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An Equitable and Integrated Approach to Paying for Roads in a Time of Rapid Change

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An Equitable and Integrated Approach to Paying for Roads in a Time of Rapid Change

A Research Report from the University of California Institute of Transportation Studies

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16. Abstract

A brief overview of transportation user fees (historically and in a contemporary context) is presented followed by a discussion on how segmenting travel into three categories – *long haul*, the *last mile*, and *at the curb* – creates a new typology for transportation pricing and access mechanisms. A case study based upon California's recent Road Charge Pilot Program demonstrates a quantitative example for a blended long haul/last mile approach using a parametric mileage-based user fee (MBUF); the case investigates distributional cost burdens under different pricing calibration scenarios. There are many ways to raise the same amount of money with a parametric structure, but compared to a gas tax and flat mileage-based fee, a parametric structure may produce a better distribution of cost burdens. Technical, political, legal, and other considerations for implementing an MBUF are discussed, drawn from a literature review of current efforts; often these aspects can direct the development of a pricing mechanism as much if not more than empirically derived goals. The conclusion discusses how this approach can aid in the development of pricing mechanisms that move closer to the user-pays principle.

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DISCLAIMER

An Equitable and Integrated Approach to Paying for Roads in a Time of Rapid Change

UNIVERSITY OF CALIFORNIA INSTITUTE OF TRANSPORTATION STUDIES

February 2019

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Glossary of Terms

Automated vehicles – vehicles with autonomous driving capabilities (typically refers to level 3-5)

Connected vehicles – vehicles equipped with internet access, which allows for the transfer of internet access, and data, with other devices both inside and outside the vehicle

Electric vehicles – vehicles that are powered by fully electric means, including, but not limited to, battery electric vehicles (BEVs), hydrogen fuel cell vehicles (FCVs)

Hybrid vehicles – vehicles that are powered by a combination of fossil fuels and electric means, including, but not limited to, parallel hybrid vehicles, series hybrid vehicles, plug-in hybrid electric vehicles (PHEVs)

Vehicle miles traveled (VMT) – a measure used in transportation planning for a variety of purposes, typically to measure the amount of travel for an individual or collection of vehicles in a geographic region over a particular period of time

Mileage-based user fee (MBUF) – a method of collecting fees for the use of roadways, typically based upon VMT, and also sometimes referred to as a VMT fee

Road user charges/Road usage charges – another piece of nomenclature to describe an MBUF or VMT fee

Road charge – another piece of nomenclature to describe an MBUF or VMT fee

Heavy vehicle fee – a fee that is commonly assessed to large vehicles used for long distance commercial transport (i.e. vernacularly referred to as eighteen wheelers) and can vary based upon total weight, emission levels, as well as miles driven within a geographic area

High-occupancy toll (HOT) lane – a type of traffic lane that is available to high-occupancy (variably defined) vehicles and other exempt vehicles (variably defined) that can also be accessed by non-exempt or low occupancy vehicles for a fee (either a flat fee or a variable fee)

Express lane – another piece of nomenclature to describe an HOT lane

Transportation Network Companies (TNCs)– a shared mobility company that matches passengers with drivers via websites and mobile apps, also sometimes referred to as Mobility Service Provider (MSPs)

Executive Summary

The United States, and much of the world, is at a turning point with respect to transportation. Private companies are testing innovative forms of mobility and automation technology daily, and the pace of innovation has gotten ahead of public policy. Although some research seeks to understand the impacts of certain transportation futures (connected vehicles (CVs), level 3 and above automated vehicles (AVs), electric vehicles (EVs), etc.), much of this work glosses over the murky transition period to a fully automated reality.

Vehicle miles traveled (VMT) and VMT per capita have been steadily increasing since as far back as the 1970s and are on the rise again after a slight dip following the great recession of 2007-8 (Davis 2017; U.S. Federal Highway Administration 2017). Rising VMT alone is not necessarily a sign of deleterious outcomes, and VMT is often used as a proxy for gross domestic product as it tracks well with the volume of goods moved throughout the economy (McMullen and Eckstein 2012; Wachs and Ecola 2012). However, the nation's top metropolitan areas have experienced significant increases in congestion since the 1980s, causing increases in wasted time and fuel (Schrank et al. 2015). Paired with this VMT increase is a surge in online commerce, or e-commerce, fueled by the proliferation of mobile and connected technology, as well as on-demand services; these trends have the potential to change the vehicle composition on city streets.

While VMT is increasing, federal and state fuel excise tax receipts are dwindling (Dumortier et al. 2017). The concept of mileage-based user fees (MBUFs) to supplement or replace excise taxes has been around for decades (Vickrey 1960; Pigou 1920). However, developing and implementing mileage-based fees in such a way that fills revenue gaps and allows cities, regions, and states to achieve their environmental goals is a complex task to an evolving issue. Although many approaches to managing transportation demand have existed for decades, each has been viewed predominantly in isolation. By taking a holistic view, travel planners and policymakers can target the most important trip segments and craft solutions that work at multiple geographic scales (e.g., urban, suburban, and rural).

Transportation User Fees

Funding for America's roadways, particularly the federal highway system, has historically come from user fees through a gasoline excise tax. The first gasoline excise tax was passed by the State of Oregon in 1919 (Jones and Bock 2017), and the federal gasoline tax was established in 1932 (Sweet 1993). At the time, both of these taxes followed the user pays principle: those who benefit from the existence of a system (e.g., roads) pay into their maintenance and upkeep. Until recently, gasoline and diesel taxes adhered to the user pays principle. However, with increased vehicle fuel efficiency (Bureau of Transportation Statistics 2017) and stagnant federal excise tax prices since 1993 (Sweet 1993; Dumortier et. al 2017), fuel taxes no longer adequately equate benefits received and payments given. Furthermore, the current funding gaps for federal and state gasoline taxes are increasing every year, and this trend will likely continue (Dumortier et al. 2017). Finding a replacement fee that follows the user pays principle will ensure sustainable future funding and move taxation toward a more equitable framework.

A New Typology for Pricing and Access

In addition to finding sustainable funding sources, municipalities and regions are also searching for adaptive solutions that can address the changing transportation landscape. This requires re-imagining the core elements of a trip (human and material good transport) and looking beyond organizational boundaries. Breaking travel into three distinct segments: the *long haul*, the *last mile*, and *the curb* and grouping pricing or access strategies by these segments clarifies areas for delineation. The long haul portion of a trip typically occurs on freeways, highways, or major arterials, whereas the last mile usually takes place on smaller streets, depending upon the context of the destination. The curb portion of a trip accounts for any time a vehicle is unattended or parked.

Management strategies for the long haul portion of a trip include truck tolling schemes and managed lanes. MBUFs and road pricing schemes, such as the Electronic Road Pricing program in Singapore, provide ways to affect both the long haul and last mile legs of a trip. Purely last mile interventions include congestion zones, low-emission zones, and car-free zones; these are often cordon-based initiatives. At the curb, spatio-temporally dynamic parking pricing and/or curb use prioritization, building code reform, and many context-specific pilot programs have been used to make operations more efficient. By examining these often-isolated approaches (long haul, last mile, at the curb) together, policymakers can develop a holistic picture of the tools available to them regarding travel and goods movement demands.

Case Study: A Blended Long Haul and Last Mile Approach

Given the state's recent Road Charge Pilot Program (RCPP), as well as legislated gasoline excise tax and vehicle registration fee increases from Senate Bill (SB) 1 (Statutes of 2017, Beall), California provides a relevant context within which to demonstrate a potential implementation process for a MBUF, road usage charge (RUC), or Road Charge (RC).

Using data provided by Caltrans from the RCPP, we present a multiplicative, parametric RUC formulation that is "revenue-neutral," producing no more revenue than the incumbent gas tax. The formulation is vehicle-specific: its parameters rely on five vehicle characteristics (weight class, vehicle use, level of automation, propulsion system, and value) to assign per-mile charges. The per-mile rate for a vehicle is determined by multiplying a calibrated base fare with values corresponding to the appropriate vehicle classification level for each parameter. The values assigned to each classification level within a parameter increase with respect to the relative impact of corresponding vehicles. For example, the classification-level values for the weight-class parameter increase with respect to vehicle weights corresponding to each level. For the case study, we include parameters for vehicle use, weight class, and propulsion, as these characteristics are temporally invariant, and necessary statistics are available from public sources.

The final cleaned sample data derived from the RCPP included 3,980 personal vehicles, 248 light commercial vehicles and 55 heavy commercial vehicles. During the RCPP, the per-mile rate was based on the average fuel economy of light and heavy vehicles, of 20 and 6.2 mpg, respectively. The flat, $0.018 per mile road charge used in the pilot resulted in a 23% increase in average monthly taxes/fees for personal vehicles and decreases of 12% and 2% of average monthly taxes/fees for light commercial vehicles and heavy commercial vehicles, respectively.

We tested three approaches to calibrating the example MBUF: 1) a naive approach using a uniform increment to distinguish between vehicle classification levels for each parameter; 2) a rigid approach that equates the relative amount of greenhouse gas (GHG) emissions for each level within a parameter to non-uniform increments for that parameter; and 3) a flexible approach relating the classification-level values to the relative amount of GHG emissions, while seeking to minimize the average change in taxes/fees for both personal and commercial vehicles. In all three approaches, the base fare of the MBUF is calibrated to maintain revenue neutrality in comparison to the total estimated gas tax revenue.

The distribution of the average MBUF given by the naive calibration approach (approach 1) reflects the uniformity of the increments in parameter values, with the average MBUF increasing steadily across the classification levels within each parameter. The second approach places an abnormally large burden on heavy-duty vehicles. The adjustments made in approach three result in a more agreeable distribution of average MBUF rates, while maintaining a variation of values that more clearly incentivizes hybrid and electric vehicles and discourages excess travel by heavier vehicles with internal combustion engines. Supplementing this approach with dynamically collected information about vehicle uses, occupancies, and automation levels gives decision makers the power and flexibility to craft dynamic pricing schemes that: 1) distribute cost burdens in a data-driven, user-pays manner and 2) incentivize technology use that will help the state reach its environmental goals.

Hurdles for Road Charge Implementation

Political challenges to MBUFs are often intertwined with social hurdles related to the perceived fairness of a MBUF, as well as personal privacy considerations. Lessons learned from failed attempts to implement cordon pricing schemes in the United States, as well as best practices from successful implementations in Europe and elsewhere in the world, provide some background on barriers to future U.S. programs. These considerations, along with recent state efforts to pilot MBUFs and city-scale parking and curb space reform and innovation provide insight into how this new typology for pricing and access can further city and regional goals.

Additionally, the issues of tax law, debt spending, and bonding also come into play when phasing out or trying to replace an existing gasoline-excise tax. Municipal bond structures and debt obligations, state vehicle codes, and federal regulations can make the details highly complex. The chosen technological option for implementation, including inter-state compatibility and user experience, can create tradeoffs between other considerations as well. While all these stated hurdles and considerations make the task of implementing an integrated pricing and access scheme seem daunting, these should not be taken as reasons to shy away from it but rather as indications of its importance.

