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Transportation Taxes and Energy Transitions: Alternative Policy Designs for Funding US Road Infrastructure and Pricing Externalities

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Abstract

Federal and state tax policies designed to fund the construction and maintenance of transportation infrastructure rely almost exclusively on excise taxes levied on petroleum products. But as the United States and the world seek to reduce greenhouse gas emissions, boosting fuel economy and electric vehicle (EV) sales will reduce the demand for petroleum and associated public revenues. In this analysis, we use an economic model of the US household vehicle market to estimate the effects of three alternative revenue policies: one that adjusts tax rates for internal combustion engine (ICE) vehicles and adds a new per-mile fee for EVs to maintain the performance of US roadways, a second that levies a per-mile fee on all vehicles in lieu of the gasoline tax, and a third that charges all motorists for the external costs of driving, including greenhouse gas emissions, "local" air pollution, traffic accidents, and congestion. We also examine the effects of extending fuel economy standards beyond their current levels. We find that current tax policies are insufficient by tens of billions of dollars per year to fund roadways and that either higher taxes on gasoline or a per-mile fee of $0.03 levied on all passenger vehicles could achieve the target revenue. Tightening fuel economy standards lowers the cost of operating ICE vehicles and reduces tax revenues. Imposing a per-mile fee on EV owners has virtually no effect on EV adoption because of interactions with other policies but does slightly reduce EV miles driven. We produce an updated estimate of the external costs of driving, averaging $0.16 per mile for gasoline vehicles ($3.85 per gallon) and $0.06 per mile for EVs, with large differences between urban and rural counties. Applying fees at this rate dramatically accelerates EV adoption, increases driving costs (especially for ICE vehicles), slightly reduces overall driving, and raises tax revenues well beyond the level needed to maintain roadway performance.

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1. Overview

Funding the construction and maintenance of US transportation infrastructure has historically relied almost exclusively on excise taxes levied on petroleum products. Adjusting for inflation, revenues from these taxes have been declining for years, as tax rates have not kept pace with inflation and improving vehicle fuel economy has reduced per capita gasoline consumption. In the coming years, the revenue shortfall will only become worse as technological advances and public policies continue to improve fuel efficiency and electrification of the US passenger vehicle fleet. Declining fuel consumption will reduce tax revenues, and changes in policies or new funding sources need to be explored.

The Highway Trust Fund (HTF), established in 1956, is the main source of funding for both federal interstate highways and many state projects—everything from new highways and expansions to maintenance and repair of bridges and roads. The major sources of revenue for the HTF have been federal taxes on gasoline and diesel fuel, and historically revenues have grown along with fuel sales. Periodically, state tax rates on these fuels have increased to fund the growth in infrastructure expenditures (Bickley 2012).

Federal tax rates on gasoline and diesel, however, have not changed for the last 30 years, remaining at 18.3 and 24.4 cents per gallon, respectively. Since about 2005, gasoline and diesel fuel sales have remained roughly flat or declined moderately (EIA 2022b) as a result of stricter regulations for vehicle fuel economy, slower growth in vehicle miles traveled (VMT), and increasing sales of electric vehicles (EVs). The result has been a widening gap between receipts and spending needs.

In 2021, outlays from the HTF exceeded revenues by $14 billion (Kile 2021), and the federal government has transferred more than $200 billion from general revenues into the HTF to maintain its solvency from 2008 through 2022 (DOT 2023).[1]

The HTF shortfall is likely to continue unless substantial changes occur in transportation policy. Regulations to further improve fuel economy for the next few model years are already in place and will likely be extended (EPA 2021), and sales of new EVs are projected to increase considerably (EIA 2022a). In the face of declining revenues and the pressing need to reduce greenhouse gas emissions and other damages from vehicle use, policymakers will need to consider raising fuel taxes or alternative policies.

One option is a tax on drivers for each mile that they travel. As of 2022, 13 states have piloted voluntary programs to raise revenue for transportation projects, using taxes applied to VMT (GAO 2022). In the 2021 Infrastructure Investment and Jobs Act, Congress authorized $50 million to support additional voluntary pilot programs at the

[1] All dollar figures in this paper are presented in 2021$.

state and federal levels to study the potential for implementing taxes based on VMT, which the legislation refers to as "mileage-based user fees" (Section 13002 (o)).[2] Although this approach has generated interest from policymakers, it faces implementation, economic, and political challenges that we discuss in this paper.

We use an economic model of the US passenger vehicle fleet to assess the effects of different transportation tax policy options. One approach to raising additional revenue to fund the HTF is to increase excise taxes on gasoline and at the same time levy a VMT tax on EVs since they do not pay gasoline taxes. Another approach is to levy a VMT tax on all vehicles and remove the fuel excise tax. We model both these scenarios, consider how high tax rates would have to be to attain the needed level of revenue, and assess how each would affect EV sales, gasoline consumption, and other outcomes. Because fuel economy standards have been set through 2026 and the stringency of post-2026 standards are uncertain, we also examine the interaction between the alternative revenue policies and stricter standards.

Finally, we look at a policy that does not set a revenue target, but instead attempts to set fees at a level that reflects the external costs of driving. In this scenario, our modeling tools allow us to vary the level of the tax across counties but not across time, which could be an important element of pricing certain externalities such as congestion. Our estimates of the magnitudes of these taxes are considerably higher than most prior estimates, and we compare the amount of revenue they raise with the revenue target that maintains highway performance.[3] We also examine the effects of this tax on EV sales, gasoline consumption, VMT, and more.

Regardless of the level of a VMT tax, these new types of policies may raise political and practical challenges. Although we are unable to model them quantitatively, we discuss some of the major issues in our literature review. For implementation costs, which could be substantial, we review the available evidence to include these costs in our modeling scenarios. The remainder of this section places our analysis in context of the vehicle taxation literature and discusses implementation of a VMT tax.

1.1. Literature review of alternative tax policies for vehicles

A substantial body of work has examined policies for addressing vehicle externalities and for raising revenue for road infrastructure. A number of papers have examined outcomes when revenue is raised from a fuel tax compared with a policy where revenue is raised from a VMT tax. Most of these estimate taxes that maximize welfare or internalize some or all externalities of driving. Externalities include tailpipe

[2] We use VMT tax to describe a mileage-based user fee or tax.
[3] By "maintains highway performance," we refer to testimony from the Congressional Budget Office (Kile 2021) in which the office used analysis from the Federal Highway Administration to estimate the costs of maintaining conditions and performance at 2014 levels, including "pavement quality, bridge conditions, and travel delays."

emissions that cause local ozone and other pollution, carbon dioxide (CO_2) emissions that contribute to global warming, congested highways that lead to increased driving times, traffic accidents, and road wear. Economic theory suggests that pricing the externalities increases social welfare because consumers consider the full marginal cost of driving when making decisions about how much, when, and where to drive.

