Economic Analysis and Review of Commercial Vehicle Road User Charges

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A Research Report from the Pacific Southwest Region University Transportation Center

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16. Abstract

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The study indicates that for revenue-neutral scenarios, since the only change is the redistribution of the costs, the economy-wide aggregate impacts in terms of changes in GSP and employment are very small. For the scenario that emission fees are added on top of the revenue neutral RUC fees, negative economic outcomes can be expected even after the stimulus offset effects from the spending of the additional government revenues. The income distributional analysis indicates that maintaining the current discounted charge rate applied to Agriculture Products help reduce income inequality. Moreover, income losses stemming from transportation cost increase caused by the emission fees are born disproportionately by middle- and higher-income groups, and thus reduce the income inequality.

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The Pacific Southwest Region UTC conducts an integrated, multidisciplinary program of research, education and technology transfer aimed at *improving the mobility of people and goods throughout the region.* Our program is organized around four themes: 1) technology to address transportation problems and improve mobility; 2) improving mobility for vulnerable populations; 3) Improving resilience and protecting the environment; and 4) managing mobility in high growth areas.

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Disclosure

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Abstract

California is currently investigating the potential to use a Road Use Charge (RUC) as an alternative tax instrument to replace fuel tax. This report examines potential RUC scenarios for heavy duty commercial vehicles and conducts an economic impact analysis to estimate the economy wide and distributional impacts of the various scenarios. Our purpose is to explore the differences in RUC relative to current state fuel and weight fees in terms of revenues generated, changes in cost sharing among truck classes and commodity categories, and implications to the State economy as well as households from different income groups.

The study indicates that for revenue-neutral scenarios, since the only change is the redistribution of the costs, the economy-wide aggregate impacts in terms of changes in GSP and employment are very small. For the scenario that emission fees are added on top of the revenue neutral RUC fees, negative economic outcomes can be expected even after the stimulus offset effects from the spending of the additional government revenues. The income distributional analysis indicates that if the current discounted charge rate applied to Agriculture Products is not applied in the RUC system, there can be a very slight decrease in income inequality. Moreover, income losses stemming from transportation cost increase caused by the emission fees are born disproportionately by lower- and middle-income groups, and thus increase the income inequality.

Economic Analysis and Review of Commercial Vehicle Road User Charges

Executive Summary

California is currently investigating the potential to use a Road Use Charge (RUC) as an alternative tax instrument to replace the gas (or fuel) tax. This report examines potential RUC scenarios for heavy duty commercial vehicles and conducts an economic impact analysis to estimate the economy wide and distributional impacts of the various scenarios. Our purpose is to explore the differences in RUC relative to current state fuel taxes and weight fees. These include considerations such as total revenues generated, changes in burden sharing in terms of distribution of total charges/fees among truck classes and commodity categories, and implications to the economy as a whole as well as households from different income groups.

Working with the experts in the Road Charge Program of Caltrans, three RUC scenarios for California are established. The first scenario assumes a fixed-rate VMT-based RUC fee to replace diesel taxes, while achieving revenue neutrality. The second scenario adds a weight-VMT fee based on pavement damage levels (replacing current DMV weight fees) on top of the fixed-rate RUC fees in Scenario 1. In the third scenario, emission fees that aim to internalize the social costs of PM2.5 emissions are added on top of the fixed-rate RUC fee in Scenario 1. For the fixed-rate RUC fees in each scenario, two options are analyzed: 1) a strict fixed-rate VMT charge is applied across all types of commodities transported by the heavy commercial vehicles; 2) the current discount in diesel sales tax applied to transporting Agriculture Products is retained in the revenue neutral calculation. The total amount of the RUC fees is estimated to be $1.45 billion, 1.93 billion, and $2.95 billion for the three RUC scenarios, respectively.

An analytical framework that integrates the micro-level analysis of changes in transportation taxes/fees distribution across economic sectors, the REMI PI+ macro-econometric model, and a Multi-sector Income Distributional Model (MSIDM) is adopted to analyze the economic and distributional impacts of the three RUC scenarios. Figure ES1 presents the integrated analytical framework of the study.

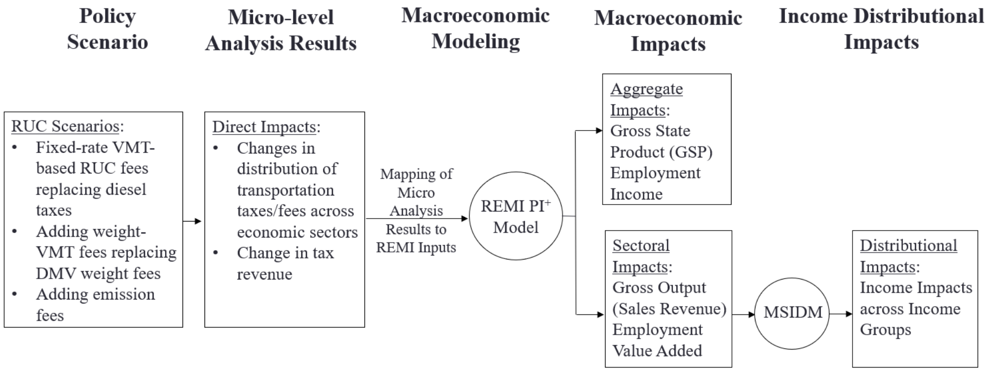

Figure ES1. Analytical Framework of the Socioeconomic Impact Analysis of RUC

The study indicates that the adoption of the RUC systems will lead to redistribution of the cost among heavy-duty truck classes. However, for revenue-neutral scenarios, because the only difference between the baseline case and the analyzed RUC scenarios is the changes in the cost distribution, the economy-wide aggregate impacts in terms of changes in GSP and employment are very small. The GSP impacts range between -$76 million to $218 million and employment impacts range between 528 job losses to 1,477 job gains. In addition, a redistribution of transportation cost burden from other sectors to Agriculture sector (i.e., for the strict across-sector fixed-rate VMT charge scenarios) would result in a small positive net impact on the economy, primarily because of the higher multiplier effects of the non-Agriculture sectors, the products of which are more proportionally used for intermediate inputs rather than for final consumptions. However, in such cases, the Agriculture sector will have to shoulder proportionally much higher costs. If the increased transportation costs of the Agriculture sector are passed onto consumers through an increase in the price of farm products, it will likely affect lower-income family disproportionally because they spend a proportionally larger share of their income on food. For the scenario that emission fees are added on top of the revenue neutral RUC fees, negative economic outcomes of about $0.85 to $1 billion decrease in GSP and 3,500 to 4,500 job losses can be expected even after the offset of the stimulus effects from the spending of the additional government revenues from collecting the emission fees. However, this has not taken into consideration the beneficial impacts from improved public health and other environmental effects.

Table ES1. Aggregate Macroeconomic Impacts of the RUC Scenarios for California

Variable	Units	Scenario 1a	Scenario 1b	Scenario 2a	Scenario 2b	Scenario 3a	Scenario 3b
Changes in Major Macroeconomic Indicators from Baseline							
Total Employment	Job-year	842	-528	1,477	108	-3,352	-4,715
GSP	M 2022$	111.3	-75.8	217.8	17.5	-842.5	-1,028.5
Output	M 2022$	213.3	-130.2	389.7	23.7	-2,039.9	-2,381.6
Disposable Personal Income	M 2022$	123.8	-54.8	192.7	15.9	-1,369.1	-1,547.0
Price Index	2012=100	-0.003	0.0010	-0.0043	-0.0004	0.0673	0.0712

The income distributional analysis indicates that if the current discounted charge rate applied to Agriculture Products is not applied in the RUC system, there can be a very slight decrease in income inequality. In addition, income losses stemming from transportation cost increase caused by the emission fees are born disproportionately by lower- and middle-income group, and thus increase the income inequality. This is primarily because heavier trucks are expected to pay a large share of the emission fees and many sectors that rely more on these heavier trucks to deliver their products (such as Mining, Metallic and Nonmetallic Mineral Products Manufacturing, and Food Product Manufacturing sectors) hire a higher proportion of workers from lower- or middle-income households.

Finally, given the size of the state economy, the impacts of all the RUC scenarios analyzed in this study are projected to be very small in percentage terms. However, the study provides valuable insights in terms of the tradeoff between economic sectors and the distributional implications among different income groups. The analytical framework and methodology developed in this study can be generalized and applied to the analysis of the economic and distribution impacts of other alternative transportation pricing instruments.

Chapter 1. Introduction

California is currently investigating the potential to use a Road Use Charge (RUC) as an alternative tax instrument to replace the gas (or fuel) tax. This report examines potential RUC scenarios for heavy duty commercial vehicles and conducts an economic impact analysis to estimate the economy wide and distributional impacts of the various scenarios. Our purpose is to explore the differences in RUC relative to current state fuel and weight fees. These include considerations such as total revenues generated, changes in burden sharing in terms of distribution of total charges/fees among truck classes and commodity categories, and implications to the economy as a whole as well as households from different income groups.

In the past two decades, the fuel economy of traditional vehicles has substantially increased, and the planned electrification transition of the vehicle fleet will further reduce gasoline consumption. As a result, revenues from gas taxes have been declining (Caltrans, 2021). The reduction in gas tax and other fuel tax revenues can be problematic because they represent major funding sources for maintaining and operating State roadways. Deferred maintenance results in additional costs, not only to the government, but also to road users. If roadway maintenance and repairs are not done on schedule, easy repairs can often become more serious and more costly damages as time passes. As for the consumers, the average annual car operating and repair costs to California drivers due to deteriorated road conditions are estimated to be about $843 (TRIP, 2018). Therefore, it is important to maintain sustained revenue sources to cover the costs of maintenance and repair of the surface transportation system.

RUC is different from a gas tax in that it is a pay-by-mile system, which is not necessarily linked to fuel consumption. In the U.S., the RUC is currently a legislative mandate only in Oregon. Other than Oregon, Utah and Virginia also have active RUC Programs for alternative fuel vehicles (UTDOT, 2021; VADMV, 2022). However, RUC program studies have been completed in several other states including Texas, Colorado, Minnesota, Iowa, New York, Pennsylvania, Maryland, and Delaware. Active formal study for possible implementation of the system is taking place in California, Washington, Nevada, and Indiana. The Eastern Transportation Coalition, a partnership of 17 eastern states and the District of Columbia, has launched mileage-based user fees (MBUF) studies for both passenger vehicle and truck pilots (ETC, 2021). Moreover, many other states are either interested members of the Western Road Usage Charge Consortium (WRUCC, or RUC West, and soon to be RUC America), having legislative or governmental interest, or beginning inquiry of this tax revenue mechanism. With respect to the freight sector, Oregon, Kentucky, New York, and New Mexico collect weight and distance-based fees from heavy trucks. On an international level, New Zealand represents the most outstanding example of RUC implementation, specifically with commercial vehicles, as the country has been charging RUC from diesel vehicles since 1977. Finally, many European countries are implementing a variation of the RUC system, based on time rather than distance (IBTTA, 2020).

A 9-month RUC Pilot program was conducted in California between July 2016 and March 2017, with more than 5000 volunteers participating. This pilot program was designed to test whether a state-wide RUC program could be successful and to provide data on various factors needed to be considered in planning and executing the policy on a large scale. The pilot program utilized 4 third party vendors to collect mileage data and to issue simulated invoices, demonstrated 6 reporting and recording methods, and included heavy commercial vehicles. Over the whole duration of this simulation, the vehicles reported more than 37 million miles traveled, showing that Californians travel great distances over relatively short periods of times, and demonstrating that the development of a sustainable system to collect adequate funding for required road maintenance within the state is essential (CalSTA, 2017).

There are both benefits and potential issues associated with the RUC system. The first benefit is to impose charges or fees to all types of vehicles, including high fuel-economy and electric vehicles, based on the actual costs the vehicles impose on the roadway infrastructure. Second, since RUC is considered a sustainable revenue stream for roadway maintenance and repairs, it provides the flexibility to incorporate other factors into the design of the pricing system, including for example, weight of the vehicle, level of road congestion, and type of road used (Sorensen et al., 2010). Consideration of these additional factors help internalize the externalities and increase societal welfare (Atkinson, 2019).

One major concern of the RUC system, which was highlighted during RUC experimental trials, is privacy of the drivers, as many RUC pilot programs used vehicles' GPS to calculate miles traveled and payments due. To address this issue, some states allowed odometer-only options or manual reporting as alternative options during the feasibility study. The second concern is that if the RUC system applies to all vehicles, the tax advantage (avoided gasoline fuel taxes) for EVs is reduced, which then would reduce the incentive to adopt green and environmental-friendly technologies in transportation from tax savings perspective.[1] One solution to this issue would be to implement some payment exemptions for electric vehicles, so that they will not lose their ecological value and appeal to the general public (Atkinson, 2019). Another would be to offer other incentives, such as reduced car registration fees.

Another important consideration is the fairness or distributional equity implications of the RUC system. A number of studies have focused on investigating this issue for passenger vehicles. If all households drive cars with similar gas mileage, shifting from a gas tax to an RUC system may not result in increased distributional inequality. However, all households do not drive cars with similar gas mileage. Since lower-income households tend to drive less fuel-efficient vehicles, they would pay relatively less for a fixed per mile fee compared to paying fuel tax. Therefore, some studies indicate that switching to RUC, especially income-based vehicle miles traveled (VMT) fees (i.e., providing more favorable rate to lower-income groups) can help reduce the cost burden of the lower-income groups (Weatherford, 2011; Larsen, 2012; Rodriguez and

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[1] However, research does indicate other important incentives, including purchase incentives and carpool access, as important factors affecting people's decision on buying EVs (Jenn et al. 2019). The effects of these incentives are unlikely to be affected by the adoption of the RUC systems.

Pulugurtha, 2020). In addition, zero and near zero emission vehicles are more likely owned by higher income households (Farkas, Shin and Nickkar, 2018). Switching to RUC would also increase the cost burden for higher income households.

On the other hand, little has been studied on the distributional impacts of the commercial vehicle RUC system. Although a system can be designed to achieve revenue neutrality for the charges and fees imposed on trucks, some segments of the industry may shoulder a higher proportion of the cost compared to the others due to type of service provided or attributes of the vehicles. For example, if weight fees were converted to distance-based RUC, heavy trucks traveling longer distances would pay more, especially if the fees are linked to the weight of the trucks and thus the damages to the roadway systems they incur. Some representatives of the freight industry indicate that it is difficult to pass increased costs to downstream customers due to the economic structure of shipping markets. Trucking firms have less economic power than wholesalers or retailers. Therefore, increased costs would be borne by trucking firms and their employees. In the long run, however, it is more likely that the costs will be eventually passed through to consumers in the form of increased prices of goods.

In this study, we conduct an economic and distributional impact analysis of RUC on commercial vehicles. Key research questions to be addressed include: How can the design of a California RUC achieve the goal of revenue neutrality? What are the changes in the distribution of the transportation costs among industry segments? If the costs are passed to consumers, what are the impacts on the prices of different types of goods and services (especially those critical to disadvantaged communities)? What are the economy-wide impacts, as well as the distributional impacts among consumer groups?

The report is divided into nine sections. A thorough literature review on the policy design and program performance of RUC systems in other states and countries is presented in Section 2. In Section 3, the overall analytical framework of the analysis and the REMI Policy Insight Plus (PI+) model are introduced. The three alternative RUC scenarios analyzed in this study are discussed in Section 4. Major data and their refinements are presented in Section 5. The diesel taxes and weight fees paid by the heavy commercial vehicles in the baseline are estimated in Section 6, and the estimated changes in the distribution of cost after replacing the current diesel taxes/weight fees by the RUC scenario systems are presented in Section 7. The economy-wide aggregate impacts and the distributional impacts of the RUC scenarios are presented in Section 8. Section 9 provides a conclusion of the study.

Chapter 2. Literature Review

2.1. Introduction

In the U.S., various types of finance mechanisms are used to raise funding for the construction, operation, and maintenance of transport infrastructure. Transportation finance sources can be generally categorized into direct user fees, indirect user fees, and non-user sources. Examples of direct user fees include road tolls and VMT taxes. Both vehicle license fees and motor fuel taxes are major types of indirect user fees. Some local governments also rely on non-user sources such as local option sales taxes to finance transportation infrastructure. In California, nearly 60% of total roadway expenditures are funded by indirect user fees, followed by non-user sources, accounting for another 35%. Road charges (mainly in the form of tolls of expressways and bridges) contribute about 6% of the total revenue (Census, 2017).

Although for decades, fuel tax has been a successful transportation funding source, its revenue has been declining given the increased fuel economy of traditional vehicles and the transition to electric-powered vehicle fleet (Caltrans, 2021). Road use charge (RUC), a pay-by-mile system that is not necessarily linked to fuel consumption, has been identified as a potentially effective alternative to fuel tax. California is investigating the potential to use RUC as an alternative tax instrument to maintain sustained transportation revenue, account for externalities such as emissions, congestion, and accidents in the transition of the state to an electric vehicle dominant fleet.

In the U.S., the RUC is a legislative mandate only in Oregon. Utah has an active RUC program for alternative fuel vehicles (UTDOT, 2021). As for commercial vehicles, California conducted a 9-month RUC pilot program that included commercial trucks in 2016-2017. The Eastern Transportation Coalition, a partnership of 17 eastern states and the District of Columbia, conducted a voluntary mileage-based user fee pilot for Class 7 and 8 trucks in 2018-2019. Moreover, four U.S. states, Oregon, Kentucky, New Mexico, and New York, have collected weight-distance fees from heavy trucks. Internationally, New Zealand started charging RUC from diesel vehicles in 1977. Several European countries (such as Germany, Switzerland, Austria) collect fees from heavy vehicles based on many features of the vehicles, including distance travelled, weight, number of axles, and/or emission class. A thorough review and understanding of the objectives, program designs, implementation method and technology, and effects (both achievement and challenges) of these RUC programs will provide valuable insights to California transportation agencies while investigating and designing an RUC system for the state.

This chapter is divided into five sub-sections. Following the Introduction, Section 2.2 first presents a theoretical discussion of RUC. It also provides a brief summary on how heavy-duty vehicles are currently priced in the U.S., and the debate on whether trucks pay their fair share. Highlights of review findings from domestic and international literature are also presented. Section 2.3 provides a more detailed review of the RUC program in Oregon and the pilots conducted in Eastern Transportation Coalition states and in California. Section 2.4 is the summary of what we learn from a review of truck pricing from international experience, including both evaluations of actual policies implemented and results of scenario simulations. Section 2.5 provides a summary and conclusion of this chapter.

2.2. General Findings of the Literature Review

In this section, we present the general findings from the review of the literature of road use charge. The section starts with a discussion of the theoretical basis of road pricing, with a special focus on the road use fees implemented on the commercial vehicles. The second part provides brief summaries of road use charge programs and pilots implemented in the U.S. that cover commercial vehicles, as well as key findings from program evaluation studies in terms of objectives, fee structures, revenue collection, and feedback from participants. Practical and political reasons for the delay in implementing the RUC systems in the U.S. are next discussed. Given limited domestic examples of commercial vehicle road use charge systems, lessons from international examples are briefly presented.

2.2.1. Theoretical Basis of Road Use Charge

Road use generates both direct public costs — for example, the costs of building, maintaining, and operating the infrastructure used for the travel — and indirect public costs — for example, the externality costs associated with congestion, accidents, and pollution. These public costs are highly variable with respect to vehicle weight, engine efficiency, and emission rates, among other factors. Yet, federal and state user fees primarily focus on recovery of direct costs only and rely on indirect fees, like the gas tax, that are not strictly proportional to the direct costs generated by use. For heavy weight vehicles, most states charge some form of additional fee for road use based on the weight class of the vehicle. As with the gas tax, these fees are not proportional to the direct costs imposed by vehicles since vehicle weight (and weight per axle) are much more variable than a few "classes". Accordingly, most road use fee structures throughout the United States do not account for the indirect costs generated by road use, only partially recover the direct costs generated by road use, and do not equitably distribute fees across vehicles relative to the costs that they impose.

Research broadly shows that the direct and indirect costs of motor travel have increased at a faster pace than user-based revenues collected over the past several decades in the United States, and that direct user fees would more efficiently internalize these costs. Literature also underscores that heavy-weight commercial vehicles contribute the most to these costs, though the degree to which they cover their costs relative to automobiles is somewhat contested. Road use charge as a type of direct user fees has been identified as a potentially effective mileage-based pricing mechanism. However, the economic impacts and policy effectiveness of more efficient road use charge systems in the United States are not well-documented in the existing literature. There are few examples of RUC systems in the US, and most of them are based on opt-in demonstrations. At best, some estimations of revenues generated and mode shift — from truck to railroad — are calculated and findings from foreign countries' policies are evaluated.

Local, state, and national governments in the United States rely heavily on indirect user fees — the gas tax, in particular — and unrelated sources of revenue to finance, operate and maintain roads. The gas tax has always served as a proxy for road use, but has become less efficient, because vehicles have become more fuel-efficient and the fuel tax has not been increased to reflect greater fuel efficiency. Vehicles are therefore consuming more road use (i.e., miles of driving) relative to the road use fees paid through gas tax. Nationally, Parry et al. (2007) found that the per mile-equivalent revenue from fuel taxes decreased 40% between 1960 and 2003. In California, even as the state's Air Resources Board (CARB) has reduced overall greenhouse gas (GHG) emissions from all emitting activities over the last decade, GHG emissions from the transportation sector have increased with the growth in vehicle-miles traveled (CARB, 2019).

Commercial vehicles are by-far the greatest contributor to many direct and indirect costs of road use (FHWA, 2000a; FHWA, 2000b; Small et al., 1989). User fee structures for commercial vehicles somewhat reflect this, as many states require commercial vehicles to pay fees that correspond to the size of the vehicle. However, most states' commercial vehicle fee structures, including California, charge either a per-axle or gross vehicle weight (GVW) fee, neither of which fully accounts for the axle weight related costs. Currently, only five states — Connecticut, Kentucky, New Mexico, New York, and Oregon — charge or plan to charge a weight-distance tax (WDT). However, as reflected in Table 1, the weight threshold for the tax, tax rate, and how the tax rate increases with vehicle weight vary across the states. In all other states, if any WDT exists, it is operated at a roadway-level rather than a state-level.

Given that the wear imposed by a vehicle is based on the weight per axle — a vehicle that distributes its weight across many axles will impose far less wear than one that concentrates the weight across few axles — a fee per axle-weight is ideal (Small et al., 1989; Winston, 1991). Today, only Oregon charges a fee that combines weight and axles for overweight vehicles (80,001 – 105,000lbs) (Oregon Department of Transportation, 2020b).

Many studies show that, despite trucks paying more than automobiles for their travel, the costs they impose — whether limited to direct costs like road wear or inclusive of indirect costs like congestion and pollution — are so high that they pay a lower share of their costs than automobiles do (e.g., FHWA 2000a; FHWA, 2000b). However, other studies show the opposite. Using ordinary least squares and Taylor Series models that account for road damage, contribution to congestion, and pollution, Holguin-Vera et al. (2006) suggest that commercial vehicles pay a disproportionately higher share of their cost relative to automobiles nationwide. While whether trucks pay their "fair share" of costs is uncertain, neither automobile nor commercial vehicle operators pay the direct or indirect costs they impose through road use charges under current fee structures.