Conclusion

As the transportation ecosystem continues to evolve rapidly in tandem with consumer preferences, it will become increasingly important to manage and maintain infrastructure effectively. Doing so will take coordinated efforts between public agencies, and active participation by the private sector. Particularly with the advent of automated and autonomous vehicles—which are heavily reliant on credible road markings—keeping streets maintained will become more and more a private interest, as well as a public one. Carrying innovative pricing concepts forward will position localities and regions to be able to respond to the changing landscape of maintenance funding and foster innovate idea sharing across the nation and the globe.

The challenges facing cities, planners, and the private passenger and goods movement industries are significant, and as such no silver bullet exists. Tackling these issues will require coordinated efforts and innovative thinking. This report outlines a host of strategies based upon the input of experts in the field and has honed in on a few concrete examples in California. The case study of the California Road Charge Pilot Program (CA RCPP) and example MBUF calibration demonstrates the potential for designing road user charges based on measurable impacts of road use by different vehicle classes, embodying the user-pays principle to a greater extent than flat-rate gas taxes and MBUFs by aligning the distribution of the cost burden across road users according to their relative road use and GHG emissions. Practitioners, researchers, advocates, and policymakers can use this document to better understand the tradeoffs present in transportation funding decisions, especially when planning over long time horizons in the midst of uncertainty.

Abstract

A brief overview of transportation user fees (historically and in a contemporary context) is presented followed by a discussion on how segmenting travel into three categories – *long haul*, the *last mile*, and *at the curb* – creates a new typology for transportation pricing and access mechanisms. A case study based upon California's recent Road Charge Pilot Program demonstrates a quantitative example for a blended long haul/last mile approach using a parametric mileage-based user fee (MBUF); the case investigates distributional cost burdens under different pricing calibration scenarios. There are many ways to raise the same amount of money with a parametric structure, but compared to a gas tax and flat mileage-based fee, a parametric structure may produce a better distribution of cost burdens. Technical, political, legal, and other considerations for implementing an MBUF are discussed, drawn from a literature review of current efforts; often these aspects can direct the development of a pricing mechanism as much if not more than empirically derived goals. The conclusion discusses how this approach can aid in the development of pricing mechanisms that move closer to the user-pays principle.

1. Introduction

The United States, and much of the world, is at a turning point, and glimpses of the transportation future are emerging. Private companies are testing innovative forms of mobility and automation technology daily, and the pace of innovation has gotten out ahead of public policy.

While some research seeks to understand the impacts of certain transportation futures (connected vehicles (CVs), automated vehicles (AVs), electric vehicles (EVs), etc.), much of this work glosses over the murky transition period to a fully automated reality. A tremendous amount of work remains, both from the public and the private sector, to set the stage for widespread adoption of EVs, AVs (cars and large trucks), or small unmanned aerial vehicles, just to name a few of the emerging future modes of transportation. Near- and mid-term solutions require innovative approaches, including public policies.

Vehicle miles traveled (VMT) and VMT per capita have been steadily increasing since as far back as the 1970s and are on the rise again after a slight dip following the great recession of 2007-8 (Davis 2017; U.S. Federal Highway Administration 2017). Rising VMT alone is not necessarily a sign of deleterious outcomes. VMT is often used as a proxy for gross domestic product as it tracks well with the volume of goods moved throughout the economy (McMullen and Eckstein 2012; Wachs and Ecola 2012). However, the nation's top metropolitan areas have experienced significant increases in congestion since the 1980s, causing increases in wasted time and fuel (Schrank et al. 2015). The direction of these trends signals a continuation, as the nation's roadways are not equipped to handle such large volumes of traffic with limited maintenance and repair. Paired with this VMT increase is the surge in online commerce, or e-commerce, fueled by the proliferation of mobile and connected technology, as well as on-demand services. E-commerce represented just over 4% of total retail sales volume at the beginning of 2010, a figure that has jumped to just under 9% by the beginning of 2017 (U.S. Department of Commerce and U.S. Census Bureau 2017). This increase in commerce has also triggered a rise in freight volume, as these goods must make their way to the individuals who purchase them (Bureau of Transportation Statistics and Federal Highway Administration 2017). Although parcel delivery volume information is difficult to obtain, work by the Brookings institution has shown a significant rise in all truck mileage on urban roads, with a particularly sharp rise in the mid-2000s (Tomer 2015). Additionally, there have been documented increases in the overall volume from UPS, and city officials have marked the trend of increasing delivery vehicles on city streets (Forscher 2016; UPS 2017; Rodriguez 2017).

At the same time that VMT is increasing, federal and state fuel excise tax receipts are dwindling (Dumortier et al. 2017). A major part of this decrease in revenue stems from a loss in buying power of the federal excise tax on gasoline, which has not been raised since 1993 (Sweet 1993), compounding the deficit is the increased vehicle fuel efficiency.

It is important to note that California adopted SB 1, the Road Recovery and Accountability Act in California, on April 28, 2017 to direct tax revenues toward "fix-it-first projects" and address prior lack of adjustment for inflation. SB-1 raises $52 billion over the next 10 years. Although some states have raised their excise taxes in recent years, these increases still cannot cover the gaps in funding that still exists.

The concept of mileage-based user fees (MBUFs) to supplement or replace excise taxes has been around for decades (Vickrey 1960; Pigou 1920). However, crafting mileage-based fees in such a way that fills revenue gaps and allows cities, regions, and states to achieve their environmental goals is a novel approach to an evolving issue. Furthermore, combining approaches to capture passenger vehicles and medium-duty vehicles empowers decision makers to create combined strategies capable of managing passenger and goods movement demands.

Splitting passenger and goods movements into three distinct segments: the *long haul*, the *last mile*, and *the curb* enables the delineation of different strategies for various points in a trip. Although many approaches to managing transportation demand have existed for decades, each has been viewed predominantly in isolation. By taking a holistic view, travel planners and policymakers can target the most important trip segments and craft solutions that work at multiple geographic scales (e.g., urban, suburban, and rural). While other approaches focus on vehicle licensing fees and registration caps, among others, we have chosen to target travel demand management strategies.

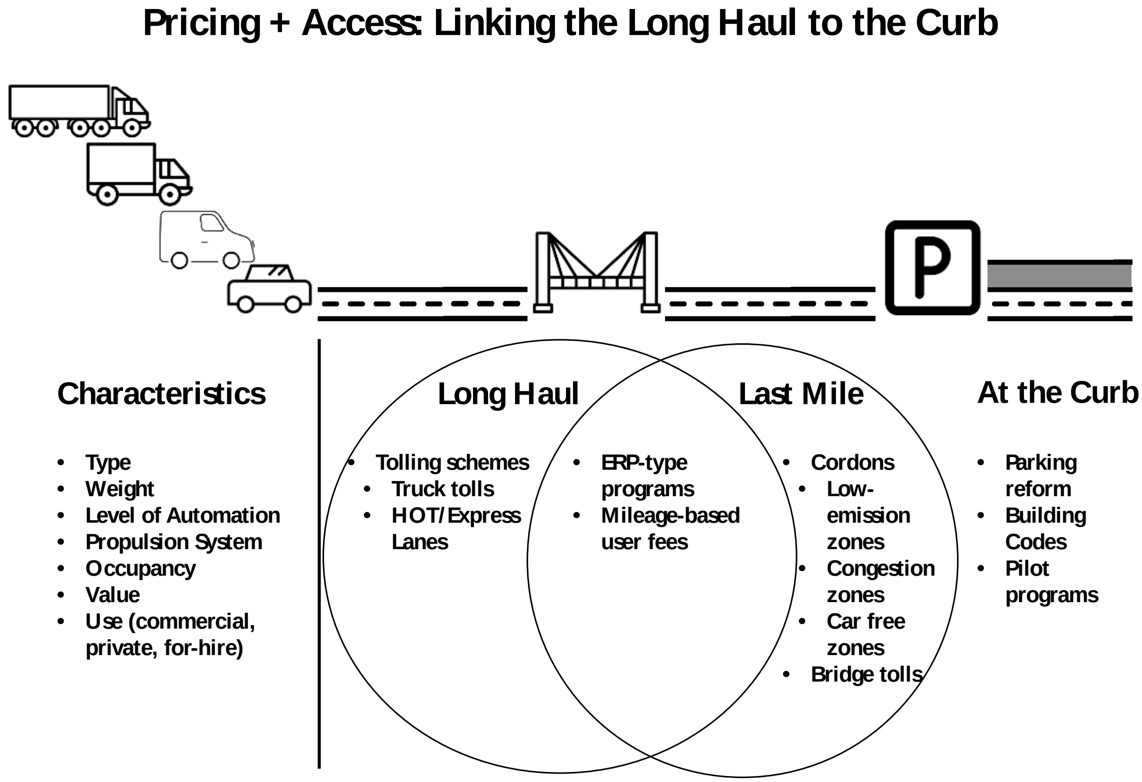
The rest of this report is organized into four key sections: 1) an overview of transportation user fees, 2) a discussion of a new typology for viewing transportation pricing mechanisms, 3) a presentation of a case study based upon California's recent Road Charge Pilot Program, and 4) some considerations for implementation, drawn from a literature review of current efforts regarding MBUFs, followed by a conclusion and next steps.

2. Transportation User Fees

Funding for America's roadways, particularly the federal highway system, has historically come from user fees. The first gasoline excise tax was passed by the State of Oregon in 1919 (Jones and Bock 2017), and the federal gasoline tax was established in 1932 (Sweet 1993). At the time, both of these taxes followed the user pays principle based on fuel consumption: those who benefit from the existence of a system (e.g., roads) pay into their maintenance and upkeep. Until recently, gasoline and diesel taxes adhered to the user pays principle. However, with increased vehicle fuel efficiency (Bureau of Transportation Statistics 2017) and stagnant federal excise tax prices since 1993 (Sweet 1993; Dumortier et. al 2017), fuel taxes no longer adequately equate benefit received and payment given. Furthermore, the current funding gaps for federal and state gasoline taxes are increasing every year, and this trend will likely continue (Dumortier et al. 2017). Finding a replacement fee that follows the user pays principle based on miles driven (i.e., a direct link between road usage and payment) will ensure sustainable future funding and move taxation toward a more equitable framework.

2.1 A new typology for pricing and access

In addition to finding sustainable funding sources, municipalities and regions are also searching for adaptive solutions that can address the changing transportation landscape. This requires re-imagining the core elements of a trip (human and material good transport) and looking beyond organizational boundaries. As shown in Figure 1 below, breaking travel into three distinct segments: the *long haul*, the *last mile*, and *the curb* and grouping pricing or access strategies by these segments clarifies areas for delineation. The long haul portion of a trip typically occurs on freeways, highways, or major arterials, whereas the last mile usually takes place on smaller streets, depending upon the context of the destination. The curb portion of a trip accounts for any time a vehicle is unattended or parked. At the left, we present vehicle characteristics that can be used to distinguish between user groups in the near-term. Using this framing, one can assess how a region or municipality currently manages travel to and through it and what additional types of approaches could be employed.



Graphics provided by: Madeleine Bennett, Tim Powell, Edwin Prayogi M, A. Stone, Hardini Dwi Lestari, Hamfif

Figure 1 a new typology for transportation pricing strategies

Below we present examples of how transportation revenue mechanisms adhere to the user pays principle by trip segment typology, as well as examples of additional strategies that could be employed to add to their effect.

