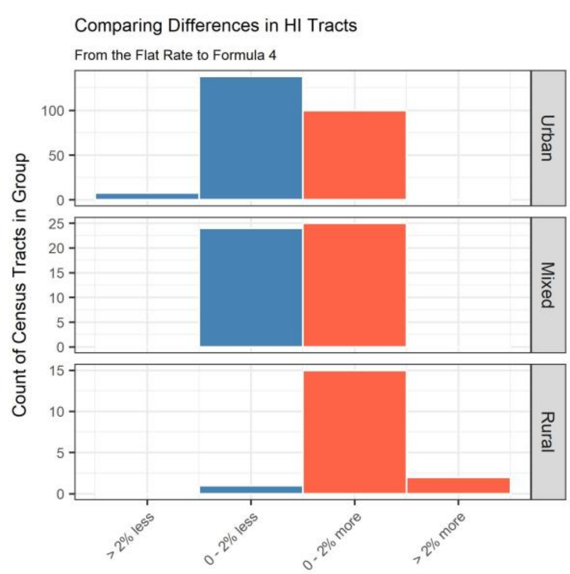


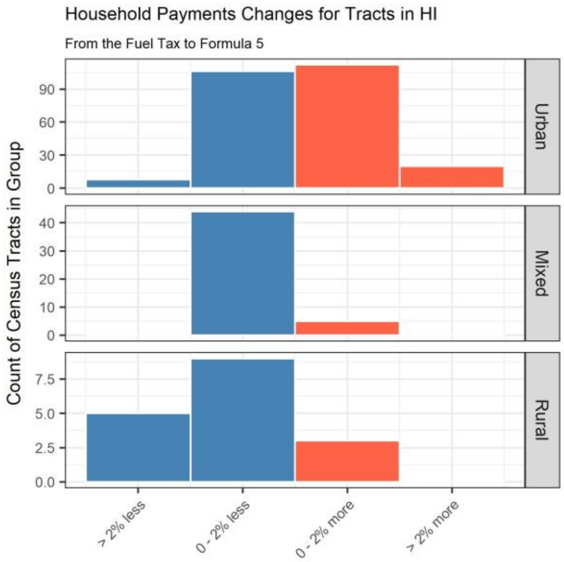
No changes relative to the flat rate are graphed, because shifts are almost all less than one percent

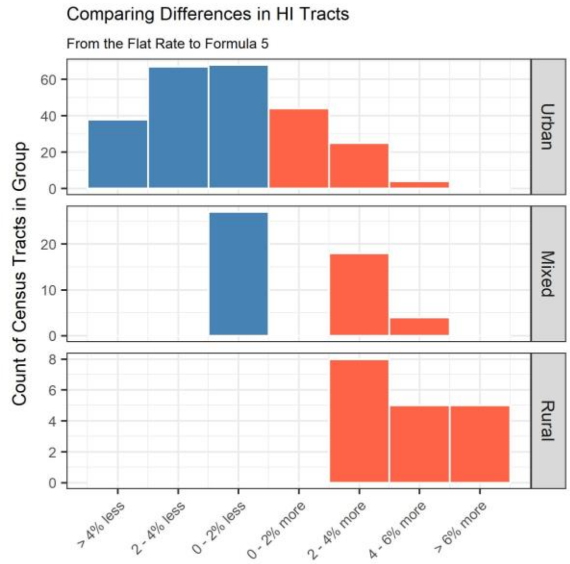


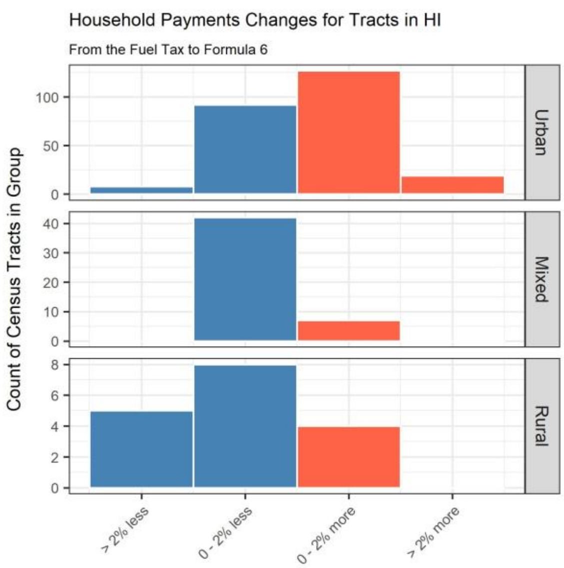
No changes relative to the flat rate are graphed, because shifts are almost all less than one percent

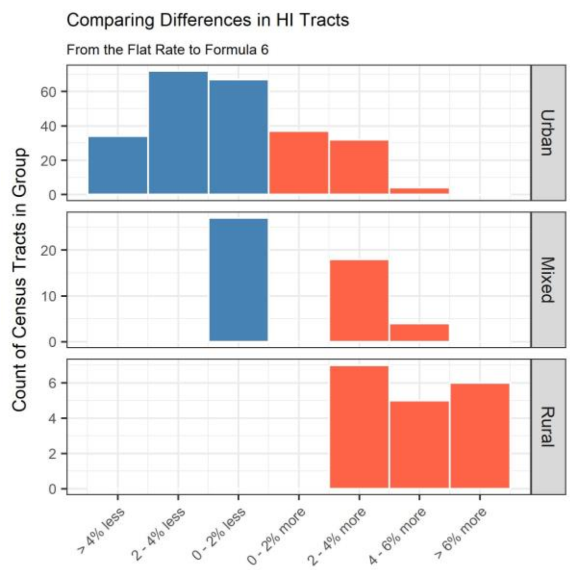




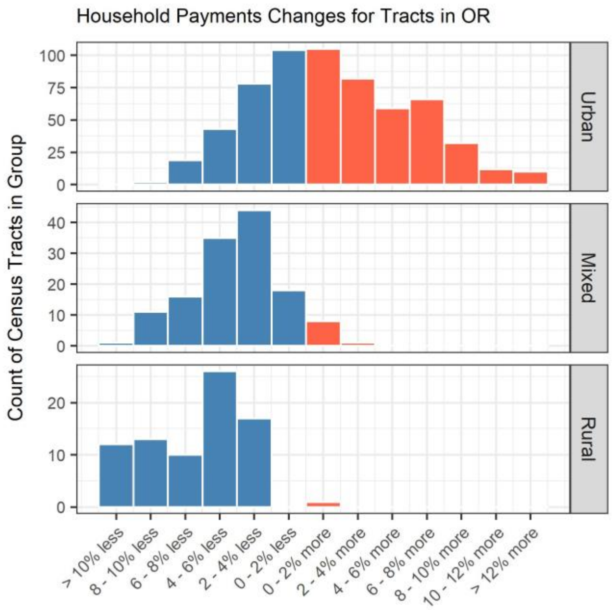

Household Payments Changes for Tracts in HI
From the Fuel Tax to Formula 5
Count of Census Tracts in Group
Urban
Mixed
Rural
> 2% less
0 - 2% less
0 - 2% more
> 2% more


Comparing Differences in HI Tracts
From the Flat Rate to Formula 5
Count of Census Tracts in Group
Urban
Mixed
Rural
> 4% less
2 - 4% less
0 - 2% less
0 - 2% more
2 - 4% more
4 - 6% more
> 6% more

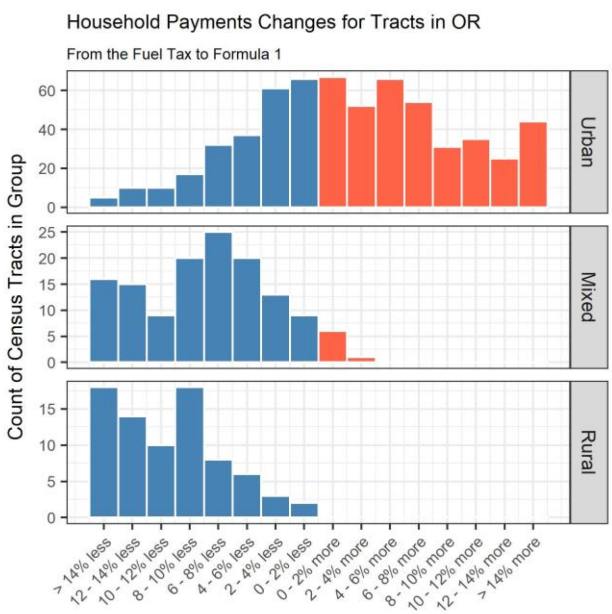

Household Payments Changes for Tracts in HI
From the Fuel Tax to Formula 6
Count of Census Tracts in Group
Urban
Mixed
Rural
> 2% less
0 - 2% less
0 - 2% more
> 2% more