Fuel taxes can be efficient for addressing CO_2 emissions because those emissions scale proportionally with the volume of fuel consumed, but they are less efficient for addressing local air pollution, which depends more on the number of miles driven and local characteristics such as population exposure, meteorology, and topography. Damages from congestion and traffic accidents are determined in part by miles traveled but also by local conditions, time of day, vehicle characteristics, and other factors. A VMT tax can address these external costs by varying across the time and location of driving, assuming the relevant technologies can be deployed at scale.

Fuel and VMT taxes will also produce different incentives for maximizing fuel economy. Under a fuel tax, drivers will tend to improve the fuel economy of their vehicles in the long run, so only part of the driver response to the tax comes from reducing VMT (Parry et al. 2007). In contrast, a VMT tax does not incentivize higher fuel economy, but will tend to reduce VMT.

1.1.1 Welfare effects

Like most analyses of the external costs of driving and associated welfare effects, our analysis uses a partial equilibrium approach, examining only the effects on parties in the vehicle market, assuming other parts of the economic system remain unchanged (in contrast to a general equilibrium modeling approach that accounts for the effects of a policy on all parts of the economy).

One exception is Parry and Small (2005), who use a general equilibrium approach to compare optimal fuel and VMT taxes. They estimate an optimal gasoline tax of $1.58 per gallon in the United States and $2.09 per gallon in the United Kingdom and an optimal VMT tax of $0.15 per mile in the United States ($3.51 per gallon, assuming 24.1 mpg) and $0.16 per mile in the United Kingdom ($3.76 per gallon). Higher rates under the VMT tax are due to the general equilibrium nature of the analysis, in which the VMT tax replaces more distortionary taxes such as labor taxes. Congestion costs, which are higher in the United Kingdom, account for the largest share of VMT taxes. The results suggest that in both countries, VMT taxes would increase welfare four times as much as would the optimal fuel tax and could significantly boost government revenue. In a partial equilibrium setting, Langer et al. (2017) similarly find that a VMT tax would improve welfare relative to a fuel tax, in their case by 20 percent.

1.1.2. Estimating the external costs of driving

Although the risks of climate change have motivated a substantial amount of recent transportation-related policy, previous analysis has estimated that climate damages constitute a modest portion of the external costs of driving ICE vehicles. Importantly, these studies, which we describe in this section, use an older estimate for the social cost of carbon, on the order of $40 per ton of CO_2, compared with central estimates of $185 per ton estimated in more recent work (Rennert et al. 2022).

In a summary analysis of vehicle externalities, Parry et al. (2007) find that the external costs of oil consumption (climate damages and oil dependency) are $0.31 per gallon, while the external costs per mile of driving (accidents, congestion, and air pollution) are more than 10 times that amount, about $3.60 per gallon (assuming average fuel economy of 21 mpg). Congestion costs account for the greatest amount of the per-mile costs, at about 50 percent.

Anderson and Auffhammer (2014) use detailed data from accidents involving cars and light trucks to estimate the externality from fatalities due to traffic accidents. They find that heavier vehicles are much more likely to cause fatalities when they strike lighter ones and that the accident externality for fatalities is $1.07 per gallon, substantially higher than previous estimates in the literature (e.g., Anderson 2008; Li 2012) but similar in magnitude to the damages from fatalities implied by calculations included in a 2021 regulatory impact analysis on emissions standards (EPA 2021, 5–10).

Coady et al. (2018) estimate that the external costs of driving in the United States are $2.29 per gallon, of which $0.64 is from environmental externalities (which could be much lower for EVs, depending on the electricity mix) and $1.75 is from congestion and accidents (which could be higher for EVs if their heavier weight increases accident externalities).

In an International Monetary Fund report on global fossil fuel subsidies, Parry et al. (2021) estimate that in the United States, external costs of gasoline consumption total $2.40 per gallon, of which $0.76 is from environmental externalities and $1.64 is from congestion and accidents. In a related analysis, Bjertnæs (2019) argues that because the majority of external costs are generated by mileage-related effects rather than fuel consumption, EVs and energy-efficient vehicles should pay a relatively high tax, and suggests an optimal tax of $0.05 per mile, or $7,600 over the lifetime of an EV on average.

In this analysis, we use an estimate of transportation-related air pollution damages from Choma et al. (2021), who estimate the county-level benefits of reduced vehicle emissions in the United States from 2008 to 2017 and find total benefits of $296 billion in 2017, due primarily to reduced fatalities from $PM_{2.5}$ emissions. They note that damages are considerably higher in large urban areas (up to $8.25 per gallon) than in other areas (as low as $0.03 per gallon) because of population exposure and demographics.

1.1.3. Distributional effects

The effects of gasoline and VMT taxes vary across demographic groups. In the United States, gasoline taxes are generally economically regressive (Poterba 1991), constituting a larger share of spending for low-income families than for high-income families (although households that do not drive do not pay the tax). At the same time, policies incentivizing EV adoption are also regressive. Davis and Sallee (2020) calculate that sales of EVs have reduced federal and state gasoline excise tax revenues by $250 million per year and in a highly regressive, geographically concentrated manner.

The distributional effects of transportation taxes may also vary across rural and urban households. For example, rural households drive on average 1 to 5 percent more than suburban and urban ones (FHWA 2018). Most evidence suggests that a VMT tax could be less regressive than current fuel taxes, but these results depend on VMT tax design and the level of fuel taxation, which varies across states (Glaeser et al. 2022; Langer et al. 2017).

Our analysis compares the effects of gasoline and VMT taxes on revenue, vehicle markets, VMT, and fuel consumption. We also update estimates of the externalities of driving, some of which are considerably higher than the estimates in the literature. We do not consider the effects on different socioeconomic groups, although such analysis would be an important extension of this work.

1.2. Implementation issues for a VMT tax

Before analyzing the effects of implementing a new type of transportation tax, we must consider the political and practical realities. VMT taxes have been piloted in 13 states, beginning in 2016. These pilots raise revenue using several different methods: GPS-based mileage fees; pay-at-the-pump fees, with VMT data transmitted during refueling; and prepaid mileage fees, with drivers purchasing miles during vehicle registration. Existing state pilots are voluntary, and enrollment has generally been low. Public concerns over VMT taxes have centered mostly around driver privacy and equity. States have attempted to address privacy concerns by avoiding GPS-based systems, anonymizing data, and using third-party vendors. Equity concerns have been voiced primarily by rural drivers, who believe the programs would disproportionately burden them (GAO 2022).