2.1.1 The long haul

The long haul of a trip can be thought of as the majority of the mileage. For a longer commute, this would be the trip segment that takes place on freeways or major arterials, away from one’s home or workplace. For freight movements, this is the majority of the travel. Although some of these miles may take place via other modes (rail, sea, air), we focus on truck transportation. Some distinguishing characteristics of the long haul include: 1) there are multiple different route options available, 2) vehicle occupancy may affect one’s ability to use faster lanes, and 3) this part of the trip is affected by residential and commercial land-use decisions (where workers live and where firms locate). The predominant pricing and access strategies for the long haul are: truck tolling schemes and tolling/High Occupancy Tolling (HOT)/Express lanes.

2.1.1.1 Truck tolling schemes

There is some precedent for transportation user fees internationally, including: England, Germany, Switzerland, Sweden, and Singapore, among other nations. Austria, Germany, and Switzerland were the first three countries in Europe to institute truck tolling schemes on their principal roadways (although Switzerland's jurisdiction applies to all roads) (McKinnon 2006). The main objective of these systems applies well to current needs in the U.S., as revenue generation for transportation infrastructure maintenance and expansion was at the forefront of adoption rationale. In the majority of these programs, trucks were charged per mile driven on specified roadways, using onboard devices to track their positions (McKinnon 2006). Additionally, equalizing fees between foreign and domestic vehicles, was an objective of all three, while Switzerland also sought to mediate trucking externalities (McKinnon 2006). As a result of the reinvestment of revenue into the transportation infrastructure, these tolling networks follow the user pays principle where those who benefit from the system pay into it. The Swiss Heavy Vehicle Fee (HVF) resulted in the added benefit of increased goods movement efficiency, raising ton-kilometers while lowering overall kilometers traveled by vehicles after its establishment. Although kilometers traveled eventually rose again, the system was maintained at a lower level than in absence of the HVF (Krebs and Balmer 2015). It is worth noting that the demand elasticity for freight travel may differ from that of passenger travel and vary by commodity, but there is limited information available to concretely identify these differences (Graham and Glaister 2004). Generally, truck tolling schemes satisfy the user pays principle because someone is paying for road use, but such strategies may not drastically shift demand as costs may eventually be passed onto consumers by transport providers. Specific truck tolling schemes do not exist widely in the United States, although Oregon has established a Weight-Mile Tax that applies to all commercial vehicles operating on public roads over a registered weight threshold (ODOT 2019). Additionally, there are voluntary fleet recognition programs, such as those run by the U.S. Environmental Protection Agency (NCFRP 33). These programs are used mainly for the promotion of environmentally friendly practices and subsequent advertising by transportation companies.

2.1.1.2 Tolling/HOT/Express lanes

Freeway tolling, either by dedicated toll lanes or by shared high-occupancy toll (HOT) or express lanes, is another way to manage the long haul portion of a trip. While the exact mechanism may differ, the general approach to long haul tolling is to convert one or two lanes of general purpose traffic into toll or carpool lanes, which can either be accessed by meeting the vehicle occupancy requirements or paying via a transponder to enter (Brownstone and Small 2001). Prices for non-carpool traffic can remain static or vary dynamically by time of day or congestion level on the roadway (Brownstone and Small 2001). Linear tolling schemes are often directly used to raise revenue for roadway capital and maintenance costs and to make travel more efficient (or less congested) for those with enough passengers or willingness to pay (Button 1984). Recently, toll lanes in the United States have become more dynamically adaptive to traffic conditions, with the explicit goal of maintaining certain vehicle speeds throughout a corridor (VDOT 2018).

2.1.2 In between the long haul and the last mile

There are a few approaches to roadway infrastructure management and pricing that are flexible enough to apply to the long haul and the last mile. Due to their technological implementation, which can employ locational and temporally aware technology, MBUFs and electronic road pricing schemes are able to create numerous separate geographic regions in which to price and different pricing and access schemes by time of day.

2.1.2.1 Mileage-based user fees

Although these can be used for the last mile as well, MBUFs represent another way to control long haul miles. In practice, an MBUF would function similarly to a toll lane, but instead of only tolling one lane of a freeway, all lane-miles of a roadway, or a region, would have a price associated with them. Prices could vary dynamically or remain static; both types of approaches have been piloted in the United States (Jones and Bock 2017; Loudon 2009). In both MAP-21 and the FAST Act[1], states received funding for pilot projects to investigate the feasibility of mileage-based fee collection programs (Mica 2012; Davis 2015). California, Delaware, Hawaii, Minnesota, Oregon, Road Usage Charge West (a consortium of 14 western states), and Washington, among other states, are all in different stages of MBUF pilot programs and exploration, and Oregon successfully launched a voluntary road usage charge program in 2015 (Jones and Bock 2017; USDOT 2016). The State of Utah has formed an advisory committee to begin the path towards implementing a Road Usage Charge and the legislature passed enabling legislation in 2018; the state Department of Transportation is set to release a Request for Proposals (RFP) in February, 2019 for a Commercial Account Manager.

The predominant goal of the current U.S. pilot programs is to test a replacement revenue source for fuel excise taxes, as such implementations are static and prices are set to match excise taxes for average vehicles in each state (Jones and Bock 2017; California State Transportation Agency 2017). Many types of user experiences have been investigated: one method attempts to resemble a gas tax and requires drivers to pay a fee at the pump, another uses onboard vehicle technology or a mobile phone to actively record and report mileage and assess a fee (via an account manager) for roadway use, while another relies on odometer readings at regular intervals. The last approach simply allows drivers to buy permits for a certain number of miles or blocks of time. Given the technological capabilities of onboard technology and mobile phones, it is possible to develop a much more dynamic pricing system based upon many, if not all, of the vehicle characteristics given in Figure 1. Doing so would require significant support, and some challenges related to implementing a program like this are discussed in Section 4.

2.1.2.2 Electronic road pricing (ERP)

Singapore remains the only region in the world with a full-scale electronic road pricing (ERP) scheme (Land Transport Authority of Singapore 2013). ERP, like MBUFs, can be used both as a long haul or a last mile approach. The Land Transport Authority (LTA) in the country established the ERP program with the goal of making motorists bear the costs of their use of congested roads. This is nearly directly in line with the user pays principle (Land Transport Authority of Singapore 2013). Currently, the system operates with a dense network of electronic gantries and onboard transponders in vehicles that charge drivers in real time when they cross a gantry. Rather than exacting a per-mile fee, drivers are charged for access to the roadway at the gantry point, regardless of how far they travel on the road. The ERP system has been hugely successful in curtailing traffic volumes into the city—it is worth noting that this system also has been supplemented by increased public transit services. Singapore is currently working on implementing ERP 2, a system update based upon satellite technology that will allow for dynamic, mileage-based pricing and further the ERP system's goal of charging drivers to use congested roadways. ERP is often looked at as the most robust implementation of road pricing worldwide, as it is

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[1] MAP-21 (enacted 2012) and the FAST Act (enacted 2015) are two successive federal surface transportation bills in the United States. These are examples of multi-year funding and authorization bills that detail expenditures for a wide variety of modes across the country.

geographically comprehensive and dynamic. This allows the LTA to use it to raise revenue, increase efficiency, manage travel demand, and serve environmental goals at the same time.

2.1.3 The last mile

After traveling long haul distances, vehicles then approach their destinations, either in city centers, suburbs, or more rural locations. This last mile of travel is dominated by different factors than long haul miles, as a fixed end location determines the availability of travel routes. Often this leg of the trip happens on urban arterials and smaller roads, thus travel speeds are lower, and externalities are produced in close proximity to citizens. Thus, many management strategies in this region of a trip have focused on congestion, emissions, and other externality-driven approaches.

2.1.3.1 Congestion zones

Area, congestion, or cordon pricing, represents another type of approach to raise revenue that follows the user pays principle. Congestion zones established in London (est. 2003) and Stockholm (est. 2007), primarily established to reduce congestion, achieved many other goals as well, including revenue generation. Each city also operates a low emission zone (LEZ), discussed in Section 2.1.2.2, following roughly the same boundaries as the cordon, designed to regulate the allowable pollutant levels from vehicles entering the city boundaries. Both cities have successfully lowered congestion levels in their metro areas, although some of the reduction stems from investment in public transit and active modes in concert with the charging schemes (Ison and Rye 2005). The London example abides the user pays principle, as money collected gets reinvested back into transportation infrastructure. Some of the revenue also goes toward public transportation (Ison and Rye 2005), which may be seen as a violation of the user pays principle. However, increased public transit services have aided in congestion decline, and vehicles passing the cordon also benefit. In Stockholm, the government initially intended to reinvest revenue into roadway and public transit infrastructure, and in particular used money from the system to construct a bypass road around Stockholm. After negotiation, however, political leadership earmarked revenues only for roadway infrastructure (Börjesson et al. 2012). Other cities in Sweden have since adopted congestion charges primarily to provide funding for transport improvements (Börjesson et al. 2012). Congestion zones can be used to raise revenue, increase efficiency within the cordon, and affect travel demand. Congestion zones, however, have famously faltered in the United States. Pilot programs in San Francisco and New York failed to launch in the mid-2000s, and conversations on the topic all but halted afterwards, although they have recently resumed in the media (Ison and Rye 2005).

2.1.3.2 Low emission zones

Similar to a congestion zone, a LEZ uses a cordon to restrict access to a central city based upon a vehicle's emission characteristics (Holguín-Veras et al. 2015; Browne et. al 2005). London and Stockholm both operate LEZs in addition to their congestion zones, and these allow for the furthering of environmental goals within the cities. There is insufficient evidence to understand the relationship between the demand for goods and LEZs (Browne et. al 2005). While this concept has not taken hold in the United States, fleet recognition programs, as mentioned in Section 2.1.1.1, have been introduced to voluntarily allow operators to excel along environmental metrics (Holguín-Veras et al. 2015).

2.1.3.3 Car free zones

At a smaller geographic scale, some European cities (such as Hamburg, Oslo, Helsinki, Madrid) are investigating the concept of car free zones in central downtown areas (Nieuwenhuijsen and Khreis 2016). The concept driving these plans is to completely free parts of the city from vehicular traffic, and its associated environmental and public health harms, and to establish pedestrian and bicycle friendly zones (Nieuwenhuijsen and Khreis 2016). Effects on transportation are secondary to health and environmental goals in these plans, and as the areas are cordoned off in them and are relatively small, the overall effect on passenger and goods transportation may be relatively minimal. However, if this trend continues, its effects could become more widespread and begin to change behavior. Additionally, many of these car free schemes do not intend to ban goods movement vehicles, as this is seen as necessary for economic purposes (Nieuwenhuijsen and Khreis 2016).

2.1.4 At the curb

All trips must end, and thus there exists another intervention point. Driving journeys require a parking space, which is either in an off-street parking lot (privately or publicly controlled) or at a parking space. Each of these places is obviously fixed in space, and thus demand is a function of availability and price. By developing demand-responsive pricing regimes or by re-allocating space usage by time of day or location, some cities are reforming parking to better meet the needs of users, while also affecting demand.