Comparing Differences in HI Tracts
From the Flat Rate to Formula 6
Count of Census Tracts in Group
Urban
Mixed
Rural
> 4% less
2 - 4% less
0 - 2% less
0 - 2% more
2 - 4% more
4 - 6% more
> 6% more

OREGON



Household Payments Changes for Tracts in OR
Count of Census Tracts in Group
Urban
Mixed
Rural
> 10% less
8 - 10% less
6 - 8% less
4 - 6% less
2 - 4% less
0 - 2% less
0 - 2% more
2 - 4% more
4 - 6% more
6 - 8% more
8 - 10% more
10 - 12% more
> 12% more



Household Payments Changes for Tracts in OR
From the Fuel Tax to Formula 1
Count of Census Tracts in Group
Urban
Mixed
Rural
> 14% less
12 - 14% less
10 - 12% less
8 - 10% less
6 - 8% less
4 - 6% less
2 - 4% less
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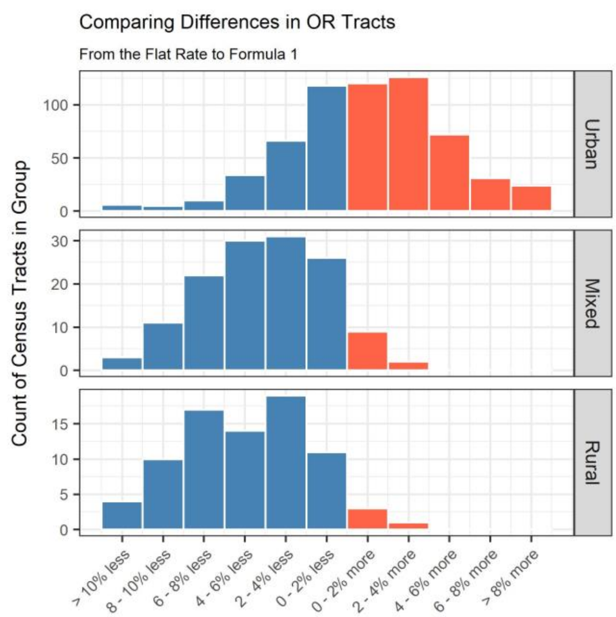
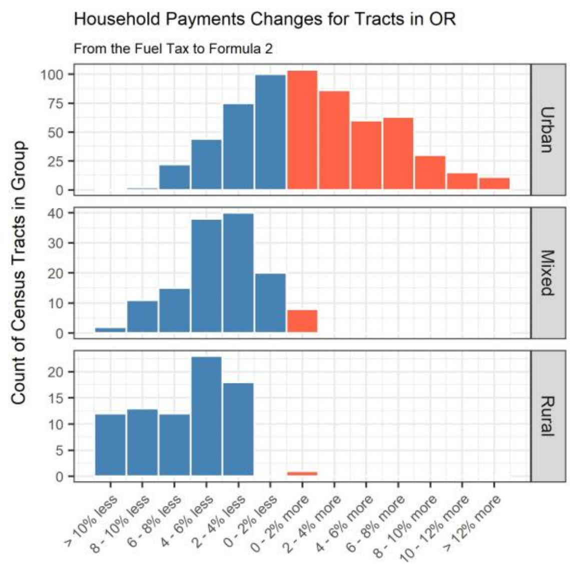
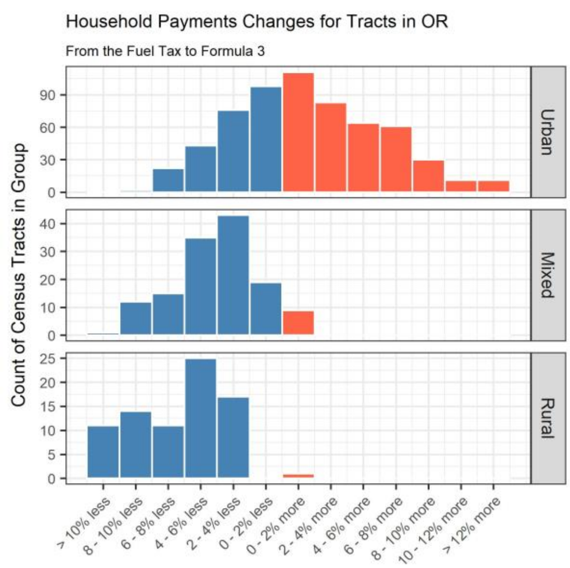
10 - 12% more
12 - 14% more
> 14% more



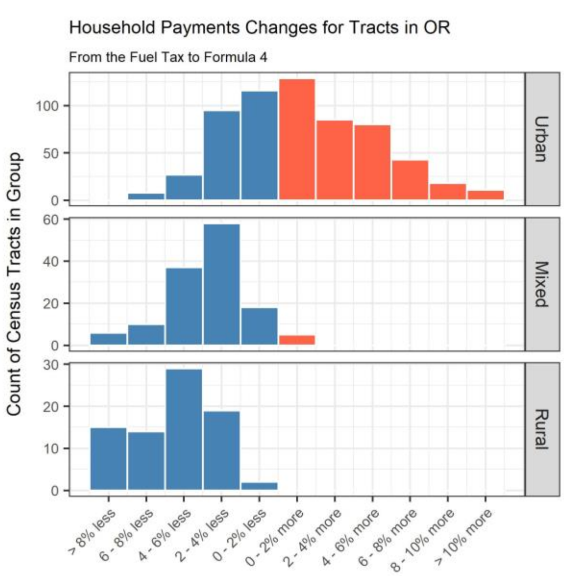
Comparing Differences in OR Tracts
From the Flat Rate to Formula 1
Count of Census Tracts in Group
Urban
Mixed
Rural
> 10% less
8 - 10% less
6 - 8% less
4 - 6% less
2 - 4% less
0 - 2% less
0 - 2% more
2 - 4% more
4 - 6% more
6 - 8% more
> 8% more

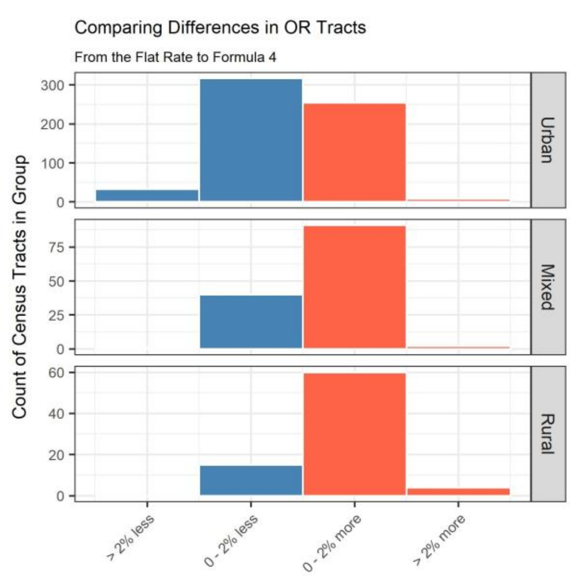


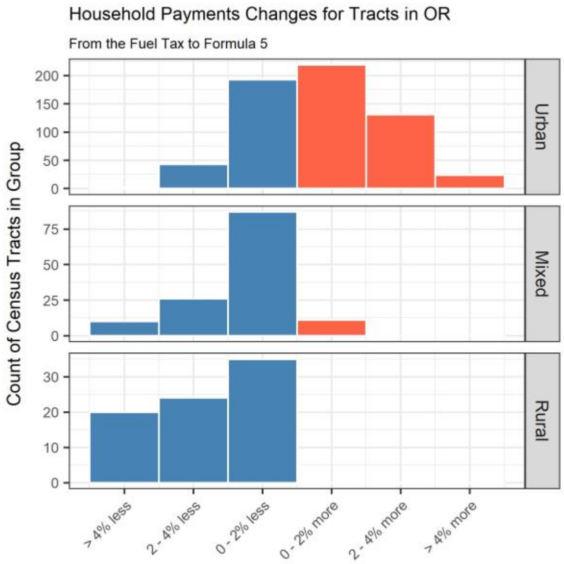
No changes relative to the flat rate are graphed, because shifts are almost all less than one percent