Duncan et al. (2017) examine public perceptions of a VMT-based tax using a nationally representative survey, finding that opponents outnumber supporters by four to one and that the intensity of opposition is stronger than the intensity of support. Support was lowest for programs that tracked drivers' geolocations and those administered by the federal government (relative to states). In a follow-on study of Indiana drivers, Duncan et al. (2020) explore whether public support varied across three VMT rate designs, finding that under some circumstances, respondents were more supportive of a flat per-mile fee than fees adjusted to vehicle weight or fuel economy.

There is some evidence that public acceptance may be growing, however. In the twelfth year of a national representative survey, Agrawal and Nixon (2021) find that public support for some form of a VMT tax has slowly increased over time, with roughly half of respondents supporting a fee charged either to all vehicles or to commercial vehicles only. Respondents also indicated support for increasing gasoline taxes, but only if the revenue were used primarily for road maintenance or pollution abatement.

One potential political benefit of VMT taxes is that unlike fuel taxes, they would not need to be updated (in real terms) as frequently to maintain consistent levels of revenue. From 1980 to 2019, VMT in the United States more than doubled, while fuel consumption increased by just 57 percent (BTS 2021). As fuel economy continues to improve and EVs become more prevalent, maintaining revenues at a consistent level would require regular increases in fuel tax rates, whereas a VMT tax rate could remain constant and still produce increasing revenue over time if VMT continues to rise. Some survey evidence shows that a VMT tax makes motorists more aware of the tax and of the cost of driving than does the current gas tax, which is included in the posted price (WSTC 2020).

The implementation of a VMT tax program also raises important technical questions. For statewide or national programs, administrators would likely need multiple tools for tracking mileage. Motorists with newer vehicles equipped with telematics can communicate GPS-based location data to centralized data repositories in real time, potentially enabling a pay-as-you-drive system. Older vehicles can be equipped with GPS devices connected to on-board diagnostic systems or with stand-alone GPS units. Other options include regular odometer readings or self-reported VMT. Offering motorists choices about which approach they prefer may enhance public acceptance.

The technologies needed to track miles traveled are well developed; however, administrative costs and enforcement issues raise important concerns. For example, Martin et al. (2021) estimate evasion rates in Oregon's weight-mile tax on commercial trucks of 8.6 to 11.3 percent between 2016 and 2018. The extent of evasion in a large-scale VMT program is unknown because current state programs are small and voluntary, but it could be substantially higher than with fuel taxes, which are difficult for motorists to evade in the United States, though evasion is a concern through the supply chain (Capps et al. 2016).

Overall, administrative costs of VMT tax programs are likely to be greater than with fuel taxes, at least in the short term. Most estimates put the costs of fuel tax collection at about 1 percent of the revenue collected (Rufolo 2011; Schultz and Atkinson 2009; Short and Murray 2021). Start-up costs for a VMT collection system are likely to be high, requiring hardware and software development and procurement, setup of fee collection systems, and installation of technologies on vehicles. Recurring costs include program administration, compliance monitoring, and fee collection (Balducci et al. 2011; WSTC 2020).

Ongoing pilot programs have had very high costs, but these should be interpreted with caution because of their small size and experimental nature. For example, the three private contractors administering Oregon's pilot program retain roughly 40 percent of program revenue, returning only 60 percent to the state (Jones and Bock 2017). In Utah, where only EVs and hybrid EVs are eligible for the VMT tax program, administrative costs have exceeded revenues (UDOT 2021).

Larger, mandatory programs that can take advantage of scale, technology, and system design improvements would likely have much lower long-run costs. Costs could fall to 10–15 percent of revenues for programs that offer a range of options for reporting mileage to vehicle owners (Al-Deek and Moradi 2015; CalSTA 2017; I-95 Corridor Coalition 2012). They could fall further if on-board systems for VMT tax collection have other purposes (Sorensen et al. 2012). For example, the automotive insurance industry is already using app- and GPS-based insurance products that vary with mileage. Given the uncertainty in long-run costs for large-scale federal and state VMT programs, we include rough estimates of these costs in our analysis.

2. Research Questions and Methods

Little economic research has been conducted on how high fuel or VMT taxes would need to be to raise revenue sufficient to fund road infrastructure or on how such changes would affect the vehicle mix, overall travel, emissions, and other outcomes. Policymakers will also need to consider how new policies may interact with existing ones such as fuel economy standards. In addition, evolving evidence from the literature suggests a need to reassess the external costs of driving, then compare those costs with policies focused on funding infrastructure. Section 2.1 describes the set of tax policy scenarios we examine, and Section 2.2 outlines the economic model of US household vehicles that we use to evaluate the effects of the policies.

2.1. Policy scenarios

We model three scenarios. First, we estimate two versions of scenario A, a business-as-usual (BAU) scenario in which state and federal excise taxes remain constant and other policies remain unchanged. These serve as a baseline against which we can compare outcomes from scenarios B and C. Scenario A1 assumes that current fuel economy standards (reaching 54 mpg by 2026) are not extended beyond 2026. Scenario A2 assumes that standards continue to tighten by 4 percent per year from 2026 through 2035, consistent with the required rates of fuel economy improvements in the current set of standards. Fuel economy standards have been the main approach to reducing emissions from vehicles in recent decades, and they are likely to be tightened further in the coming years.

Next, we develop three variations of B scenarios focused on policies that will raise sufficient revenue to maintain highway performance. Based on the revenue requirements estimated by the federal Office of Management and Budget (see Section 2.3), this scenario sets tax rates at levels designed to raise $35 billion and $29 billion annually in federal and state revenues, respectively, from household vehicles. In scenario B1, the revenue target is achieved through a mix of higher fuel excise tax rates and a VMT tax applied only to EVs sold in 2025 or later. The EV-only VMT tax is set such that an EV owner pays the same amount per mile as the owner of an average ICE vehicle. The rationale for the EV-only fee is that EV owners do not pay gasoline taxes, and implementation would be easier because all EVs have on-board telematics. Scenario B2 takes the same approach as B1 but extends federal fuel economy standards through 2035 as in scenario A2.