Table 1. Comparing Rates for Weight-Distance Fees Across Five States ($/mile)

	CT (26,000 – 80,000+ lbs) *(planned 2023)*	KY (over 59,999 lbs)	NM (26,000 – 80,000 lbs)	NY (18,000 – 80,000+ lbs)	OR (26,000 – 80,000+ lbs)
Lowest Weight Rate ($/mile)	0.0250	A constant fee of $0.0285 for all commercial vehicles over 59,999 lbs	0.01101	0.0084	0.0654
Highest Weight Rate ($/mile)	0.1000		0.04378	0.0546	0.2150
Over 80,000 lbs ($/mile)	0.1750		N/A	0.0028 per additional ton	WDF varies by number of axles

Sources: Oregon Department of Transportation (2020a), New York Department of Taxation and Finance (2020), Kentucky Transportation Cabinet (2018), Connecticut General Assembly (2021), Unnikrishnan et al. (2019).

2.2.2. Domestic Policies and Empirical Findings

Oregon was the first state to implement a weight-distance tax for commercial vehicles and can be viewed as an example for implementing distance-based charges in the rest of the US. Since 1948, Oregon has charged commercial vehicles based on the distance they travel and their gross weight. The charges also vary by the number of axles for trucks that are between 80,000 and 105,500 pounds, the latter of which is the maximum weight limit for trucks in Oregon. Since its implementation, commercial vehicle operators have had to submit monthly weight-mile tax reports that tracked vehicles weight and miles travelled that month. Before GPS tracking, commercial operators could either submit odometer readings and be subject to taxation on all miles driven or submit their routes with distances verified by maps (U.S. Department of Transportation, 1968).

Beginning in the early 2000s, electronic tracking and reporting using GPS was explored in Oregon. Various studies have analyzed the impacts that this road use charge has had on truck configuration as well as the success of the technology used for electronic collection of this tax. Rufolo et al. (2000) found that for trucks over 80,000 pounds, the tax break for adding additional axles was not large enough to incentivize the addition of more axles. However, the damage incurred on roads did decrease overall from the implementation of the weight-mile tax because there was a shift to using fewer, but heavier commercial vehicles as opposed to many slightly lighter commercial vehicles. With the introduction of electronic weight-mile tax tracking, Dal Ponte and Michie (2015) show that using GPS on-board units increases the accuracy of tax reports and provides value for commercial operators in addition to easier mileage tracking, such as electronic IFTA reporting, fleet tracking, and electronic driver log books. No quantification of administration costs has been done, but the hope is that electronic tracking will improve efficiency in tracking and audits, therefore lowering administrative costs.

Aside from the five states mentioned above, the rest of the U.S. lacks a robust mileage-based road use system for autos or trucks. Opt-in trial programs have been completed in some states/regions, including California and states along the Interstate 95 corridor managed by the Eastern Transportation Coalition. The findings from these trials suggest that mileage-based road use fees have the potential to successfully replace the gas tax as a source of sustainable revenue. The California pilot consisted of 5,000 vehicles, including commercial vehicles, and was designed to be revenue neutral with the gas tax. The pilot began on June 13, 2016 and ran until March 31, 2017. Commercial vehicles were charged 1.8 cents per mile and given a refund for any taxes they paid for fuel. They tracked and reported mileage using the EROAD system. Over the course of the pilot program, the gross revenue collected was approximately $600,000. After applying the credits for the fuel taxes paid, the net revenue was $100,000 (Caltrans, 2017).

The Eastern Transportation Coalition pilot was exclusively for commercial vehicles and also aimed at being revenue neutral with fuel taxes. The pricing structure of this pilot was designed so that each state in the transportation coalition had their own per mile fee equivalent to their current state diesel excise tax divided by the average fuel efficiency for trucks. When the average miles per gallon (MPG) was set at 4.1, the mileage-based user fee (MBUF) generated

$138,420, which was only $190 less than the revenue from state fuel taxes. It is important to note that fleets that are fuel efficient pay more under the MBUF system than the fuel tax, while less efficient fleets pay less. This raises the concerns of potentially penalizing fleets that have invested in increasing fuel efficiency (Jacobs and EROAD, 2020). Overall, both pilots received promising feedback from participants, with over 85% being satisfied with the mileage-based user fee in the California pilot program (Caltrans, 2017). However, these findings are inherently biased through self-selection because of the opt-in structure of the program.

More detailed summaries of the Oregon RUC system and the pilots in California and Eastern Transportation Coalition are presented in Appendix A of this report.

2.2.3. Practical and Political Barriers to Implementing RUC Systems

Forkenbrock (2005), and Kirk and Levinson (2016), point out several practical reasons for the delay in implementation of a mileage-based road use tax. Among them are operability and administrative cost concerns. Whereas the gas tax is paid by suppliers who are refunded by consumers, charging a fee per mile would require a payment network to track and collect tolls from travelers, often using credit cards that charge transaction fees. The California Department of Transportation (Caltrans) estimates that its Road Charge Pilot Program’s administrative costs ran between 5-10% of revenues compared to administrative costs for the state’s gas tax costing only 0.54% of gas tax revenues (Caltrans, 2017). With economies of scale, this difference can theoretically be reduced, though likely not to the point of convergence. Administrative costs of toll roads across the country account for around 7-12% of revenue (Kirk and Levinson, 2016). Furthermore, whereas fuel is a necessity to operate most vehicles, making the tax relatively evasion-proof at the user-level; a VMT or tolling system can be evaded through the absence of license plates or non-enrollment in the tolling system, among other examples, leading to a “leakage rate” of between 5% and 10% along most current toll roads (Kirk and Levinson, 2016). In addition, tracking and collecting VMT using GPS technology requires modernity of vehicles and cellular technologies to send and receive data, and not all cars nor communities are equipped with these, respectively (Forkenbrock, 2005). As well, interjurisdictional trips would require some form of geo-fencing for price charging and collection (Forkenbrock, 2005). Finally, this all poses privacy concerns, as many members of the public express wariness of this facilitating government tracking of them.

2.2.4. Lessons from International Examples

In the absence of domestic examples of (involuntary) road use charge systems, international examples have been the source of much analysis. de Bok et al. (2021), Gomez and Vassallo (2020), McKinnon (2006), and Kveiborg (2005) discuss the impacts that mileage-based use fees on heavy goods vehicles in European countries have had on vehicle configuration, route choice, modal shift, and efficiency. These studies found that configuration of vehicles does change based on the fees levied on them and the increased transport costs are passed through to consumers (de Bok et al., 2021; McKinnon, 2006; Kveiborge, 2005). Some studies also estimated that trucks would attempt to evade the tax by using roads not covered by the charge (de Bok et al., 2021; Kveiborg, 2005; Broaddus and Gertz, 2008), but this could be avoided by extending the tax to major secondary roads used for evasion. Additionally, Robinson (2008) states that truck haulers are often bound by the timelines that customers demand and therefore they cannot stray far from the fastest route (highways) to meet those deadlines.

There are inconclusive findings regarding the impact on employment and modal shift from distanced-based charges. The various case studies discussed in Kveiborg (2005) list both positive and negative impacts on employment. The model output from de Bok et al. (2021) estimated that there is a modal shift from road freight transport to rail and inland waterways. However, other before-and-after studies have suggested that the pricing instruments have been so far unsuccessful at generating this mode-shift (e.g., Gomez and Vassallo, 2020). On the other hand, it has likely supported a market for “collaborative transportation,” wherein freight shippers consolidate their freight to share in the costs (Frisk et al., 2010; Guajardo and Ronnqvist, 2016). A more detailed summary of the international literature is presented in Appendix A of this report.

Additionally, several studies evaluate various European road pricing policies, their outcomes, and the implications that they have for application to the U.S. Key advice surrounds setting simple prices and clear objectives that can guide the implementation of the program (Robinson, 2008; Broaddus and Gertz, 2008; Warren et al., 2005). Many papers also emphasize the importance of obtaining support from the key stakeholders that will be impacted by a road use charge (Robinson, 2008; Broaddus and Gertz, 2008; Suter and Walter, 2001). These include the trucking industry, consumers, and the department of transportation that will be implementing the fee. In a few of these cases, namely Germany and Switzerland, both citizens and the trucking industry supported the implementation of a distance-based charge for commercial vehicles to limit the number of trucks driving on highways and ensure that foreign trucks paid their fair share for damages inflicted.

The financial objectives of transportation pricing in EU countries tend to be quite distinct from the U.S., potentially limiting the transferability of findings. Whereas the U.S. restricts transportation fees and taxes to use in the transport sector and subsidizes transport in many ways, EU countries have a long tradition of using road-based taxation to both finance the roads and generate general fund revenues. The expenditure on roads in the U.S. consistently exceeds its user-based revenues, while European countries tend to generate more user-based revenues than their road expenditures (Gomez and Vassallo, 2014). There is more political opposition to road pricing in the U.S. Based on the evolution of road pricing policies in London, Stockholm, and Switzerland, Sorenson et al. (2013) suggest that achieving a paradigm shift in road pricing practices rests on there being a combination of carrots and sticks in the pricing and allocation formulae, a willingness of government to negotiate with stakeholders, using (imposed) trials, and strategically timing when to implement the change.

2.2.5. Measuring Outcome Potentials for a Freight RUC System in the United States

Finally, as will be done in this research, any analysis of the economic and mode-shift impact of road use charge in the U.S. inherently relies on projected estimations. Among the few studies that have been completed in this way is Austin (2018, 2019), who ran national simulation models to test the effects of a weight-miles tax on freight. Using Government Accountability Office values for freight costs of accident risk, pavement damage, emissions, and traffic congestion, he found that internalizing these costs with a ton-miles charge would generate a 3.1% truck-to-rail mode shift and a 0.7% reduction in net freight demand. He also found that a VMT tax (no weight component) could achieve similar results as a weight-miles tax at an aggregate level but would inherently lead to lower-weight freight subsidizing higher-weight freight.

Missing from this literature is any estimation of who would bear the incidence of a road use charge in the United States and how? Would fees simply be passed forward to consumers, or would the trucking industry absorb the costs? Would certain communities in particular bear the increase in cost or loss of supply because of a road use charge program for freight? In addition, the net environmental gains or losses of a road use charge, such as where pollution would be reduced and by how much, is not well examined. The major contribution of this project is to devise a model to estimate the economic and distributional effects of a freight road use charge in California.

2.3. Conclusion

In the U.S., the road use fee structures have largely been dependent on indirect user fees, such as fuel taxes, to recover the direct costs of road use and finance the construction, operation, and maintenance of the road system. Served as a proxy for road use, fuel taxes are considered less efficient than direct user fees, such as road use charges, to internalize both the direct and indirect (such as congestion and pollution) costs of road uses. The primary reason is that indirect user fees are not proportional to the damages caused by the vehicles, especially heavy commercial vehicles. Additionally, the gap between costs from road use and revenues from indirect fees has been growing despite constant and increasing road use because of the increasing fuel efficiency of vehicles (Parry et al., 2007; Caltrans, 2021). There has also been the debate whether trucks have paid their “fair share” of costs they impose compared to automobiles.

A review of the literature of road use charge pilot programs in the U.S. and the existing systems implemented in other countries provides several important lessons:

- Road freight demand is fairly inelastic to toll prices and the total amount transported over the road system is less likely to decrease unless complementary policies are implemented (Gomez and Vassallo, 2020; Axsen and Wolinetz, 2021).

- In RUC systems that do not cover all roads, there is generally some percentage of avoidance and rerouting that occurs to secondary roads.

- While modal shift did not happen in many instances of road user charge systems in European countries, they often led to a transition to more fuel-efficient vehicles, an increase in the proportion of heavier and larger vehicles conducting the trips, and a reduced percentage of empty runs for trucks.

- A transition to electronic reporting for the RUC systems has been found to be more efficient for both governments and trucking firms.
- All studies that discussed political feasibility indicated that consistent and early communication with affected stakeholders is the key to reducing pushback from the industry.
- Studies show that the barriers to implementing RUC extensively in the U.S. include concerns around interoperability, administrative costs, evasion, privacy, and vehicle modernity requirements.

Chapter 3. Methodology

3.1. Overall Analytical Framework

The impact analysis adopts the analytical framework (see Figure 1) we developed in previous economic impact studies of transportation-related policies. It starts with the establishment of the policy scenario(s) to be evaluated, followed by the estimation of the micro-level impacts of the policy on the regulated industry (or sector). The micro-level analysis results will be used as the inputs in the REMI macro-economic model to analyze the aggregate and sectoral impacts of the policy on the state economy. A Multi-sector Income Distributional Model (MSIDM) will be integrated into the modeling system to analyze the distributional impacts of the policy.

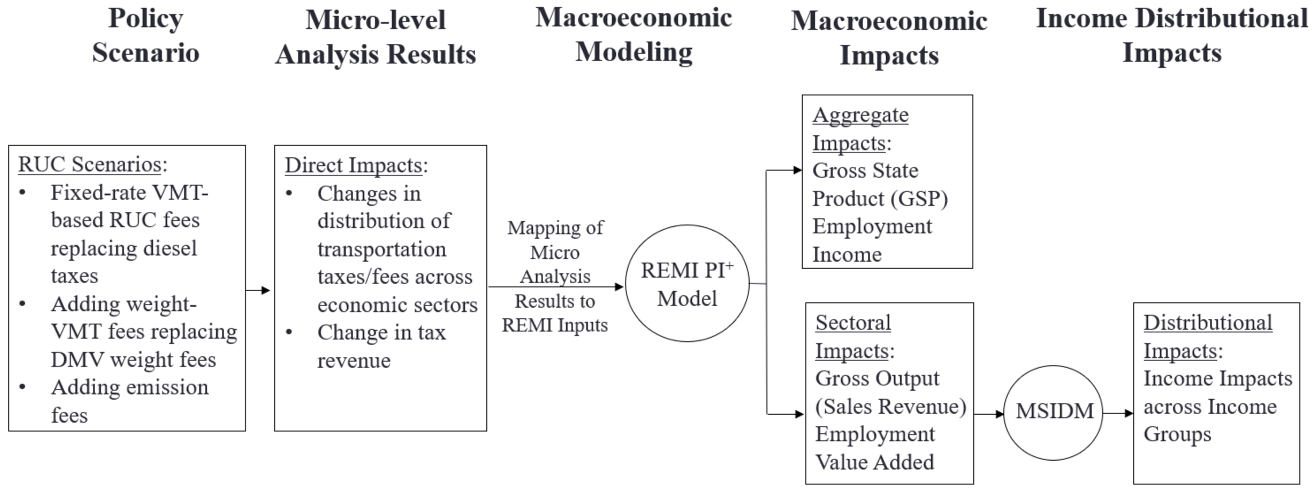

Figure 1. Analytical Framework of the Socioeconomic Impact Analysis of RUC

3.2. REMI PI+ Model

The REMI PI+ Model was selected to evaluate the macroeconomic impacts (including gross state product, employment, and personal income) of the various road use charge scenarios. It is the most widely used macro-econometric model to analyze the economic impact of energy and climate policies in the U.S. The REMI Model has evolved over the course of more than 30 years of refinement (see, e.g., Treyz, 1993). It is a packaged program but is built with a combination of national and region-specific data. In addition to the widespread use in the academic community, government agencies in practically every state in the U.S. have used a REMI Model for a variety of purposes. In California, the REMI Model is used by Department of Finance, California Air Resources Board, the South Coast Air Quality Management District, Southern California Association of Governments, Association of Bay Area Governments, and many other government and regional planning agencies to analyze the economic impacts of proposed regulations and regional development policies and initiatives (REMI, 2022).

As a macro-econometric forecasting model, the REMI model covers the entire economy based on macroeconomic aggregate relationships such as consumption and investment. REMI differs somewhat in that it includes some key relationships, such as exports, in a bottom-up approach that allows evaluation of specific sector-based policy options. In fact, it makes use of the finely-grained sectoring detail of an input-output (I-O) model, i.e., it divides the economy into 160 sectors, and thereby depicts important distinctions among them.

The REMI model is able to analyze the quantity of interactions between sectors (ordinary multiplier effects) but with refinements for price changes not found in I-O models. That is, the Model incorporates the responses of producers and consumers to price signals and the changes in other market and regulatory conditions and captures the substitution effects and other price-quantity interactions. The REMI Model also brings into play features of labor and capital markets, as well as trade with other states or countries, including changes in competitiveness. The labor market in the REMI model is linked to a demographic module of population migration. It also includes input substitution between labor and other factors of production, market supply and demand, wage rate determination, and economic geography considerations of labor accessibility of individual industries.

The econometric feature of the REMI Model refers to the fact that the model is based on inferential statistical estimation of key parameters based on pooled time series and cross-regional (panel) data. This gives the Model an additional capability of being able to extrapolate the future course of the economy, a capability that most other types of economic impact models usually lack. A more detail description of the REMI Model is presented in Appendix C.

The version of the REMI Model used in this study includes two geographical regions: California and rest of U.S. The model divides the whole economy into 160 sectors and is established based on U.S. and California historical data through 2018.

Chapter 4. RUC Scenarios

This project evaluates three different scenarios with various objectives regarding what the fees are in respect to. Each scenario is outlined below.

4.1. Scenario 1 Fixed-Rate RUC Fees Replacing Diesel Taxes

This represents the RUC Base Case Scenario, which is assumed to be revenue neutral with respect to diesel taxes – Fixed-rate RUC replaces diesel taxes but not DMV weight fees.

- Objective: Revenue neutral with respect to current condition (using FY18 as the base year) diesel taxes (including excise taxes and sales taxes on diesel) paid by trucks traveling in California. We do not consider other taxes or fees, such as registration fees or excise tax on tires.
- Types of commercial vehicles to cover:
    - Both MDVs (Class 3-6) and HDVs (Class 7 and 8) – gasoline trucks to be excluded
    - California registered trucks + interstate trucks traveling in California
- Fee structure: use the fixed rate approach (same approach used in the CA 2016-2017 RUC Pilot Program) in which the per mile charge is calculated by dividing the annual total fuel taxes paid by the covered fleet of vehicles by the total VMT of these vehicles
    - According to Regulation 1533.2, qualified use of on road diesel fuel for agricultural purposes is subject to a discounted sales tax rate of 2.25% (as opposed to the regular tax rate of 13% (CDTFA, 2022). Therefore, we examine two sub-scenarios. The first (**Scenario 1a**) is to apply a strict fixed per mile fee to all trucks while obtaining the revenue-neutral goal, which means that trucks transporting Agriculture Products will pay proportionally more under the RUC scenario. In the second sub-scenario (**Scenario 1b**), we extend the current discount to the RUC system so that the revenue neutral will be kept for trucks transporting Agriculture Products and for trucks transporting other types of commodities, separately.
- Disposition of revenues: We assume use of the revenues is the same as the current pattern.

4.2. Scenario 2 Adding Weight-VMT Fees

This scenario incorporates the weight per mile fees, which is assumed to be revenue neutral with respect to diesel taxes + DMV weight fees.

- Objective: In this scenario, we take into consideration DMV weight fees. We assume revenue will be neutral with respect to the total diesel taxes currently collected plus the DMV weight fees. The part of the RUC rates that replaces the DMV weight fees will be determined based on costs of pavement damage by weight class.
- Types of commercial vehicles to cover: same as in the Base Case
- Fee structure: in order to better internalize the direct cost of roadway use, the charge structure will be designed to impose a higher share of fees on heavier vehicles that cause more damage to the roadway system. Therefore, except for the fixed per mile fees that replace the current diesel taxes (determined in Scenarios 1a and 1b), the weight fees for each truck class will be determined based on the share of damages imposed by different weight classes of trucks.

- Disposition of revenues: We assume use of the revenues is the same as the current pattern.

4.3. Scenario 3 Adding Emission Fees

In this scenario, emission fees are added to the revenue neutral RUC, which is calculated as Scenario 1 Fixed RUC (replacing diesel taxes) + Emission Fee.

- Objective: This scenario is based on the argument that current fuel taxes do not consider the costs of environmental damages associated with air toxic emissions. In this scenario, in addition to the fixed RUC as discussed in Scenario 1, we also add emission fees with the goal to further internalize the costs imposed by the trucks. This scenario is not revenue neutral with respect to current diesel taxes as the emissions fee is in addition to the Scenario 1 fixed RUC replacing diesel taxes. The weight fees would remain as per the DMV registration fee scale.
- Types of commercial vehicles to cover: same as in the Base Case
- Fee structure: per mile fees will again be fixed across truck classes as in Scenario 1; emission fees will be calculated based on fuel consumptions of the trucks, the corresponding emission factor of PM 2.5, and the social costs of PM 2.5 emissions.
- Disposition of revenues: We assume use of the revenues is in the same proportion as current patterns.

Chapter 5. Data

5.1. Data on Truck Census

Data from the California Vehicle Inventory and Use Study (CA-VIUS) (Cambridge Systematics, 2018) was principally relied on for determining the census of trucks by GVW class, their in-state miles, the commodities they transported, and the payload of each commodity transported. The CA-VIUS dataset is comprised of survey responses from drivers of a sample of trucks whose distribution is representative of the makeup defined in California Department of Motor Vehicle records and International Registration Plan clearinghouse for trucks registered in-state and out-of-state, respectively (Cambridge Systematics, 2018). The dataset has a survey expansion factor that is intended to calibrate each observation to its representation of the population of trucks that travel in the State of California. The CA-VIUS consultant reports that this expansion factor can be broadly used for expanding various aspects of the survey data to represent attributes and patterns of the population of trucks (Cambridge Systematics, 2018). That is, just as the survey expansion factor can be used to calibrate the sample of commercial trucks to the population of commercial trucks, it can also be used to calibrate the sample of commercial truck vehicle-miles and weight-miles to the population of total commercial truck vehicle-miles and weight-miles. We accepted these guidelines as given and used the survey expansion factor accordingly.

5.2. Data for Numerical-to-Alphabetical Weight Class Conversion

Determining a weight-VMT rate by GVW class required mapping trucks in the CA-VIUS database specified in the numerical GVW class to the alphabetical GVW class used by DMV for weight fees collection. Table 2 shows the numerical-to-alphabetical GVW class conversion.

Table 2. Numerical-to-Alphabetical GVW Class Conversion

Numerical GVW Class	**Lower-bound GVW (in pounds)**	**Upper-bound GVW (in pounds)**	**Alphabetical GVW Class**
3	10,001	14,000	A
4	14,001	16,000	A, B
5	16,001	19,500	B
6	19,501	26,000	B, C
7	26,001	33,000	D, E
8	33,001	∞	E, F, G, H, I, J, K, L, M, N, N*

* Denotes a class in which the vehicle exceeds the allowable GVW and must pay the highest GVW class fee plus additional charges.

As is clear, some numerical GVW classes map to multiple potential alphabetical GVW classes, making it important to narrow down the GVW of any given truck in the CA-VIUS database. The GVW of a vehicle is the sum of its unladen (i.e., empty) weight and the maximum payload it carries, as shown in **Equation 1**.

$$GVW = Weight_{unladen} + Weight_{MaxPayload} \qquad (1)$$

where

GVW is the gross vehicle weight of a vehicle

$Weight_{unladen}$ is the weight of an empty vehicle

$Weight_{MaxPayload}$ is the maximum weight of good transported on the vehicle

Unfortunately, the CA-VIUS dataset only includes the numerical GVW class and the typical payload transported for each truck, as reported by the survey respondent. The unladen weight of each truck in the sample is unknown. This is problematic for the trucks whose GVW is Class 4, 6, or 7 because different unladen weights could cause the truck to map to different alphabetical class (e.g., Class 7 can be mapped to either Class D or Class E). This made it important to determine the unladen weight of vehicles so that they could be properly mapped to their alphabetical GVW class.