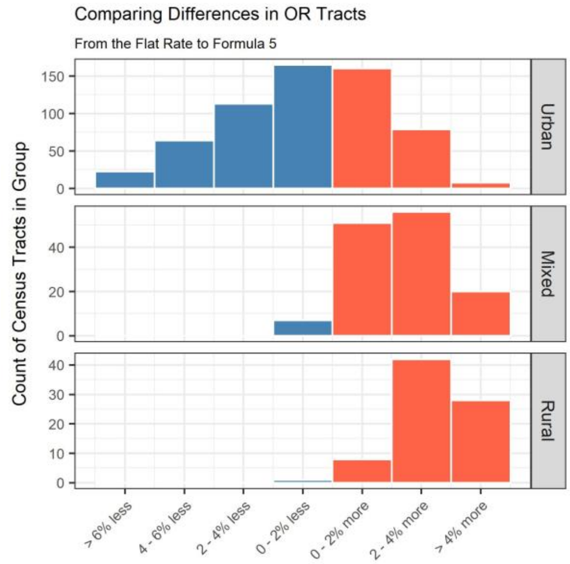


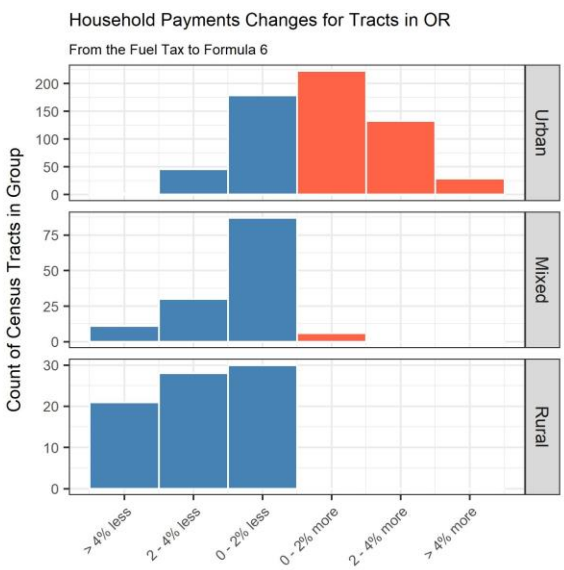
No changes relative to the flat rate are graphed, because shifts are almost all less than one percent

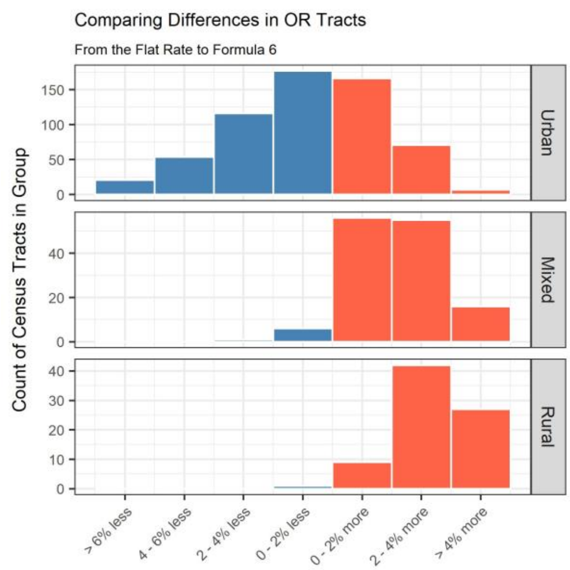




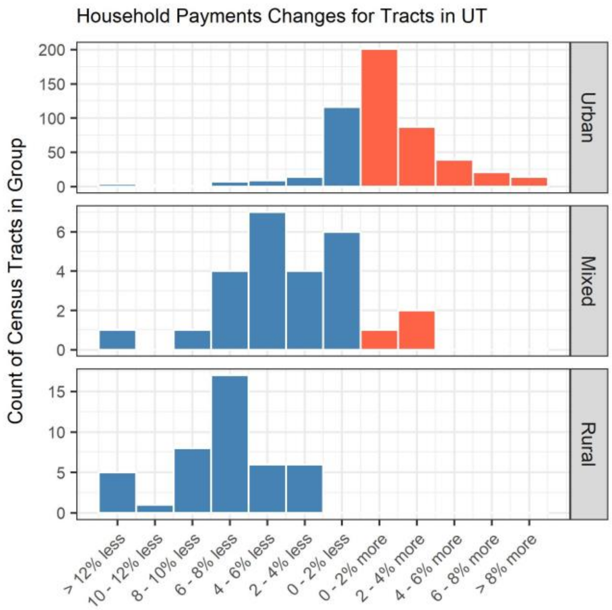

Household Payments Changes for Tracts in OR
From the Fuel Tax to Formula 5
Count of Census Tracts in Group
Urban
Mixed
Rural
> 4% less
2 - 4% less
0 - 2% less
0 - 2% more
2 - 4% more
> 4% more

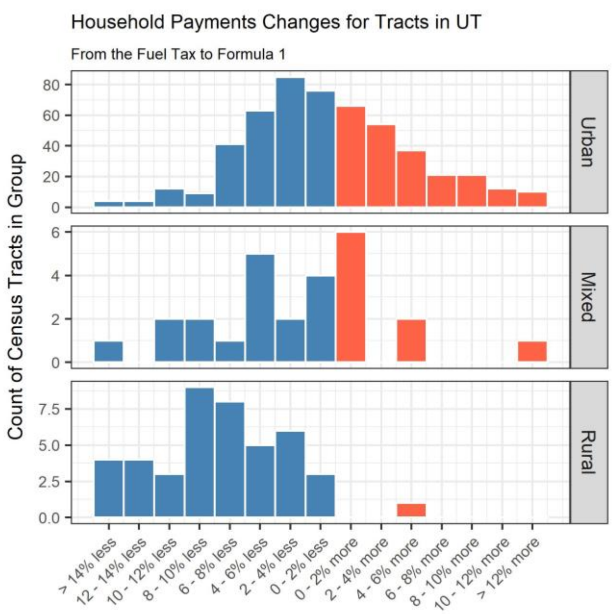

Comparing Differences in OR Tracts
From the Flat Rate to Formula 5
Count of Census Tracts in Group
Urban
Mixed
Rural
> 6% less
4 - 6% less
2 - 4% less
0 - 2% less
0 - 2% more
2 - 4% more
> 4% more

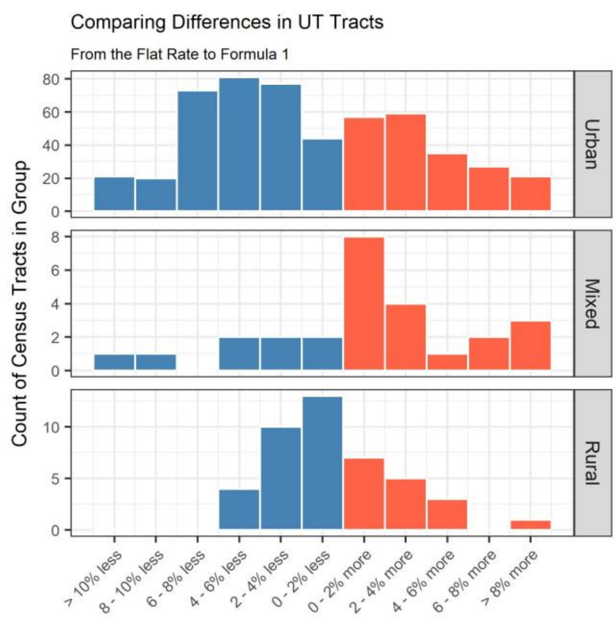

Household Payments Changes for Tracts in OR
From the Fuel Tax to Formula 6
Count of Census Tracts in Group
Urban
Mixed
Rural
> 4% less
2 - 4% less
0 - 2% less
0 - 2% more
2 - 4% more
> 4% more

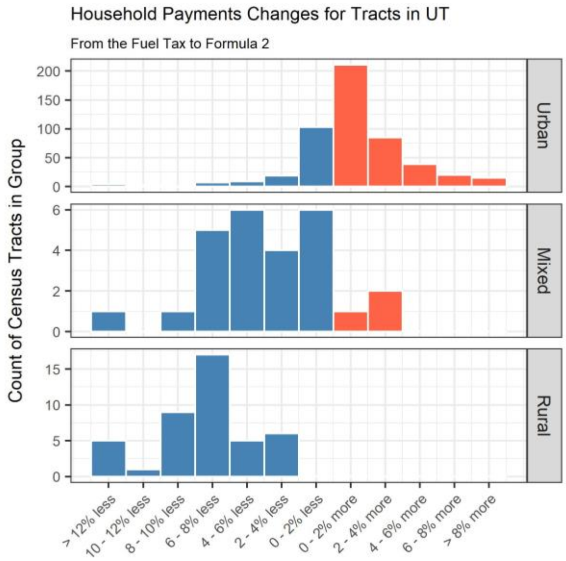

Comparing Differences in OR Tracts
From the Flat Rate to Formula 6
Count of Census Tracts in Group
Urban
Mixed
Rural
> 6% less
4 - 6% less
2 - 4% less
0 - 2% less
0 - 2% more
2 - 4% more
> 4% more