Scenario B3 raises the same revenue as B1 and B2 but includes a VMT fee on all on-road vehicles beginning in 2025. Although switching to national and state VMT taxes so quickly is impractical, [4] this scenario provides policymakers with a sense of the effects of a complete shift from fuel excise taxes to VMT taxes.

A final C scenario includes taxes that account for four of the major external costs of driving: GHG emissions, tailpipe emissions that contribute to local air pollution, congestion, and accidents. These taxes replace current state and federal fuel excise taxes, and we are agnostic to the level of revenue raised. This approach is more theoretical because it ignores the technical and political barriers to implementing such a large change in the near term. Still, this scenario is a useful comparison to the B scenarios, particularly because it helps illustrate the gaps between current tax rates, tax rates needed to maintain highway performance, and tax rates that would reflect the major external costs of driving. Table 1 summarizes the scenarios and notes their key objectives.

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[4] Voluntary federal pilot VMT tax programs are scheduled to begin in 2025, and states have identified the late 2020s or early 2030s as a potential time frame for the start date of larger-scale VMT tax programs (e.g., RUFTF 2021; UDOT 2021).

Table 1. Scenarios Modeled in Our Analysis

	Name	Description	Key objective
A1	BAU flat standard	Current state and federal excise taxes. Current state and federal fuel economy standards (54 mpg by 2026). No VMT tax.	None
A2	BAU tight standard	Identical to A1 but extends federal fuel economy standards through 2035 at 4 percent annual growth rate starting in 2026.	None
B1	HTF flat standard	Higher state and federal excise taxes for ICE vehicles to maintain highway performance. Comparable ($/mile) VMT tax phased in for all EVs (including those sold before 2025) starting in 2025.	Raise highway revenues
B2	HTF tight standard	Identical to B1 but extends federal fuel economy standards through 2035 at 4 percent annual growth rate starting in 2026.	Raise highway revenues
B3	HTF VMT	Replaces excise taxes with state and federal VMT taxes that maintain highway performance. Extends federal fuel economy standards through 2035 at 4 percent annual growth rate starting in 2026.	Raise highway revenues
C	Externalities	Replaces excise taxes with state and federal VMT and fuel taxes that price all major externalities. Maintains current state and federal fuel efficiency standards (54 mpg by 2026).	Address external costs

2.2. Overview of RFF transportation model

The RFF transportation model contains two components: new vehicle sales and on-road fuel consumption. The first component characterizes vehicle sales by year (2018 through 2035) across three regions: California, other states adopting California's zero emissions vehicle (ZEV) standards, and all other states.[5] Each consumer in the model

[5] Because the model parameters are estimated using data from 2010 through 2018, the simulations begin in 2018. We report results beginning in 2019. California, Colorado, Connecticut, Delaware, Maine, Maryland, Massachusetts, New Jersey, New York, Oregon, Pennsylvania, Rhode Island, Vermont, and Washington participate. Minnesota will join the program in 2025 but is not included among the ZEV states for modeling purposes. California has tightened ZEV standards after 2025, requiring plug-in or fuel-cell vehicles to account for all new vehicle sales by 2035. Other states will decide whether to adopt the post-2025 standards. We model ZEV standards through 2025 and assume that by 2035, California and other ZEV states achieve 50 percent plug-in vehicle market share. We include weaker post-2025

chooses the new vehicle that maximizes subjective well-being, which depends on vehicle prices, fuel costs, and other factors. Preferences vary across 60 demographic groups based on income, age, urbanization, and region.

Consumer preferences are estimated from survey responses of 1.5 million new car buyers between 2010 and 2018. The survey data include information about income and other demographics and details about the vehicle purchased. Vehicles are defined at a highly disaggregated level to recognize model, trim (e.g., LX or premium), fuel type, body style (e.g., sedan or sport utility vehicle), drive type, and engine size. This definition of a vehicle matches the options consumers face at dealerships when they choose new vehicles.

Each manufacturer chooses vehicle prices and fuel economy to maximize profits while facing federal GHG and regional ZEV standards. Each year, vehicle manufacturers also choose whether to introduce new EVs, depending on the expected profitability and entry costs of those vehicles. Manufacturers face state-level ZEV requirements that tighten through 2025. Between 2025 and 2035, the required market share of plug-in vehicles sales increases to 50 percent. Manufacturers also face federal fuel economy and GHG standards. Vehicle production and entry costs, as well as shadow prices of the ZEV, fuel economy, and GHG standards, are estimated from observed choices of vehicle prices, fuel economy, and entry, under the assumption that each manufacturer makes these choices to maximize its own profits.

We simulate the equilibrium in a market (model year and region) given assumptions on the total number of consumers in the market, fuel prices, battery costs, plug-in vehicle subsidies, and ZEV and GHG standards. For each simulated market, the output includes entry of new electric vehicles and the price, fuel economy, and sales of each vehicle. The number of consumers in the market and fuel prices are taken from the *Annual Energy Outlook 2021* (EIA 2021, Table 36). Battery costs are from 2021 projections by Bloomberg New Energy Finance Electric Vehicle Outlook (BNEF 2021).

The output of the new vehicle component feeds into the on-road fuel consumption component of the model. The model tracks ownership of vehicles by county, vehicle class (car or light truck), and vehicle age. Each year, households purchase new vehicles and decide whether to scrap their older vehicles. Scrappage rates depend on vehicle age and class and are estimated from historical registration data from R. L. Polk. Consumers decide how much to drive their vehicles depending on driving preferences and fuel costs. We compute fuel consumption and tailpipe emissions from estimated miles traveled and emissions rates of the vehicles. For non-plug-in vehicles, we assume all gasoline contains 10 percent ethanol in determining GHG emissions rates. For plug-in vehicles, we use average regional emissions intensities for electricity

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standards because, given other policies included in the model and estimated consumer preferences, manufacturers will not be able to attain 100 percent plug-in and fuel cell market share by 2035.

generation from the RFF Haiku model.[6] To calculate local air pollution emissions rates, we use the results from EPA (2021) analysis of light-duty GHG standards. For GHG and local air pollutants, the analysis includes emissions from fuel combustion as well as upstream fuel production. Fuel tax expenditure is by state and year. Section 2 describes the assumed fuel tax rates, which vary across scenarios.

For the A scenarios, we use national VMT projections through 2035 from the *Annual Energy Outlook 2021* (EIA 2021, Table 36). National VMT is allocated across states and vehicles according to the per-mile fuel costs and estimated consumer driving preferences from the *National Household Travel Survey 2017* (FHWA 2018), which vary by vehicle class and age. In scenarios B and C, which include higher per-mile driving costs than the A scenarios, we adjust national VMT by the difference in average driving costs and assume an elasticity of VMT to driving costs of −0.1. Driving costs also affect the distribution of VMT across vehicles.