5.3. Truck Unladen Weight

5.3.1. Straight Truck Unladen Weight Estimation

The unladen weights of straight trucks by class and number of axles are estimated from reports from Chapter 5 of the Comprehensive Truck Size and Weight Study from the Federal Highway Administration and National Research Council (2010). In the dataset, the number of axles for a straight truck ranges from two to over five axles, however the majority of these trucks in the CA-VIUS dataset are ones with two axles, where the rear axle has four tires (68.5% of straight trucks). A detailed table of the distribution of different configurations of diesel straight trucks in the dataset and their corresponding unladen weights are presented in Table 3.

Table 3. Straight Truck Unladen Weights

Class	Truck Axles	Weight (lbs)	Freq	Source
Class 3 (10,001-14,000 lbs)	Two axles (each axle has 2 tires)	7,650	7.14%	Table 2-1 (National Research Council, 2010)
	Two axles (front axle has 2 tires, rear axle has 4 tires)	8,750	11.25%	Table 2-1 (National Research Council, 2010)
	Three axles	8,750	0.13%	Table 2-1 (National Research Council, 2010)
Class 4 (14,001-16,000 lbs)	Two axles (each axle has 2 tires)	7,650	4.97%	Table 2-1 (National Research Council, 2010)
	Two axles (front axle has 2 tires, rear axle has 4 tires)	8,750	12.52%	Table 2-1 (National Research Council, 2010)
	Three axles	8,750	0.12%	Table 2-1 (National Research Council, 2010)
Class 5 (16,001-19,500 lbs)	Two axles (each axle has 2 tires)	9,500	3.85%	Table 2-1 (National Research Council, 2010)
	Two axles (front axle has 2 tires, rear axle has 4 tires)	10,000	12.66%	Table 2-1 (National Research Council, 2010)
	Three axles	10,000	0.12%	Table 2-1 (National Research Council, 2010)
Class 6 (19,501-26,000 lbs)	Two axles (each axle has 2 tires)	11,500	6.71%	Table 2-1 (National Research Council, 2010)
	Two axles (front axle has 2 tires, rear axle has 4 tires)	14,500	24.32%	Table 2-1 (National Research Council, 2010)
	Three axles	22,600	0.42%	Table V-3 (FHWA, 2010)
Class 7 (26,001-33,000 lbs)	Two axles (each axle has 2 tires)	11,500	1.22%	Table 2-1 (National Research Council, 2010)
	Two axles (front axle has 2 tires, rear axle has 4 tires)	14,500	6.32%	Table 2-1 (National Research Council, 2010)
	Three axles	22,600	0.76%	Table V-3 (FHWA, 2010)
	Four axles	26,400	0.03%	Table V-3 (FHWA, n.d.)
Class 8 (> 33,000 lbs)	Two axles (each axle has 2 tires)	11,500	0.17%	Table 2-1 (National Research Council, 2010)
	Two axles (front axle has 2 tires, rear axle has 4 tires)	14,500	1.45%	Table 2-1 (National Research Council, 2010)
	Three axles	22,600	4.50%	Table V-3 (FHWA, 2010)
	Four axles	26,400	1.26%	Table V-3 (FHWA, 2010)

5.3.2. Tractor/Trailer Unladen Weight Estimation

To estimate the empty weight of tractor-trailer trucks, we estimated the weights of the unattached tractors and then the empty weights of the different types of trailers. These values will then be added together to get the total empty weight of the tractor-trailer. For straight trucks that tow a trailer more than 50% of the time, total empty weights are estimated by adding together the unladen weight of the straight truck (from Table 3 above) and the unladen weight of the trailer. The weights of tractors with different numbers of axles were estimated by taking the range from a Department of Energy Empty Vehicle Weight Table (pictured in the Appendix) and dividing it between the different number of axles. Table 4 below shows that for each additional axle the weight increases by 2,000 lbs. and for an additional set of wheels the weight increases by 500 lbs. (Scherer-Carlson, 2015). It also shows the frequency of each type of tractor.

The different types of trailers in the dataset, the types, frequency, empty weights, and sources are listed in Table 5. Information on the trailers was mainly gathered from manufacturing and resale websites. These sites provide the full specifications of the trucks that they manufacture and distribute. The most common configurations are highlighted in green in the table and represents 47% of trailers in the dataset. The weights of reefer trailers are estimated as the weight of a dry van of a similar configuration (length and number of axles) plus 2000 pounds for the reefer unit (Utility Keystone, 2021).

Table 4. Tractor Weights and Frequency

Number of Truck Axles	Unladen Tractor Weight	Frequency
Two axles (each axle has 2 tires)	20,000	3.53%
Two axles (front axle has 2 tires, rear axle has 4 tires)	20,500	14.11%
Three axles	22,000	77.82%
Four axles	24,000	1.60%
Five axles	26,000	2.48%
More than five axles	28,000	0.25%
Other (average of all other weights)	23,416	0.21%

5.3.3. Unladen Weight Data Limitations

Certain information on trailers has been difficult to find, leaving gaps in the empty weight estimations of different configurations of trailers. With the estimated empty weights currently obtained from the literature and manufacturer websites, 12.02% of trailer weights are missing (represented by "-" in Table 5). For trailers, it has been most difficult to find empty weight data for specialty and tank trailers. It has also been difficult to find certain combinations of lengths and trailer axles, such as a trailer longer than 53 feet with only one axle, or trailers shorter than 40 feet with three axles. For trailers with missing empty weight information, we replace their estimated summed weight (tractor weight plus trailer weight plus maximum reported payload) with their estimated maximum Gross Vehicle Weight as estimated by the maximum allowed weight from the Federal Highway Administration “Bridge Formula Weight” pamphlet (FHWA, 2019). This is explained further in Section 3.6.

There are also some discrepancies in the data, where trailers with more axles or a longer length have a lower weight. Specifically, this is an issue for Dry Vans and Reefers. Both have a similar discrepancy because all of the Reefer weights were estimated by adding 2,000 lbs. to the Dry

Table 5. Trailer Type, Frequency, Weight, and Sources

Type	Number of Axles	Length	Percent	Weight	Source
Auto	One axle	40 feet or less	0.09	-	
	One axle	Between 41 and 53 feet	0.02	-	
	Two axles	40 feet or less	0.04	1,800	Texas Pride Trailers (n.d.a)
	Two axles	Between 41 and 53 feet	1.19	6,000	Texas Pride Trailers (n.d.b)
	Two axles	More than 53 feet	0.32	-	
	Three or more axles	Between 41 and 53 feet	0.49	8,750	Kaufman Trailers (2022)
	Three or more axles	More than 53 feet	0.04	-	
Bulk	One axle	40 feet or less	0.54	-	
	Two axles	40 feet or less	0.88	7,823	Southeastern Pneumatic (2022)
	Two axles	Between 41 and 53 feet	2.51	9,400	Tank Mart (n.d.b.)
	Two axles	More than 53 feet	0.05	-	
	Three or more axles	40 feet or less	0.07	-	
	Three or more axles	Between 41 and 53 feet	1.24	21,000	Tank Mart (n.d.a)
	Three or more axles	More than 53 feet	0.32	-	
Container Chassis	One axle	40 feet or less	0.43	-	
	Two axles	40 feet or less	0.65	6,412.5	Chassis King (n.d.b)
	Two axles	Between 41 and 53 feet	2.61	6,800	Chassis King (n.d.d)
	Two axles	More than 53 feet	0.16	7,500	Chassis King (n.d.f)
	Three or more axles	40 feet or less	0.20	9,650	Chassis King (n.d.a)
	Three or more axles	Between 41 and 53 feet	0.36	9,750	Chassis King (n.d.a)
	Three or more axles	More than 53 feet	0.05	10,680	Chassis King (n.d.e)
Dry Van	One axle	40 feet or less	0.87	-	
	One axle	Between 41 and 53 feet	0.04	-	
	Two axles	40 feet or less	0.29	-	
	Two axles	Between 41 and 53 feet	18.84	12,511.54	Allen County (2009)
	Two axles	More than 53 feet	1.93	13,550	Hyundai Translead (2018b)
	Three or more axles	40 feet or less	0.02	-	
	Three or more axles	Between 41 and 53 feet	1.21	16,534	Titan Vehicle (n.d.)
	Three or more axles	More than 53 feet	0.32	14,400	Allen County (2009)
Flat	One axle	40 feet or less	0.79	6,100	Allen County (2009)
	One axle	Between 41 and 53 feet	0.02	-	

Type	Number of Axles	Length	Percent	Weight	Source
	Two axles	40 feet or less	1.33	7,200	Big Tex Trailers (n.d.)
	Two axles	Between 41 and 53 feet	13.65	9,900	Hyundai Translead (2018a)
	Two axles	More than 53 feet	0.32	-	
	Three or more axles	40 feet or less	0.14	-	
	Three or more axles	Between 41 and 53 feet	1.55	15,460	Allen County (2009)
	Three or more axles	More than 53 feet	0.52	22,570	Allen County (2009)
Livestock	One axle	40 feet or less	0.04	-	
	Two axles	40 feet or less	0.02	10,500	Featherlite Trailers (n.d.b)
	Two axles	Between 41 and 53 feet	0.67	12,125	Featherlite Trailers (n.d.b)
	Two axles	More than 53 feet	0.02	14,500	Featherlite Trailers (n.d.a)
	Three or more axles	Between 41 and 53 feet	0.07	14,125	Scherer-Carlson (2015)
Reefer	One axle	40 feet or less	0.18	-	
	One axle	Between 41 and 53 feet	0.04	-	
	Two axles	40 feet or less	0.18	10,270	Portable Refrigeration Storage (n.d.)
	Two axles	Between 41 and 53 feet	15.27	14,511.54	Utility Keystone (2021)
	Two axles	More than 53 feet	1.35	15,550	Utility Keystone (2021)
	Three or more axles	40 feet or less	0.04	-	
	Three or more axles	Between 41 and 53 feet	0.67	18,534	Utility Keystone (2021)
	Three or more axles	More than 53 feet	0.16	16,400	Utility Keystone (2021)
Specialty	One axle	40 feet or less	0.47	-	
	One axle	Between 41 and 53 feet	0.07	-	
	Two axles	40 feet or less	1.01	-	
	Two axles	Between 41 and 53 feet	3.93	-	
	Two axles	More than 53 feet	0.13	-	
	Three or more axles	40 feet or less	0.04	-	
	Three or more axles	Between 41 and 53 feet	1.06	-	
	Three or more axles	More than 53 feet	0.60	-	
Tank	One axle	40 feet or less	0.14	-	
	Two axles	40 feet or less	0.40	-	
	Two axles	Between 41 and 53 feet	2.92	13,275	Chassis King (n.d.g)
	Two axles	More than 53 feet	0.02	-	
	Three or more axles	Between 41 and 53 feet	0.22	-	
	Three or more axles	More than 53 feet	0.05	-	

Van weight (Utility Keystone, 2021). Given how difficult it was to find empty trailer weight information, we leave the discrepancy as is because it only impacts 0.48% of the trailers in the dataset.

Another limitation was the wide range of weights for a certain type of trailer with a certain specification, especially regarding the "40 feet or less" category with one or two axles. Because of how variable weights are within these categories, it was difficult to gather an appropriate estimate or average. For example, a two axle, 18-foot auto trailer weighs 1,800 pounds, while a two axle, 32-foot trailer weighs 5,640 pounds. Additionally, many of the empty weights (when listed) are for newer models that are lighter than previous models. Given that the composition of California's fleets are not the newest model trucks and trailers, these weights may underestimate the true weights of these trucks.

5.4. Fuel Economy and PM2.5 Emission Factors

We collected data on total VMT, diesel fuel consumptions, and PM2.5 emissions by truck class and model year from the EMFAC dataset, and then calculated the weighted average (using VMT as weights) fuel economy and PM 2.5 emission factors for trucks of given Class/Model Year combinations. The results are presented in Figure 2 and Figure 3.

According to Figure 2, the Class 8 trucks have a much lower fuel efficiency (around 6 miles per gallon for the more recent model years) compared to 8 miles per gallon for Class 4-7 trucks[2] and about 15 miles per gallon for Class 3 trucks. The fuel economy estimates based on the EMFAC dataset show a dip in the Class 3 truck curve between 2005 and 2018, and a jump in the Class 4-7 truck curves between 2010 and 2015. We have not been able to identify good explanations for these deviations.

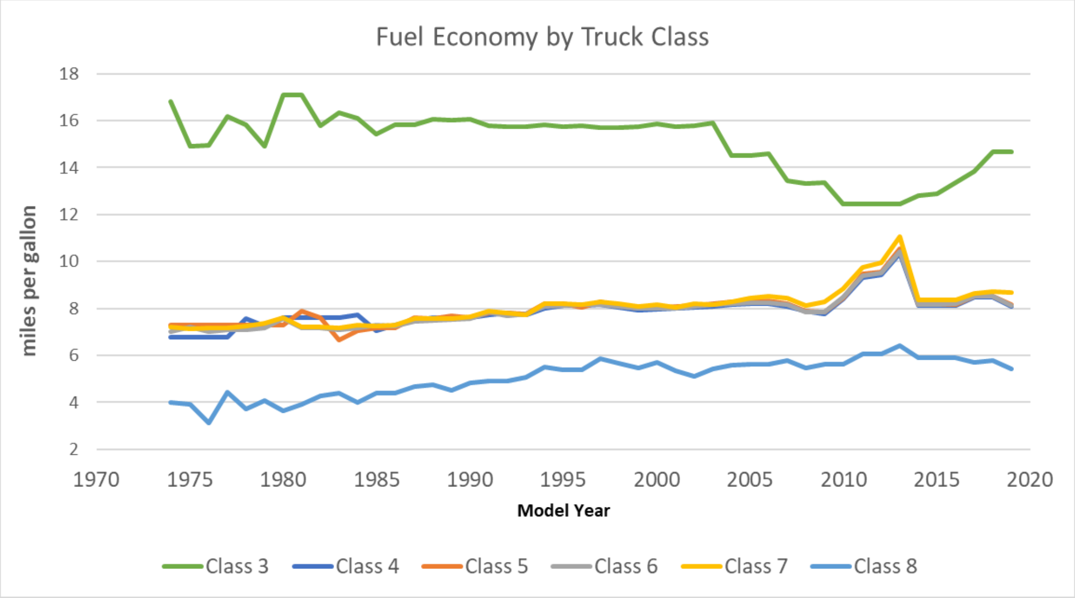

Figure 2. Fuel Economy by Truck Class and Model Year

Source: calculated by the authors based on the EMFAC dataset (CARB, 2021).

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[2] In the EMFAC dataset, since Class 4 through 7 are all classified as medium commercial trucks, their mpg appears to be similar.

For PM2.5 emission factors, we observe substantial volatility for early model years, which appears to be very unreliable. However, since trucks of model years earlier than 1995 only account for 0.7% in the CA-VIUS sample, the volatility in early model years would not affect our analysis much. The curves also show a significant drop in 2010, which is plausibly explained by the diesel air pollution regulations requirements that either upgrade old trucks with a new engine model year of 2010+, or the older trucks must have a particulate filter installed.

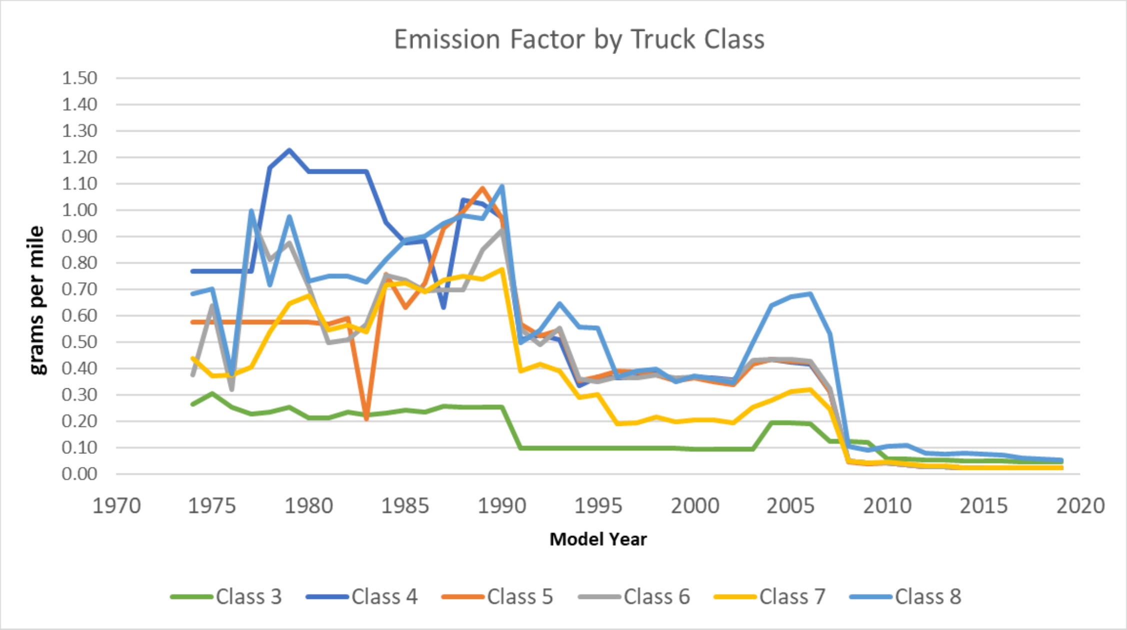

Figure 3. PM2.5 Emission Factors by Truck Class and Model Year

Source: calculated by the authors based on the EMFAC dataset (CARB, 2021).

5.5. Social Cost of PM 2.5 Emissions

According to CARB (2018) and Lee et al. (2012), diesel particulate matter (PM) accounts for 80% of health impacts in California attributable to air pollution. This is particularly true for PM 2.5. Cui and Levinson (2020) identified the health cost per ton emitted for PM 2.5 to be $306,500, while for SO2 it was $39,600 per ton and for NOx it was $6,700 per ton. Wolfe et al. (2019) identified that the cost per ton of PM 2.5 emitted from heavy duty diesel vehicles in the Western US was between $580,000 to $1,300,000, while for SO2 and NOx the ranges were $380,000-$860,000 and $5,200-$12,000, respectively. It is important to note that Minet et al. (2020) found that the greatest health impacts from reducing emissions from heavy duty vehicles would come from the reduction in NO2. However, this study was conducted in Toronto, where the different climate may cause the different atmospheric conditions that make NO2 more problematic than PM 2.5 compared to California.

It is also important to verify that diesel fuel is one of the major sources of PM. This is important because, if diesel fuel combustion were not a large generator of PM, an emission fee based on the health costs of PM emitted by diesel trucks would not provide an adequate incentive to effectively reduce this type of pollutant. Multiple studies throughout California have shown that vehicles, and particularly diesel vehicles, produce a large portion of PM pollution. Studies specific to California have found that, in southern California, vehicle emissions account for 17-18% of PM 2.5 air pollution (Hasheminassab et al., 2014). More recent studies have shown that vehicle tailpipe and non-tailpipe emissions, like emissions from break and tire wear, account for 66% and 32% of PM 0.1 (ultrafine particulate matter that can penetrate even deeper into the lungs) and PM 2.5, respectively (Habre et al., 2021). Another study that also looks at the sources of ultrafine particles, PM 0.1, found that, on average, natural gas combustion accounts for the majority of PM pollution (22%-52%). However, the authors found that in certain areas, such as Rubidoux, the Inland Valley, and Anaheim, diesel emissions accounted for a larger portion of PM pollution, ranging from 28%-31%, compared to natural gas's 22%-26% (Yu et al., 2019).

For Scenario 3 of a potential RUC system on commercial vehicles in California, we add emissions fee to the revenue neutral VMT charges with respect to current diesel taxes. The total amount of emission fees that need to be collected to internalize the health costs of PM emissions and incentivize the switch from diesel vehicles to cleaner fuel vehicles can be calculated using **Equation 2**:

$$EF\ rate = \frac{Cost_{PM} \times Total\ Emissions_{PM}}{VMT_{Trucks}} \tag{2}$$

where

$EF\ rate$	per mile rate of the emission fee
$Cost_{PM}$	per ton health cost of PM emissions
$Total\ Emissions_{PM}$	total tons of PM emissions from trucks covered by the RUC system
VMT_{Trucks}	total VMT of trucks covered by the RUC system

The numerator of this equation gives us the total revenue that we would like to obtain from the emission fees to compensate the health costs of PM emissions. Dividing it by total truck VMT, we will get the per mile rate to be added on top of the revenue neutral RUC.

Given that the total emissions and total truck VMT will be calculated in this project, the missing piece of the equation is the cost of particulate matter, reported in cost per ton of PM emitted. The following studies all estimated the cost of PM emissions relating to the health impacts of the emissions, using a variety of measures.[3] According to Wolfe et al. (2019), the benefit per ton of reduced PM 2.5 ranges between $580,000 and $750,000, depending on whether the vehicle is a heavy-duty diesel vehicle or a light-duty diesel vehicle, respectively. Cui and Levinson (2020) have a lower estimate for cost per ton of PM 2.5 at $306,500. While these values have quite a large range, the number from Wolfe et al. (2019) are specific to the

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[3] Wolfe et al. (2019) and Goodkind et al. (2019) based their cost estimates off of PM-related mortality; Minet et al. (2020) based their cost estimates off of the years of life lost from PM emissions; and Lee et al. (2012) and Cui and Levinson (2020) both use estimates of the cost of adverse health impacts from emissions, such as the cost of asthma and other lung diseases.

Western US, while Cui and Levinson (2020) are concerned with Minnesota. Another study conducted by Goodkind et al. (2019) found that the per ton cost of damages for PM 2.5 in Los Angeles range from $52,000 the farthest you are away from the port area to $2,900,000 within close proximity to the ports.

We finally decided to use a social cost estimate of $623,250/ton in our analysis, which is the average of the estimates presented in Wolfe et al. (2019) and Cui and Levinson (2020). This per ton cost of PM2.5 is used to calculate the emission fees that are needed to internalize the social cost the emissions in Scenario 3.

Chapter 6. Calculation of Baseline Taxes and Fees

6.1. Diesel Taxes

This section provides a summary on producing baseline estimates of diesel excise and sales taxes paid by heavy-duty commercial vehicles — referred to as Class 3 through Class 8 trucks in the California Vehicle Inventory and Use Survey (CA-VIUS) database — in the State of California during fiscal year 2018 (FY18). Developing these baselines are a prerequisite to evaluate how a change in tax structure would affect taxes and fees paid by different classifications of commercial trucks and types of commodities being transported in the State. In the following sections, we summarize the relevancy of this analysis to the broader project, the data and methodologies used to develop baseline estimates, and the results.

Introduction and Problem Statement

To estimate how a revenue-neutral conversion from the State's diesel sales and excise taxes to a fixed vehicle-miles traveled (VMT) charge or a weight-based VMT charge would distributivity affect taxes and fees paid by different classifications of commercial trucks and types of commodities being transported, we must calculate the difference between what different trucks and commodity shippers paid in diesel taxes and what they would have paid under a VMT charge and weight-based VMT charge structure in lieu during the same time period. Our study period is FY18 due to the CA-VIUS dataset being based on surveys collected in FY18.

Data and Methods

The data used for this portion of the analysis includes the total diesel gas tax revenues, as presented in Table 6, with the variables of interest highlighted.

Table 6. Transportation Revenue by Fiscal Year and Tax/Fee Source

Transportation Revenue Source	FY18
Gasoline Excise	$6,432,835,000
Diesel Excise	$1,124,876,000
Weight Fees	$1,184,506,000
Diesel Sales	$925,818,000
Transportation/Road Improvement Fee	$1,666,256,000
TOTAL	***$11,334,291,000***

Source: Department of Finance (provided by Caltrans).