2.1.4.1 Curb management, parking reform, and pricing

Many municipalities across the United States are currently re-envisioning the use of curb space in and around downtown areas through parking reform (Barter 2015). These strategies vary in their goals, but many include occupancy targets, demand responsive pricing, coordination between on-street and off-street capacity, and proactive communication and stakeholder input. Some are intended to smooth commercial vehicle operations as well. In San Francisco, the SF*park* pilot used a target block occupancy level of 85% with the goal of minimizing cruising time for parking spaces. Hourly meter prices were changed roughly on a monthly basis, and the evaluation found that parking search times and VMT decreased, and occupancy targets were achievable by small tweaks in pricing (SFMTA 2014). The pilot was later made into a permanent program. The city of Portland, Oregon released a citywide parking strategy in 2015, which also referenced the 85% occupancy target. The strategy went a bit beyond to establish curb use priorities and delineated areas by their land use and city functions (Doherty-Chapman et al. 2015). Washington, D.C. similarly took a neighborhood by neighborhood approach in its curb management study, and the city also performed a gap analysis to better understand the necessary inputs to future successful policies (Nelson\Nygaard 2015). The District Department of Transportation has also established one of the leading freight demand models, and established freight districts for analysis, similarly to the curbside management districts (CDM) (Smith 2014). In New York City, a strategy to smooth commercial vehicle operations in Midtown relied on user-paid loading zones and helped to reduce double-parking and unnecessary long-duration stays (Holguín-Veras et al. 2015). Curb management and parking reform are both effective tools for controlling the endpoint of a trip and can be particularly useful if user response to pricing is inelastic, as restricted access to parking can still affect a trip.

2.1.4.2 Building codes

Some cities are streamlining their building codes to facilitate off-street loading functions. This could also be expanded to incorporate passenger pick-up and drop-off in the future. In San Francisco, for example, the Planning Department released an updated Transit Impact Development fee structure to streamline the process for developers in determining their required financial or other outlays based upon a prioritized point system. The point system clearly delineates what sorts of infrastructure (loading docks, etc.) can lead to a reduction in fees. This system also dovetails well with San Francisco's recently adopted VMT-based analysis of transportation impacts under the California Environmental Quality Act and Senate Bill 743 (Madhavan 2016). Improving the efficiency of off-street activities can in turn make street functions flow more smoothly, particularly with regard to double-parking for loading (passenger or goods) purposes.

2.1.4.3 Pilot programs

Some recent university and industry partnerships are showing promise regarding future innovative solutions that go beyond the curb. The University of Washington has set up its Urban Freight Lab, with key industry and public partners such as the Seattle Department of Transportation, UPS, USPS and others and has also established its Final 50 Feet research focus to make the final hand-to-hand delivery process more streamlined in urban settings (University of Washington 2018). The Volvo Research and Education Foundation (VREF) also hosts an annual conference on Urban Freight, now in its third year; the topic for 2018 is centered on freight and livable cities (VREF 2018). Such endeavors, particularly merging academic, public, and private stakeholders, provide a model of ways forward for freight and passenger demand strategies.

2.1.5 Discussion regarding pricing and access

In Error! Reference source not found., we provide examples of pricing and access strategies. By examining these often-isolated approaches together, policymakers can develop a holistic picture of the tools available to them regarding travel and goods movement demands. In conducting transportation planning (e.g., Regional Transportation Plans, Long Range Plans, etc.), categorizing existing programs and policies in this way can help to provide a more holistic view of current management strategies and can help enumerate other possible strategies. Reviewing strategies and typologies along with stated or planned future goals can highlight alignment between strategies and potentially reveal further benefits than pursuing one strategy alone.

As MBUFs have gained a lot of attention recently, we delve into details in Section 3 regarding one potential methodology for enacting a broad-based access and pricing mechanism based on vehicle-specific MBUFs. Section 4 covers some of the hurdles to implementing such a strategy.

Table 1 A comprehensive look at pricing and access strategies by typology

Typology	**Municipal/Regional Strategies**	**Boundary**	**Geographic Scale**	**Commercial and/or Private Vehicles?**	**Dynamic vs. Static**	**Goals Supported**
Long Haul						
	Truck tolling schemes	Highway	Regional	C, P	S	environmental; travel demand; goods movement demand
	HOT/Express Lanes	Highway	Regional	C, P	D	revenue; efficiency; travel demand
Blended Long Haul / Last Mile						
	Mileage-based user fees	Zonal	Regional, State, City	C, P	D	revenue; efficiency; travel demand; environmental
	Electronic road pricing (ERP) I & II	Zonal	Regional, State, City	C, P	D	revenue; efficiency; travel demand; environmental
Last Mile						
	Low-emission zone	Cordon	Regional, City	C, P	S	environmental; travel demand; goods movement demand
	Congestion tone	(Directional) Cordon	Regional, City	C, P	S	revenue; efficiency; travel demand
	Car free zones	Neighborhood	Neighborhood, City	C	S	environmental; efficiency; travel demand
	Bridge/tunnel toll	Directional Toll Plaza	Regional, City	C, P	S	revenue; efficiency
At the curb						
	Parking reform	Parking Meter	Neighborhood, City	C, P, or separately	D	revenue; efficiency; travel demand; environmental
	Building Codes	Curb; Loading Bay	Building, Neighborhood	C, P, or separately	S	revenue; efficiency
	Pilot Programs	Parking Meter	Neighborhood, City	C,P, or separately	D, S	revenue; efficiency; travel demand; environmental

3. A Blended Long Haul and Last Mile Approach

Building upon the typology we established in Figure 1, and given the recent momentum regarding MBUFs as described in Section 2.1.2.1 above, California provides a relevant context within which to demonstrate a potential implementation process. In any real-world environment, the caveats discussed in Section 4 will provide constraints on the design and operation of a management strategy, but for demonstration purposes, we choose to temporarily ignore such factors. Additionally, state and local contexts would change the formulation. Not all regional governments function in the same ways, and local controls differ widely. However, we still feel that by expounding on this process, its value can be demonstrated. For consistency, while a pricing and access strategy could easily apply to commercial vehicles, lack of available data constrains this discussion—see Section 4 for more on this topic. However, as an increasing number of delivery vehicles fall into the light-duty weight category, such a strategy likely covers them. This raises the question of where cost burdens fall. In sections 3.2 and 3.3, we present a possible MBUF formulation and numerical example for the California context in section 3.1.

Such an exercise is of particular importance with respect to MBUFs as recent reporting on OreGO, Oregon's voluntary MBUF program, noted a decrease in revenue due to the types of vehicles enrolled in the program (Jones and Bock 2017). Guaranteeing future revenue streams is key for any decision maker when examining a policy or tax proposal.

3.1 Setting the California context

As of July 1, 2017 in California, the total gasoline excise tax was 29.17 cents per gallon. With the recent passage of SB 1 in April 2017, this increased to 39.8 cents per gallon in November 2017, and it will increase to 47.3 cents per gallon in July 2019. As planned, after July 2020, the tax will be indexed to inflation to account for future changes. Similarly the state diesel excise tax increased from 16 cents per gallon to 36 cents per gallon in November 2017, and will be indexed to inflation beginning in July 2020. The state also collects two two categories of sales taxes for diesel fuel sales: state and local taxes (which average 8.44 percent of sale), and an additional 1.75 percent of sale; the additional 1.75 percent increased to 5.75 percent in November 2017.

Through the Department of Motor Vehicles (DMV), the state also collects a suite of vehicle license and registration fees which differ for personal and commercial vehicles. As these fees are not directly tied to vehicle use and revenues not directly redistributed to transportation at this time, we do not consider them directly in this report, but future research could inspect the conversion of such fees into a user-pays adherent structure.

This measure, although intended to raise sustainable future revenue, will continue to lose its buying power once the state moves closer to its goals set forward in climate legislation looking toward 2050. The California Air Resources Board stated in its 2016 Mobile Source Strategy that the majority of the vehicle fleet must be zero emission or plug-in hybrid to meet greenhouse gas emissions (GHG) reductions targets (California Air Resources Board 2016). This would require nearly 100% of sales to be of zero emission vehicles in 2050, according to the plan. Additionally, Governor Brown signed an Executive Order in 2012 (Executive Order B-16-12), stating the goal of 1.5 million zero emission vehicles on California's roads by 2025, and in 2018 issued another Executive Order (Executive Order B-48-18) that set a target of 5 million zero emission vehicles by 2030. In such a scenario, it is evident that a gasoline-based excise tax is no longer a sustainable revenue source. In fact, it would have become vastly ineffectual long before 2050. Thus, it is important to examine how an MBUF system, paired with prioritized destination and curb space access, could raise revenue and promote more efficient transportation modes.

3.2 A vehicle-specific MBUF formulation

An MBUF can be formulated on the basis of any number of constraints according to the policy goals of the road charge (RC). As an example, we present an RC formulation that is "revenue-neutral," producing no more revenue than the incumbent gas tax. Given the current gas and projected tax receipts and revenues (Brown et al. 2016), fleet characteristics and mileage profiles by urbanized area (Federal Highway Administration 2015) can be projected applying the following:

$$Total\ Revenue = \frac{tax}{gallon} \sum_{v} \frac{miles_v}{mpg_v}$$

Where mpg_v is the fuel efficiency of vehicle *v* (in units of miles per gallons), and the miles driven per vehicle *v*, $miles_v$, is a random variable whose distribution is determined by the mileage profiles of each vehicle type in the fleet. The total revenue of a gas tax is given by multiplying the sum of the fuel consumed by all vehicles in the fleet by the *tax* (in units of dollars per gallons).

A revenue-neutral, vehicle-specific MBUF is thus constrained by the following equation:

$$Total\ Revenue = \sum_{v} miles_v MBUF_v$$

Where $miles_v$ is the total miles driven by vehicle *v*, and $MBUF_v$ is the road use charge per mile driven by vehicle *v*, defined as follows:

$$MBUF_v = Base\_Fare \cdot \prod_{n}^{N} \alpha_{vn}$$

The per mile road use charge for vehicle *v*, $MBUF_v$, is the product of a $Base\_Fare$ that is the same for all vehicles and *N* vehicle-specific price scaling parameters, α_{vn}. Each of the *N* scaling parameters are computed based on L_n mutually exclusive classification levels.

The scaling parameters α_{vn} are defined as follows:

$$\alpha_{vn} = D_n + \sum_{l=1}^{L_n} \beta_{nl} X_{vnl}$$

$$X_{vnl} \in \begin{cases} 1\ if\ vehicle\ v\ has\ l\ class\ of\ parameter\ n \\ 0\ otherwise \end{cases}$$

$$\sum_{l=1}^{L_n} X_{vnl} = 1$$

$$D_n \,\epsilon \begin{cases} 1 \; if \; parameter \; n \; is \; a \; disincentive \\ 0 \; if \; parameter \; n \; is \; an \; incentive \end{cases}$$

$$1 \geq \beta_{nl} > \beta_{nl-1} \geq 0$$

Where X_{vnl} is an indicator (or dummy) variable that denotes whether classification level *l* of parameter *n* corresponds to vehicle *v*. The vehicle can have one and only one classification per parameter. β_{nl} is the scaling value corresponding to classification level *l* for parameter *n*. For convention, successive scaling values will correspond to successively less preferable classifications and will therefore increase in value. An incentive/disincentive dummy variable D_n is included to denote whether the charge basis for parameter *n* for that vehicle characteristic is intended as an incentive or disincentive. In the case of vehicle propulsion, for example, policymakers may wish to set the RUC structure in such a way that is perceived as *incentivizing* cleaner vehicles, rather than punishing vehicles that are less clean. The resulting parameter will be a discount, or less than 1.