2.3. Key data inputs

2.3.1. Estimating revenue needs for the B scenarios

Identifying the "correct" level of government revenue and public transportation infrastructure investments is beyond the scope of this analysis. To develop such an estimate, an economic approach would first assess the marginal social benefits of investments across the public policy domain, including national security, public health, and climate change mitigation. Efficiency-minded decisions on how to raise the revenue needed to support the spending require a similarly comprehensive analysis, assessing the distortionary and distributional consequences of a wide array of revenue instruments.

In this paper, we take a simpler approach to develop a revenue target. We rely on an analysis by the Office of Management and Budget on the revenue needed to maintain highway performance at 2014 levels, which finds that federal and state spending would need to total $99 billion annually from 2023 through 2031 (Kile 2021). This approach is highly policy-relevant because it aligns with the goals articulated in legislation authorizing state and federal VMT tax pilot programs, which focuses on maintaining the HTF's solvency and performance of the road transportation system (Section 13002 (o) of the 2021 Infrastructure Investment and Jobs Act). If the share of federal and state spending on capital improvements and maintenance remained constant, the federal Office of Management and Budget estimates that maintaining performance at 2014 levels would require annual federal and state spending of $56 billion and $44 billion (Kile 2021).

[6] The analysis uses the average emissions rates of each region, rather than marginal emissions rates. Whereas marginal rates are more appropriate than average rates when considering incremental charging needs, the scenarios involve substantial charging growth over time.

2.3.2. Estimating the share of revenue from household vehicles

Because our model includes only household vehicles, we are unable to estimate how taxes affect commercial and fleet vehicles such as large trucks or rental cars. As a result, our revenue estimates only account for the share of state and federal fuel excise taxes from household vehicles. Estimating these figures requires two key steps, which we summarize in this section and detail in the appendix.

First, using fuel consumption data from 2015 through 2020 from EIA (2021), tax policy analysis from the Alternative Fuels Data Center (Putzig et al. 2021), and tax rate data from the Federal Highway Administration (FHWA 2021), we estimate that light-duty vehicles account for 66.2 percent of federal and 70.9 percent of state fuel excise tax revenues. Second, we estimate the share of fuel consumed by household light-duty vehicles from 2015 through 2020. We use data from the US Department of Energy's *Transportation Energy Data Book* (Davis and Boundy 2021) to estimate that fleet vehicles account for 5.1 percent of fuel consumption among light-duty vehicles. Combining these two steps, we estimate that from 2015 to 2020, household vehicles contributed 62.8 and 67.3 percent of federal and state fuel tax revenues, respectively. This indicates that household vehicles would need to contribute $35 billion annually in federal revenues out of a total of $56 billion necessary to maintain highway performance. For states revenues, we estimate that household vehicles would have to generate $29 billion out of a total of $44 billion per year.

Because our model does not estimate how policies affect commercial or fleet vehicles, we assume that the share of revenue from household vehicles remains constant over time and that revenues from other vehicles change proportionately. Future work can build on our estimates by incorporating estimates for how tax policies (or other factors) affect purchasing, driving, scrappage, and other decisions concerning commercial and fleet vehicles.

2.3.3. Cost of implementing a VMT tax

As noted in section 1.2, the costs of implementing a large-scale VMT tax program are uncertain. However, start-up costs, such as software development and program design, are likely to be substantial. We assume that start-up costs are paid for with general revenues, while ongoing costs (e.g., program staffing, monitoring, and enforcement) are funded by a portion of the VMT tax. We make this assumption because start-up costs for a nationwide program would likely be large, and governments may see this cost as a necessary investment to avoid higher VMT taxes, particularly in the initial years of the program when driver backlash may be strongest.

For each scenario with a VMT tax, we assume that implementation costs are $10 per vehicle per year.[7]

2.3.4. Estimating external costs

In the C scenario, we explore the effects of a tax that is set equal to the social costs of externalities associated with household vehicle driving from traffic congestion, accidents, greenhouse gas emissions, and "local" air pollution. In this approach, we are agnostic as to the level or use of the revenue, but expect it to easily exceed highway spending needs, as previous economic literature has shown that the external costs of driving are well above current US excise taxes (Coady et al. 2018; Parry et al. 2007).

Because externalities from driving have different causes, we apply either a fuel consumption tax or a VMT tax, depending on which activity causes the externality. Congestion and accidents are priced per VMT, while GHG emissions and air pollution are priced per gallon of fuel consumed. We include only tailpipe and not upstream emissions (such as electricity generation and fuel production), and EVs do not pay fuel taxes in our analysis.

For external damages that vary across space, we apply different levels of specificity depending on data availability and modeling capacity. GHG emissions are directly proportional to gallons consumed, since the carbon content of the fuels does not vary across our scenarios. We assume that local pollution emissions also scale with gallons of gasoline. For congestion and air pollution externalities, we draw on available evidence to approximate costs at the county level, which is consistent with the county-level aggregation of our economic model. We are unable to estimate location-specific external damages from accidents and are also unable to vary congestion tax rates over time because of limitations in available data and modeling capacity. As our transportation model does not estimate choice of fueling location or specific driving routes, we make the simplifying assumption that drivers pay the appropriate tax rate for each mile driven in a given county, even if they may have fueled their vehicles in another county.

To estimate the optimal tax for traffic congestion, we begin with data from the Texas A&M Transportation Institute, which publishes a variety of statistics for roughly 400 urban areas in the United States, including the number of hours lost in commuting on congested roadways (Schrank et al. 2021). We estimate the current congestion costs per mile in each urban area by multiplying hours lost per driver by half the national average hourly wage in 2019 and dividing by the number of miles driven.[8] We then develop