In addition, we relied on the dataset from the CA-VIUS survey to estimate the vehicle-miles traveled (VMT) in the State of California. Every observation in the dataset has assigned a survey expansion factor to scale up from the sample to the entire population of fleet in the state (Cambridge Systematics Inc., 2018). The reported in-state VMT of each observation is weighted to this survey expansion factor, the summation across which defines the total in-state VMT generated by heavy-weight commercial vehicles. This arithmetic is defined in **Equation 3**.

$$VMT_{net} = \sum_{i=1}^{n} VMT_i \times a_i \tag{3}$$

where
VMT is vehicle-miles traveled in California
α is a survey expansion factor
i is an observation in the CA-VIUS dataset
n is the total number of observations in the CA-VIUS dataset

Given that we are focused solely on diesel-powered vehicles, we filter the data to only include these observations. Our calculation indicates an annual total VMT inside California at 14.25 billion miles by diesel-powered trucks. The total annual VMT in CA by all trucks are estimated to be about 15.2 billion miles according to the CA-VIUS Final Report, which compares closely to the independent estimates of 16 billion miles for heavy-duty commercial vehicles reported in EMission FACtor (EMFAC) 2017 report (Cambridge Systematics Inc., 2018).

Finally, external data sources were used to estimate some values in the analysis, including the California Department of Tax and Fee Administration (CDTFA) for the State's diesel excise and sales tax rates in effect in FY18 (CDTFA, 2022); the United States Federal Highway Administration's (FHWA) Statistics Series for the federal excise tax rates (FHWA, 2021); the United States Energy Information Agency (EIA) for estimation of the average price per gallon of diesel fuel in 2018 (EIA, 2022); and the mile per diesel-gallon-equivalent (MPDGE) of heavy-duty commercial trucks by weight class estimated by using EMFAC database. The values of these for FY18 are defined in Table 7. This table also presents the calculation of both the regular and discounted sales tax rate for diesel fuel.

We have found in our research that the EIA average per gallon price of diesel fuel is based on the posted price of fuel at the stations they sample. These posted prices are inclusive of all taxes, including the State's sales tax at the standard rate. As well, we have found that the State's sales tax rate is applied to the price after the federal excise tax is charged, but before the State's excise tax rate is charged (CDTFA, 2021). Thus, the base price of diesel fuel — in this case, the price inclusive of the federal excise tax but before any State taxes are applied — for each year is calculated using **Equation 4**.

$$Cost_{base} = \frac{Cost_{EIA} - Tax_{StateExcise}}{1 + Tax_{StateSales}} \tag{4}$$

where

Costbase is the estimated price per gallon of diesel fuel in California, inclusive of the federal excise tax but before any state taxes are applied
CostEIA is the EIA-reported average annual price per gallon of diesel fuel in California
TaxStateExcise is the state excise tax rate on diesel fuel
TaxStateSales is the standard state sales tax rate on diesel fuel

Table 7. Tax Rates, Fuel Economies, and Fuel Costs of Diesel for FY18

Calculation based on Retail Price of Diesel	
Retail Price of Diesel Fuel ($/gallon)	3.874
State Excise Tax Rate ($/gallon)	0.36
Price of Diesel Fuel minus State Excise Tax ($/gallon)	3.514
Regular CA Sales Tax Rate	13%
Tax Base Retail Price of Diesel Sales Tax ($/gallon)	3.110
Regular Sales Tax ($/gallon)	0.4043
Discounted Sales Tax Rate[a]	2.25%
Discounted Sales Tax ($/gallon)	0.0700
Calculation based on Wholesale Price of Diesel	
Wholesale Price of Diesel Fuel ($/gallon)	2.13
State Excise Tax Rate ($/gallon)	0.36
Price of Diesel Fuel minus State Excise Tax ($/gallon)	1.77
Regular CA Sales Tax Rate	13%
Tax Base Wholesale Price of Diesel Sales Tax ($/gallon)	1.566
Regular Sales Tax ($/gallon)	0.2036
Discounted Sales Tax Rate	2.25%
Discounted Sales Tax ($/gallon)	0.0352
Total VMT by Diesel Trucks	14,252,180,537
Fuel Efficiency (miles/gallon)	6.05
Total Diesel Fuel Consumed	2,355,670,206

[a] Qualified use of onroad diesel fuel for agricultural purposes is subject to a discounted sales tax rate of 2.25% (CDTFA, 2022).

After applying this calculation, we estimate that the base price per gallon of diesel fuel (Costbase) in 2018 was $3.11. In addition, since the State affords qualified agricultural uses of diesel fuel with a discount (CDTFA, 2022), we estimate the share of in-state VMT-miles that are associated with the transport of agriculture products from the CA- VIUS dataset. We estimate that 15.4% of the total in-state VMT generated by commercial diesel trucks are associated with the transport of agricultural goods.

With these data and findings, we calculate estimates for the total amount of diesel sales and excise taxes generated by heavy-duty commercial vehicles that ran on diesel fuel during FY18. Specifically, the amount of diesel fuel consumed is the ratio between the total amount of VMT generated and the assumed fuel economy (**Equation 5**). Since the state affords qualified agricultural uses of diesel fuel with a discount, we estimate diesel sales tax revenue based on the share of in-state VMT-miles that are and are not associated with the transport of agriculture products. The corresponding amount of total diesel sales tax revenue generated will be equal to the product of the base price per gallon of diesel fuel, gallons of diesel fuel consumed, and diesel sales tax rates, proportioned by the share of fuel associated with the transport of agricultural goods versus all other goods (**Equation 6**). Finally, the excise tax revenue generated is the product of the amount of diesel fuel consumed and the excise tax rate (**Equation 7**).

$$\mathrm{Fuel}_{\mathrm{net}} = \mathrm{VMT}_{\mathrm{net}}/6.14 \qquad (5)$$

$$\mathrm{Tax}_{\mathrm{sales}} = \mathrm{Cost}_{\mathrm{base}} * \mathrm{Fuel}_{\mathrm{net}} * [(84.6\% * 13\%) + (15.4\% * 2.25\%)] \qquad (6)$$

$$\mathrm{Tax}_{\mathrm{Excise}} = \mathrm{Fuel}_{\mathrm{Net}} * \$0.36 \qquad (7)$$

Where
$Fuel_{net}$ is the annual volume of diesel fuel consumed by heavy-duty commercial vehicles, in gallons
VMT_{net} is the annual total VMT generated by diesel-powered heavy-duty commercial vehicles
$Cost_{base}$ is the estimated price per gallon of diesel fuel in California, inclusive of the federal excise tax but before any state taxes are applied
Tax is the total amount of tax generated — *sales* corresponding to sales tax; *excise*, to excise tax.

Results

Tables 8 and 9 show the results of our calculations for diesel excise and sales taxes paid by Class 3 – 8 diesel trucks registered or traveling in California, respectively.

Table 8. Estimated Diesel Excise Tax Paid by Class 3-8 Diesel Trucks

Fiscal Year	FY18
VMT_{net}	14,252,180,537 miles
$Fuel_{net}$	2,322,404,712 gallons
Tax_{excise}	$836,065,696
Actual Annual Total Diesel Excise Tax Revenue	$1,124,876,000
Revenue Share (Tax_{excise} / Actual Total Diesel Excise Tax Revenue)	74.3%

Table 9. Estimated Diesel Sales Tax Paid by Class 3-8 Diesel Trucks

Fiscal Year	FY18
VMT_{net}	14,252,180,537 miles
$Fuel_{net}$	2,322,404,712 gallons
Tax_{sales}	$615,621,777
Actual Annual Total Diesel Sales Tax Revenue	$925,818,000
Revenue Share (Tax_{sales} / Actual Total Diesel Sales Tax Revenue)	66.5%

As is evident from the last row in Table 8 and Table 9, our diesel excise and sales tax estimates are below the total in diesel excise and sales tax revenue generated by the State of California in FY18. This seems plausible, as diesel-powered heavy-duty commercial vehicles are not the only equipment that uses diesel fuel, but likely accounts for a large share of diesel fuel consumption. Based on the EMFAC data of diesel consumption of on road vehicles, we estimate that excise taxes of diesel consumed by buses, light commercial trucks, passenger cars and trucks are about $0.208 billion. If we add this to the $0.836 billion estimate in Table 8, we get $1.044 billion, which is about 93% of the control total of $1.125 billion. Similarly, we estimate that the sales taxes of diesel fuels consumed by buses, light commercial trucks, passenger cars and trucks, as well as offroad equipment are about $0.250 billion. By adding this additional diesel sales tax to what we obtained in Table 9, which is $0.616 billion, we get $0.866 billion, which is about 94% of the control total of $0.926 billion state diesel sales tax revenues.

Therefore, under the baseline condition (i.e., the current diesel tax system), based on the above estimates, the total diesel taxes (including both excise and sales taxes) paid by Class 3 – 8 diesel trucks registered or traveling in California is estimated to be $1,451,687,473. This estimate will be used in the revenue neutral calculation of the per mile RUC rate for Scenario 1 in Chapter 7.

Table 10 and Table 11 present the estimated distribution of the diesel taxes among GVW truck classes and transported commodity categories in the baseline condition. Not surprisingly, Class 8 trucks contribute nearly 80% of the total diesel taxes paid by the heavy-duty trucks because they account for about 70% VMT traveled and their relatively low fuel economy. Among the 15 commodity categories used in the CA-VIUS database, trucks transporting Manufactured Products and Food, Beverage, Tobacco Products contribute 20% and 18.6% diesel taxes collected by the state, followed by trucks transporting Transportation Equipment (11.4%) and Agriculture Products (11.2%). The reason that the percentage of excise tax paid by trucks transporting Agriculture Products (16.9%) is much higher than the percentage of sales tax they pay (3.4%) is because of the discount rate of diesel sales tax applied to the qualified trucks using for farm-related activities and delivering agriculture products.

Table 10. Baseline Distribution of Diesel Taxes by GVW Truck Class

GVW Class	Diesel Excise Tax ($)	Percentage	Diesel Sales Tax ($)	Percentage	Total Diesel Taxes ($)	Percentage
Class 3	15,067,022	1.8%	12,165,659	2.0%	27,232,681	1.9%
Class 4	24,615,517	2.9%	19,506,036	3.2%	44,121,553	3.0%
Class 5	32,881,937	3.9%	26,821,741	4.4%	59,703,678	4.1%
Class 6	55,801,223	6.7%	44,586,388	7.2%	100,387,610	6.9%
Class 7	42,456,224	5.1%	29,129,708	4.7%	71,585,932	4.9%
Class 8	665,243,774	79.6%	483,412,245	78.5%	1,148,656,019	79.1%
Total	836,065,696	100.0%	615,621,777	100.0%	1,451,687,473	100.0%

Table 11. Baseline Distribution of Diesel Taxes by Transported Commodity Category

Commodity Category	Diesel Excise Tax ($)	Percentage	Diesel Sales Tax ($)	Percentage	Total Diesel Taxes ($)	Percentage
Agriculture products	141,243,658	16.9%	20,923,355	3.4%	162,167,013	11.2%
Wood, printed products	49,794,633	6.0%	42,619,243	6.9%	92,413,876	6.4%
Crude petroleum	4,119,314	0.5%	3,525,722	0.6%	7,645,036	0.5%
Fuel and oil products	26,941,913	3.2%	23,059,593	3.7%	50,001,506	3.4%
Gravel / Sand and nonmetallic minerals	64,943,079	7.8%	55,584,804	9.0%	120,527,884	8.3%
Coal / Metallic minerals	292,950	0.0%	250,736	0.0%	543,686	0.0%
Food, beverage, tobacco products	145,315,044	17.4%	124,375,197	20.2%	269,690,241	18.6%
Manufactured products	156,250,776	18.7%	133,735,093	21.7%	289,985,870	20.0%
Chemical / Pharmaceutical products	21,419,027	2.6%	18,332,553	3.0%	39,751,580	2.7%
Nonmetal mineral products	8,144,114	1.0%	6,970,550	1.1%	15,114,663	1.0%
Metal manufactured products	58,814,530	7.0%	50,339,376	8.2%	109,153,906	7.5%
Waste material	43,527,266	5.2%	37,255,002	6.1%	80,782,268	5.6%
Electronics	20,758,945	2.5%	17,767,588	2.9%	38,526,534	2.7%
Transportation equipment	89,437,882	10.7%	76,549,914	12.4%	165,987,796	11.4%
Logs	5,062,564	0.6%	4,333,050	0.7%	9,395,614	0.6%
Total	836,065,696	100.0%	615,621,777	100.0%	1,451,687,473	100.0%

6.2. Weight Fees

To estimate the weight fees paid by the Class 3-8 diesel trucks in the baseline, we first need to map the trucks in the CA-VIUS database, which are specified in numerical GVW classes, to the alphabetic class used in the DMV weight fee structure. After we estimate the unladen weights for the straight trucks, tractors, and trailers in the CAVIUS dataset, we are able to create an estimate of the total weight of these vehicles by summing the unladen weights of the trucks with their reported typical payload. For the trucks that we could not find an appropriate estimate for one or more components of the unladen weight, we estimated what the maximum gross vehicle weight (GVW) would be for that truck based on the length of the truck and the number of axles. According to the Federal Highway Administration, certain combinations of weights and axles can carry the maximum weight outlined in the “Bridge Formula Weights” pamphlet. For example, trucks with three axles are able to carry more weight than a truck of the same length with two axles because the additional weight is spread over more axles.

It was important to estimate the total weight of trucks so they could be assigned to different alphabetic classes as opposed to the numerical classes listed in the CAVIUS dataset. A key assumption when assigning trucks to different alphabetic classes was that the trucks had correctly reported their GVW numerical class (Class 3 – 8) in the CAVIUS dataset. To assign the trucks to different alphabetic classes, we separated the CAVIUS dataset into straight trucks and tractor-trailer trucks (which include straight trucks that tow trailer more than 50% of the time) and sorted and ranked their estimated summed weights from lightest to heaviest. We assigned all trucks in GVW numeric classes that only map to one alphabetic class and then used the

Automobile Inventory from the California Department of Motor Vehicles to determine cutoff ranks within numerical classes split between multiple alphabetic classes (CA DMV, 2021). A key assumption for this step was that trucks in the split GVW numeric classes are distributed proportional to how the weight ranges are split. For example, Class 4 can map to both Class A and Class B. The weight range for Class A is 10,000 to 15,000 lbs. and the range for Class B is 15,000 to 20,000 lbs. and the range for Class 4 is 14,001 – 16,000 lbs. In this instance, 60.05% of Class 4 will go to Class A and 39.95% of Class 4 trucks will go to Class B. Tables B-1 and B-2 in the Appendix show the cutoff percentages generated for each Class for both straight trucks and tractor-trailer trucks (the last column). These percentages were used to create cutoff ranks for each GVW numeric class in the CAVIUS dataset. For Class 8, cumulative percentages were used to determine cutoff for the alphabetic classes (Class E – Class N) that can be mapped to Class 8.

After the trucks were assigned to different alphabetic classes, we expanded the CA-VIUS dataset to represent the full population of trucks operating in California. Given that the CA DMV Inventory only shows trucks that are registered in CA, we estimate the total population of IRP trucks operating in CA by taking the portion of IRP trucks from the CAVIUS dataset and using that proportion in **Equation 8**.

$$IRP\ Population = \frac{(DMV\ Truck\ Population)}{(CAVIUS\ DMV\ Truck\ Share)} \times CAVIUS\ IRP\ Truck\ Share \tag{8}$$

Then, using the assumption that IRP trucks had the same distribution among classes as trucks registered with the DMV, we created expansion factors by dividing the population number of trucks by the number of trucks in the CAVIUS dataset per alphabetic class. For example, for straight trucks in Class A that are registered with the DMV in CA, there are 2,000 trucks in the CAVIUS dataset and 79,242 trucks in the DMV inventory. Therefore, the expansion factor is 79,242/2,000 = 39.62. Since that CAVIUS dataset was from 2017/2018 and the DMV inventory is from 2021, there are approximately 25% more trucks in the DMV population. To account for this, expansion factors are scaled to be 75% of their original values.

After each class for straight and tractor-trailer trucks for both CA registered and IRP trucks were expanded by their estimated expansion factor, we calculate the weight fees that these trucks currently have to pay to the state of California. For trucks that only operate in CA part of the year, their weight fees are scaled to reflect the number of months operating in CA, as outlined by the CA DMV weight fee tables (California DMV, 2022). Trucks that did not operate for all 12 months in California also paid an additional $122 on top of their weight fees (California DMV, 2022). Finally, IRP trucks also apportion their weight fees by the percentage of miles travelled in CA (California DMV, 2022). The CA-VIUS database provides data on the number of months over the year that the truck operated in CA, as well as the percent of truck mileage during the 12-month period that was inside of CA. Based on all these information, the total weight fees paid by Class 3 – 8 diesel trucks operated in CA is estimated to be $482,849,165. This only accounts for about 40.7% of the total weight fees revenues collected by the state of California in FY18 (see Table 1). A large portion of the gap can be explained by the weight fees paid by commercial vehicles operated with a GVW under 10,000lbs (e.g., our very rough estimate indicates that this portion of the weight fee revenues can be close to another $400 million) because of the large number of commercial vehicles in this weight range compared to the number of heavy-duty vehicles in the DMV inventory. The other sources of revenues of weight fees that have not included in our calculations include weight fees paid by non-diesel commercial vehicles and fines/penalties collected from oversize/overweight vehicles.

Table 12 and Table 13 present the estimated distribution of weight fees among GVW truck classes and transported commodity categories in the baseline condition. Not surprisingly, Class 8 trucks account for about 77.4% of the total weight fees paid by the heavy-duty trucks because they account for about 42% in the fleet population and the higher weight fees they pay. Among the 15 commodity categories used in the CA-VIUS database, trucks transporting Agriculture Products and Manufactured Products contribute 21.3% and 18.7% weight fees collected by the state, followed by trucks transporting Food, Beverage, Tobacco Products (13.0%) and Gravel / Sand and Nonmetallic Minerals (11.5%).

Table 12. Baseline Distribution of Weight Fees by GVW Truck Class

GVW Class	Weight Fees	Percentage
Class 3	18,186,224	3.8%
Class 4	14,383,019	3.0%
Class 5	17,473,558	3.6%
Class 6	45,519,880	9.4%
Class 7	13,639,780	2.8%
Class 8	373,646,705	77.4%
Total	482,849,165	100.0%

Table 13. Baseline Distribution of Weight Fees by Transported Commodity Category

Commodity Category	Weight Fees	Percentage
Agriculture products	102,667,294	21.3%
Wood, printed products	35,069,757	7.3%
Crude petroleum	2,793,010	0.6%
Fuel and oil products	12,655,256	2.6%
Gravel / Sand and nonmetallic minerals	55,476,232	11.5%
Coal / Metallic minerals	206,587	0.0%
Food, beverage, tobacco products	62,892,087	13.0%
Manufactured products	90,261,509	18.7%
Chemical / Pharmaceutical products	8,876,975	1.8%
Nonmetal mineral products	4,223,098	0.9%
Metal manufactured products	30,771,718	6.4%
Waste material	24,015,266	5.0%
Electronics	10,477,319	2.2%
Transportation equipment	39,584,302	8.2%
Logs	2,878,754	0.6%
Total	482,849,165	100.0%

Chapter 7. Estimation of Changes in Fee Distributions

This chapter presents estimations of the changes in fee distributions associated with each scenario.

7.1. Scenario 1

For this scenario, we calculate the fixed per mile RUC rate to obtain the revenue neutral objective with respect to the diesel taxes (including both excises and sale taxes) paid by the diesel trucks operating in California. For Scenario 1a, a strict fixed per mile fee is calculated for all trucks while obtaining the revenue-neutral goal, without taking into consideration the current discounted sale tax rate applied to diesel consumption by trucks that transport agriculture products. By dividing the total diesel taxes of $1,451,687,473 we calculated for the baseline by the total estimated VMT of 14,252,180,532 for the heavy-duty diesel trucks, the fixed per mile RUC fee is estimated to be $0.102 to obtain the revenue neutral goal. In the first section of Table 14, the changes in the distribution among the truck GVW classes of the $1.45 billion transportation revenues when the fixed per mile RUC fees replace the current diesel taxes are presented (Scenario 1a). As expected, in general lighter trucks with higher fuel efficiency will be worse off under the new fixed rate RUC system because they consume less fuel for each mile traveled and thus would pay relatively less for diesel taxes compared to heavier trucks. The second section of Table 14 presents the results for Scenario 1b, in which the revenue neutral calculation is carried out for Agriculture Products and Non-Ag Commodities, separately. In other words, the current discount in diesel tax rate applied to transporting Agriculture Products is retained in the new RUC system. Under this assumption, the per mile RUC rate for transporting Agriculture Products is $0.069 and the rate for transporting all other types of commodities is $0.108. Compared to the results of Scenario 1a, Class 7 and Class 8 trucks would pay less under Scenario 1b, which indicates that a relatively higher portion of Agriculture Products are transported by heavier trucks.

Table 14. Changes in Distribution of Fees by Truck GVW Class for Scenario 1

	Baseline	**Scenario 1a (fixed rate across commodities)**			**Scenario 1b (discounted rate to transportation of Ag products)**		
GVW Class	**Total Diesel Tax Payment ($)**	**Fixed Rate RUC Fees ($)**	**Change in Fees ($)**	**% Change**	**Fixed Rate RUC Fees (with Discount Rate for Ag) ($)**	**Change in Fees ($)**	**% Change**
Class 3	27,232,681	63,982,384	36,749,703	134.9%	66,451,196	39,218,515	144.0%
Class 4	44,121,553	58,239,943	14,118,389	32.0%	59,977,253	15,855,699	35.9%
Class 5	59,703,678	77,833,870	18,130,192	30.4%	81,212,325	21,508,647	36.0%
Class 6	100,387,610	130,540,084	30,152,474	30.0%	134,936,249	34,548,639	34.4%
Class 7	71,585,932	101,995,244	30,409,312	42.5%	98,711,451	27,125,519	37.9%
Class 8	1,148,656,019	1,019,095,948	-129,560,070	-11.3%	1,010,399,000	-138,257,019	-12.0%
Total	1,451,687,473	1,451,687,473	0	0%	1,451,687,473	0	0%

Table 15 presents the results for Scenario 1 by commodity type. In Scenario 1a, when a strict fixed-rate RUC rate is applied, trucks that deliver agriculture products would pay almost 50% more compared to the baseline condition. Trucks that transport other types of commodities would pay less than under the current diesel taxation system. In Scenario 1b, the change in the payment of trucks transporting agriculture products would be zero since we keep revenue neutral for these trucks. For other types of commodities, payments would decrease if the transportation of them typically uses heavier trucks (such as Gravel / Sand and nonmetallic minerals) and increase if lighter (and thus more fuel efficient) vehicles are used for their transportation (such as Transportation equipment, Manufactured products, Wood, printed products).