Plugging in all of the variables, the equation for total revenue under the proposed RUC model is:

$$Total\ Revenue = \ Base\_Fare \cdot \sum_{v} \left(miles_v \cdot \prod_{n}^{N} \left(D_n + \sum_{l=1}^{L_n} \beta_{nl} X_{vnl} \right) \right)$$

One possible simplification of the MBUF model is to restrict the classification scaling values in order to make them strictly incremental. For example, parameter *n* could be restricted to increments of value β_n such that:

$$\beta_{nl} = (l-1)\beta_n \ \ \forall l \,\epsilon\, [1, L_n]$$

Where the “base” classification value would be zero. This reduces the model to *n+1* decision variables (the *n* parameter scaling values and the base fare):

$$Total\ Revenue = \ Base\_Fare \cdot \sum_{v} \left(miles_v \cdot \prod_{n}^{N} \left(D_n + \beta_n \cdot \sum_{l=1}^{L_n} l X_{vnl} \right) \right)$$

To illustrate the application of this model, we present six potential vehicle-specific scaling parameters:

n = {1: Weight Class, 2: Use, 3: Driver, 4: Propulsion, 5: Below Median Value, 6: Above Median Value}

The classification levels for each of the six scaling parameters are shown in Table 2.

Table 2 Proposed RUC Scaling Parameters and Classification Levels

	D_n	*l=1*	*l*=2	*l*=3	*l*=4	*l*=5
Weight Class (*n*=1)	1	Light Duty	Medium Duty	Heavy Duty	n/a	n/a
Use (*n*=2)	1	Personal	For-Hire/ Commercial	n/a	n/a	n/a
Driver (*n*=3)	1	Human	Level 3 AV	Levels 4-5 AV	n/a	n/a
Propulsion (*n*=4)	0	n/a	Electric	Hybrid	Natural Gas	Internal Combustion

Value – Below Median (n=5)	0	n/a	≤ Median – 2SD	Median - SD	Median	n/a
Value – Above Median (n=6)	1	Median	Median + SD	≥ Median + 2SD	n/a	n/a

3.3 A numerical example

In this section, we demonstrate an application of the proposed vehicle-specific MBUF using data from the California Road Charge Pilot Program (CA RCPP), which studied road charging as an alternative to the gas tax. The Road Charge Technical Advisory Committee (TAC), which was created by Senate Bill (SB) 1077—Sen. Bill 1077, 2013-2014 Reg. Sess. 2014 Cal. Stat.—and formulated by the Chair of the California Transportation Commission (CTC) in collaboration with the CA State Transportation Agency (CalSTA), provided recommendations for the design of the live pilot demonstration (CalSTA, 2017). Volunteers for the CA RCPP were given several options for mileage reporting technology or non-technology, and account management providers to record the mileage driven during the pilot, receive "faux"-reimbursement for gas taxes paid, and be "faux"-charged the mileage-based fees incurred. The CA RCPP ran from July 1, 2016 to March 31, 2017. In total, 5,129 vehicles participated of which 4,471 were personal vehicles.

We developed a simplified method for calibrating the model parameters based on estimates of greenhouse gas (GHG) emissions per mile for each vehicle class. The MBUF parameters are scaled in order to align the per-mile road charge as closely as possible with the estimate for GHG emissions per mile of each vehicle classification. This method is a simplified approach for implementing the "user pays" principle using just one of many externalities of road use as a proxy for the marginal social costs imposed by each mile driven by a particular vehicle.

3.3.1 Data cleaning and merging

Data from the CA RCPP was provided in aggregate form with all personal information removed for the purposes of this academic research by Caltrans. The data included the registered year, make, and model of each participating vehicle as well as the total miles driven during the nine-month pilot program and the classification of the vehicle into one of three vehicle categories: personal, light commercial, and heavy commercial. We cleaned the data for inconsistencies in vehicle make and model reporting and joined these data with the following data fields from the 2019 EPA Fuel Economy Dataset: fuel economy, fuel type, and vehicle class (EPA, 2018).

We took measures to estimate the fuel economy of vehicles with incomplete vehicle information. In cases where the year of a participating vehicle was not reported, the vehicle was matched to the newest model year of the same make in the EPA dataset to make a best-case estimate of fuel economy. Few participant vehicle entries, with the exception of hybrid vehicles and heavy commercial vehicles, included explicit information about the vehicle fuel type. Thus, in all cases where the EPA dataset included vehicles of multiple fuel types of the same make, model, and year of a participant vehicle with no fuel type designation, we selected the gasoline-fuel version for merging. For simplicity, all heavy commercial vehicles are assumed to use diesel. Finally, since the EPA dataset does not include two-wheeled vehicles or heavy vehicles, the fuel efficiencies of these vehicles were estimated as follows:

- Two-wheelers (e.g., motorcyles): 43.5 miles per gallon (mpg) (DoE, 2015)

- Heavy commercial vehicles: 6.2 mpg (CalSTA, 2017)

3.3.2 California Road Charge Pilot participant statistics

Of the 5,129 participants in the CA RCPP, only personal vehicles, light commercial vehicles, and heavy commercial vehicles were considered eligible to be charged during the pilot. The RCPP also included government fleet, out of state, and tribal vehicles that were exempt from being charged. After removing the 10% of those vehicles that drove zero miles during the course of the pilot, 3,980 personal vehicles, 248 light commercial vehicles, and 55 heavy commercial vehicles remain. The average miles driven per vehicle per month and the average fuel economy of each group are listed in Table . Monthly averages are computed based on the average length of enrollment in the 8.2 month pilot program[2] (CalSTA, 2017).

Table 3 Average Vehicle Fuel Economy, Mileage, and Tax Revenue of the CA RC Pilot Vehicles by Vehicle Weight Class

	Personal Vehicles, N = 3980	Light Commercial Vehicles, N = 248	Heavy Commercial Vehicles, N = 55
Average miles driven per month per vehicle	773	1318	5654
Average MPG	28	20	6
Average gas tax incurred per month per vehicle	$11	$27	$104
Average road charge incurred per month per vehicle	$14	$24	$102

On a per-vehicle basis, personal vehicles drove the least miles per month on average than did either of the commercial vehicle categories, on average. In total, personal vehicles made up 93% of the vehicles in the pilot and were responsible for 83% of the total miles driven by all vehicles. Light commercial vehicles contributed 9% of the total miles driven while heavy commercial vehicles contributed 8%.

The TAC determined the per-mile rate for the pilot program based on the average fuel economy of light and heavy vehicles, of 20 and 6.2 mpg, respectively as well as a time-weighted average tax rates of 35.4 and 11.4 cents per gallon for light and heavy vehicles, respectively (CalSTA, 2017)[3]. The flat, $0.018 per mile road charge used in the pilot resulted in a 23% increase in average monthly taxes/fees for personal vehicles and decreases of 12% and 2% of average monthly taxes/fees for light commercial vehicles and heavy commercial vehicles, respectively. The finding that the CA RCPP generated a net revenue is consistent with the final report produced by the CalSTA (2017). However, CalSTA did not report specific percentages for revenue increase.

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[2] Approximately 59% of participants enrolled on the first day of the pilot, while the remaining 41.1% enrolled during the following two months. (CalSTA, 2017)

[3] Using an average fuel economy of 20 mpg and the fuel tax rate of $0.354/ gallon, CalSTA calculated the per-mile rate as follows: 0.354/20 = 0.018.

Figure 2 displays the percent change in monthly costs for vehicles in the pilot by fuel economy, excluding electric vehicles (EVs), which did not pay the gas tax. Besides EVs, no vehicles with a fuel economy greater than 55 mpg participated in the pilot. [4] EVs naturally incurred the largest increase in average monthly taxes/fees, from $0 to $9 per month. Vehicles with fuel economy between 30 and 55 mpg almost doubled their monthly taxes/fees, while the least fuel efficient personal and light commercial vehicles reduced expenses due to taxes/fees by 28%. Hybrid vehicles experienced an increase in taxes/fees of 107%, while internal combustion (IC) vehicles experienced a 7% increase, on average.

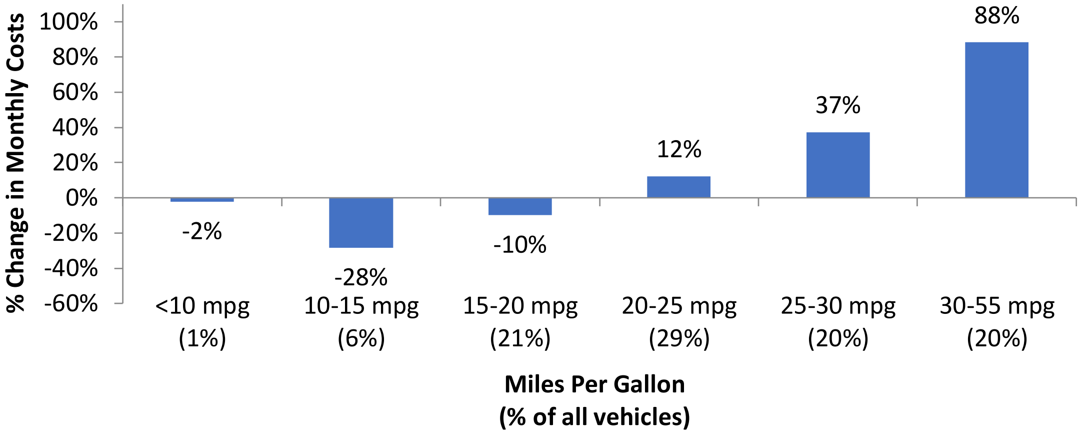

Figure 2 Percent Change in Monthly Driving Costs: Gas Tax to. CA RCPP Charge (by Vehicle Fuel Economy)

In the vehicle-specific MBUF implementation that follows, we demonstrate an approach to calibrating an MBUF based on an estimate of the GHG emissions produced by each vehicle in the CA RCPP. The GHG emissions are estimated using the miles driven per vehicle during the pilot, the fuel economy of the vehicle, and the emission factors presented in Table .

Table 4 EPA Emissions Factors for Greenhouse Gas Inventories

Gas (g CO_2/gal)	Diesel (g CO_2/gal)	Electricity (g CO_2/kwh)
8780	10210	239

On average, heavy commercial vehicles produced the most GHG emissions on a monthly basis of all three vehicles types in the CA RCPP. Figure 3 displays the distribution of average monthly GHG emissions per vehicle and average montly miles driven per vehicle in the CA RCPP by vehicle fuel economy. As fuel economy increases from zero to 20 mpg, both the average monthly mileage and GHG emissions per vehicle decrease. Although GHG emissions continue to decrease in relation to increases in fuel economy above 20 mpg, average monthly mileage per vehicle increases slightly as vehicle fuel economy increases from 20 to 55mpg. Electric vehicles drove the least miles per month, on average, of all vehicles in the pilot. The increase in average monthly mileage for vehicles between 20 and 55 mpg may reflect the fact

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[4] Note that all of the vehicles with a fuel economy less than 10 mpg are heavy commercial vehicles, while 44% of the vehicles with a fuel economy of 10 to 15 mpg are light commercial vehicles.

that individuals that travel more are incentivized to purchase more fuel efficient vehicles to save on fuel costs. This relationship could be tested in a real implementation of road charging that examines feedback and user behavior. A distribution of the miles driven per month for each vehicle in the pilot would enable an analysis of the impact of the road charge on the travel behavior of pilot participants, including sensitivity to price of participants based on vehicle classification.