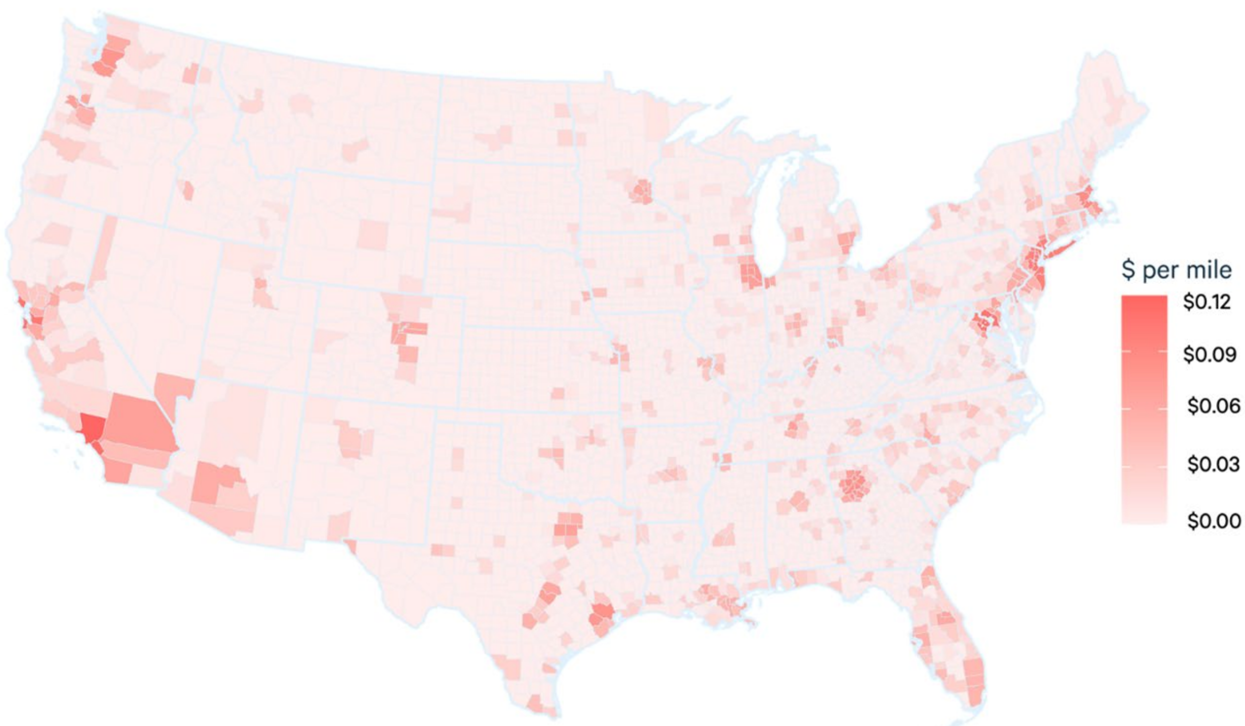
[7] This estimate comes from conversations with an industry expert from the firm Azuga, which is involved in designing and implementing multiple voluntary VMT tax pilot programs in the United States. For more information, see Azuga (2023).

[8] Assuming that the value of time is half of the wage rate is common in the literature (DOT 2014; Yang et al. 2020).

county-specific estimates for marginal social costs following Parry (2009) and Yang et al. (2020), which we detail in the appendix.

Figure 1 illustrates the congestion externalities by county, with a maximum tax rate of \$0.12 per mile in Los Angeles County and a population-weighted mean tax rate of \$0.011 per mile across the nation. The distribution of congestion taxes is right-tailed, with 70 percent of counties effectively facing zero congestion costs in the Texas A&M data.

Figure 1. Estimated Congestion Externalities, by US County



For accidents, we rely on Parry and Small (2015), who estimate marginal external cost of accidents in the United States of \$0.045 per mile (equivalent to \$1.08 per gallon assuming 24 mpg). This estimate does not account for differences across vehicle types, geographies, speeds, and traffic patterns, which can all influence external damage from accidents. Future research can improve on our analysis by developing more precise external cost estimates.

For carbon dioxide emissions, we rely on Rennert et al. (2022), whose central estimate for the social cost of carbon (SCC) is \$193 per metric ton, more than three times the previous central federal estimate of \$51 per metric ton. This SCC translates to \$1.71 per gallon, assuming CO_2 emissions of 8.9 kilograms per gallon of gasoline consumed (EPA 2016). Because CO_2 is a well-mixed global pollutant, the social cost of carbon does not vary spatially.

For local air pollutants, we turn to Choma et al. (2021), who estimate county-level health damages from air pollution across different vehicle types. We use their estimates of per-mile marginal damages from light-duty vehicles, which average $0.03 per mile, ranging from a low of $0.001 per mile in Washington County, Maine, to a high of $0.31 per mile in New York City. We convert these values to a per-gallon equivalent assuming fuel economy of 24 mpg, resulting in an average tax of $0.79 per gallon (ranging from $0.03 to $8.25 per gallon). Figure 2 illustrates the results across the nation, and for context, the means in urban and rural counties are $1.74 per gallon and $0.77 per gallon, respectively.