Table 15. Changes in Distribution of Fees by Commodity Type for Scenario 1

Commodity Type	**Baseline**	**Scenario 1a (fixed rate across commodities)**			**Scenario 1b (discounted rate to transportation of Ag products)**		
	Total Diesel Tax Payment ($)	**Fixed Rate RUC Fees ($)**	**Change in Fees ($)**	**% Change**	**Fixed Rate RUC Fees (with Discount Rate for Ag) ($)**	**Change in Fees ($)**	**% Change**
Agriculture products	162,167,013	238,780,163	76,613,151	47.2%	162,167,013	0	0.0%
Wood, printed products	92,413,876	87,989,657	-4,424,219	-4.8%	93,547,514	1,133,637	1.2%
Crude petroleum	7,645,036	7,028,001	-617,035	-8.1%	7,471,924	-173,112	-2.3%
Fuel and oil products	50,001,506	46,242,574	-3,758,932	-7.5%	49,163,481	-838,025	-1.7%
Gravel / Sand and nonmetallic minerals	120,527,884	106,250,842	-14,277,042	-11.8%	112,962,164	-7,565,719	-6.3%
Coal / Metallic minerals	543,686	470,853	-72,833	-13.4%	500,594	-43,092	-7.9%
Food, beverage, tobacco products	269,690,241	238,574,346	-31,115,895	-11.5%	253,643,867	-16,046,374	-5.9%
Manufactured products	289,985,870	279,899,760	-10,086,110	-3.5%	297,579,596	7,593,726	2.6%
Chemical / Pharmaceutical products	39,751,580	36,665,229	-3,086,351	-7.8%	38,981,184	-770,396	-1.9%
Nonmetal mineral products	15,114,663	13,595,356	-1,519,307	-10.1%	14,454,105	-660,558	-4.4%
Metal manufactured products	109,153,906	108,318,001	-835,905	-0.8%	115,159,895	6,005,989	5.5%
Waste material	80,782,268	76,049,569	-4,732,699	-5.9%	80,853,232	70,963	0.1%
Electronics	38,526,534	36,918,461	-1,608,072	-4.2%	39,250,412	723,878	1.9%
Transportation equipment	165,987,796	166,331,076	343,279	0.2%	176,837,359	10,849,563	6.5%
Logs	9,395,614	8,573,585	-822,029	-8.7%	9,115,135	-280,479	-3.0%
Total	1,451,687,473	1,451,687,473	0	0%	1,451,687,473	0	0%

7.2. Scenario 2

After the total VMT and baseline revenue from weight fees were estimated from the expanded CAVIUS data as discussed in Chapter 6 we estimate the revenue neutral per mile road use charge necessary for Scenario 2. The road damages imposed by vehicles of different weight levels are estimated using the fourth power rule (Yiu, 2020). Figure 4 and Table 16 present the relationship between road damage level and vehicle weight. The road damage level for a vehicle relative to a 4,000 lbs “Average Car” (this is a unitless measure that is representative of the comparative damage of vehicles) can be estimated using **Equation 9**.

$$Damage\ Level_{vehicle} = \left(\frac{Weight_{vehicle}}{Weight_{average\ car}}\right)^{4} \tag{9}$$

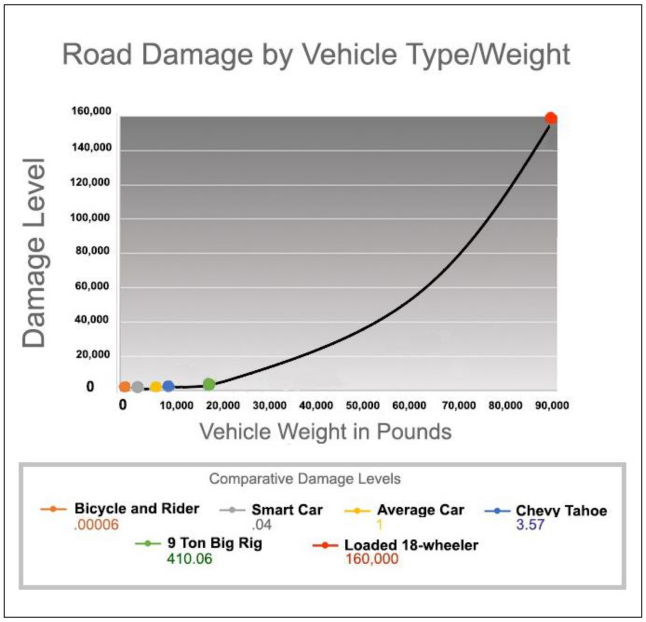

Figure 4. Relationship between Road Damage and Vehicle Weight

Source: Caltrans (2021)

Table 16. Relative Damage Level by Vehicle Type and Weight

Vehicle	Weight	Damage Level
Bicycle and Rider	350	0.00006
Smart Car	1,800	0.04
Prius	3,050	0.338
RAV 4	3,550	0.6204
Average Car	4,000	1
Toyota Highlander	4,250	1.2744
Chevy Tahoe	5,500	3.57
Hummer H2	8,600	21.3675
9 Ton Big Rig	18,000	410.06
Loaded 18-wheeler	80,000	160000

Based on the mean weights from each alphabetic weight class, we estimated the weight damage of each alphabetic class compared to the weight of an “Average Car” and using equation 9. We then multiplied the average damage done by trucks in each class by the total VMT of that class to create a damage-miles measure that represents the total relative pavement damage level done by each class. Then, we portioned the total baseline weight fee revenue, using the share of total damage done by each weight class as a percentage of the total weight fee revenue. We then divided the portion of revenue for each weight class by their total vehicle miles travelled to get the revenue neutral, per mile fee that is representative of the comparative damage inflicted by each truck of a certain weight class. Table 17 presents the data used in the calculations as well as the final per mile fees we use in Scenario 2.

Next, we calculate the changes in the distribution of fees/charges among truck GVW classes and across commodity types for Scenario 2. The total revenue neutral dollar amount in this scenario is $1.93 billion, which includes $1.45 billion diesel taxes and $0.48 billion weight fees calculated for the baseline condition. For the $1.45 billion diesel tax revenues, the fixed per mile RUC rate calculated in Scenario 1 is used. The $0.48 billion weight fees are distributed based on the road pavement damage levels. Table 18 compares the distributions of weight fees among GVW classes under the current and proposed RUC fee structures. Class 8 trucks contribute 77.4% of the total under current weight fee system. Their share is estimated to increase to 99.6% if the fees are distributed based on road damage levels. Table 19 and Table 20 presents the changes in cost distribution by truck GVW class and by commodity type for Scenario 2. Comparing to Scenario 1 (Table 14), more costs are distributed to heavier trucks in Scenario 2 (Table 19) when we add damage-based weight-VMT fees on top of the fixed-rate VMT fees that replace diesel taxes.

Table 17 – Calculation of Per Mile Fee for Scenario 2

Class	Median Weight	Damage Per Truck	Vehicle Miles Travelled	Total Damages *(Damage x Miles)*	Portion of Total Damage	Portion of Fees	Per Mile Fee
A (10,001 – 15,000)	12,501	95	1,462,195,741	139,468,165,040	0.01191%	$57,525.48	$0.00003934
B (15,001 – 20,000)	17,501	366	1,246,682,558	456,791,217,943	0.03902%	$188,409.54	$0.00015113
C (20,001 – 26,000)	23,001	1,093	1,746,046,884	1,908,820,296,368	0.16306%	$787,318.02	$0.00045091
D (26,001 – 30,000)	28,001	2,401	153,903,861	369,549,565,628	0.03157%	$152,425.58	$0.00099039
E (30,001 – 35,000)	32,501	4,358	462,196,424	2,014,404,974,837	0.17208%	$830,867.81	$0.00179765
F (35,001 – 40,000)	37,501	7,725	81,716,602	631,274,962,098	0.05393%	$260,377.65	$0.00318635
G (40,001 – 45,000)	42,501	12,745	101,586,490	1,294,708,934,950	0.11060%	$534,019.72	$0.00525680
H (45,001 – 50,000)	47,501	19,886	105,757,131	2,103,112,091,994	0.17965%	$867,456.22	$0.00820234
I (50,001 – 54,999)	52,500	29,675	427,930,557	12,699,029,954,980	1.08479%	$5,237,881.80	$0.01224003
J (55,000 – 60,000)	57,500	42,700	220,861,190	9,430,849,665,428	0.80561%	$3,889,877.89	$0.01761232
K (60,001 – 65,000)	62,501	59,607	181,193,508	10,800,320,254,357	0.92259%	$4,454,734.03	$0.02458551
L (65,001 – 70,000)	67,501	81,094	216,304,707	17,540,984,474,979	1.49840%	$7,235,009.58	$0.03344823
M (70,001 – 75,000)	72,501	107,925	16,399,188	1,769,890,420,641	0.15119%	$730,014.56	$0.04451529
N (75,001 – 80,000)	77,501	140,922	7,873,083,911	1,109,488,825,390,520	94.77561%	$457,623,247.33	$0.05812503
Total			**14,295,858,751.50**	**1,170,648,030,369,760.00**		**$482,849,165.20**	

Table 18. Comparison of Weight Fee Distributions between Current and Proposed RUC Fee Structures

GVW Class	Baseline Weight Fees ($)	Percentage	Weight Fees Distributed base on Pavement Damage Level ($)	Percentage
Class 3	18,186,224	3.8%	44,990	0.0%
Class 4	14,383,019	3.0%	61,072	0.0%
Class 5	17,473,558	3.6%	132,415	0.0%
Class 6	45,519,880	9.4%	794,776	0.2%
Class 7	13,639,780	2.8%	741,247	0.2%
Class 8	373,646,705	77.4%	481,074,665	99.6%
Total	482,849,165	100.0%	482,849,165	100.0%

Table 19. Changes in Distribution of Fees by Truck GVW Class for Scenario 2

	Baseline	Scenario 2a (Scenario 1a + new weight fees)			Scenario 2b (Scenario 1b + new weight fees)		
GVW Class	Diesel Taxes +Weight Fees ($)	RUC Fees ($)	Change in Fees ($)	% Change	RUC Fees (with Discount Rate for Ag) ($)	Change in Fees ($)	% Change
Class 3	45,418,905	64,027,374	18,608,469	41.0%	66,496,186	21,077,281	46.4%
Class 4	58,504,572	58,301,014	-203,558	-0.3%	60,038,325	1,533,752	2.6%
Class 5	77,177,236	77,966,285	789,049	1.0%	81,344,740	4,167,504	5.4%
Class 6	145,907,490	131,334,861	-14,572,629	-10.0%	135,731,026	-10,176,465	-7.0%
Class 7	85,225,712	102,736,491	17,510,779	20.5%	99,452,698	14,226,986	16.7%
Class 8	1,522,302,724	1,500,170,613	-22,132,110	-1.5%	1,491,473,665	-30,829,059	-2.0%
Total	1,934,536,638	1,934,536,638	0	0.0%	1,934,536,638	0	0.0%

Table 20. Changes in Distribution of Fees by Commodity Type for Scenario 2

Commodity Type	Baseline	Scenario 2a (Scenario 1a + new weight fees)			Scenario 2b (Scenario 1b + new weight fees)		
	Diesel Taxes +Weight Fees ($)	RUC Fees ($)	Change in Fees ($)	% Change	RUC Fees (with Discount Rate for Ag) ($)	Change in Fees ($)	% Change
Agriculture products	264,834,307	361,497,964	96,663,657	36.5%	284,884,813	20,050,506	7.6%
Wood, printed products	127,483,633	120,830,600	-6,653,033	-5.2%	126,388,457	-1,095,177	-0.9%
Crude petroleum	10,438,046	9,332,838	-1,105,208	-10.6%	9,776,761	-661,285	-6.3%
Fuel and oil products	62,656,762	61,207,686	-1,449,077	-2.3%	64,128,592	1,471,830	2.3%
Gravel / Sand and nonmetallic minerals	176,004,116	153,841,268	-22,162,848	-12.6%	160,552,590	-15,451,526	-8.8%
Coal / Metallic minerals	750,273	687,941	-62,332	-8.3%	717,683	-32,590	-4.3%
Food, beverage, tobacco products	332,582,329	321,225,999	-11,356,329	-3.4%	336,295,520	3,713,192	1.1%
Manufactured products	380,247,379	359,239,611	-21,007,768	-5.5%	376,919,447	-3,327,932	-0.9%
Chemical / Pharmaceutical products	48,628,556	45,469,448	-3,159,108	-6.5%	47,785,403	-843,153	-1.7%
Nonmetal mineral products	19,337,761	18,610,100	-727,661	-3.8%	19,468,849	131,088	0.7%
Metal manufactured products	139,925,623	134,016,866	-5,908,758	-4.2%	140,858,760	933,136	0.7%
Waste material	104,797,534	93,227,175	-11,570,359	-11.0%	98,030,837	-6,766,697	-6.5%
Electronics	49,003,852	46,215,405	-2,788,447	-5.7%	48,547,355	-456,497	-0.9%
Transportation equipment	205,572,099	196,975,032	-8,597,067	-4.2%	207,481,315	1,909,216	0.9%
Logs	12,274,368	12,158,706	-115,661	-0.9%	12,700,256	425,888	3.5%
Total	1,934,536,638	1,934,536,638	0	0.0%	1,934,536,638	0	0.0%

7.3. Scenario 3

In this scenario, in addition to the fixed VMT-based RUC fees calculated in Scenario 1, emission fees of PM2.5 are added to internalize the social costs associated with these air toxic emissions. The PM2.5 emissions are estimated by multiplying the VMT of the trucks by the PM2.5 emission factors calculated in Chapter 5. A social cost of $623,250/ton, the average of the estimates in Wolfe et al. (2019) and Cui and Levinson (2020), is used to calculate the emission fees that are needed to cover the cost of these environmental damages. The total estimated PM2.5 emission fees for the Class 3 – 8 trucks are $1,502,634,879. In Table 21 and Table 22, the distributions of the new fees (fixed-rate RUC plus emission fees) and the changes in the distribution compared to the baseline condition (under current diesel taxations) in both dollars and percentage terms are presented. According to Table 21, although Class 8 trucks would be paying less under the fixed-rate RUC system replacing the current diesel taxation (again see the results in Table 14), they would pay the largest share (about 73%) of the total emission fees.

Table 21. Changes in Distribution of Fees by Truck GVW Class for Scenario 3

GVW Class	Baseline	Scenario 3a (Scenario 1a + emission fees)			Scenario 3b (Scenario 1b + emission fees)		
	Total Diesel Tax Payment ($)	RUC Fees + Emission Fees ($)	Change in Fees ($)	% Change	RUC Fees (with Discount Rate for Ag) + Emission Fees ($)	Change in Fees ($)	% Change
Class 3	27,232,681	101,318,583	74,085,902	272.0%	103,787,394	76,554,713	281.1%
Class 4	44,121,553	143,309,964	99,188,410	224.8%	145,047,274	100,925,720	228.7%
Class 5	59,703,678	155,156,380	95,452,702	159.9%	158,534,835	98,831,157	165.5%
Class 6	100,387,610	288,462,197	188,074,586	187.3%	292,858,362	192,470,751	191.7%
Class 7	71,585,932	157,026,270	85,440,338	119.4%	153,742,477	82,156,545	114.8%
Class 8	1,148,656,019	2,109,048,959	960,392,940	83.6%	2,100,352,010	951,695,992	82.9%
Total	1,451,687,473	2,954,322,352	1,502,634,879	103.5%	2,954,322,352	1,502,634,879	103.5%

Table 22. Changes in Distribution of Fees by Commodity Type for Scenario 3

Commodity Type	Baseline	Scenario 3a (Scenario 1a + emission fees)			Scenario 3b (Scenario 1b + emission fees)		
	Total Diesel Tax Payment ($)	RUC Fees + Emission Fees ($)	Change in Fees ($)	RUC Fees + Emission Fees ($)	Change in Fees ($)	RUC Fees + Emission Fees ($)	Change in Fees ($)
Agriculture products	162,167,013	457,451,441	295,284,428	182.1%	380,838,290	218,671,277	134.8%
Wood, printed products	92,413,876	195,324,019	102,910,143	111.4%	200,881,876	108,467,999	117.4%
Crude petroleum	7,645,036	14,701,170	7,056,134	92.3%	15,145,093	7,500,057	98.1%
Fuel and oil products	50,001,506	87,766,238	37,764,732	75.5%	90,687,145	40,685,639	81.4%
Gravel / Sand and nonmetallic minerals	120,527,884	244,502,488	123,974,604	102.9%	251,213,810	130,685,926	108.4%
Coal / Metallic minerals	543,686	1,065,121	521,435	95.9%	1,094,862	551,176	101.4%
Food, beverage, tobacco products	269,690,241	488,911,342	219,221,100	81.3%	503,980,863	234,290,622	86.9%
Manufactured products	289,985,870	574,748,001	284,762,131	98.2%	592,427,837	302,441,968	104.3%
Chemical / Pharmaceutical products	39,751,580	65,708,915	25,957,335	65.3%	68,024,870	28,273,290	71.1%
Nonmetal mineral products	15,114,663	25,135,194	10,020,531	66.3%	25,993,944	10,879,280	72.0%
Metal manufactured products	109,153,906	218,140,681	108,986,775	99.8%	224,982,575	115,828,669	106.1%
Waste material	80,782,268	150,215,655	69,433,387	86.0%	155,019,318	74,237,049	91.9%
Electronics	38,526,534	72,513,471	33,986,938	88.2%	74,845,422	36,318,888	94.3%
Transportation equipment	165,987,796	340,271,697	174,283,900	105.0%	350,777,980	184,790,184	111.3%
Logs	9,395,614	17,866,918	8,471,304	90.2%	18,408,468	9,012,853	95.9%
Total	1,451,687,473	2,954,322,352	1,502,634,879	103.5%	2,954,322,352	1,502,634,879	103.5%

Chapter 8. Macroeconomic Impact Analysis Results

8.1. Application of the REMI Model

Before undertaking the economic simulations in the REMI Model, the direct impact data (changes in the distribution of fees and charges) are prepared for utilization in the model. This step involves the selection of appropriate variables and determination of the proper economic sectors in REMI to simulate the policy's changes. Table 23 illustrates how the direct costs and savings of the CHE electrification are translated into REMI economic variable inputs.

In Table 23, the second column shows different types of direct impacts (or "drivers") of the replacement of the current diesel taxes (and weight fees) with the analyzed RUC systems. The third column presents the corresponding economic variables in the REMI PI+ Model and indicates their position within the Model (i.e., in which one of the five major model blocks in REMI described in Appendix C that the policy variables can be found). In the last column, we indicate the scenarios that a specific economic "driver" is relevant in the REMI analysis.

Table 23. Linkages between Direct Impacts and REMI Simulation Inputs

Linkage	Direct Impact	Policy Variable Selection in REMI	Relevant Scenarios
1	Changes in fees and charges for non-Agriculture Sectors	Compensation, Prices, and Costs Block →Production Cost (amount) of individual industrial and commercial sectors →Increase or Decrease	Scenarios 1, 2
2	Changes in fees and charges for Agriculture Sector	Output and Demand Block → Farm Revenue → Decrease Compensation, Prices, and Costs Block →Consumer Price of Farm Food →Increase	Scenarios 1, 2
3	Changes in Government Revenues	Output and Demand Block →State and Local Government Spending →Increase	Scenarios 1, 2, 3

8.2. Aggregate Economic Impacts

The aggregate economic impacts of the three RUC scenarios (each has two sub-scenarios) on the economy of the state of California are presented in Table 24 for the following indicators: employment, gross state product (GSP), output (sale revenues), disposable personal income, and price index. The first partition of Table 24 presents the impacts in levels and the second partition presents the impacts in terms of percentage changes with respect to the baseline levels. The corresponding spillover effects to rest of the U.S. are presented in Table 25.

Major highlights of simulation results include:

- Scenario 1 is revenue neutral with respect to the current diesel taxes. Keeping the total revenues of $1.45 billion constant, the difference between the baseline condition and the analyzed RUC system in this scenario is the distribution of the same total amount among the economic sectors that deliver their products using truck transportation. The economic impacts are relatively small in both absolute and percentage terms because some sectors are better off and others worse off in terms of experiencing decreased or increased fees/charges under the new pricing system (see details in the discussion in Section 7.1), so the total impact is the net of the positive impacts on some sectors and negative impacts on others. Comparing the results of Scenario 1a (with a fixed-rate VMT RUC fee across all sectors) and Scenario 1b (keeping the lower charges to transportation of Ag products), the former results in slight positive impacts ($111.3 million increase in GSP and an increase of 842 jobs) and the latter results in slight negative impacts ($75.8 million decrease in GSP and a decrease of 528 jobs). This indicates that when the burden of transportation pricing is shifted from the Agriculture sector to other sectors, a negative impact on the economy would be expected. One reason can be that a larger portion of the agriculture products are consumed by the end users, while other categories of products (such as mineral products, manufactured products, chemical / Pharmaceutical products) have a higher share to be used as intermediate production inputs, and thus the latter can have higher multiplier effects.
- Scenario 2 is also revenue neutral, however, the total revenues include both the current diesel taxes and weight fees. The total of $1.93 billion is redistributed among the economic sectors that combines a fixed-rate VMT RUC fee and a pavement damage-based weight-VMT fee. Similarly to Scenario 1, since it is a redistribution of a constant amount of transportation charges among the economic sectors, the net impacts are relatively small in both absolute and percentage terms. Scenario 2a results in a net $217.8 million increase in GSP and an increased employment of 1,477 jobs. Scenario 2b yields a much smaller increase in GSP and employment ($7.5 million and 108 jobs, respectively), which confirms the finding in Scenario 1b that a redistribution of transportation cost burden from Agriculture sector to other sectors would result in a negative impact on the economy
- In Scenario 3, it is assumed that $1.5 billion emission fees will be collected from the heavy-duty trucks in addition to the revenue neutral RUC fees that replace the current diesel taxes. This incremental cost on truck transportation can result in $4.4 billion (Scenario 3a) to $4.6 billion (Scenario 3b) decrease in GSP. After taking into consideration the stimulus effects of government spending of these additional revenues, the estimated decrease in GSP is reduced to $0.84 billion to $1.0 billion (as shown in Table 24).
- Although some of the aggregate impacts are relatively large in terms of absolute levels, they remain small in percentage terms because of the size of the state economy.[4]

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[4] In 2019, the GSP of California was $3.1 trillion and the total employment was over 18 million.

Table 24. Aggregate Macroeconomic Impacts of the RUC Scenarios for California

Variable	Units	1a	1b	2a	2b	3a	3b
Changes in Major Macroeconomic Indicators from Baseline							
Total Employment	Job-year	842	-528	1,477	108	-3,352	-4,715
GSP	M 2022$	111.3	-75.8	217.8	17.5	-842.5	-1,028.5
Output	M 2022$	213.3	-130.2	389.7	23.7	-2,039.9	-2,381.6
Disposable Personal Income	M 2022$	123.8	-54.8	192.7	15.9	-1,369.1	-1,547.0
Price Index	2012=100	-0.003	0.0010	-0.0043	-0.0004	0.0673	0.0712
Percent Change from Baseline Level							
Total Employment	Job-year	0.003%	-0.002%	0.006%	0.000%	-0.014%	-0.019%
GSP	M 2022$	0.003%	-0.002%	0.006%	0.001%	-0.023%	-0.028%
Output	M 2022$	0.003%	-0.002%	0.006%	0.000%	-0.032%	-0.038%
Personal Income	M 2022$	0.005%	-0.002%	0.007%	0.001%	-0.052%	-0.059%
Price Index	2012=100	-0.002%	0.001%	-0.003%	0.000%	0.051%	0.054%

Table 25 indicates that the spillover effects to the rest of the U.S. closely mirror the negative or positive impacts in California. On average, the magnitude of GDP and employment impacts in rest of the U.S. is similar to those in the California in absolute terms for Scenarios 1 and 2. For Scenario 3, the magnitude of the negative impacts on GDP and employment to regions outside of CA are 3 to 6 times of those in California. This can be a result of negative impacts in California spill over to other regions through interregional trade flows, e.g., increased production costs in California resulting in higher prices of intermediate and final products exported to other regions.