UTAH

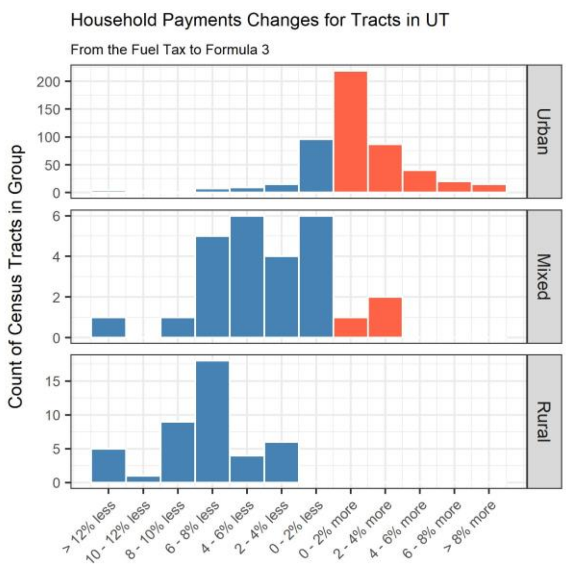

Household Payments Changes for Tracts in UT
Count of Census Tracts in Group
Urban
Mixed
Rural
> 12% less
10 - 12% less
8 - 10% less
6 - 8% less
4 - 6% less
2 - 4% less
0 - 2% less
0 - 2% more
2 - 4% more
4 - 6% more
6 - 8% more
> 8% more


Household Payments Changes for Tracts in UT
From the Fuel Tax to Formula 1
Count of Census Tracts in Group
Urban
Mixed
Rural
> 14% less
12 - 14% less
10 - 12% less
8 - 10% less
6 - 8% less
4 - 6% less
2 - 4% less
0 - 2% less
0 - 2% more
2 - 4% more
4 - 6% more
6 - 8% more
8 - 10% more
10 - 12% more
> 12% more

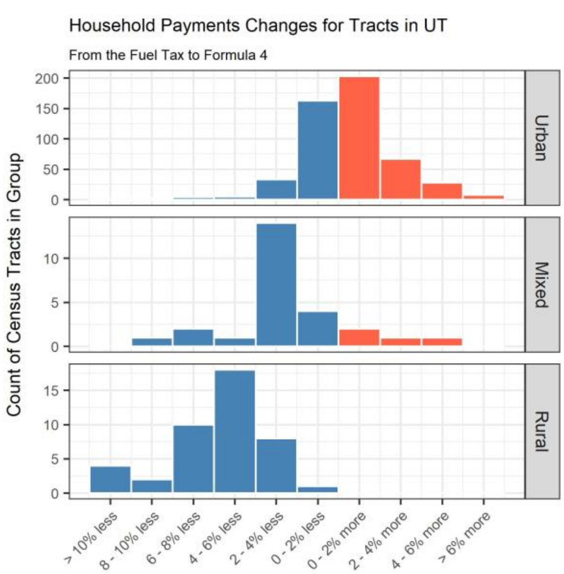

Comparing Differences in UT Tracts
From the Flat Rate to Formula 1
Count of Census Tracts in Group
Urban
Mixed
Rural
> 10% less
8 - 10% less
6 - 8% less
4 - 6% less
2 - 4% less
0 - 2% less
0 - 2% more
2 - 4% more
4 - 6% more
6 - 8% more
> 8% more

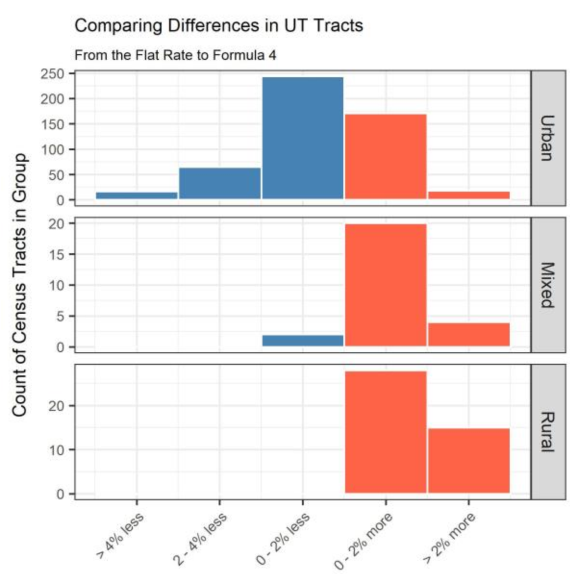


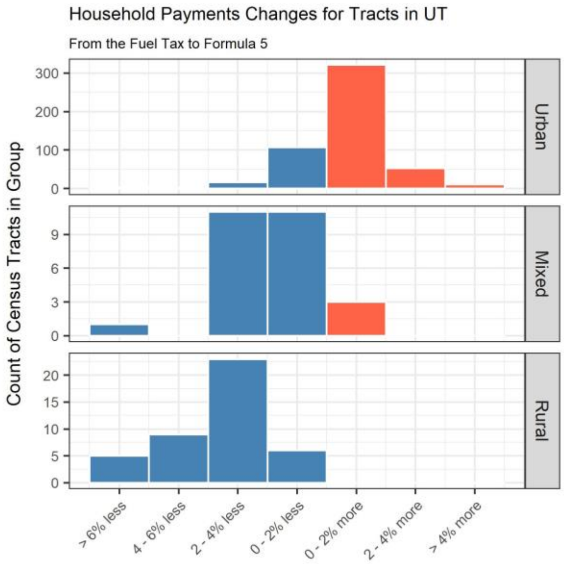
No changes relative to the flat rate are graphed, because shifts are almost all less than one percent

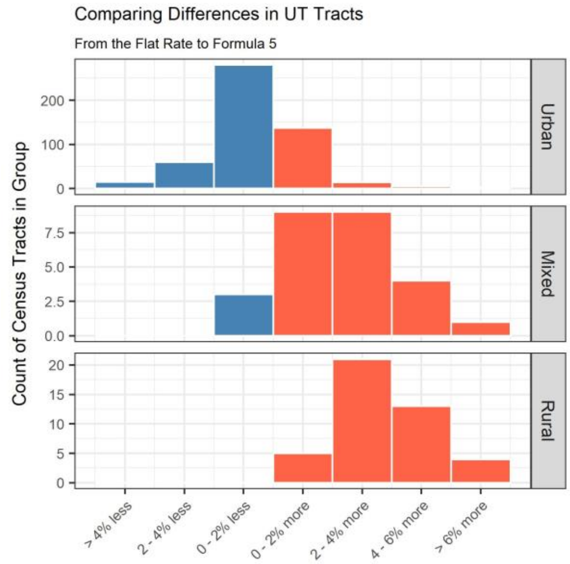


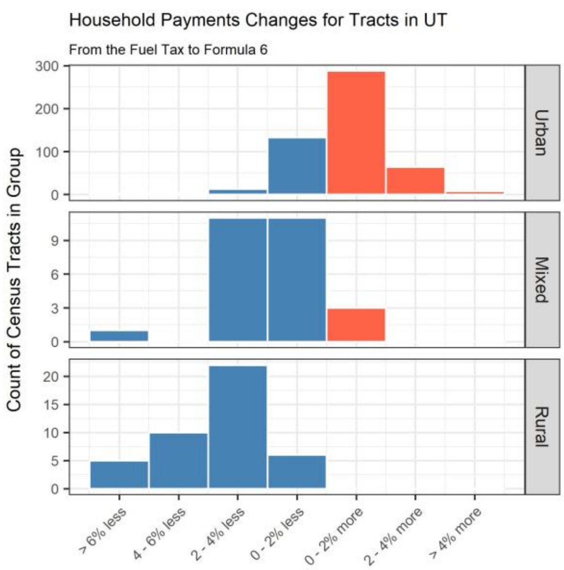
No changes relative to the flat rate are graphed, because shifts are almost all less than one percent