Figure 2. Estimated Air Pollution Externalities, by US County

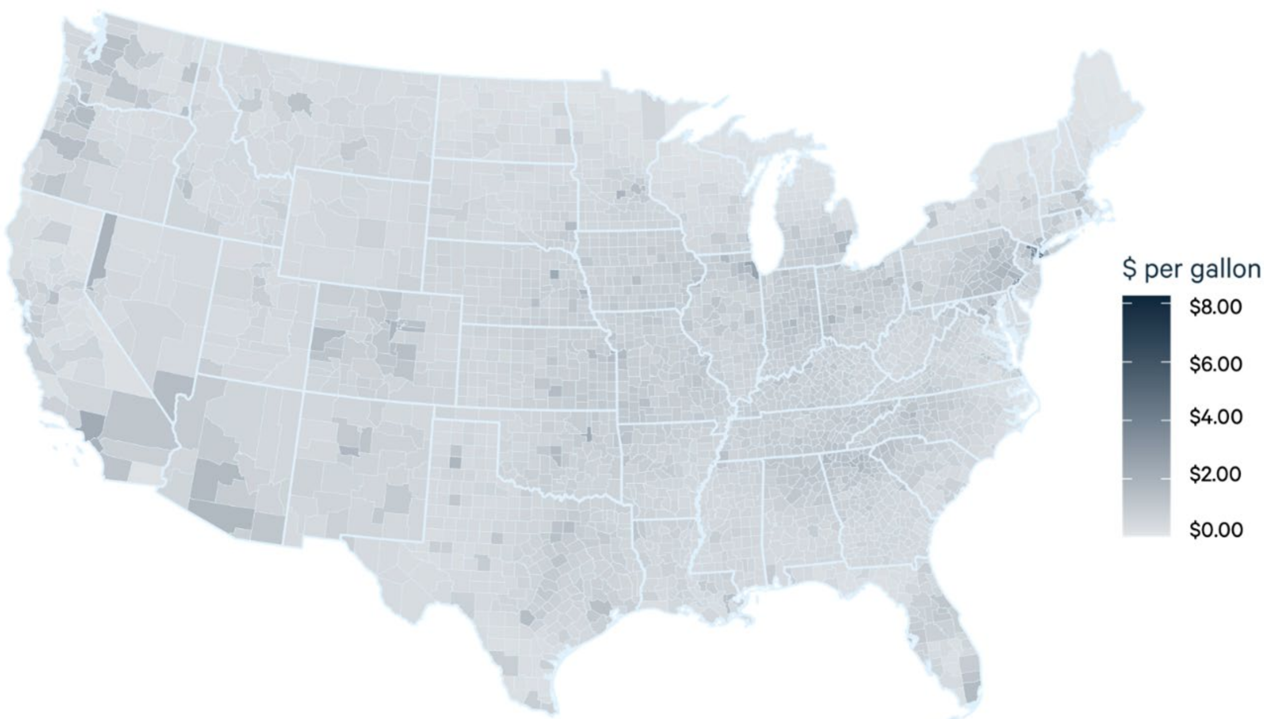


Table 2 summarizes our estimates of the external costs of driving. The damages from GHG emissions and from tailpipe emissions of local pollution accrue per gallon of gasoline consumption, and congestion and accidents are related to miles traveled. For comparison, we show all four components in both dollars per gallon and dollars per mile using a conversion rate of 24 mpg.

Table 2. Summary of External Cost Estimates (2021$)

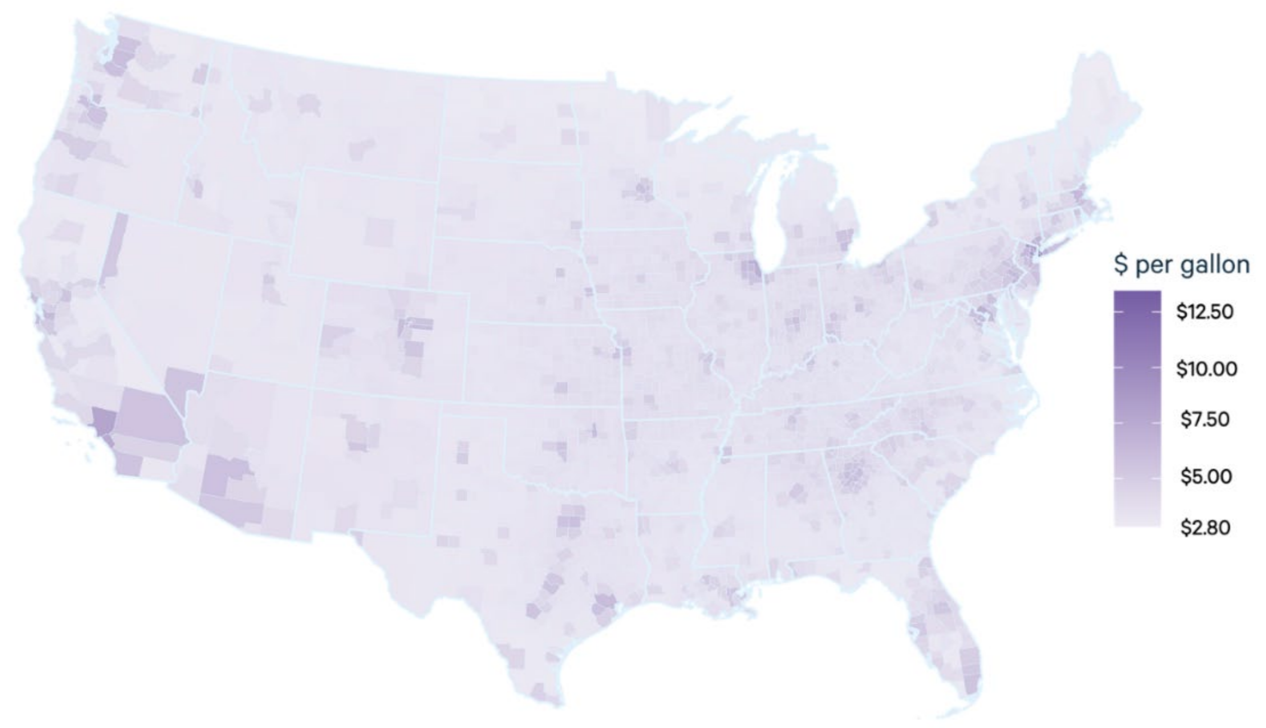
External damages category	National average (per gallon)	National average (per mile)	Range across counties	Comparison with previous estimates
Carbon dioxide emissions	$1.71	$0.07	None	Well above previous estimates due to higher social cost of carbon (Rennert et al. 2022)
Local pollution	$0.79	$0.03	$0.03–$8.25 per gallon	Similar to previous estimates, e.g., Parry et al. (2007)
Congestion	$0.27	$0.01	$0.00–$0.12 per mile	Similar to previous national-level estimates, but we show substantial variation by county
Accidents	$1.08	$0.05	None	Estimate is from the literature; consistent with most other studies
Sum	$3.85	$0.16	$2.83–$13.44 per gallon $0.12–$0.56 per mile	Higher than most previous estimates, with wider range

Notes: Average pollution and congestion damages are weighted by county-level population. GHG damages are uniform across counties. Accident externalities are assumed to be equal across counties because of a lack of data.

The damages from GHG emissions are the largest component of external damages, a considerable departure from previous estimates (Parry et al. 2007; Davis and Sallee 2020) and a reflection of large upward revisions to the estimate of the SCC (Rennert et al. 2022). The table reports population-weighted averages, using county population as the weight. The combined damages across the four categories are $3.85 per gallon or $0.16 per mile on average across the nation.

In some urban counties, tax rates exceed $10 per gallon ($0.41 per mile). This reflects the higher congestion and air pollution damages associated with driving in urban areas. In most rural counties, congestion and air pollution damages are lower, but tax rates are still much higher than current fuel taxes, averaging about $3 per gallon ($0.13 per mile), as illustrated in Figure 3.