Table 25. Aggregate Macroeconomic Impacts of the RUC Scenarios for Rest of U.S.

Variable	Units	1a	1b	2a	2b	3a	3b
Changes in Major Macroeconomic Indicators from Baseline							
Total Employment	Job-year	782	-926	1,894	120	-22,216	-23,922
GSP	M 2022$	77.8	-110.1	208.0	11.0	-2,602.5	-2,790.4
Output	M 2022$	123.9	-202.5	363.7	19.7	-4,571.7	-4,897.8
Disposable Personal Income	M 2022$	70.6	-76.0	159.4	9.1	-2,329.6	-2,476.0
Price Index	2012=100	0.000	0.0002	-0.0004	0.0000	0.0075	0.0079
Percent Change from Baseline Level							
Total Employment	Job-year	0.0004%	-0.0005%	0.0010%	0.0001%	-0.0121%	-0.0131%
GSP	M 2022$	0.0004%	-0.0005%	0.0009%	0.0000%	-0.0118%	-0.0127%
Output	M 2022$	0.0003%	-0.0005%	0.0009%	0.0001%	-0.0118%	-0.0126%
Personal Income	M 2022$	0.0004%	-0.0005%	0.0010%	0.0001%	-0.0140%	-0.0149%
Price Index	2012=100	-0.0002%	0.0001%	-0.0003%	0.0000%	0.0061%	0.0064%

8.3. Sectoral Impacts

GSP impacts for each RUC scenario by economic sector (at 2-digit NAICS level) are presented in Table 26. For Scenarios 1a and 2a, in which the same fixed-rate RUC fees are also applied to transportation of Agriculture Products, the agriculture-related sectors are the only sectors that experience declines in GSP (about -$20 to -$24 million, or 0.04% to 0.05% decrease from the baseline level for the two scenarios, respectively). All the other sectors experience increases in GSP, with Manufacturing and Construction sectors having the largest increase in absolute terms and Mining and Construction sectors having the largest increase in percentage terms. For Scenario 1b, when the revenue neutrality goal is applied separately for Ag and non-Ag products, many non-Ag sectors are projected to experience a decrease in GSP. When the emission fees are integrated in Scenarios 3a and 3b, all sectors are projected to experience negative impacts, except for the State and Local Government sector because of the increased transportation revenues and thus spendings of this sector compared to the baseline level.

Table 26. GSP Impacts by Sector and by Scenario for California

Sector/Scenario	1a	1b	2a	2b	3a	3b
Changes in GSP (in millions of 2022 dollars)						
Forestry, fishing, and hunting	-6.98	0.13	-7.69	-2.02	-43.01	-35.90
Mining	4.23	1.69	6.71	4.05	-39.38	-41.86
Utilities	1.23	-0.82	2.70	0.23	-17.92	-19.95
Construction	16.21	-8.13	27.47	2.73	-67.71	-91.94
Manufacturing	38.13	-17.20	60.16	3.25	-782.02	-837.13
Wholesale trade	4.17	-4.56	11.80	0.31	-137.91	-146.58
Retail trade	9.36	-5.29	15.90	1.20	-136.20	-150.80
Transportation and warehousing	3.07	-1.91	6.17	0.34	-50.05	-55.00
Information	5.87	-5.53	12.68	0.99	-88.22	-99.57
Finance and insurance	4.57	-3.90	9.91	0.95	-51.36	-59.78
Real estate and rental and leasing	12.55	-10.43	28.96	2.69	-206.11	-228.97
Professional, scientific, and technical services	7.45	-4.96	14.46	1.32	-69.53	-81.88
Management of companies and enterprises	1.49	-0.81	2.62	0.21	-26.89	-29.18
Administrative, support, waste management, and remediation services	3.53	-2.04	7.31	1.36	-31.23	-36.76
Educational services; private	1.00	-0.61	1.77	0.16	-2.14	-3.76
Health care and social assistance	6.78	-4.80	12.74	1.31	-59.40	-70.93
Arts, entertainment, and recreation	1.27	-1.01	2.51	0.21	-16.96	-19.23
Accommodation and food services	3.38	-1.69	5.61	0.47	-26.07	-31.13
Other services (except public administration)	1.95	-1.42	3.80	0.36	-18.05	-21.41

Sector/Scenario	1a	1b	2a	2b	3a	3b
State and Local Government	4.45	-2.48	7.86	0.63	1,075.57	1,068.68
Federal Civilian	0.00	0.00	0.00	0.00	0.00	0.00
Federal Military	0.00	0.00	0.00	0.00	0.00	0.00
Farm	-12.43	0.00	-15.68	-3.25	-47.89	-35.46
Total	111.27	-75.75	217.77	17.49	-842.46	-1,028.54
Percentage Changes in GSP						
Forestry, fishing, and hunting	-0.045%	0.001%	-0.050%	-0.013%	-0.280%	-0.234%
Mining	0.037%	0.015%	0.059%	0.035%	-0.345%	-0.366%
Utilities	0.002%	-0.002%	0.005%	0.000%	-0.035%	-0.038%
Construction	0.012%	-0.006%	0.020%	0.002%	-0.049%	-0.067%
Manufacturing	0.008%	-0.004%	0.013%	0.001%	-0.163%	-0.174%
Wholesale trade	0.002%	-0.002%	0.006%	0.000%	-0.070%	-0.074%
Retail trade	0.005%	-0.003%	0.009%	0.001%	-0.074%	-0.082%
Transportation and warehousing	0.003%	-0.002%	0.006%	0.000%	-0.045%	-0.050%
Information	0.002%	-0.001%	0.003%	0.000%	-0.023%	-0.026%
Finance and insurance	0.002%	-0.002%	0.005%	0.000%	-0.026%	-0.030%
Real estate and rental and leasing	0.003%	-0.002%	0.006%	0.001%	-0.041%	-0.046%
Professional, scientific, and technical services	0.002%	-0.001%	0.004%	0.000%	-0.018%	-0.022%
Management of companies and enterprises	0.002%	-0.001%	0.004%	0.000%	-0.045%	-0.049%
Administrative, support, waste management, and remediation services	0.003%	-0.002%	0.007%	0.001%	-0.029%	-0.034%
Educational services; private	0.003%	-0.002%	0.005%	0.000%	-0.005%	-0.010%
Health care and social assistance	0.003%	-0.002%	0.006%	0.001%	-0.026%	-0.031%
Arts, entertainment, and recreation	0.003%	-0.002%	0.005%	0.000%	-0.034%	-0.039%
Accommodation and food services	0.003%	-0.001%	0.005%	0.000%	-0.022%	-0.026%
Other services (except public administration)	0.003%	-0.002%	0.006%	0.001%	-0.029%	-0.035%
State and Local Government	0.002%	-0.001%	0.003%	0.000%	0.373%	0.370%
Federal Civilian	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
Federal Military	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
Farm	-0.034%	0.000%	-0.043%	-0.009%	-0.130%	-0.096%
Total	0.003%	-0.002%	0.006%	0.000%	-0.022%	-0.027%

8.4. Distributional Impacts

Another important consideration when we evaluate the RUC system as an alternative transportation pricing instrument is its impacts on fairness or distributional equality. Even for the revenue neutral scenarios, some economic sectors and household income groups may shoulder a higher proportion of the cost compared to the others. This can be caused by the difference in the dependence on truck transportation services across sectors and the proportions of expenditures on various types of commodities across income groups.

To perform the income distribution analyses for the various RUC scenarios, we utilize the Multi-Sector Income Distribution Matrix (MSIDM) for the state of California developed in Wei et al. (2020). The matrix we use for this analysis provides the earnings profile according to six income brackets for each producing sector in the economy, i.e., what proportion of the personal income (focusing on labor income in this study) paid out by each sector accrues to each income bracket (Rose et al., 1988; Li et al., 1999; Wei et al., 2022). The following steps are adopted for the analysis:

1. Obtain labor income by sector for both the baseline case and the RUC scenario cases from the REMI Model.
2. For each case, multiply the personal income in each sector by the MSIDM to determine the profile of income by bracket. The results are summed across sectors to obtain an overall income distribution across bracket of the economy for the baseline case and individual RUC scenario cases.
3. Calculate the changes in labor income for each RUC scenario with respect to the baseline condition in both dollar and percentage terms (Table 27).
4. To determine whether the income distribution has been worsened or improved, the Gini coefficient is calculated for each scenario. The Gini coefficient is a one-parameter estimate of the skewness of the income distribution by comparing the Lorenz curve with the perfect equality line. The coefficient ranges from 0 to 1, with 0 representing perfect equality and 1 representing perfect inequality.

Table 27 presents the income distribution impacts for the various RUC scenarios. The first section of the table presents the distribution of labor income across income brackets in the baseline, then in the second and third sections, the changes in income distribution with respect to the baseline level are presented in dollar terms and percentage terms, respectively. The results indicate that for Scenarios 1 and 2, the impacts are relatively evenly distributed in percentage terms across the income brackets (i.e., each income group experiences similar percentage changes in personal income). However, under Scenario 3, the lower-income households are projected to experience a higher percentage loss of their income when the emission fees are collected on top of the fix-rate RUC fees from the heavy-duty trucks.

To obtain a single-parameter metric of income distribution change, we calculate the Gini coefficient for both the baseline condition and each RUC scenario in Table 28. The second row of the table presents the changes in Gini coefficient relative to the baseline level. Since the magnitude of net income change is very small with respect to the baseline level for Scenarios 1 and 2, there are negligible changes in Gini coefficient for these scenarios. The results indicate that for Scenarios 1a and 2a, in which the current lower rate of transportation charges is not applied to the Agriculture Products, the Gini coefficient slightly decreases, which means that the income inequality is very marginally decreased. For Scenarios 3a and 3b, the Gini coefficient increases. This means that the income losses stemming from transportation cost increase caused by the emission fees are born disproportionately by lower- and middle- group, and thus worsen the income distributional inequality. This is because as discussed in Section 7.3., the largest share of the emission fees will be collected from Class 8 trucks, which in turn increases the transportation cost for the sectors that rely more on heavier trucks to deliver their products to customers downstream their supply-chain (including both industries that use their products as intermediate production inputs and end users of the products). Examples of such sectors include Mining, Metallic and Nonmetallic Mineral Products Manufacturing, and Food Product Manufacturing sectors. These sectors are found to hire a higher proportion of workers from lower- or middle-income households. Therefore, the negative economic impacts caused by the collection of emission fees are likely to be passed onto people from these income groups through both the reduced output and income generated by the aforementioned sectors and increased price of the products of these sectors.

Table 27. Baseline Income Distribution and Income Changes in Various RUC Scenarios (in M$)

Scenario	Baseline	1a	1b	2a	2b	3a	3b
Income Bracket	**Income Distribution (M $)**						
<25k	92,399	92,405	92,397	92,407	92,400	92,293	92,285
25-50k	470,458	470,490	470,444	470,507	470,462	470,027	469,981
50-75k	411,010	411,037	410,998	411,053	411,014	410,837	410,799
75-100k	342,538	342,558	342,529	342,571	342,541	342,479	342,449
100-150k	468,199	468,225	468,187	468,241	468,203	468,142	468,104
150k+	573,851	573,881	573,834	573,900	573,854	573,408	573,362
Total	2,358,456	2,358,595	2,358,389	2,358,679	2,358,474	2,357,186	2,356,981
	Income Changes relative to Baseline (M$)						
<25k		5.3	-2.8	7.3	0.3	-105.9	-114.0
25-50k		31.3	-14.3	48.4	3.7	-431.6	-477.0
50-75k		26.4	-12.0	43.0	4.0	-173.4	-211.6
75-100k		20.1	-9.6	32.7	2.9	-59.3	-88.8
100-150k		25.5	-12.7	42.2	3.6	-57.4	-95.5
150k+		30.3	-16.3	49.3	3.6	-442.3	-488.7
Total		138.9	-67.7	222.8	18.1	-1,269.9	-1,475.7
	Income Changes relative to Baseline (%)						
<25k		0.0058%	-0.0030%	0.0079%	0.0003%	-0.1146%	-0.1234%
25-50k		0.0067%	-0.0030%	0.0103%	0.0008%	-0.0917%	-0.1014%
50-75k		0.0064%	-0.0029%	0.0105%	0.0010%	-0.0422%	-0.0515%
75-100k		0.0059%	-0.0028%	0.0095%	0.0008%	-0.0173%	-0.0259%
100-150k		0.0055%	-0.0027%	0.0090%	0.0008%	-0.0123%	-0.0204%
150k+		0.0053%	-0.0028%	0.0086%	0.0006%	-0.0771%	-0.0852%
Total		0.0059%	-0.0029%	0.0094%	0.0008%	-0.0538%	-0.0626%

Table 28. Gini Coefficient Impacts

	Baseline	1a	1b	2a	2b	3a	3b
Gini Coefficient	0.451981	0.451979	0.451981	0.451979	0.451981	0.452052	0.452054
Change in Gini Coefficient		-0.000002	0.000000	-0.000002	0.000000	0.000071	0.000073

Chapter 9. Conclusions

Due to the trend of improvements in fuel economy of traditional vehicles and the electrification transition of more vehicle fleets over the years, transportation revenues collected from gasoline and diesel taxes have been declining. Problems associated with this trend are the reduced government funding sources to maintain good conditions of the State roadway systems and invest in the enhancement of other transportation facilities. To maintain a sustained stream of revenue to cover these costs, California is currently evaluating the potential to use a Road Use Charge (RUC), a VMT-based fee system, as an alternative transportation pricing instrument to replace transportation fuel taxations.

In this report, we developed an analytical framework to investigate the macroeconomic and distributional impacts of three alternative RUC scenarios for California. The first scenario assumes a fixed-rate VMT-based RUC fee to replace diesel taxes, while achieving revenue neutrality. The second scenario adds a weight-VMT fee based on pavement damage levels (replacing current DMV weight fees) on top of the fixed-rate RUC fees in Scenario 1. In the third scenario, emission fees that aim to internalize the social costs of PM2.5 emissions are added on top of the fixed-rate RUC fee in Scenario 1. For the fixed-rate RUC fees in each scenario, two options are analyzed: 1) a strict fixed-rate VMT charge is applied across all types of commodities transported by the heavy commercial vehicles; 2) the current discount in diesel sales tax applied to transporting Agriculture Products is retained in the revenue neutral calculation. The total amount of the RUC fees we include in our analysis is $1.45 billion, 1.93 billion, and $2.95 billion for the three RUC scenarios, respectively.

The adoption of the RUC systems will lead to redistribution of the cost among heavy-duty truck classes. For scenario 1, lighter trucks with higher fuel efficiency will be paying more under the new fixed-rate RUC system because they consume less fuel for each mile traveled and thus would pay relatively less per mile for diesel taxes compared to heavier trucks. Under this scenario, Class 8 trucks are estimated to incur decreased cost compared to the baseline condition. From the perspective of different types of commodities transported by heavy commercial trucks, payments would decrease if heavier trucks are more frequently used for the transportation (such as for Gravel / Sand and nonmetallic minerals) and increase if lighter (and thus more fuel efficient) vehicles are used for their transportation (such as Transportation equipment, Manufactured products, Wood, printed products). In Scenario 2, the additional damage-based weight-VMT fees result in proportionally more costs being distributed to heavier trucks compared to Scenario 1. Finally, not surprisingly, Class 8 trucks pay the largest share of the total PM2.5 emission fees in Scenario 3.

The macroeconomic modeling results indicate that because the total amount of transportation charges remains the same in Scenarios 1 and 2 compared to the baseline condition and the only difference between the baseline case and the analyzed RUC scenarios is the changes in distribution of the costs, the economy-wide aggregate impacts in terms of changes in GSP and employment are very small. The GSP impacts range between -$76 million to $218 million and employment impacts range between 528 job losses to 1,477 job gains. Comparing the results of Scenarios 1a and 1b as well as between Scenarios 2a and 2b, a redistribution of transportation cost burden from other sectors to Agriculture sector would result in a positive net impact on the economy, primarily because of the higher multiplier effects of the non-Agriculture sectors, the products of which are more proportionally used for intermediate inputs rather than for final consumptions. However, in such cases, the Agriculture sector will have to shoulder proportionally much higher costs. It is estimated that trucks that deliver agriculture products would pay almost 50% more compared to the baseline condition if the same discount rate is not retained in the new RUC system. Also, if the increased transportation costs are passed onto consumers through an increase in the price of farm products, it will likely affect lower-income family disproportionally because they spend proportionally larger share of their income on food. For Scenario 3, the $1.5 billion emission fees could lead to a $0.85 to $1 billion decrease in GSP and about 3,500 to 4,500 job losses even after we take into consideration the stimulus effects from the spending of the $1.5 billion additional government revenues.

The income distributional analysis indicates that Scenarios 1a and 2a marginally decrease the Gini coefficient, indicating that these scenarios help slightly reduce the income distribution inequality. When the same favorable transportation pricing discount is applied to the transportation of Agriculture Products as in the baseline, changes in income distribution is negligible. The emission fees imposed in Scenario 3 result in a small increase in the Gini coefficient, which indicate that income losses caused by the increased costs are projected to distribute disproportionally more to the lower- and middle-income groups, and thus lead to a slight worsening of income distribution inequality. This is primarily because heavier trucks will pay a large share of the emission fees and many sectors that rely more on these heavier trucks to deliver their products (such as Mining, Metallic and Nonmetallic Mineral Products Manufacturing, and Food Product Manufacturing sectors) hire a higher proportion of workers from lower- or middle-income households.

Finally, given the size of the state economy, the impacts of all the RUC scenarios analyzed in this study are projected to be very small in percentage terms. However, the study provides valuable insights in terms of the tradeoff between economic sectors and the distributional implications among different income groups. The analytical framework and methodology developed in this study can be generalized and applied to the analysis of the economic and distribution impacts of other alternative transportation pricing instruments.

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Data Management Plan

Products of Research

Our research is primarily based on the analysis of the 2018 California Vehicle Inventory and Use Study (CA-VIUS) dataset. We use this dataset to determine VMT of trucks by GVW class and the commodities they transported. The CA-VIUS dataset is comprised of survey responses from drivers of a sample of trucks whose distribution is representative of the makeup defined in California Department of Motor Vehicle records and International Registration Plan clearinghouse for trucks registered in-state and out-of-state, respectively.

To estimate truck unladen weights which enable us to calculate the GVW of trucks, we also collected data from various sources that open to public. These include the Comprehensive Truck Size and Weight Study from the Federal Highway Administration and National Research Council (2010), Department of Energy data on the relationship between Empty Vehicle Weight and Gross Vehicle Weight, and many other manufacturer data. The data on the fuel economy and PM2.5 emission factor of Class 3 – Class 8 trucks are estimated based on data collected from the California Air Resources Board's (CARB's) Emission Factor (EMFAC) 2021 database. Finally, the social cost of PM2.5 emissions is estimated based on the review of the literature.

Data Format and Content

All of the datasets are stored in Excel format.

Data Access and Sharing

The 2018 CA-VIUS dataset is proprietary and confidential data, which cannot be disclosed or shared. The other data, which are publicly available, are either presented in the report or provided links to the sources in the list of references.

Reuse and Redistribution

The 2018 CA-VIUS data cannot be reused or redistributed to the general public. Other data cited or produced in this research have no restrictions on reuse and redistribution.

Appendix

Appendix A. Detailed Review of U.S. and International Literature on RUC

A1. United States Literature

The purpose of this section is to highlight the studies that have been conducted in the U.S. regarding weight-distance road use charges for commercial vehicles. In the U.S., currently only four states have implemented distance-based charges for heavy commercial vehicles: Kentucky, New Mexico, New York, and Oregon. The first part of this section describes the current policies in Oregon for trucks over 26,000 pounds, it's evolution since initially being implemented in the mid-1900s, and the impacts that the policies have had on the trucking sector. The second part of this section describes the voluntary pilot performed by the Eastern Transportation Coalition specifically for commercial vehicles and their findings. Lastly, the section summarizes the voluntary pilot conducted by Caltrans in 2016-2017 with a specific focus on the commercial vehicle aspect and how it impacted operations and revenue. All of these studies are beneficials to review because they shed light on the impacts that heavy vehicle road use charges can have, as well as the perspectives of the trucking industry and administrations that have implemented road use charges.

1. Oregon Commercial Vehicle Road Use Charge System

Oregon has been on the forefront of road use charges for commercial vehicles. First, it established a ton-mile tax in 1925 where all for-hire trucks faced the same tax rate multiplied by their tonnage and miles travelled. Tonnage was determined by the light weight of the vehicle plus the maximum weight of loads to be carried. In 1933, the ton-mile tax was expanded to all private carriers (Economic Services, 1977). However, this did not adequately charge heavier trucks that caused proportionally more damage to the roads, so a weight-mile tax was implemented in 1947 where heavy trucks were split into weight classes and charged per-mile fees based on the weight class. The weights of trucks were determined by the registered gross-weight of the vehicle and mileage was determined either by odometer recordings or verified mapped routes. After 1947, the fees were adjusted from time to time, but largely resembles the system that Oregon still has today for trucks between 26,000 and 80,000 pounds (City Club of Portland, 2000). In 1990, Oregon added a weight-axle tax for commercial vehicles between 80,001 and 105,500 pounds, which account for 16.7% of total estimated VMT by vehicles over 10,000 pounds in 2017 (Kitchen et al., 2021). The weight-axle tax charges overweight trucks different per-mile rates based on how many axles the truck has. Road damage is closely related to axle weight. For any given gross vehicle weight, more axles reduce the force on the road surface. The fee is intended to incentivize use of trucks with more axles. Trucks that pay the weight-mile (or weight-axle-mile) fee are exempt from fuel taxes in Oregon (Oregon Department of Transportation, 2020b). Revenue from the taxes on heavy goods vehicles totaled $297 million in 2014. This revenue goes to the state's highway trust fund and is used to construct and maintain public highways, roads, and roadside rest areas (Dal Pointe and Michie, 2015).

Rufolo et al. (2000) conducted an analysis of the Oregon weight-axle-mile data from 1992-1997. The data does show that in weight groups over 80,000 pounds there was a small increase in the average number of axles per truck. The study estimates an approximate 8.8% reduction in damage per net ton associated with the increase in axles. The authors also conducted structured interviews in the trucking industry to further learn about the decision-making of firms in the industry. The selected 25 firms varied in size and type and were asked to indicate the importance of certain factors (including regulations, fuel costs, fuel taxes, safety, weight-mile taxes, registration fees, commodity hauled, and customer request) in determining the configurations of trucks. For all firms, regulations were the most important aspects for truck configuration and weight-mile taxes were often chosen as one of the least important. Some of the reasons indicated by firms include the weight-axle-mile tax often not providing an incentive to add more axles because of the costs associated with adding axles, as well as the potential of being moved up a weight class.

Rufolo et al. (2000) note that more comprehensive data is needed in order to establish a causal relationship between the tax and additional axles. Since the states surrounding Oregon all have different regulations surrounding weight limitations and the fees that they charge trucks, the authors propose that more data that includes trucking firms from out of state will provide a more holistic picture of the impacts that the weight- axle-mile taxes have on truck configuration and road damage in Oregon.