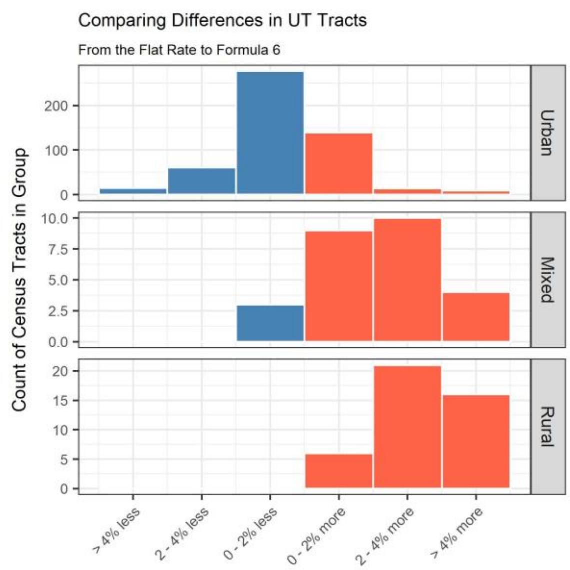




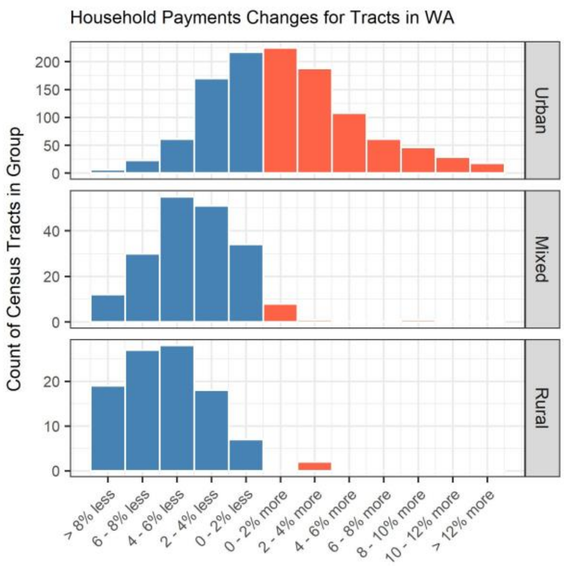

Household Payments Changes for Tracts in UT
From the Fuel Tax to Formula 5
Count of Census Tracts in Group
Urban
Mixed
Rural
> 6% less
4 - 6% less
2 - 4% less
0 - 2% less
0 - 2% more
2 - 4% more
> 4% more

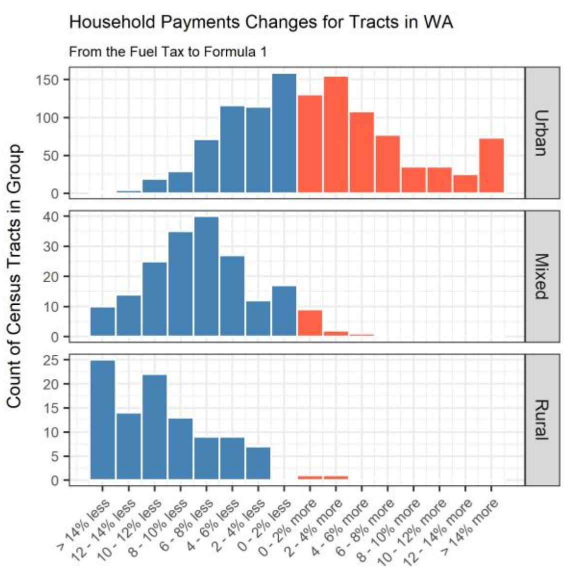

Comparing Differences in UT Tracts
From the Flat Rate to Formula 5
Count of Census Tracts in Group
Urban
Mixed
Rural
> 4% less
2 - 4% less
0 - 2% less
0 - 2% more
2 - 4% more
4 - 6% more
> 6% more

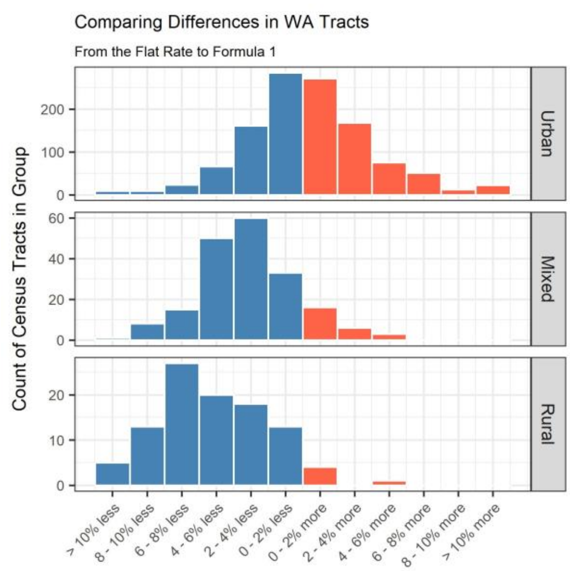

Household Payments Changes for Tracts in UT
From the Fuel Tax to Formula 6
Count of Census Tracts in Group
Urban
Mixed
Rural
> 6% less
4 - 6% less
2 - 4% less
0 - 2% less
0 - 2% more
2 - 4% more
> 4% more

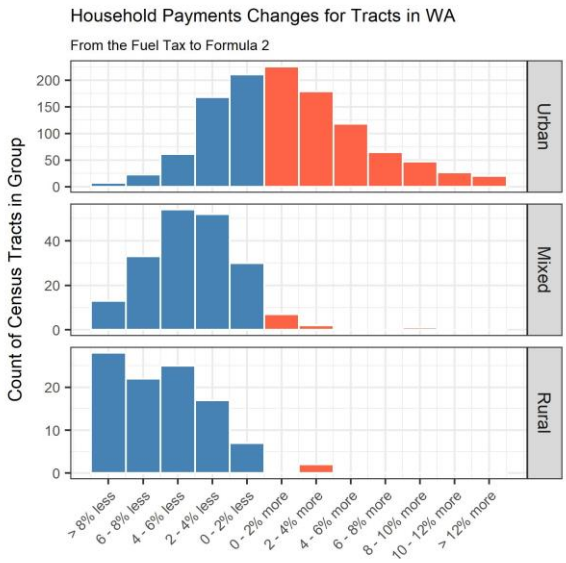

Comparing Differences in UT Tracts
From the Flat Rate to Formula 6
Count of Census Tracts in Group
Urban
Mixed
Rural
> 4% less
2 - 4% less
0 - 2% less
0 - 2% more
2 - 4% more
> 4% more

WASHINGTON

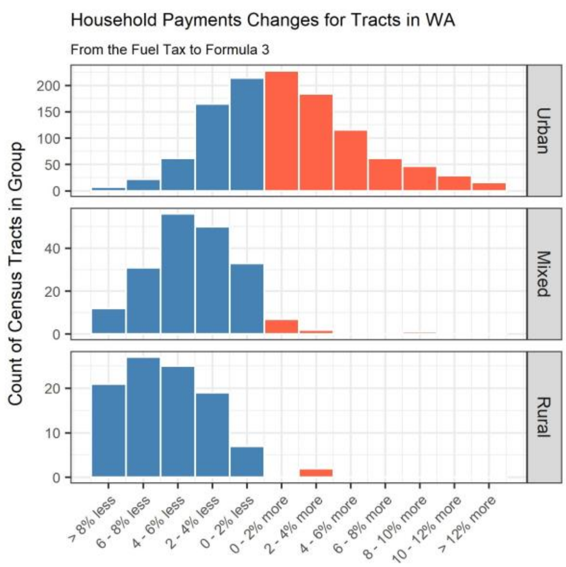

Household Payments Changes for Tracts in WA
Count of Census Tracts in Group
Urban
Mixed
Rural
> 8% less
6 - 8% less
4 - 6% less
2 - 4% less
0 - 2% less
0 - 2% more
2 - 4% more
4 - 6% more
6 - 8% more
8 - 10% more
10 - 12% more
> 12% more


Household Payments Changes for Tracts in WA
From the Fuel Tax to Formula 1
Count of Census Tracts in Group
Urban
Mixed
Rural
> 14% less
12 - 14% less
10 - 12% less
8 - 10% less
6 - 8% less
4 - 6% less
2 - 4% less
0 - 2% less
0 - 2% more
2 - 4% more
4 - 6% more
6 - 8% more
8 - 10% more
10 - 12% more
12 - 14% more
> 14% more

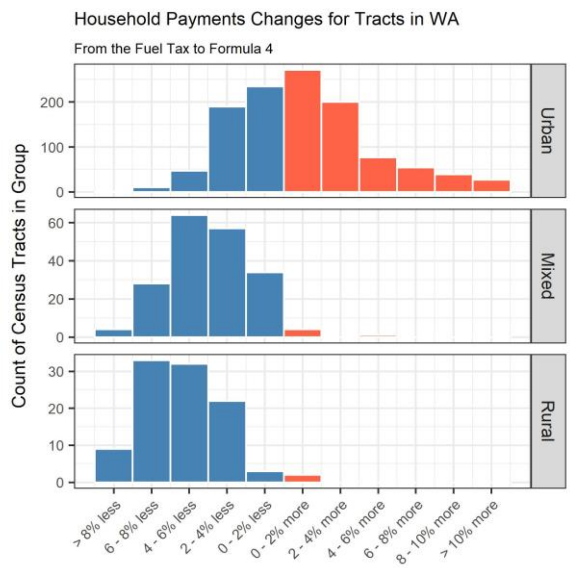

Comparing Differences in WA Tracts
From the Flat Rate to Formula 1
Count of Census Tracts in Group
Urban
Mixed
Rural
> 10% less
8 - 10% less
6 - 8% less
4 - 6% less
2 - 4% less
0 - 2% less
0 - 2% more
2 - 4% more
4 - 6% more
6 - 8% more
8 - 10% more
> 10% more