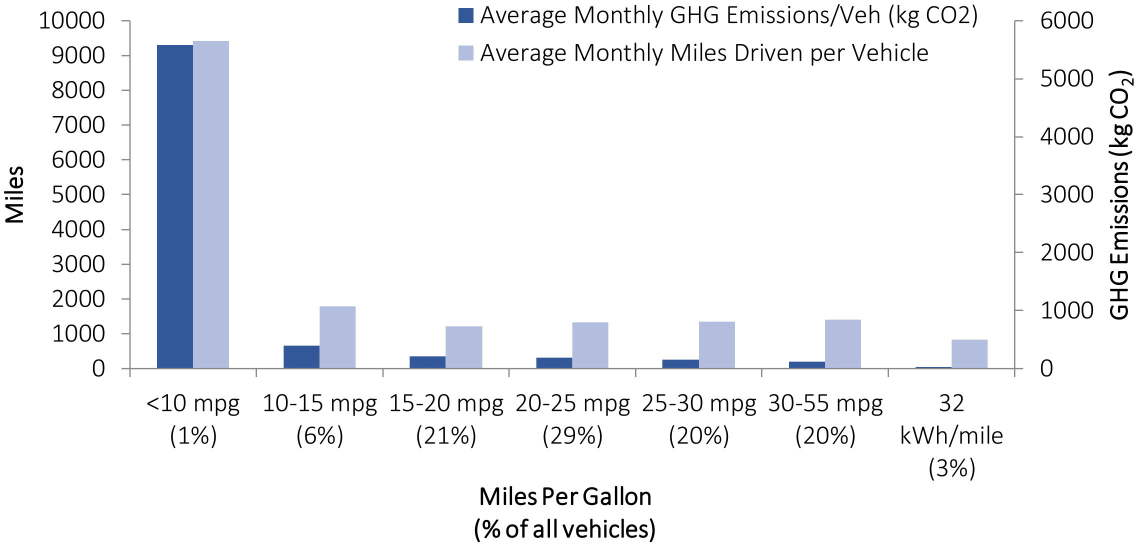

Figure 3 Average Monthly GHG Emissions and Miles Driven per CA RCPP Vehicle by Vehicle Fuel Economy

As shown in Figure 4, heavy commercial vehicles (all vehicles with a fuel economy of less than 10 mpg) produced more than a quarter of the total GHG emissions from all vehicles during the CA RCPP despite representing just 1% of vehicles and 8% of total miles driven. This comes as no surprise. Heavy commercial vehicles are involved in intra- and inter-state commerce activities including the shipping of goods to and from some of the state’s large ports. If a user were charged purely on the basis of GHG emissions or road damage, it is clear that heavy vehicles would incur a very high cost per mile. However, determining the user in this situation is not as simple as with a passenger vehicle. Although there is a vehicle driver, there can be a multitude of proxy users, such as the end consumers, retail stores, logistics companies, etc. In reality, any charge levied on the driver of a heavy commercial vehicle would be passed onto the other parties involved in the goods delivery. This creates a need for thoughtfulness on the part of policymakers: more emitting and damaging roadway users should in fact pay a higher share, but how much higher? And how can it be guaranteed that the costs are spread equitably among those who create the demand for such miles?

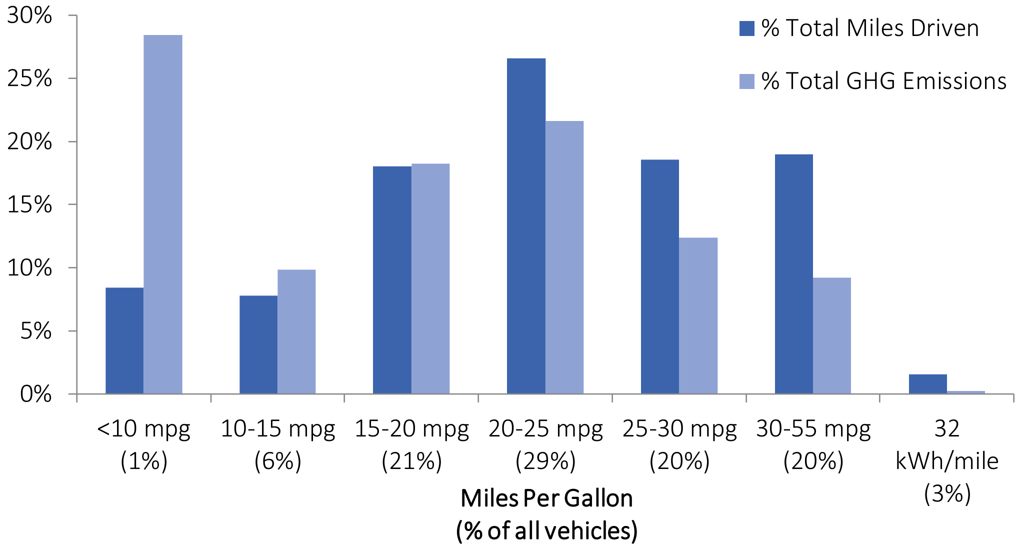

Figure 4 Distribution of Total Miles Driven and Total GHG Emissions During the CA RCPP, by Vehicle Fuel Economy

3.3.3 Vehicle-specific RUC implementation

Given the information available from the US Environmental Protection Agency (EPA) and CA RCPP datasets, we classify the pilot vehicles based on three parameters: vehicle use, weight class, and propulsion. Vehicle weight class is determined using the EPA size classes (EPA, 2018). We choose such parameters from among those defined earlier as they are static for each vehicle (i.e., they do not depend upon the specific use of the vehicle at any given time as do occupancy or vehicle use) and statistics are also readily available from public sources. The classification parameters presented in Table result in a total of 17 unique vehicle classifications for the CA RCPP vehicles.

Table 5 Vehicle Scaling Parameters and Classification Levels for CA RCPP Example

	D_n	*l*=1	*l*=2	*l*=3	*l*=4	*l*=5
Use (*n*=1)	1	Personal	Commercial	n/a	n/a	n/a
Weight Class (*n*=2)	1	Two-Wheeler	Car	Small Truck, Van, or SUV	Standard Truck, Van, or SUV	Heavy Duty Vehicle
Propulsion (*n*=3)	0	n/a	Electric	Hybrid	Internal Combustion	n/a

The distributions of average GHG emissions per vehicle and average monthly taxes/fees incurred per vehicle for each classification level of the three scaling parameters are shown in Figure 5. While the average monthly costs incurred from the gas tax generally follows a similar distribution as the average GHG emissions per mile, we see that the flat rate used in the CA RCPP results in most vehicles paying an average of $14 to $16 per month. Only the heavy-duty commercial vehicles seem to be paying in direct relation to their road use, as they log the most miles of all of the vehicles.

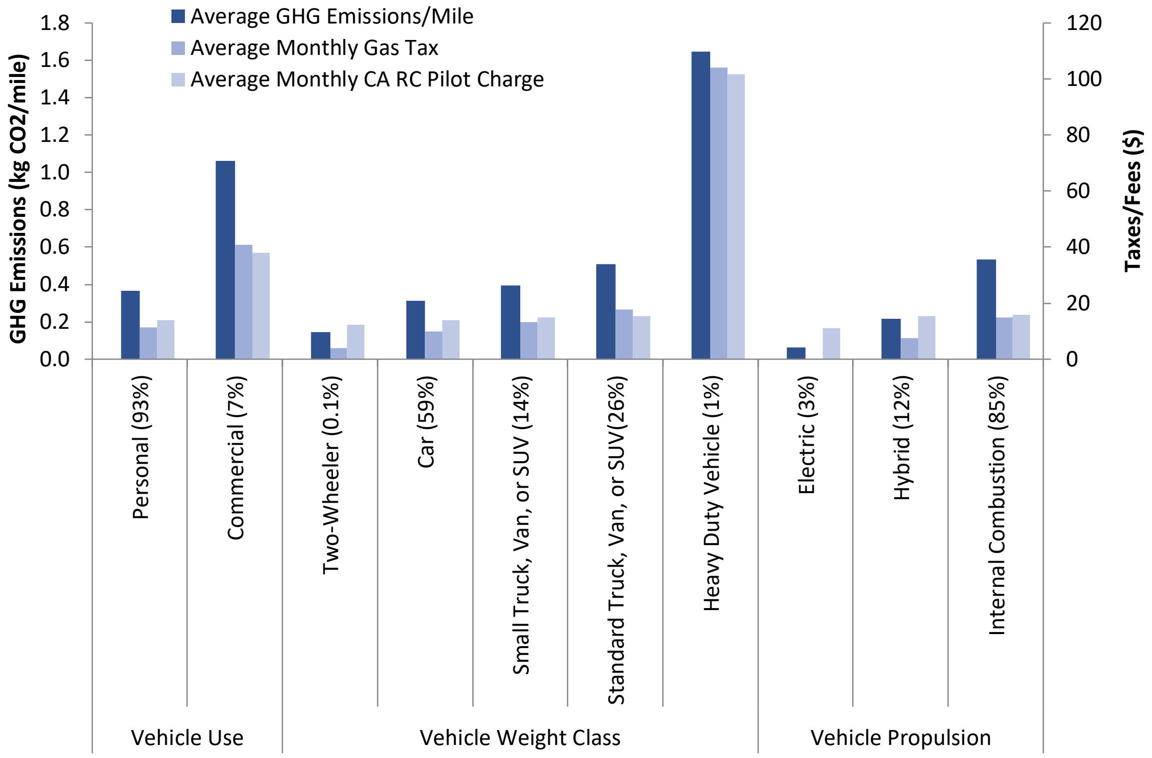

Figure 5 Average GHG Emissions per Mile and Average Monthly Taxes/Fees per Vehicle by Scaling Parameter Classification

We explore three approaches to calibrating this MBUF: 1) a naive approach using a uniform increment of 0.1 to distinguish between levels for each parameter, 2) a rigid approach that equates the relative amount of GHG emissions for each level within a parameter to non-uniform increments for that parameter, and 3) a flexible approach to relating the parameter values to the relative amount of GHG emissions that seeks to minimize the average change in taxes/fees for both personal and commercial vehicles. In all three approaches, the base fare of the MBUF is calibrated to maintain revenue neutrality in comparison to the total estimated gas tax revenue as follows:

$$Base\_Fare = \frac{Total\ Gas\ Tax\ Revenue}{\sum_v miles_v \prod_n^N \alpha_{vn}}$$

Where *N* is equal to three since there are three parameters being used in this example. The following three subsections briefly describe the three calibration approaches taken and present the resulting increment values and base fares.