In the 1990s, Oregon was facing many arguments that the weight-mile tax was administratively too burdensome because of the record keeping required. The Oregon Department of Transportation (ODOT) responded by exploring different electronic tracking systems to automate the tax collection. Dal Ponte and Michie (2015) examine the technology used for the electronic weight-mile tax, the public policy environment, and the response of the industry. ODOT needed to establish a service provider that could track all of the appropriate weight-mile tax requirements. EROAD, the company that provided New Zealand with the technology to implement their electronic weight-mile tax, had approached ODOT in 2011, and was verified as the best partner through a commercial pilot, regulatory pilot, ODOT audit, Oregon Secretary of State Audit, and self-certification.

During the pilots, manually recorded trips and weight-mile taxes were compared to the same trips that were electronically tracked. Vehicles from five different industries (Line-haul, Urban Delivery, Logging, Inter-state, and Heavy Haulage) participated in the pilots. Dal Ponte and Michie (2015) found that the manually recorded data and electronic data were within ±1.0% of each other and the electronic records met the requirement of the tax code. Additionally, trucking firms had positive reactions to the system and technical issues were identified and addressed. Lastly, the pilot fleet suggested that support for in-vehicle configuration and technology changes be provided to ensure a smooth installation and transition period.

2. Eastern Transportation Coalition Pilot

The Eastern Transportation Coalition (ETC) conducted a voluntary pilot for a commercial truck mileage-based user fee (MBUF) from 2018-2019. Participants of this pilot were fleets that are registered with the International Fuel Tax Agreement (IFTA), have their headquarters in a state within the Eastern Transportation Coalition, and travel across state lines. The trucks included in the pilot were Class 7 (26,001 to 33,000 pounds) and Class 8 (33,001 pounds and over). The MBUF was intended to be revenue neutral: total mileage fees should equal total fuel tax revenues. Because each state had a different fuel tax, the pricing structure was designed so that each state had their own per mile fee equivalent to their current state diesel excise tax divided by the average fuel efficiency for trucks. In the pilot, participating fleets would be given a rebate for the difference between what they paid in fuel taxes and the mileage-based user fee during the period of the pilot.

Initially, the average MPG was set at 6 MPG, however given the composition of the pilot fleets, this resulted in fleets that are less fuel efficient paying less and more efficient fleets paying more in MBUF compared to what they pay in fuel tax. The ETC also tried using an average MPG of 4.1 to set the fee. While this corrected for many of the less fuel-efficient vehicles in the pilot paying far below what they were paying in fuel taxes, it still led to the more fuel-efficient vehicles paying far more. Differentiated rates based on fuel efficiency would need to be set in order to holistically address this issue.

Fleets tracked the miles that individual trucks drove in each state by equipping trucks with the EROAD system's on-board unit, Ehubo. This technology is already used for IFTA and the International Registration Plan (IRP) record keeping because of its ability to capture position and route information, which makes it viable for the tracking needed in the MBUF pilot. The participating fleets were sent faux statements at the end of the pilot that included information on the number of participating trucks, average miles per gallon, number of states travelled through, miles travelled in each state, gallons of fuel purchased and the location of purchase, and a summary with estimated costs of fuel, federal fuel tax, state fuel tax, and hypothetical MBUF. When the average MPG is set at 6, the MBUF generated $93,390 revenue across the four fleets, which is $45,220 less than the revenue generated from state fuel taxes. When the average MPG was lowered to 4.1, the MBUF generated $138,420, which was only $190 less than the revenue from state fuel taxes.

The ETC thought it was important to receive input from the trucking sector while building the pilot program. As opposed to MBUF on passenger vehicles, far fewer truck participants were concerned with data privacy. The most important concerns were ensuring compliance, keeping data secure, and keeping the system simple (Jacobs and EROAD, 2020).

3. California Pilot

California has also explored the idea of using road use charges to replace the fuel tax to collect revenue for the transportation system. The California State Transportation Agency (CalSTA) and Caltrans conducted a pilot of road user fees from 2016 to 2017. The goal of the program was to explore the possibility of using a road user charge instead of a fuel tax to maintain a sustainable and equitable source of transportation funding for the state of California. CalSTA also sought to answer questions regarding the feasibility of recording and reporting vehicle miles traveled on the statewide road system, the degree of difficulty of implementing a statewide road charge, how to safeguard personal information, and how the public will accept the road charge as an alternative to the gas tax.

This pilot was funded by the state of California and consisted of 5,000 volunteers. The participating vehicles included passenger vehicles, business fleets, and commercial trucks. The charge covered all public California roads. The per mile rate was set at 1.8 cents, the five-year average of the state gas tax divided by the average miles per gallon of the entire fleet of vehicles in California. Participants were given credits for the fuel taxes they paid during the pilot time frame and multiple technology options (such as an On-Board Diagnostic Unit, a smartphone app, or an in-vehicle telematic system) are used to track their mileage. For heavy and commercial vehicles, the EROAD system was used. Participants could either report their mileage manually online, purchase a time or mileage permit, or pay an odometer charge. In addition to miles travelled data, information was collected about the number of each type of vehicle that participated and their general location in California, the general demographics of participants, and the satisfaction of participants with the pilot program.

Over the course of the pilot program, the gross revenue collected was approximately $600,000. After applying the credits for the fuel taxes paid, the net revenue was $100,000. Caltrans (2017) also estimated the operational costs of the road user charge compared to the gas tax. They found that a road user charge will have a collection cost of 5-10% of revenue compared to 0.54% of revenue for the collection cost of fuel taxes. Other important observations were that participants often overran the time and mileage permits that they purchased. Regarding concerns about privacy, despite being given multiple options that did not use GPS tracking, 62% of pilot participants chose a location-based mileage reporting method.

From the participant surveys, Caltrans (2017) found that 85% of participants were satisfied with the pilot. They also found that the major issues and concerns raised by participants included privacy protection, the disproportionate impacts on rural versus urban drivers, and how to address out of state drivers. Other issues included jurisdictional issues, such as local rate setting, whether or not to charge on toll roads, the applicability of the sales tax, and the availability of data for local planning purposes. Lastly, general concerns about the higher administrative costs were discussed in the report, although it is predicted that costs will decrease over time for an established program.

A2. International Literature

New Zealand and many countries in Europe have had commercial truck road use charges since late 20th century. The purposes of the policies were to reduce truck vehicle miles travelled (VMT) and associated road damages and generate revenue to cover infrastructure costs. Since they were implemented, they have evolved to reduce emissions, promote shifts to alternative modes (rail and water), and generate additional revenue. This section reviews the fee structures, motivations, implementation, evolution, and impacts of these international road use charges for heavy goods vehicles. Additionally, it covers the outcomes of predictive models for some proposed road use charges in various countries.

1. Fee Structures and Evolution

In 1999, the European Union and European Commission implemented a truck tolling policy where trucks could be charged according to their mileage driven, vehicle category, and emission standards. Initially, this was adopted as the Eurovignette, which is a time-based charge where trucks can buy permits for various intervals of time that allows them to travel on a country's roads. Over time, countries in the European Union developed more complex charging systems based on weight, number of axles, emission class, and distance-travelled. Switzerland was the first European country to impose distance-based fees on heavy trucks in 2001. Most EU members have distance-based fees, but some countries have retained the Eurovignette, including the United Kingdom, Sweden, the Netherlands, Denmark, Estonia, Latvia, Romania, and Bulgaria. Similar to European countries, New Zealand's road use charge for heavy goods vehicles considers weight, axles, and distance travelled. Table A1 shows the share of truck fleet, fee structure, and range of fees for the various countries mentioned above.

Each of these fees is tracked in a variety of ways. Nowadays, most commercial vehicles track their mileage through GPS systems and on-board units. New Zealand utilized EROAD technology for commercial vehicles that need to track and submit their RUC payments. In Austria all commercial vehicles that pay the road use fee are required to have an on-board unit that tracks mileage. However, many other countries allow trucks to purchase permits or licenses for any number of kilometers, which are checked periodically by police and have fines associated with them if they are not renewed.

For countries in the EU and Switzerland, the HGV road use fees have evolved since their implementation. The structure of the Switzerland fee has not changed much, the rates have simply been updated as costs have been recalculated. For the EU, various directives after the initial Eurovignette directive in 1999 have slightly changed the rules for tolling systems, such as lowing the weight minimum from 12 tons to 3.5 tons and allowing countries to incorporate external costs, such as pollution, into the rate calculations as opposed to merely infrastructure cost recovery (Gomez and Vassallo, 2020).

Table A1. Major Features of Road Use Charge Systems across Countries: Truck Fleet Covered, Fee Structure, and Roads Covered

Fee	Heavy Goods Vehicles (HGV) Covered	Pricing Structure	Fee Range	Roads Covered
Eurovignette	Commercial vehicles over 3.5 tons	Licenses purchased per day, week, month, or year Rates determined by each country	Varies by each country	Highways and major secondary roads
German HGV Toll	Commercial vehicles over 7.5 tons	Number of axles, emissions class, and distance	€0.079 to €0.26 per kilometer ($0.14-$0.47 per mile)	Highways and major secondary roads
Austrian GO Toll	Commercial vehicles over 3.5 tons	Number of axles, emissions class, time of day (day vs. night), and distance	€0.05010 to €0.48482 per kilometer ($0.0911 - $0.88167 per mile)	Motorways and expressways
Swiss Heavy Vehicle Charge	Commercial vehicles over 3.5 tons	Based on distance travelled, the weight of the truck/trailer, and the emission class of the vehicle Measured in cents per ton-km	CHF 0.0228 to CHF 0.0310 per ton-km ($0.0399 - $0.0544 per ton-mile)	All roads in Switzerland
New Zealand RUC	Non-gas commercial vehicles over 3.5 tons	Weight, axles, and distance	NZ $0.076 to NZ $0.346 per kilometer ($0.081 - $0.368 per mile)	All roads in New Zealand

Sources: (AGES, 2021; ASFiNAG, 2022; FOCBS, 2022; New Zealand Transport Agency, 2021)

In New Zealand, the first road use charge was implemented through legislation in 1977. Since then, the fee structure has gone through one major change in 2011. Other than the structural change, updates to the rate are determined and proposed by the Ministry of Transportation and set by Order in Council (Ministry of Transport, 2018). Until 2012, most diesel vehicles had paid the same fees except for heavy vehicles, whose rates largely depended on weight and number of tires/axles. In the new system, which was passed with the Road User Charges Act 2012, various changes were made to the system in hopes of modernizing and simplifying the RUC system. These changes included: creating fixed 'RUC weights' to set fee rates based on maximum permissible gross laden vehicle weight; simplifying the list of vehicles exempt from RUCs based on vehicle design, rather than vehicle use; introducing a combined approval process for electronic RUC system providers as opposed to the previous multi-level authorization process; and implementing more stringent penalties to improve the compliance process (Carter et al., 2013). After the changes implemented by the Road User Charges Act 2012, the rates have been updated according to a cost allocation model set by the Ministry of Transport. In 2018, RUC rate increases were agreed on by the Ministry of Transport in order to increase transportation revenue to meet the budget that was set by the New Zealand government (Ministry of Transport, 2018). This led to most commercial vehicles seeing their rates increase between 5-7%, though some remained unchanged, such as towing vehicles with a combined total of at least eight axles (Ministry of Transport, 2018).

2. Motivation and Implementation

There are various motivations for implementing heavy goods vehicle road use fees. In the European Union, the main initial goal of heavy goods weight-distance fees was to recover the construction, operation, and maintenance costs of infrastructure (Broaddus and Gertz, 2008). In Switzerland, the goal of heavy goods vehicle charges was to decrease the volume of trucks travelling through the country (Broaddus and Gertz, 2008). For New Zealand, the initial motivation was to recover the costs of damages from road wear caused by heavy-duty vehicles. As the programs evolved, so did the goals of the programs. In Germany, in addition to connecting road use with the impact that vehicles have on roads, secondary goals of the RUC system include generating additional funds for alternative transportation infrastructure, incentivizing the shift from road freight to rail and waterways, encouraging the deployment of more efficient heavy goods vehicles, and promoting innovative tolling technologies (Robinson, 2008). Switzerland wanted to internalize the external costs of truck traffic, such as noise pollution, air pollution, healthcare, accidents, and damage to buildings, and also encourage a shift from road to rail transport (Broaddus and Gertz, 2008; Suter and Walter, 2001). Eventually, the European Union also allowed pollution costs to be considered in the rate setting process for countries that use the Eurovignette.

In all countries that have implemented road use charges for heavy commercial vehicles, the charges are administered by the transportation departments. In Switzerland, the heavy goods vehicles (HGV) fee was adopted as a constitutional amendment and law that was approved by the people of Switzerland through referendums with minimal stakeholder resistance (Suter and Walter, 2001). In 1994, the country voted on the target number of trucks that should be crossing the Swiss Alps, which prompted the exploration of policies to limit the number of trucks. Additionally, the user/polluter pays principle was well accepted in Switzerland by the public and the heavy vehicle fee would generate a significant part of the funding for the New Alpine Rail Tunnels. Lastly, the heavy vehicle fee increased the weight limit in Switzerland with little environmental impact, which was a beneficial situation for both the transport industry and citizens. During the public debates before the referendum on the heavy vehicle goods, Suter and Walter (2001) state, most interestingly, that many of the public comments surrounded fairness and cost recovery as opposed to efficiency.

The Eurovignette and other truck tolling policy rules were first outlined in directives set forth by the EU and the European Commission (EC) in 1999 (Gomez and Vassallo, 2020). After the directive was outlined, various countries began to adopt the Eurovignette of other truck tolling systems through their own governments. In Germany, various commissions were formed to address the growing HGV use of federal highways as a throughway to other countries in the EU. Eventually, Germany created an independent financing company for road infrastructure that would work with a private toll company, Toll Collect, to implement the HGV fee under the supervision of the federal government (Broaddus and Gertz, 2008). Similar to Switzerland, the HGV charge was passed through the legislative with little stakeholder pushback because citizens thought that there was too much truck traffic on highways and the trucking industry wanted foreign trucks to pay their fair share for the damage and space they take up on the roads (Broaddus and Gertz, 2008).

3. Impacts of the RUC Systems

Distance Traveled

As discussed in the previous section, the main goals of the implementation of the distance-based fees were to decrease distance traveled, reduce emissions, raise revenue, and in some cases, encourage a modal shift to other forms of freight transportation. Various studies have sought to answer how well these fee policies achieved their goals, as well as identifying secondary impacts on issues such as route choice and economic indicators like employment and gross domestic product (GDP). In Switzerland, truck traffic rapidly decreased. After being implemented in 2001, vehicle trips through the Alps had decreased by 8% by 2003 and the trips were made by heavier and larger vehicles (Broaddus and Gertz, 2008). In Germany, there is also evidence that the tolls achieved their goals of reducing vehicle-miles traveled as well as emissions. After the toll was implemented in Germany, the number of empty trips run by trucks fell by 20%, from 24.7% of trips in 2000 to 19.7% of trips in 2006, one year after the toll was implemented (BAG, 2006). Additionally, the proportion of cleaner trucks increased from 50% to 64% primarily because of the higher toll rate for older and more polluted trucks (Robinson, 2008). Lastly, after adopting the Eurovignette in Slovakia, their volume of road freight decreased by 560 million ton-km (Gomez and Vassallo, 2020).[5]

Revenue Generation

Revenue generation has also been largely successful for commercial vehicle road use charges. After the changes implemented for the New Zealand RUC in 2011[6], initial data showed that the new system raised 2.7% more revenue than the old system (Carter et al., 2013). This increase in revenue may have occurred because fees for vehicles that operate at a weight significantly lower than their max weight have increased, while those that operate frequently at their max weight have seen their rates decrease. It also may have occurred because there was a large decrease in RUC evasion. Based on the NZ Police Heavy Vehicle Compliance Measurement Operation, it is estimated that weight and distance-based evasion has dropped from 4% to 1.2% in a year (Carter et al., 2013). In Germany, toll revenue exceeded the expectation of €3 billion after the first year of operation and grew to €3.4 billion by 2007 (Robinson, 2008).

Modal Shift

Road use charges have been relatively unsuccessful in achieving their goals of inspiring a modal shift in Europe. Although some data suggests that Germany has seen an increase in rail freight since the introduction of its heavy goods vehicle charge (Robinson, 2008), most studies indicate that tolling fees in Europe have had very little impact on a modal shift to rail (Gomez and Vassallo, 2020; Broaddus and Gertz, 2008; Suter and Walter, 2001). Several reasons indicate why there is no or very limited modal shift. First, many studies have found that road freight is a fairly inelastic sector and road pricing does not induce large changes in the volume of goods transported by road freight (Gomez and Vassallo, 2020). Additionally, the growth in foreign trade in both Austria and the Czech Republic after the implementation of HGV fees was shown to have offset 100% of the reduction in international road

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[5] The study did not further analyze the causes of the volume reductions. This can be the combined effect of efficiency gains and diversion of traffic to somewhere else. For example, as further explained in the "Route Choice" sub-section, initially traffic was diverted from highways to major secondary roads. However, this did not persist once tolls were implemented on those roads as well (McKinnon, 2006; Broaddus and Gertz, 2008)

[6] The changes to the RUC system in New Zealand that were implemented in 2011 included: changes to the definitions of license weight; reforms to the time license system; revisions of the list of exempt vehicles; implementation of a regulatory system for electronic management systems; and improvements to the compliance process (Carter et al., 2013).

freight traffic from the charging policy (Gomez and Vassallo, 2020). However, a lack of rail infrastructure or high rail transport costs can also deter companies from shifting their freight transport to rail. Specifically for the Swiss case, in conjunction with implementing the heavy goods charge the weight limit on trucks was raised from 28 tons to 40 tons (Gomez and Vassallo, 2020). This made road freight cost-effective even with the new tolls. However, impacts on mode shifts towards rail may appear as revenue from the HGV charges in Europe are used to build rail infrastructure, as is happening in Germany and Switzerland.[7] In New Zealand, there has been some evidence of a modal shift from road freight to rail and coastal freight. After the changes to the RUC were implemented in 2011, a number of commercial operators indicated in interviews and surveys that they maximized the amount of rail and coastal services they utilized in order to minimize road use and avoid the increased charges (Carter et al., 2013).

Route Choice

While the commercial vehicle road use charges have met some of their goals, there are a multitude of other impacts that need to be considered, including the impact on route choice. In Germany, approximately 5% of truck traffic diverted from highways to secondary roads after the initial implementation of the tolling system (McKinnon, 2006). This was mitigated shortly afterwards by applying the HGV fee to major secondary roads as well as federal highways (Broaddus and Gertz, 2008). In Austria, there were reports of up to a 60% increase in truck traffic on secondary roads after the toll was implemented (McKinnon, 2006). These impacts indicate the importance of the extent of the road system covered by the HGV fee, because only applying the fee to federal highways leaves space for trucks to avoid tolls. While studies have found that commercial vehicles are less responsive to pricing than passenger vehicles, it has been found that smaller companies will take more action to avoid tolls (Axsen and Wolinetz, 2021).

Costs on Trucking Industry

Cost changes for the trucking industry are important impacts of road use charges. In Germany, the trucking industry has borne higher costs because of the toll. Research has estimated an annual increase of €1,116 per truck for the trucking industry since the toll was implemented (Broaddus and Gertz, 2008). In New Zealand, compliance costs were relatively unchanged after the new system was implemented in 2012. In this instance, unchanged costs were a bit of a disappointment because there was an expectation throughout the commercial industry that the new system would bring about time and money savings with regard to RUC compliance. Large operators still spend between 20-40 hours per week administering the RUC and smaller operators still spend around 1-8 hours per week (Carter et al., 2013).

Economic Impacts and Cost Pass-Through

Another main consideration for all taxes or fees is the impacts that they have on economic factors. Various studies agree that tolling heavy vehicles does not create a significant ripple effect in the economy, which supports the previous statement that freight business is fairly price inelastic and thus largely absorbs the impact of higher cost (Axsen and Wolinetz, 2021). Although it is often predicted that HGV fees will be passed onto customers through price increases to some extent, a few studies indicated that there is no evidence of cost pass-through (Robinson, 2008; Carter et al., 2013). However, after the

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[7] Although many European countries adopted a railway gauge system originally designed by the British, different gauges exist for various reasons such as adaptations to specific topographies (de Kemmeter, 2022). The differences in the gauge systems across countries, especially between lines of the main railway networks, present another difficulty of modal shift from truck transportation to rail transportation for international trade within Europe.

HGV fee was implemented in Germany, one study (using an input-output model) indicated that the transport industry faced a price increase of 5% which then led to a price increase in the entire German economy of 0.11% (Kvieborg, 2005). Despite the overall price increases, this same study showed that the HGV toll generated 45,000 jobs as revenue from the fee is recycled back into the economy (Kvieborg, 2005).

4. Scenario Simulation Modelling

An important subset of international literature that is crucial for our study are the papers that predict the impacts of various tolling scenarios that have not been implemented. The authors of these studies use various types of modelling tools and fee structures to predict the economic impacts for a variety of countries in Europe. A study regarding Denmark used a spatial computable general equilibrium (CGE) model, called LINE, to analyze the impact from various scenarios of distance-based fees (Kveiborg, 2005). The first scenario explored is where only Germany, Austria, the UK, and Switzerland have distance-based fees and the Netherlands and Scandinavia (including Denmark) have the Eurovignette. In the second scenario, all of the countries mentioned above would have a distance-based heavy vehicle fee. In both scenarios, revenues from the fees are recycled into the economy through lowering income taxes. In this LINE model, transport prices are calculated exogenously to the regional economic model and include details like variations in road type and spatial differentiation. The results from this model show that the increased prices of imported goods used for production impact the Danish economy through raised prices of goods for both domestic consumption and exports. In this model, transport cost increases by 6-14%, the overall economic price increase is 0.05-0.21%, disposable income changes by -0.04% to 0.19%, and employment decreases by 1,821 to 2,723 jobs, depending on the scenario (Kvieboeg, 2005). It is interesting to note that disposable income increases in scenario two because the revenue generated from the commercial vehicle road use tax in Denmark is used to lower income taxes. These impacts vary greatly based on the region of Denmark. The central and capital regions are less impacted because they have more service industries as opposed to manufacturing industry, which are much more prevalent in regions outside of the capital. The manufacturing sectors are more affected compared to service sectors because the production cost of the former is more sensitive to the increased prices of imported goods that are used as intermediate production inputs.

Another study focuses on Norway and uses a spatial CGE model called PINGO that describes the flow of trade between regions in Norway (Kveiborg, 2005). It is also connected to NEMO, a network model. This model accounts for pollution, infrastructure deterioration, noise, accidents, and congestion when evaluating road pricing strategies using a welfare function. The author notes that the most surprising result from this model was that the effect on consumer surplus was negative, despite revenue recycling. They theorize that this is because revenue is recycled as a lump sum opposed to the removal or lowering of distortionary taxes, as was the case with previously examined models. They also note that revenue is much higher for Norway than in Denmark, but this is because both heavy vehicles and passenger vehicles are taxed in the proposed Norwegian system. Lastly, the study indicates that there is no significant difference between the economic impacts of a pricing scenario and a do-nothing scenario, potentially because Norway already imposes some transport taxes.

A paper by Doll et al. (2017) used ASTRA-EC, a European system dynamics model to evaluate the effects of tolls in various Spanish and German provinces. The ASTRA-EC model used in this study has nine modules that represent transportation, energy, emission, trade, and economic features of the EU countries, with more geographical details of Spain and Germany. For this specific paper, three scenarios were compared in the model: current toll rate, no toll rate, and high toll rate. The study reported that in Germany, for the high toll scenario compared to the current scenario, road ton-kilometers would decrease by 1.13% by 2030. Additionally, they note that rail ton-kilometers would increase by 3.35% by

2030. Lastly, overall domestic ton-kilometers would increase by 0.29% and cross-border and total (domestic plus cross-border) ton-kilometers would decrease by 0.32% and 0.07%, respectively. One region in Spain shows very similar results to the German model predictions by 2030, with the exception that overall domestic ton-kilometers would also decrease in predicted years. For another region in Spain, overall ton-kilometers for domestic, cross-border, and total are all expected to increase by 0.32% by 2030.