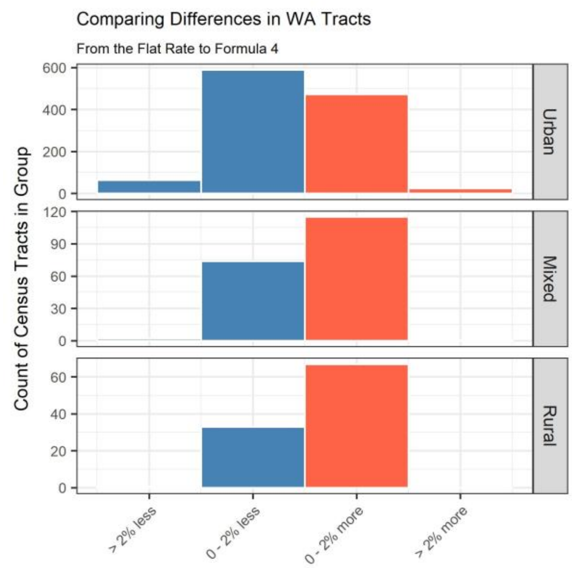


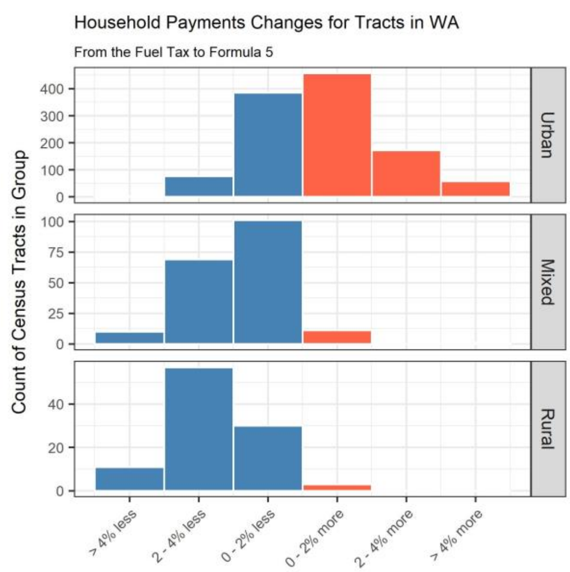
No changes relative to the flat rate are graphed, because shifts are almost all less than one percent

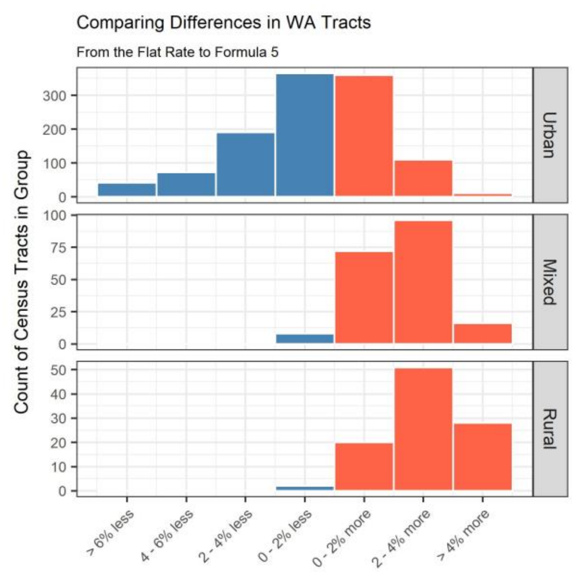


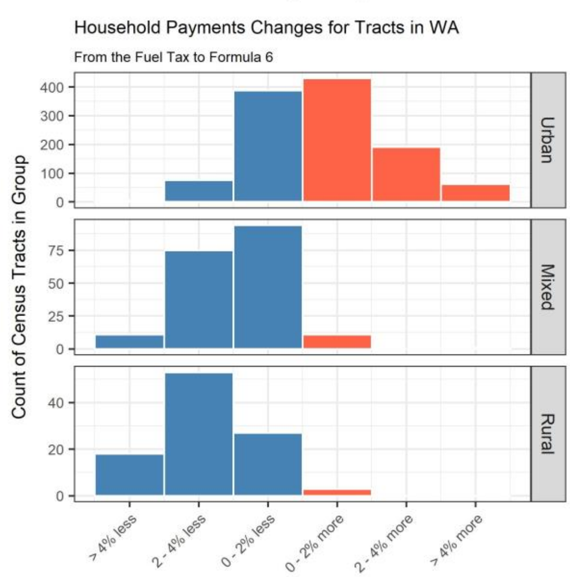
No changes relative to the flat rate are graphed, because shifts are almost all less than one percent

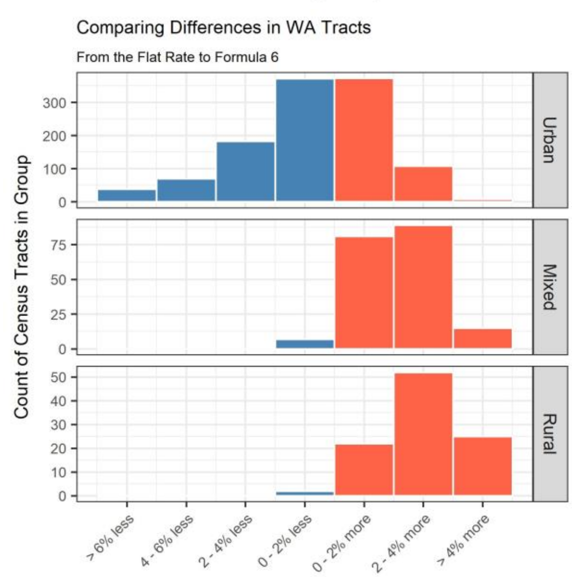

Household Payments Changes for Tracts in WA
From the Fuel Tax to Formula 4
Count of Census Tracts in Group
Urban
Mixed
Rural
> 8% less
6 - 8% less
4 - 6% less
2 - 4% less
0 - 2% less
0 - 2% more
2 - 4% more
4 - 6% more
6 - 8% more
8 - 10% more
> 10% more


Comparing Differences in WA Tracts
From the Flat Rate to Formula 4
Count of Census Tracts in Group
Urban
Mixed
Rural
> 2% less
0 - 2% less
0 - 2% more
> 2% more


Household Payments Changes for Tracts in WA
From the Fuel Tax to Formula 5
Count of Census Tracts in Group
Urban
Mixed
Rural
> 4% less
2 - 4% less
0 - 2% less
0 - 2% more
2 - 4% more
> 4% more


Comparing Differences in WA Tracts
From the Flat Rate to Formula 5
Count of Census Tracts in Group
Urban
Mixed
Rural
> 6% less
4 - 6% less
2 - 4% less
0 - 2% less
0 - 2% more
2 - 4% more
> 4% more


Household Payments Changes for Tracts in WA
From the Fuel Tax to Formula 6
Count of Census Tracts in Group
Urban
Mixed
Rural
> 4% less
2 - 4% less
0 - 2% less
0 - 2% more
2 - 4% more
> 4% more


Comparing Differences in WA Tracts
From the Flat Rate to Formula 6
Count of Census Tracts in Group
Urban
Mixed
Rural
> 6% less
4 - 6% less
2 - 4% less
0 - 2% less
0 - 2% more
2 - 4% more
> 4% more

APPENDIX D - HAWAII COUNTY FUEL TAXES

Hawaii's fuel tax is administered in almost equal proportions by the state and the counties, and all counties collect fuel excise taxes. For this reason, it was appropriate and analytically straightforward to include these county excise taxes in the analysis. Table D-1 shows the tax rates used for this additional analysis layer. Within our methodology, applying additional layers of excise taxes would be possible for counties and municipalities but would require more complex geographic manipulation than was the case for Hawaii.

Table D-1. Fuel Tax Rates for Hawaii Counties (dollars per gallon, on top of state rate)

HI County	Gasoline	Other Fossil	Biofuel
Hawaii	0.15	0.074	0.022
Honolulu	0.165	0.082	0.024
Kauai	0.17	0.084	0.025
Maui	0.23	0.114	0.115

Table D-2 shows the county-level RUC rates that would be needed to replace the fuel taxes under current law. The patterns across formulas are very similar to those discussed for states.