3.3.3.1 Uniform increment calibration

In the naive approach to calibration, the values for each classification level of each of the three parameters increase by 0.1 at each level. This results in the values presented in

Table and a base fare of \$0.045. Using these values, a personal hybrid car would pay the following MBUF:

$$MBUF = Base\_Fare \cdot (1 + \beta_{1,1}) \cdot (1 + \beta_{2,2}) \cdot \beta_{3,3} = \$0.045 \cdot 1 \cdot 1.1 \cdot 0.2 = \$0.0099$$

Table 6 Parameter Classification Level Values for the Uniform Increment Calibration Approach

	D_n	*l*=1	*l*=2	*l*=3	*l*=4	*l*=5
Use (*n*=1)	1	0	0.1	n/a	n/a	n/a
Weight Class (*n*=2)	1	0	0.1	0.2	0.3	0.4
Propulsion (*n*=3)	0	n/a	0.1	0.2	0.3	n/a

3.3.3.2 Non-uniform increment calibration using GHG emissions per mile - rigid

In this approach, we first calculate the average GHG emissions per mile for the vehicles in each classification level of each parameter. Then, for each classification level, we calculate the ratio of the average GHG emissions per mile in that level to that of the classification level that has the most GHG emissions per mile for that parameter. This results in the values presented in Table and a base fare value of $0.0028. Using these values, a personal hybrid car would pay the following MBUF:

$$MBUF = Base\_Fare \cdot (1 + \beta_{1,1}) \cdot (1 + \beta_{2,2}) \cdot \beta_{3,3} = \$0.0028 \cdot 1 \cdot 2.21 \cdot 0.4 = \$0.0025$$

Table 7 Parameter Classification Level Values for the Uniform Increment Calibration Approach

	D_n	*l*=1	*l*=2	*l*=3	*l*=4	*l*=5
Use (*n*=1)	1	0	1.91	n/a	n/a	n/a
Weight Class (*n*=2)	1	0	1.21	1.62	2.53	10.45
Propulsion (*n*=3)	0	n/a	0.12	0.4	1	n/a

The parameter values and base fare determined by this approach result in a range of MBUF rates from $0.0003 per mile for personal electric two-wheelers to $0.093 per mile for commercial heavy-duty internal combustion (IC) vehicles. These rates would cause the average monthly taxes/fees incurred by heavy-duty IC vehicles to quadruple. Acknowledging the undesirability of this result, we devised the third approach, which is less rigid in calibrating the parameter values of the MBUF.

3.3.3.3 Non-uniform increment calibration using GHG emissions per mile - flexible

In this approach, we follow an identical methodology for determining the vehicle weight class and vehicle propulsion parameters as in the previous approach. First, the vehicle use parameter is set to a value of zero for both classification levels, and the base fare is calculated. We compute the percent change in average monthly taxes/fees from the gas tax to this MBUF for personal vehicles and commercial vehicles and find that, with no further adjustments, commercial vehicles and personal vehicles would have an 82% increase and 23% decrease, respectively, in average monthly taxes/fees. We then relaxed the constraint that consecutive classification levels must increase in value and incrementally increase the value of the personal vehicle use classification level until the average change in monthly taxes/fees is equal to zero for both personal and commercial vehicles. The resulting values are presented in

Table, and the base fare is equal to \$0.021. Using these values, a personal hybrid car would pay the following MBUF:

$$MBUF = Base\_Fare \cdot (1 + \beta_{1,1}) \cdot (1 + \beta_{2,2}) \cdot \beta_{3,3} = \$0.021 \cdot 3.35 \cdot 2.21 \cdot 0.4 = \$0.062$$

Table 8 Parameter Classification Level Values for the Uniform Increment Calibration Approach

	D_n	*l*=1	*l*=2	*l*=3	*l*=4	*l*=5
Use (*n*=1)	1	2.35	1	n/a	n/a	n/a
Weight Class (*n*=2)	1	0	1.21	1.62	2.53	10.45
Propulsion (*n*=3)	0	n/a	0.12	0.4	1	n/a

3.3.3.4 Comparison of three approaches to MBUF calibration

Figure 6 displays the average MBUF for vehicles in each classification level of the three parameters using each of the three calibration approaches. The distribution of the average MBUF given by the naive calibration approach (approach 1) reflects the uniformity of the increments in parameter values, with the average MBUF increasing steadily across the classification levels within each parameter. The second approach places an abnormally large burden on heavy-duty vehicles, which would be undesirable for the sake of political feasibility and due to passing on costs to other parties, as discussed above. The adjustments made in approach three result in a more agreeable distribution of average MBUF rates, as Figure 7 shows, while maintaining a variation of values that more clearly incentivizes hybrid and electric vehicles and discourages excess travel by heavier vehicles with IC engines. Supplementing this approach with dynamically collected information about vehicle uses, occupancies, and levels of automation gives decision makers the power and flexibility to craft dynamic pricing schemes that: 1) distribute cost burdens in a data-driven, user-pays manner and 2) incentivize technology use that will help the state reach its environmental goals. Please note Figure 7 shows that the majority of weight class categories experience a decreased rate in approach three, with only SUVs and heavy-duty vehicles seeing an increase. In future scenarios, relaxing the constraint on revenue neutrality can open up a wider variety of testable scenarios, including raising revenue for specific uses (roadway maintenance, etc.) and more targeted incentive and disincentive programs.

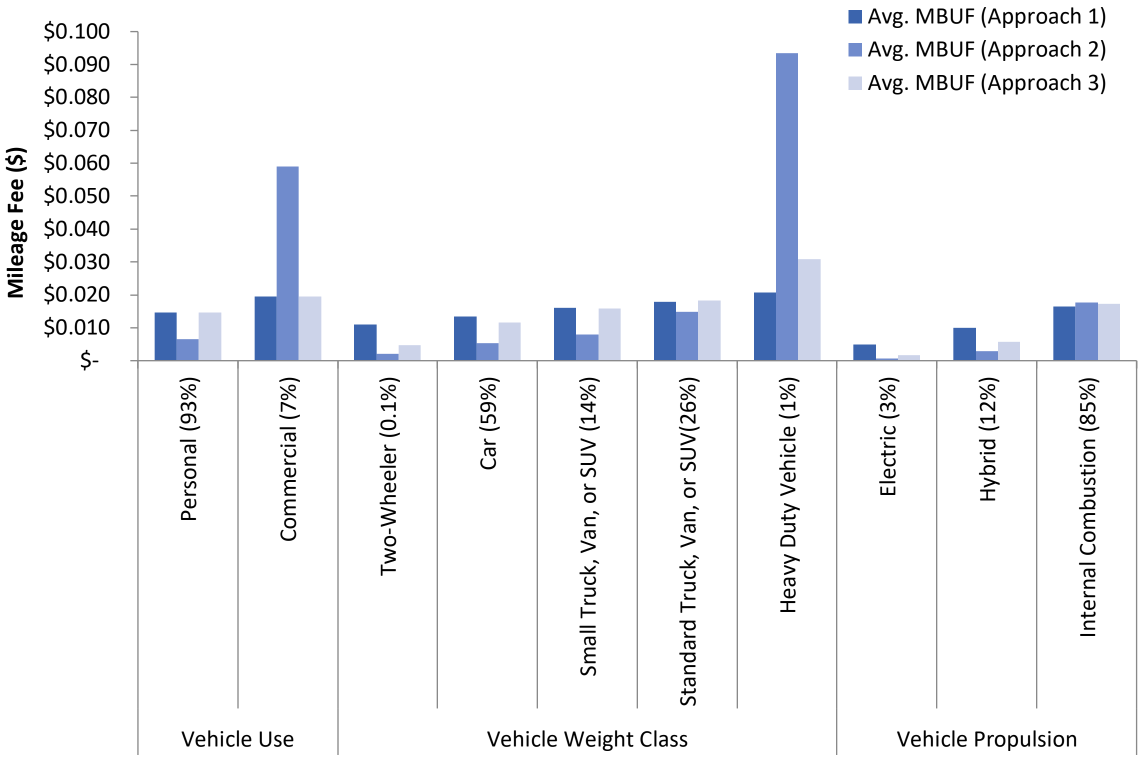

Figure 6 Average MBUF for Vehicles by Classification Parameter

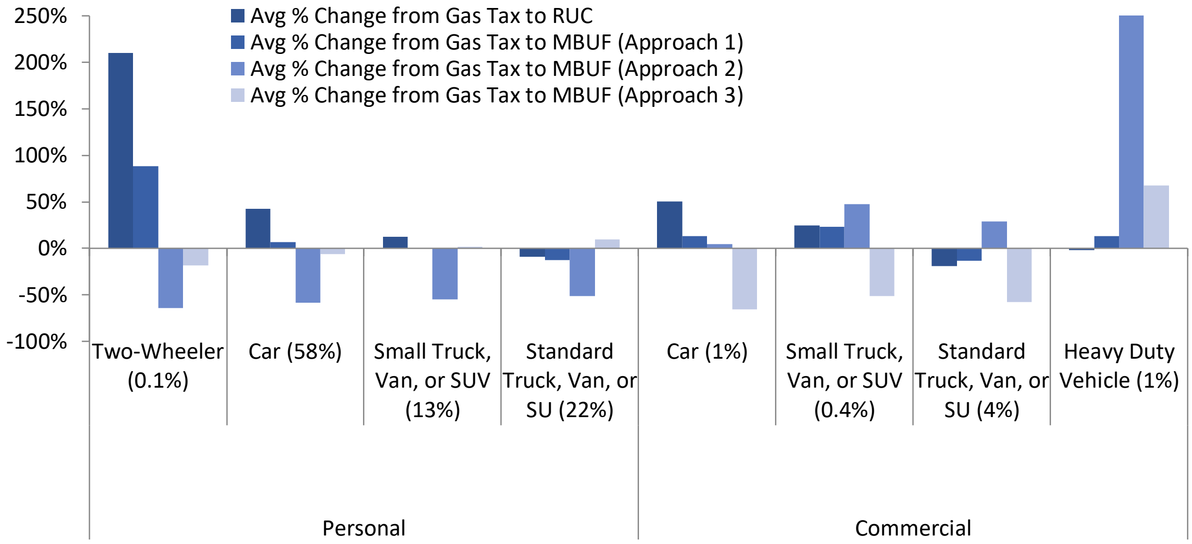

Figure 7 Distribution of Percent Change in Average Monthly Taxes/Fees from the Gas Tax to the RCPP RUC and the MBUF (Approaches One to Three))

3.4 Hurdles for Road Charge implementation

Lessons learned from failed attempts to implement cordon pricing schemes in the United States, as well as best practices from successful implementations in Europe and elsewhere in the world provide some background on barriers to future programs in the U.S. These considerations, along with recent state efforts to pilot MBUFs and city-scale parking and curb space reform and innovation provide insight into how this new typology for pricing and access can further city and regional goals. Buckeye (2016) offered some insights into a phased implementation of a mileage-based fee system using shared mobility; however, he was focusing on value propositions and did not provide many details on how a public agency would go about maneuvering such hurdles as public perception, legality, and politics. In this section, we address political, social, legal, fiscal and organizational, and technical considerations related to the development of a pricing and access scheme. As MBUFs entail larger uncertainty than parking reform and curb access prioritization -- both of which fall squarely within the enforceable jurisdiction of a city or county -- much of this section focuses on implementing user fees.