Lastly, a recent study was conducted in the Netherlands to determine the impacts of various distance-based road use charge scenarios proposed by the Dutch government. de Bok et al. (2021) utilized multiple models, including BasGoed, elasticity, and the National Transport Model to make their predictions. While they examined various charging scenarios that covered different extents of the road system in the Netherlands, the following results are from the scenario where the entire road system is covered under the charge. They found that the charge would lead to a reduction of 0.2% - 2.1% tons lifted by road transport, depending on the level of the charge. Total vehicle kilometers varied between a 1.2% decrease with the €0.05 charge and an 11.6% decrease with the €0.29 charge. The ton-kilometers would decrease by 0.6% - 4.8% because the increase in transport costs will decrease average transport distance. Impacts on demand were also visible in this analysis. The increase in transport costs showed that both the total volume of road transport and average distance of road transport decreased, creating more concentrated freight flows. This indicates that consumers were choosing to purchase goods that are located closer when the commercial truck fees were introduced. This model also predicts a mode shift towards more inland waterways freight transport in the Netherlands when road use charges are introduced for heavy goods vehicles.

A summary table of these studies are presented in Table A2.

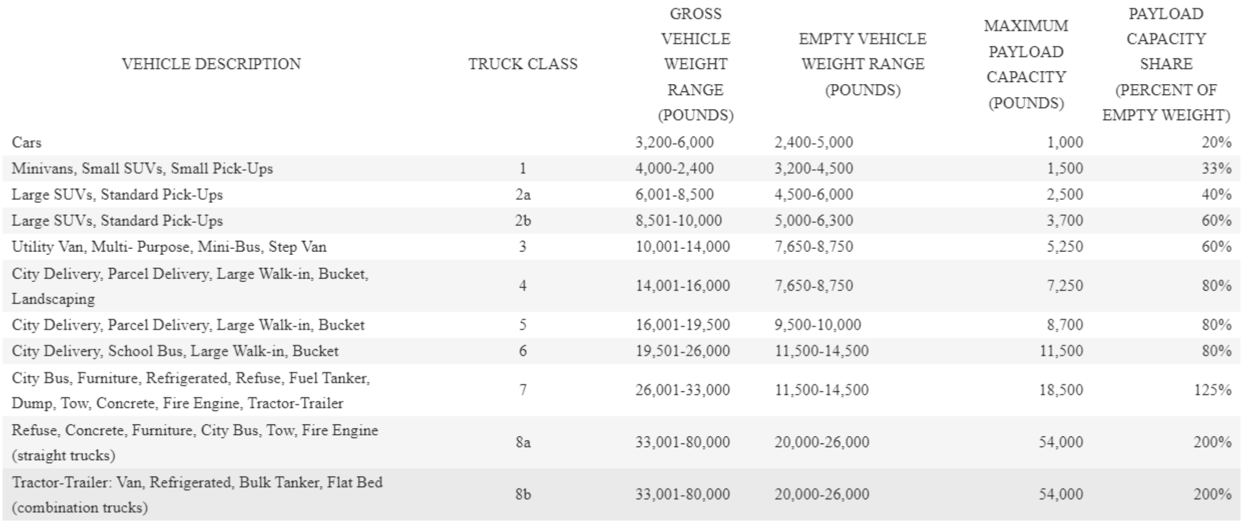
Table A2. Summary of Studies on RUC Scenario Simulation Modelling

Study	Country	Model	Scenarios	Findings
De Bok et al., 2021	Netherlands	Model: BasGoed (simulate impacts on freight transport demand and mode choice) and National Transport Model "LMS" (simulate route choice) Tool: Elasticity (predict the impact of increased transport costs on logistic efficiency)	Scenario 1: Total road network at 3 rate levels: €0.29, €0.15, and €0.05 Scenario 2: Highway network at 3 rate levels Scenario 3: Highway Network + major secondary roads at €0.15 Actual policy, when implemented, may vary by EU Emission Class rating or weight class	- 0.2-2.1% decrease in tons carried by road transport - Total km travelled by road decreased by 1.2-11.6% - Predicted modal shift to inland waterways - Model predicts changes in consumer demand, with consumers purchasing goods created closer
Kveiborg, 2005	Germany, Denmark, Norway	LINE (spatial computable general equilibrium)	Scenario 1: Germany, Austria, UK, & Switzerland -- per km fee; Netherlands & Scandinavia -- reduced form Eurovignette (time based) Scenario 2: All countries have a per km fee Fees from both scenarios are recycled through lowering income taxes	- Transport costs increase by 6-14% - Goods prices increase by 0.05-0.21% - Disposable income changes by -0.04% to 0.19% - Employment decreases by 1,821 to 2,723 jobs - Impacts vary by region, with those that are predominantly service industries less affected

Study	Country	Model	Scenarios	Findings
Doll et al., 2017	Spain and Germany	ASTRA-EC, a European system dynamics model, and stakeholder interviews to evaluate effects of tolls in various Spanish and German provinces	Germany - See other reports specific to Germany's HGV tolls Spain - Currently, HGVs with 1 or 2 axles pay €0.1659/km and HGVs with more than two axles pay €0.2035/km Proposed Scenarios for Model: No toll, current toll, higher toll rate	Germany: High toll scenario would cause a 1.13% decrease in ton-km travelled Rail ton-km would increase by 3.35% Spain: Some regions saw very similar results to Germany while others showed increases in road ton-km despite the fee

Appendix B. Detailed Calculations for Numerical to Alphabetical Weight Class Conversion

Figure B-1: Department of Energy Gross Vehicle Weight vs. Empty Weight Table



VEHICLE DESCRIPTION	TRUCK CLASS	GROSS VEHICLE WEIGHT RANGE (POUNDS)	EMPTY VEHICLE WEIGHT RANGE (POUNDS)	MAXIMUM PAYLOAD CAPACITY (POUNDS)	PAYLOAD CAPACITY SHARE (PERCENT OF EMPTY WEIGHT)
Cars		3,200-6,000	2,400-5,000	1,000	20%
Minivans, Small SUVs, Small Pick-Ups	1	4,000-2,400	3,200-4,500	1,500	33%
Large SUVs, Standard Pick-Ups	2a	6,001-8,500	4,500-6,000	2,500	40%
Large SUVs, Standard Pick-Ups	2b	8,501-10,000	5,000-6,300	3,700	60%
Utility Van, Multi- Purpose, Mini-Bus, Step Van	3	10,001-14,000	7,650-8,750	5,250	60%
City Delivery, Parcel Delivery, Large Walk-in, Bucket, Landscaping	4	14,001-16,000	7,650-8,750	7,250	80%
City Delivery, Parcel Delivery, Large Walk-in, Bucket	5	16,001-19,500	9,500-10,000	8,700	80%
City Delivery, School Bus, Large Walk-in, Bucket	6	19,501-26,000	11,500-14,500	11,500	80%
City Bus, Furniture, Refrigerated, Refuse, Fuel Tanker, Dump, Tow, Concrete, Fire Engine, Tractor-Trailer	7	26,001-33,000	11,500-14,500	18,500	125%
Refuse, Concrete, Furniture, City Bus, Tow, Fire Engine (straight trucks)	8a	33,001-80,000	20,000-26,000	54,000	200%
Tractor-Trailer: Van, Refrigerated, Bulk Tanker, Flat Bed (combination trucks)	8b	33,001-80,000	20,000-26,000	54,000	200%

Table used to be available following this link:
https://www.energy.gov/eere/vehicles/fact-621-may-3-2010-gross-vehicle-weight-vs-empty-vehicle-weight__;!!LIr3w8kk_Xxm!ryyhFaagWRXK7EyXVVPYdx2V2jNN5DN1bU1i_qvEPxnE4qaA7PNAir9vGFXjy4ZBpiCr6QOWZ6Yu$

Table B-1: Straight Truck Class Splits

Alphabetic Class	GVW Numeric Class	Portion GVW range in alpha range	Number of Trucks	Portion of Numeric Class in Alpha Class (percentage used to generate cutoff)
A (10,000 – 15,000)	3 (10,000 – 14,000)	(14,000 – 10,000) / (15,000 – 10,000) = **0.8002**	0.8002*79,242 = **63,409**	1
Total Class 3			**63,409**	
A (10,000 – 15,000)	4(a) (14,001 – 15,000)	(15,000 – 14,001) / (15,000 – 10,000) = **0.1998**	0.1998*79,242 = **15,833**	15,833/26,365 = 0.6005
B (15,001 – 20,000)	4(b) (15,001 – 16,000)	(16,000 – 15,001) / (20,000 – 15,001) = **0.1998**	0.1998*52,704 = **10,532**	10,532/26,365 = 0.3995
Total Class 4			**26,365**	
B (15,001 – 20,000)	5 (16,001 – 19,500)	0.7003	36,911	1
Total Class 5			**36,911**	
B (15,001 – 20,000)	6(b) (19,501 – 20,000)	0.0998	5,261	0.0723
C (20,001 – 26,000)	6(c) (20,001 – 26,000)	1	67,485	0.9277
Total Class 6			**72,746**	
D (26,001 – 30,000)	7(d) (26,001 – 30,000)	1	5,603	0.4162
E (30,001 – 35,000)	7(e) (30,001 – 33,000)	0.6001	7,859	0.5838
Total Class 7			**13,462**	
E (30,001 – 35,000)	8(e) (33,001 – 35,000)	0.3999	5,236	0.0980
F (35,001 – 40,000)	8(f)	1	2,349	0.0440
G (40,001 – 45,000)	8(g)	1	1,731	0.0324
H (45,001 – 50,000)	8(h)	1	2,773	0.0519
I (50,001 – 55,000)	8(i)	1	10,617	0.1987
J (55,001 – 60,000)	8(j)	1	5,770	0.1080
K (60,001 – 65,000)	8(k)	1	2,910	0.0545
L (65,001 – 70,000)	8(l)	1	3,745	0.0701
M (70,001 – 75,000)	8(m)	1	243	0.0045
N (75,001 – 80,000)	8(n)	1	18,060	0.3380
Total Class 8			**53,434**	

Table B-2: Tractor Trailer Truck Class Splits

Alphabetic Class	GVW Numeric Class	Portion GVW range in alpha range	Number of Trucks	Portion of Numeric Class in Alpha Class (percentage used to generate cutoff)
A (10,000 – 15,000)	3 (10,000 – 14,000)	(14,000 – 10,000) / (15,000 – 10,000) = **0.8002**	0.8002*24,261 = **19,414**	1
Total Class 3			**19,414**	
A (10,000 – 15,000)	4(a) (14,001 – 15,000)	(15,000 – 14,001) / (15,000 – 10,000) = **0.1998**	0.1998*24,261 = **4,847**	4,847/9,274 = 0.5226
B (15,001 – 20,000)	4(b) (15,001 – 16,000)	(16,000 – 15,001) / (20,000 – 15,001) = **0.1998**	0.1998*22,151 = **4,427**	4,427/9,274 = 0.4774
Total Class 4			**9,274**	
B (15,001 – 20,000)	5 (16,001 – 19,500)	0.7003	15,513	1
Total Class 5			**15,513**	
B (15,001 – 20,000)	6(b) (19,501 – 20,000)	0.0998	2,211	0.0546
C (20,001 – 26,000)	6(c) (20,001 – 26,000)	1	38,297	0.9454
Total Class 6			**40,508**	
D (26,001 – 30,000)	7(d) (26,001 – 30,000)	1	5,456	0.5094
E (30,001 – 35,000)	7(e) (30,001 – 33,000)	0.6001	5,255	0.4906
Total Class 7			**10,711**	
E (30,001 – 35,000)	8(e) (33,001 – 35,000)	0.3999	3,502	0.0167
F (35,001 – 40,000)	8(f)	1	2,944	0.0141
G (40,001 – 45,000)	8(g)	1	1,682	0.0080
H (45,001 – 50,000)	8(h)	1	2,262	0.0108
I (50,001 – 55,000)	8(i)	1	9,134	0.0437
J (55,001 – 60,000)	8(j)	1	4,605	0.0220
K (60,001 – 65,000)	8(k)	1	3,996	0.0191
L (65,001 – 70,000)	8(l)	1	4,871	0.0233
M (70,001 – 75,000)	8(m)	1	385	0.0018
N (75,001 – 80,000)	8(n)	1	175,857	0.8405
Total Class 8			**209,238**	

Appendix C. Description of the REMI PI+ Model

REMI PI$^+$ is a structural economic forecasting and policy analysis model. It integrates input-output, computable general equilibrium, econometric and economic geography methodologies. The model is dynamic, with forecasts and simulations generated on an annual basis and behavioral responses to wage, price, and other economic factors.

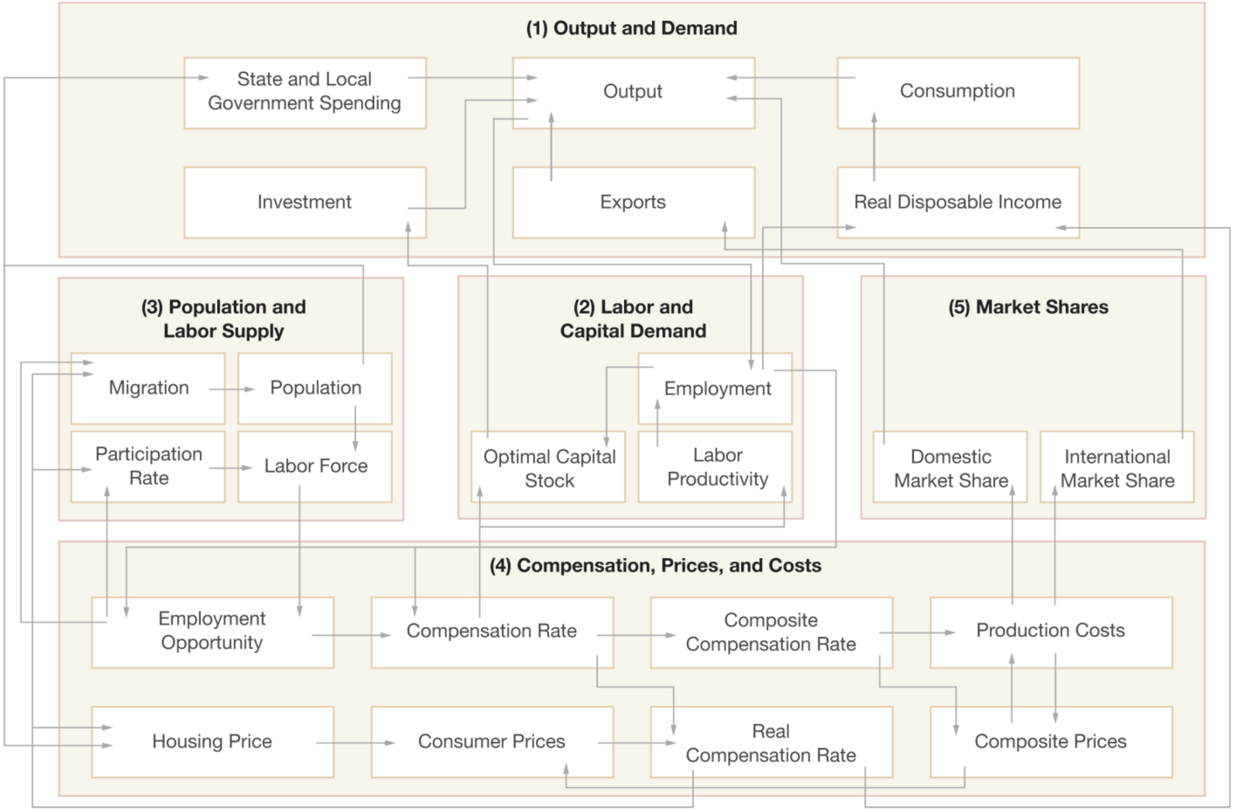
The REMI model consists of thousands of simultaneous equations with a structure that is relatively straightforward. The exact number of equations used varies depending on the extent of industry, demographic, demand, and other detail in the model. The overall structure of the model can be summarized in five major blocks: (1) Output and Demand, (2) Labor and Capital Demand, (3) Population and Labor Supply, (4) Compensation, Prices, and Costs, and (5) Market Shares. The blocks and their key interactions are shown in Figures C1 and C2.

The Output and Demand block includes output, demand, consumption, investment, government spending, import, product access, and export concepts. Output for each industry is determined by industry demand in a given region and its trade with the US market, and international imports and exports. For each industry, demand is determined by the amount of output, consumption, investment, and capital demand on that industry. Consumption depends on real disposable income per capita, relative prices, differential income elasticities and population. Input productivity depends on access to inputs because the larger the choice set of inputs, the more likely that the input with the specific characteristics required for the job will be formed. In the capital stock adjustment process, investment occurs to fill the difference between optimal and actual capital stock for residential, non-residential, and equipment investment. Government spending changes are determined by changes in the population.

The Labor and Capital Demand block includes the determination of labor productivity, labor intensity and the optimal capital stocks. Industry-specific labor productivity depends on the availability of workers with differentiated skills for the occupations used in each industry. The occupational labor supply and commuting costs determine firms’ access to a specialized labor force.

Labor intensity is determined by the cost of labor relative to the other factor inputs, capital and fuel. Demand for capital is driven by the optimal capital stock equation for both non-residential capital and equipment. Optimal capital stock for each industry depends on the relative cost of labor and capital, and the employment weighted by capital use for each industry. Employment in private industries is determined by the value added and employment per unit of value added in each industry.

The Population and Labor Supply block includes detailed demographic information about the region. Population data is given for age and gender, with birth and survival rates for each group. The size and labor force participation rate of each group determines the labor supply. These participation rates respond to changes in employment relative to the potential labor force and to changes in the real after tax compensation rate. Migration includes retirement, military, international and economic migration. Economic migration is determined by the relative real after tax compensation rate, relative employment opportunity and consumer access to variety.



Source: REMI (2018).

Figure C1. REMI Model Linkages (Excluding Economic Geography Linkages)

The Compensation, Prices, and Costs block includes delivered prices, production costs, equipment cost, the consumption deflator, consumer prices, the price of housing, and the wage equation. Economic geography concepts account for the productivity and price effects of access to specialized labor, goods and services.

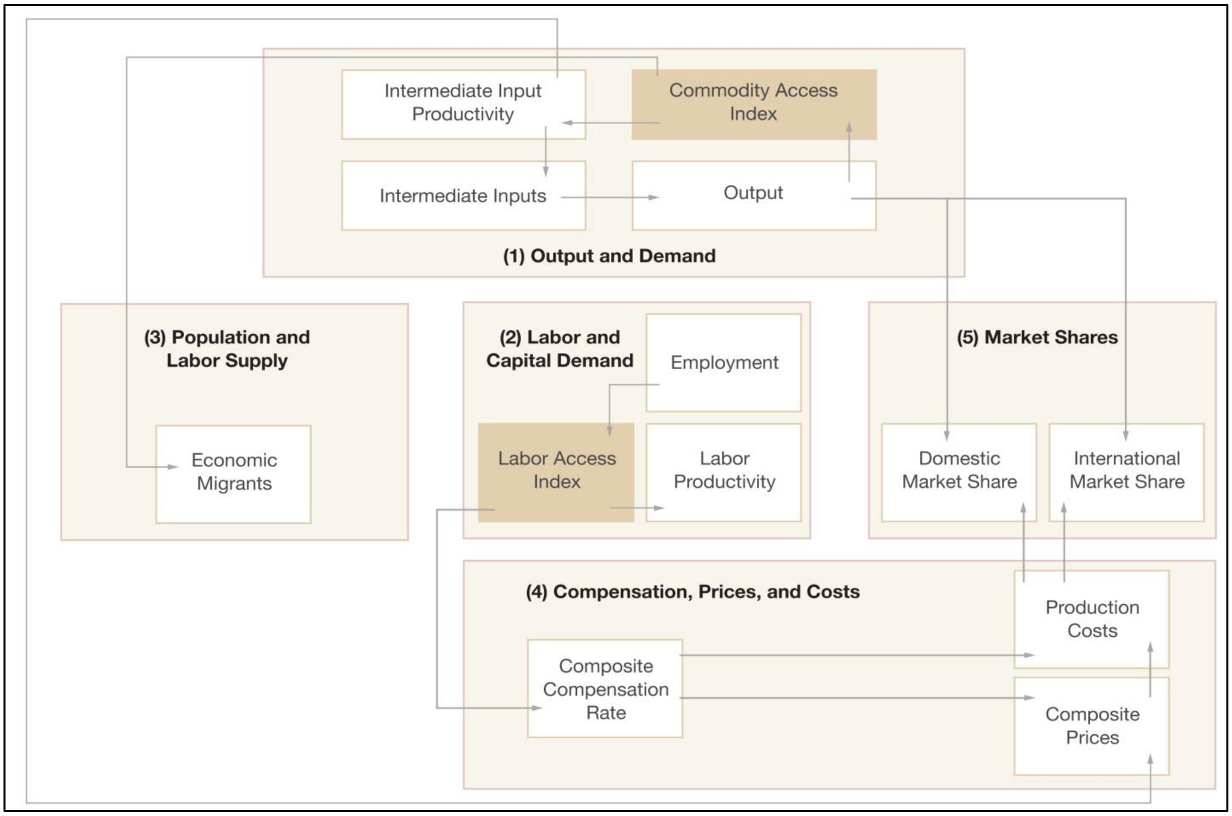
These prices measure the value of the industry output, taking into account the access to production locations. This access is important due to the specialization of production that takes place within each industry, and because transportation and transaction costs associated with distance are significant. Composite prices for each industry are then calculated based on the production costs of supplying regions, the effective distance to these regions, and the index of access to the variety of output in the industry relative to the access by other uses of the product.

The cost of production for each industry is determined by cost of labor, capital, fuel and intermediate inputs. Labor costs reflect a productivity adjustment to account for access to specialized labor, as well as underlying compensation rates. Capital costs include costs of non-residential structures and equipment, while fuel costs incorporate electricity, natural gas and residual fuels.

The consumption deflator converts industry prices to prices for consumption commodities. For potential migrants, the consumer price is additionally calculated to include housing prices. Housing price changes from their initial level depend on changes in income and population density. Regional employee compensation changes are due to changes in labor demand and supply conditions, and changes in the national compensation rate. Changes in employment opportunities relative to the labor force and occupational demand change determine compensation rates by industry.

The Market Shares equations measure the proportion of local and export markets that are captured by each industry. These depend on relative production costs, the estimated price elasticity of demand, and effective distance between the home region and each of the other regions. The change in share of a specific area in any region depends on changes in its delivered price and the quantity it produces compared with the same factors for competitors in that market. The share of local and external markets then drives the exports from and imports to the home economy.

As shown in Figure C2, the Labor and Capital Demand block includes labor intensity and productivity, as well as demand for labor and capital. Labor force participation rate and migration equations are in the Population and Labor Supply block. The Compensation, Prices, and Costs block includes composite prices, determinants of production costs, the consumption price deflator, housing prices, and the wage equations. The proportion of local, interregional and international markets captured by each region is included in the Market Shares block.



Source: REMI (2021).

Figure C2. Economic Geography Linkages