Table D-2. Base RUC Rates for Fuel Tax Equivalent Revenue (cents per mile)

HI County	Flat Rate	Formula 1	Formula 2	Formula 3	Formula 4	Formula 5	Formula 6
Hawaii	0.69	0.90	0.69	0.69	0.72	0.67	0.68
Honolulu	0.72	0.91	0.72	0.72	0.76	0.73	0.73
Kauai	0.79	1.02	0.79	0.79	0.82	0.76	0.77
Maui	1.05	1.34	1.05	1.05	1.10	1.03	1.03

Table D-3 provides the same type of analysis covered in the section *Urban, Mixed, and Rural Analysis of Revenue-Neutral* Formulas*.* The Hawaii counties are reasonably unique because of their small geographic size and significantly different fuel type patterns by geography location compared what was seen for most states in the state-level analysis. The small size and relatively uniform economic structure are determining factors in the lack of rural tract classification on the island of Honolulu. The primary commuting flow for all tracts is to an urbanized area or within one. Hawaii does not show the same tendency towards electric and hybrid vehicles in urban areas and flex fuel and other fossil fuel vehicles in mixed and rural areas. Most counties are much more balanced or show opposite trends.

Table D-4 provides the type of analysis covered in the section *Formula Impacts by Fuel Type.* The patterns across vehicle types are similar to those seen at the state level. Because of the different vehicle characteristics and predicted use patterns there are some variations between the formula impacts in the Hawaii counties and the states. Variations across Hawaii counties are largely due to variation in rates under current fuel excise tax policy.

Table D-3. Change in Average Payments from Fuel Excise Tax to Parameterized RUC Formulas

Location	Formula	Urban	Mixed	Rural	Urban-Rural Range[32]
Hawaii County	Flat	1.2%	-1.2%	-1.1%	2.4%
	F1	1.8%	-3.8%	-0.6%	2.4%
	F2	1.2%	-1.2%	-1.1%	2.2%
	F3	1.2%	-1.2%	-1.1%	2.3%
	F4	1.1%	-1.2%	-0.9%	2.0%
	F5	0.4%	-0.4%	-0.4%	0.9%
	F6	0.4%	-0.4%	-0.4%	0.8%
Honolulu County	Flat	0.3%	-1.6%	NA	1.9%
	F1	0.5%	-3.0%	NA	3.5%
	F2	0.3%	-1.7%	NA	1.9%
	F3	0.3%	-1.6%	NA	1.9%
	F4	0.2%	-1.5%	NA	1.8%
	F5	0.0%	-0.3%	NA	0.3%
	F6	0.1%	-0.3%	NA	0.4%
Kauai County	Flat	1.9%	-1.9%	-2.0%	3.9%
	F1	2.8%	-3.1%	-2.3%	5.1%
	F2	1.8%	-1.8%	-1.9%	3.7%
	F3	1.8%	-1.7%	-1.9%	3.6%
	F4	1.5%	-1.6%	-1.5%	3.1%
	F5	0.9%	-0.9%	-0.8%	1.7%
	F6	0.8%	-0.8%	-0.7%	1.5%
Maui County	Flat	1.1%	-0.6%	-7.9%	9.0%
	F1	2.1%	-2.5%	-9.5%	11.5%
	F2	1.1%	-0.7%	-7.7%	8.8%
	F3	1.1%	-0.6%	-7.7%	8.8%
	F4	1.0%	-0.7%	-6.4%	7.4%
	F5	0.3%	0.0%	-2.9%	3.2%
	F6	0.3%	0.1%	-2.7%	3.0%

[32] Honolulu's figures are for the urban-mixed range instead due to the lack of census tracts classified as rural.

Table D-4. Per Vehicle Payment Changes from Fuel Excise Tax to Parameterized RUC Formulas

HI County	Formula	Gasoline	Hybrid	Flexfuel	Other Fossil	Electric
Hawaii	Flat	$ (0.37)	$ 14.04	$ 3.33	$ 9.28	$ 26.34
	F1	$ (0.37)	$ 14.13	$ 3.40	$ 9.22	$ 26.47
	F2	$ (0.20)	$ 11.10	$ 0.40	$ 6.34	$ 23.41
	F3	$ (0.22)	$ 11.54	$ 0.85	$ 6.83	$ 23.83
	F4	$ (0.32)	$ 9.29	$ 3.41	$ 10.09	$ 21.23
	F5	$ (0.37)	$ 8.65	$ 4.44	$ 11.79	$ 20.54
	F6	$ (0.20)	$ 6.32	$ 1.39	$ 8.57	$ 18.26
Honolulu	Flat	$ (0.53)	$ 15.68	$ 2.42	$ 9.17	$ 30.91
	F1	$ (0.53)	$ 15.68	$ 2.44	$ 9.06	$ 30.92
	F2	$ (0.32)	$ 12.62	$ (0.22)	$ 6.20	$ 27.84
	F3	$ (0.33)	$ 12.78	$ (0.09)	$ 6.40	$ 28.01
	F4	$ (0.47)	$ 11.16	$ 2.81	$ 10.33	$ 25.82
	F5	$ (0.55)	$ 10.53	$ 4.21	$ 13.40	$ 25.09
	F6	$ (0.34)	$ 7.99	$ 1.40	$ 10.01	$ 22.60
Kauai	Flat	$ (0.45)	$ 13.66	$ 3.10	$ 8.15	$ 26.56
	F1	$ (0.46)	$ 13.61	$ 3.22	$ 8.10	$ 26.49
	F2	$ (0.24)	$ 10.78	$ 0.77	$ 5.29	$ 23.67
	F3	$ (0.27)	$ 11.18	$ 1.04	$ 5.69	$ 24.08
	F4	$ (0.40)	$ 8.89	$ 2.98	$ 9.24	$ 21.36
	F5	$ (0.45)	$ 8.15	$ 3.66	$ 11.24	$ 20.53
	F6	$ (0.24)	$ 5.87	$ 1.26	$ 8.04	$ 18.29
Maui	Flat	$ (0.72)	$ 20.94	$ 2.90	$ 15.42	$ 41.45
	F1	$ (0.72)	$ 20.78	$ 3.08	$ 15.31	$ 41.25
	F2	$ (0.42)	$ 16.74	$ (0.38)	$ 11.18	$ 37.05
	F3	$ (0.45)	$ 17.23	$ (0.11)	$ 11.65	$ 37.57
	F4	$ (0.59)	$ 14.26	$ 2.68	$ 16.01	$ 33.72
	F5	$ (0.65)	$ 13.32	$ 3.71	$ 18.66	$ 32.57
	F6	$ (0.36)	$ 9.93	$ 0.33	$ 14.07	$ 29.10

Appendix E - Chronology of Tested RUC Mechanisms

This list is compiled from references to provide some context on the evolution of methods being used to administer road usage charges.

- Oregon first pilot (ODOT 2017)
  - Date: 2006/2007
  - Scheme: Pay-at-the-pump
  - Description: A GPS-enabled device counts miles travelled within different zones. The RUC was calculated based on total mileage and time-of-day since last use of a fuel pump. The gas tax was deducted from the participants fuel purchase and the mileage fee was then added.
- Minnesota pilot (Rephlo 2013)
  - Date: 2011/2012
  - Scheme: Account management system
  - Description: A smartphone app recorded total mileage driven. Monthly invoices showed road-usage charge, payable by mail, internet or in person.
- Nevada pilot (WSTC 2016)
  - Date: 2012
  - Scheme: Pay-at-the-pump
  - Description: A non-GPS device recorded total mileage, regardless of where those miles occurred. A wireless transponder sent mileage data to fuel pumps equipped with a wireless receiver. The fuel receipt stated the total mileage fee. Rates did not vary by vehicle weight, type, or classification.
  - Note: Hypothetical, not an actual pilot
- Washington Road Usage Charge Pilot Program (D'Artagnan Consulting 2013)
  - Date: 2012/2013
  - Scheme: Pay-at-the-pump
  - Description: Two options to report mileage: a GPS-enabled device counted miles travelled on public roads in Washington State or a non-GPS enabled device counted all miles traveled, regardless of where they occurred. Monthly invoices showed RUC and associated charges less estimated gas tax.
- Oregon second pilot (ODOT 2017)
  - Date: 2012/2013
  - Scheme: Account management system
  - Description: Four options to report mileage: a non-GPS device with no location detection capability recording total miles driven; a GPS-enabled device differentiating

taxable and non-taxable miles based on location and offering connected-car services; a smartphone plan allowing participants to choose to record all miles or only Oregon mileage; and a flat fee plan that waives mileage reporting all together. Refunds applied to fuel taxes paid.