3.4.1 Political challenges

Although MBUFs have gained traction with statewide proponents and among interstate consortiums, considerable opponents still exist. To allay public concerns, all pilot programs to date have been voluntary. Even OReGO remains as a voluntary program, with limited enrollment. This creates a perverse incentive for those with less fuel efficient vehicles to opt-in to the program and reap a reward for owning such vehicles. Although this type of behavior has not dominated the initial OReGO rollout (Jones and Bock 2017), future voluntary programs could easily fall victim to this. In the same assessment, OReGO reviewers suggested the potential for not refunding gasoline taxes for vehicles attaining fewer than 20 MPGe; however, this raises legal questions related to new taxes and equity issues related to socio-demographics and vehicle ownership.

Aside from the public, representatives of freight and trucking associations remain reticent on the MBUF issue. Our previous work identified that trucking association representatives were somewhat interested in a per-mile fee, given the stipulation that revenues were reinvested into the federal or state highway systems (Forscher 2016). Revenue redistribution toward non-automotive modes would draw criticism from those whose livelihood depends on the continued maintenance of highway systems. Furthermore, the topic of restricted access by vehicle type to certain areas of a city has not been raised with commercial trucking interests; this concept would likely arouse concerns regarding increased logistics costs and could unduly hurt small-scale operations. These political considerations highlight the importance of convening stakeholders as early as possible during the development process, in an attempt to reach an agreeable consensus, or at least understanding, on key issues.

3.4.2 Social hurdles

For the general public, while the negative impacts of underfunded roads are well documented, auto maintenance arguments alone may not be enough to convince citizens to favor a new tax, even if it is to replace an existing one. The account managers or private sector intermediaries with pilot program participants offer value-added services in addition to tracking vehicle mileage; examples include limited diagnostic capabilities and reports about driving patterns. These benefits, combined with the perception that MBUFs represent a return to the “user pays” principle that underlies the fuel excise tax, could be enough to build a platform; however, there are a few other privacy and user experience-related issues to note.

In all of the technology-based data collection methodologies (most states have offered a time- or distance-based permit that uses no ongoing data collection) is the concession of a user's personal information. Some mileage tracking tools also collect spatial and temporal information from users to calculate eventual fees. In addition, this capability would be necessary for any dynamic pricing scheme, such as what is currently being used in Singapore, or what was piloted in Minnesota (Abou-Zeid et al. 2008; Rephlo 2013). However, user surveys have continually shown that citizens are somewhat concerned about their privacy being protected under these schemes. While fee calculation can take place without transmitting user location data through the use of virtual trip lines (and this architecture could work for a dynamic implementation), communicating the details of this privacy-preserving approach to prospective users might prove difficult. Without a perceived understanding of how their information is used, users might remain reticent regarding the privacy of their information. Additionally, privacy concerns track closely with data security concerns. It is important to note that the State of California has been addressing data security issues, including conducting a theoretical hacking session of the pilot system (California State Transportation Agency 2017). All vendors had to go through a data security assessment, which is an appendix to CalSTA's final report. Surveys have shown that user privacy and security concerns decrease with system exposure, so continued education could alleviate some of these fears.

On the user experience front, some states have made efforts to pursue strategies that employ account managers and monthly statements, which necessitate credit cards and more effort on the user side, when compared to pay-at-the-pump systems employed in other pilots (Jones and Bock 2017; California State Transportation Agency 2017). While facilitating easy payments can garner more public support, implementing a pay-at-the-pump system severely limits the scope of a mileage fee, and also creates significant challenges to implementation due to fueling station retrofits. Restricting programs to pay-at-the-pump collection would make dynamic rate setting, such as based upon time-of-day or location, more challenging from a system architecture perspective.

3.4.3 Fiscal and legal considerations

The issues of tax law, debt spending, and bonding also come into play when phasing out the gasoline excise tax. A report by the Treasurer of the State of Washington, produced in 2014, found that repealing the state's motor vehicle fuel tax (MVFT) would represent an unconstitutional breach of the state's contract with owners of outstanding general obligation bonds (McIntire 2014). Although this stipulation varies state by state, the act of refunding fuel taxes to highway users can violate use restrictions on fuel excise taxes (McIntire 2014). The Treasurer also noted that draining the MVFT revenues could hurt the state's ability to borrow, if interpreted incorrectly by the markets (McIntire 2014). This last point seems more an issue of communication than legality, but it is worth noting. The report suggested implementing road usage charges as something akin to licensing fees and to use the fees to cover any revenue shortfalls in the MFVT revenue. Under current Washington law, road usage revenues could only be used for revenue bonds, incurring a higher borrowing rate than general obligation bonds (McIntire 2014). Merely supplementing MVFT revenues with road usage charges limits the ability of such a program to raise revenue beyond what the MVFT could in the future.

California, which recently passed instituted a new Transportation Improvement Fee as part of vehicle registration–which progressively increases based upon a vehicle's purchased value—has also explored the potential of road usage charging, finding its own legal hurdles. The San Francisco County Transportation Authority (SFCTA), when studying the potential for a cordon pricing scheme in San Francisco, discovered that the California vehicle code prohibits any local agency from imposing a new charge for the use of existing streets and roads (SFCTA 2010). This does not limit an agency from increasing an existing toll. building a new road and putting a toll on it, or a county from implementing a self-help sales tax, but it does prohibit any kind of road usage charge. While this section of the vehicle code could be changed by the state legislature, such rulemaking would require significant public support, and it would necessitate stipulations to prevent areas from simply charging for entry into their jurisdictions. A debate of that nature could prevent any meaningful progress on road usage charging for some time. The state could also grant an exemption to a pilot agency for testing a system (SFCTA 2010), but this would also require some level of public support.

It is worth noting that any road usage charge scheme, which operates at the level of the individual, may cost significantly more to administer than a fuel excise tax collected from a select number of fuel suppliers and distributors (Jones and Bock 2017).

3.4.4. Technological options

While the technical details of any road usage charge or access and pricing scheme are highly dependent upon the specifics of the implementation, and the state of a rapidly changing technological environment, a few points stand out at this early stage. First, as demonstrated by the state pilots, there are many potential technologies that can be used to form the backbone of a fee system; developing one that is compatible with those of neighboring states and regions is of critical importance. Having numerous devices to calculate charges state by state would be highly cumbersome, particularly for members of the trucking or goods movement industries. With the potential for broadened scope comes the issue of compatibility, and technical simplicity can severely limit the potential for added benefits and dynamic systems. Striking a balance between these two concepts will be massively important for any early adopters hoping to create a standard. The desire for a singular method or rulemaking mimics recent conversations among automakers, states, and the federal government over rules for automated vehicles. Recent federal advisory rulemaking could set a precedent for advisement about, but not management of, road usage charges in the future.

The State of Minnesota has won a grant to study the potential for using shared mobility service providers as the mechanism for implementing a road usage charge. This type of approach has many a priori benefits, such as user ease, transparency, simplicity of governmental fee collection, and integration with future mobility modes; however, it also has its risks. Public perception of ridesourcing/transportation network companies (TNCs) has waxed and waned precipitously in recent years, so linking any governmental action to private entities could pose a problem. Furthermore, establishing a system that has the ability to rebate drivers while charging passengers adds a layer of complexity, especially given the ways that ridesourcing companies/TNCs currently calculate and distribute payment for to independent contractors (drivers).

3.4.5. Highlights from California

During, throughout, and at the conclusion of the CA RCPP, CalSTA, Caltrans, and the other program stakeholders released a suite of additional reports, covering many of the topics in sections 3.4.1 to 3.4.4, as well as others. Additionally, there was an independent evaluation conducted of the CA RCPP; the findings from this report echo many of the findings contained in that evaluation. The TAC, CalSTA, Caltrans, and the independent evaluators worked diligently to collect user feedback throughout the pilot which informed a thorough review of how each the program performed relative to each of the goals set forward at the outset (Caltrans 2017). Six policy papers were produced as well at the conclusion of the pilot, and these have been informative to many stakeholders (e.g., other states, international governmental agencies) as they work towards implementing mileage-based user-pays adherent fee programs.

3.4.6. Getting over the hurdles

While all of these stated hurdles and considerations (and others such as enforcement and compliance, dispute resolution, and consistency across jurisdictions) make the task of implementing a pricing and access scheme seem daunting, these should not be taken as reasons to shy away from it but rather as indications of its importance. The creation of the Highway Trust Fund, or the interstate highway system, was not simple, but it has lasted for over 75 years. The search for a new revenue source to accommodate the future of mobility will require creative thinking, and solutions that step outside of traditional boundaries.

4. Conclusion

As the transportation ecosystem continues to evolve rapidly, it is increasingly important to manage and maintain infrastructure effectively. Doing so will take coordinated efforts between public agencies and active participation by the private sector. Particularly with the advent of automated and autonomous vehicles—which are heavily reliant on credible road markings—keeping streets maintained will become more and more a private interest, as well as a public one. There are some examples of proactive partnerships between transportation agencies and ridesourcing/transportation network companies (TNCs), including the use of ridesourcing to complement or replace underperforming bus routes and geographically-bounded ridesourcing pilot programs for specific groups. Furthermore, some of the leading ridesourcing companies in addition to leaders in the public and private sectors have expressed significant interest in road pricing strategies that favor higher vehicle occupancies. Recently, in response to increased congestion, some cities have pursued ridesourcing-specific mobility fees, clearly targeting specific characteristics of a vehicle or roadway user. Carrying innovative and progressive pricing concepts forward will position localities and regions to be able to respond to the changing landscape of maintenance funding and to foster innovative idea sharing across the nation and world. Academia can play a role by establishing forums within which to discuss ideas and forge partnerships and serve as an independent evaluator. Overcoming political inertia will require a significant push; nevertheless, as citizen grassroots actions become more coordinated, the arguments for user-pay systems may become more accepted on a widespread scale.

The challenges facing cities, planners, and private passenger/goods movement industries are significant, and no silver bullets exist. Tackling these issues will require coordinated efforts and innovative thinking. This report has outlined a host of strategies based upon the input of experts in the field and has honed in on a few concrete examples in California. The case study of the CA RCPP and example MBUF calibration demonstrates the potential for designing road user charges based on measurable impacts of road use by different vehicle classes. While additional data and analysis are necessary to develop a robust pricing scheme, the vehicle-specific RUC presented in this report seeks to embody the user-pays principle to a greater extent than flat-rate gas taxes and MBUFs by aligning the distribution of the cost burden across road users according to their relative road use and GHG emissions. Practitioners, researchers, advocates, and policymakers can use this document to better understand the tradeoffs present in transportation funding and management decisions, especially when planning over long time horizons in the midst of uncertainty.

Parallel research directions include examining public knowledge and perception of many of these strategies. It remains likely that the majority of the alternatives outlined above will be subject to public acceptance and approval—understanding the ways public perception (either of the whole population or of segments of interests) develops with exposure to these novel concepts will be key to successful implementation. This type of work could also reveal secondary effects resulting from MBUFs that planners and researchers might have missed in their initial scoping and formulating exercises or previous modeling work.

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