- OReGO program (response to technology questionnaire)
  - Date: 2015 (permanent)
  - Scheme: Account management system
  - Description: Oregon employs vehicle-only technology with both non-GPS-enabled and GPS-enabled OBD-II devices and cellular communication (3G, 4G, LTE). The system achieves vehicle location records every 1 to 10 seconds with a spatial accuracy of about 40 feet / 12.2 meters. Location information is used to distinguish chargeable from non-chargeable roads (out-of-state and non-public roads).
  - Congestion Charges: There is currently no tolling or congestion charging infrastructure deployed in Oregon. However, during the 2017 round of STSFA grants, Oregon was awarded funding to study area and corridor pricing strategies.
- California pilot (CaliforniaRoadChargePilot.com, report pending)
  - Date: 2016/2017
  - Scheme: Account management system
  - Description: Six options to report mileage are available: plug-in device; smartphone; telematics; time permit; mileage permit; odometer reading. There are several account managers to choose from as well and payment is done by mail or via a secure website.
- Colorado pilot (WSTC 2016)
  - Date: 2016/2017
  - Scheme: Mileage-recording device
  - Description: Three options to report mileage: odometer reading, GPS-enabled device that differentiates miles based on location (in-state vs. out-of-state roads), or a non-GPS device that records distance only. Monthly invoices show total mileage and taxable mileage. Participants pay gas tax and receive a refund based on taxable mileage.
- Upcoming Washington pilot (WSTC & WSDOT 2017)
  - Date: 2018
  - Scheme: Account management system
  - Description: Four options to report mileage: a mileage permit, with a pre-selected block of miles; quarterly odometer readings computed electronically or in-person; GPS and non-GPS devices for monthly electronic travel reports; and a smartphone app used to collect and report miles.
- Upcoming California Pilot round (response to technology questionnaire)
  - Date: 2018
  - Scheme: Pay-at-the-pump

- Description: A vehicle and roadside (pump) infrastructure will be used, the communication between the vehicle and pump likely relying on DSRC (Dedicated Short-Range Communications, a wireless communication channel in the 5.9 GHz band reserved for intelligent transportation systems (ITS) applications).

Additional information was collected from participating states regarding the technologies they are using or exploring for road usage charging and congestion charging. Four states gave responses to an information request in Spring 2017.

- Additional California information
  - California has employed vehicle-only technology with cellular communication. The decision to use a thin-client or thick-client architecture was up to vendors. So far, all vendors have opted for a thin client. The mileage data originates from an OBD-II device. For cars whose drivers opted for location-based reporting methods, the GPS data is only used for defining if a specific road is chargeable or not (non-chargeable: private roads, off-road, out of state roads). This closely follows the location-based policies in Oregon.
  - Some vendors indicated the possibility of installing virtual gantries in their systems, which could facilitate more advanced congestion charges and RUC accuracy.
  - Congestion Charges: California's FasTrak tolling system utilizes roadside infrastructure including transponders and gantries, and a back-up of Automatic Number Plate Recognition (ANPR).
- Additional Colorado information
  - Odometer readings are submitted remotely by the driver via a website or a smartphone application and the three reporting options allow flexibility for users and information collection for the agency regarding privacy, technology and cost considerations.
  - For Colorado Corridor Tolling, drivers can either opt for installing transponders in their vehicle that allow them to use express lanes (free of charge with enough passengers, otherwise charged) or choose to not install a transponder and then be billed based on ANPR[33].
- Utah is in the process of determining technologies for a potential RUC demonstration program but expects to use vehicle-only infrastructure to avoid an additional investment in road-side infrastructure.
- Hawaii's upcoming pilot will use manual and automated odometer meetings taken during visits to inspection stations.

Washington and Arizona did not provide technical information on their planned systems.

33 https://www.codot.gov/programs/expresslanes/proposed-toll-rates/us-36-express-lanes/programs/expresslanes/using-the-lanes

APPENDIX F - TABLES OF KEY FINDINGS FROM AGRAWAL, NIXON, AND HOOPER (2016)

Studies included in the comprehensive review:

TABLE 2

THEMES RELATED TO MBUFs, BY QUALITATIVE RESEARCH STUDY

Theme (and number of studies discussing it)	MN DOT, et al. (Strgar-Rosco-Faush et al.) 1995	OR DOT (Whitty and Imholt) 2005	MN DOT (Dieringer Research Group) 2007	MN DOT (Dieringer Research Group) 2008	University Trans'n Center for Mobility (Baker et al.) 2008	Mineta Trans'n Institute (Agrawal et al.) 2011	Texas DOT (Baker and Goodin) 2011	WI DOT (Nelson and Petchenik) 2012	OR DOT (DMH Research) 2013	CO DOT (Ungemah et al.) 2013	Nat'nal Capital Region Trans'n Planning Board (Swanson and Hampton) 2013	MassInc (Koczela and Parr) 2014
Concerns about administering MBUFs												
Technology and administrative problems (8)	√	√	√	√			√		√	√	√	
Fraud (8)	√	√	√		√		√	√		√	√	
High administration costs (8)	√		√	√	√		√	√		√	√	
Charging the MBUF on out-of-state miles (5)	√			√				√	√	√		
Out-of-state vehicles won't pay their share (4)	√						√			√	√	
Concerns about how MBUFs impact drivers												
MBUFs invade privacy (11)		√	√	√	√	√	√	√	√	√	√	√
MBUFs are unfair (9)	√	√	√	√	√		√		√	√	√	
MBUFs eliminate the incentives/rewards for purchasing fuel-efficient vehicles (6)	√	√	√	√			√		√			
Lump-sum MBUF payments are a hardship (5)					√		√	√	√		√	
Other												
Benefit: Efficient vehicles pay their share (3)							√		√	√		
Views on MBUF with congestion-pricing (4)		√	√	√							√	
Want simplicity/dislike complexity (7)	√		√	√	√		√			√	√	
Prefer to raise gas tax instead (8)	√		√		√		√	√	√		√	√

TABLE 5
MBUF SURVEY QUESTION THEMES

Question Themes	Percentage of Survey Questions	*N*
General support for an MBUF	20	33
Support for *replacing* the gas tax with an MBUF	16	27
Privacy	7	11
Fairness	8	14
Other topics	49	82

Note: Total number of survey questions on mileage-based user fees = 167.

TABLE 6

SUPPORT FOR GENERAL MBUF SURVEY QUESTIONS, BY RESPONDENT CHARACTERISTICS

Variable	Mean Support (%)	Minimum Support (%)	Maximum Support (%)	*N*[a]
Overall[b]	24	8	50	33
Gender				
Female	26	7	56	25
Male	26	10	45	25
Age[c]				
Young	30	8	58	25
Middle	27	8	50	22
Older	27	7	50	22
Race/Ethnicity				
White	26	11	47	18
Black	28	6	53	16
Asian	45	19	72	11
Hispanic	30	13	54	12
Other	29	8	49	12
Income[d]				
Lower	29	1	54	20
Middle	28	12	52	20
Higher	28	5	49	22
Education				
High school or less	28	6	52	16
More than high school	26	8	50	17
Political affiliation[e]				
Democrat/Liberal	32	15	57	16
Republican/Conservative	21	6	43	16
Independent/Moderate/Decline to State/Other	23	9	44	16

Note: Total number of survey questions focused on general support for mileage-based user fees = 33.

[a] Sample size varies across the variables because some polls did not provide data for all demographic categories or did not provide data in a way that could be coded for analytical purposes.

[b] "Support" included responses in the following categories: strongly support or support; 8–10 on a 10-point Likert scale (1 to 10) with 10 = strongly support; and 7–10 on an 11-point Likert scale (0 to 10) with 10 = strongly support.

[c] "Young" included responses in the following categories: 18–24 years, 18–29 years, and 18–34 years. "Middle" included responses in the following categories: 25–54 years, 34–54 years, 30–49 years, and 30–59 years. "Older" included responses in the following categories: 50+ years, 55+ years, and 60+ years.

[d] "Lower" included responses in the following categories: less than $50,000, less than $40,000. "Middle" included responses in the following categories: $50,000–$100,000 and $40,000–$100,000. "Higher" included responses in the following categories: $100,000+ and $110,000+.

[e] Political affiliation was categorized differently in different surveys, using the following groupings: (1) Democrats, Republicans, Independents, and Decline to State; (2) Democrat, Republican, and Independent; (3) Democrat, Republican, and Other, including Independent; (4) Democrat, Republican, and Other; and (5) Liberal, Conservative, and Moderate.

TABLE 7

SUPPORT FOR GENERAL MBUF SURVEY QUESTIONS, BY SURVEY CHARACTERISTICS

Survey Characteristic	Mean Support (%)	*N*
Sponsor type		
Academic institution	27	18
Government agency	25	9
Industry/Industry trade group	11	2
Polling firm	15	3
Other	17	1
Census region		
Midwest	17	5
Northeast	17	1
South	27	2
West	37	7
Midwest/West[a]	20	5
Geography		
National	23	13
Regional	20	5
Local	33	1
State	26	14
Survey administration mode		
Mail	20	5
Online	26	2
Phone	25	23
Multiple	44	1
Sampling frame		
Adults	25	30
Registered voters	16	3

Note: Total number of survey questions focused on general support for mileage-based user fees = 33.

[a] One poll with five unique MBUF-related questions extended over two census regions.