Figure 3. Full External Costs of Driving, by US County



3. Results

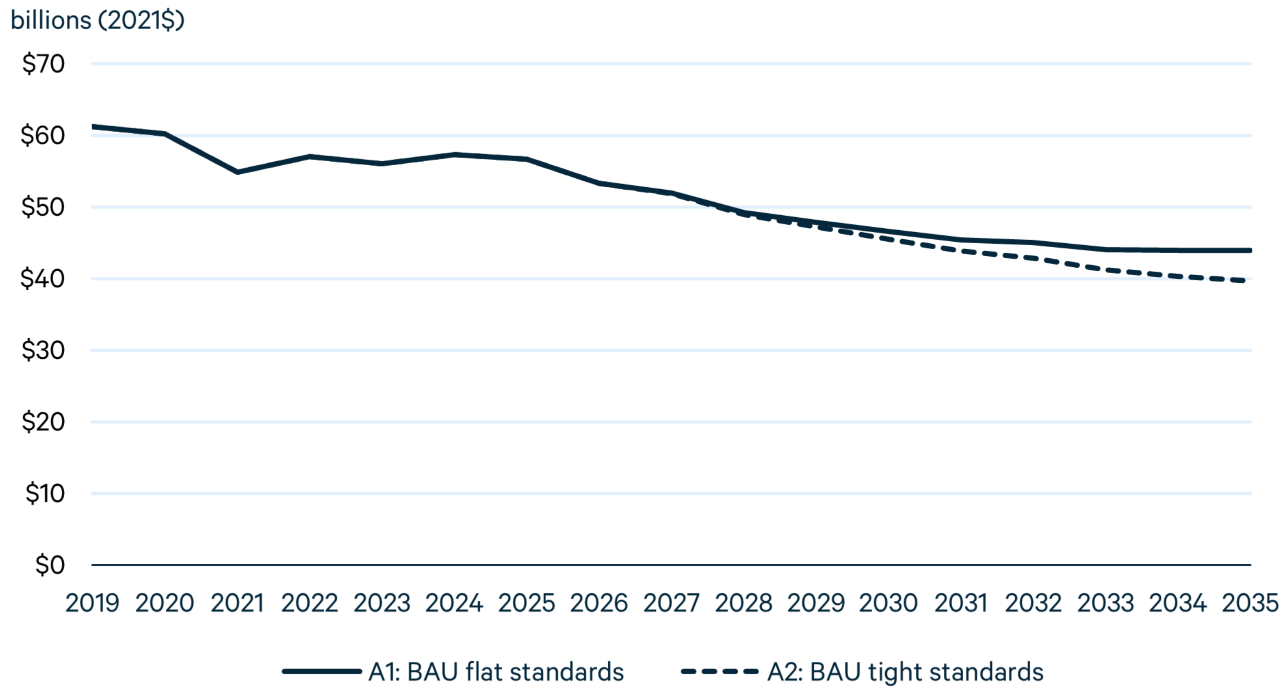
This section reports results from the A, B, and C scenarios described in Table 1. The transportation model is simulated over the years 2019–35. The VMT taxes in the B and C scenarios begin in 2025, and the tax rates in the B scenarios are calibrated to raise sufficient revenue from 2025 to 2035 to maintain highway performance.

3.1. State and federal revenues

The A scenarios assume current federal and state taxes remain at their current levels through 2035: $0.18 per gallon (federal) and $0.27 per gallon (state). For a vehicle with fuel economy of 24.1 miles per gallon, this equates to a VMT tax of 1.9 cents per mile.

As expected, revenues decline over time as ICE vehicle fuel economy increases and EV sales increase. Figure 4 shows the decline in revenues projected by the model through 2035. To maintain highway performance, annual average revenues would need to be 43 percent higher than in A1 from 2025 to 2035. Strengthening fuel economy requirements further reduces tax revenues to roughly 10 percent below the A1 scenario by 2035. This finding is consistent with a large body of evidence that current tax policies are insufficient to maintain US roadways (e.g., CBO 2020; Doshi and Metcalf 2023; Kile 2021).

Figure 4. Projected State and Federal Revenues from Gasoline Excise Taxes under Current Policies



The B scenarios illustrate the levels of fuel or VMT taxes that will maintain highway performance at 2014 levels, as described in Section 2.1. In these scenarios, annual average revenue is roughly 70 percent higher than in the A scenarios from 2025 to 2035. The B1 and B2 scenarios raise the excise tax on gasoline and tax EVs at a rate that is equivalent to what an ICE vehicle of the same vintage would pay on average per mile. Under the B1 scenario, federal taxes on gasoline triple, state gasoline taxes increase by about 40 percent, and EVs pay a fee of about 2.6 cents per mile (1.4 and 1.2 cents for federal and state taxes, respectively).[9] This EV fee is similar to current state-level voluntary programs (e.g., participating Utah motorists pay about 1 cent per mile). Table 3 shows these and other key revenue-related results from our simulations.

[9] Federal taxes go up more than state taxes because, under current policies, the gap between revenue needs and current tax rates is larger for the federal government than for the states.

Table 3. Federal and State Tax Rates and Revenues in Each Scenario

	$ per gallon		$ per mile		Average annual revenue, 2025–35 (billions 2021$)
	Federal	**State average**	**Federal**	**State average**	**Federal and state total**
A1/A2	$0.18	$0.27	—	—	A1: $48 A2: $46
B1	$0.54	$0.38	EVs only: $0.014	EVs only: $0.012	$82
B2	$0.58	$0.41	EVs only: $0.010	EVs only: $0.009	$82
B3	—	—	All: $0.017	All: $0.014	$82
C	CO_2: $1.71 Air pollution: $0.79		Accidents: $0.045 Congestion: $0.011		$310

Note: For taxes that vary spatially, population-weighted averages across all counties are shown.

The B2 scenario includes tighter fuel economy standards after 2026. Compared with B1, tax rates in B2 are higher on ICE vehicles because the tighter fuel economy standards reduce their fuel consumption per mile, which reduces tax revenue and necessitates a higher tax rate to achieve the revenue target. Although tax rates in B2 are higher per gallon than in B1, each ICE pays lower taxes per mile in B2 because of improved fuel economy. The EV tax rate is also lower in B2 because it is calibrated to match the average ICE vehicle tax per mile.

The B3 scenario replaces all fuel taxes with a VMT tax of 3.1 cents per mile on all household vehicles from 2025 through 2035 (1.7 and 1.4 cents for federal and state taxes, respectively). The VMT tax is calibrated to achieve the same revenue (net of program costs) during that period. If such a tax were implemented, it would likely vary across states just as the current gasoline excise taxes do. Some states, such as California and Washington, are considering 2–2.5 cents per mile for a future VMT tax, with some cities considering additional VMT taxes on top of that. However, for simplicity, all states impose the same VMT tax in our B3 scenario.

Our tax rates in scenario B3 are higher than those in one recent analysis (Boesen 2020) that simply divides revenues needed for the HTF by VMT in 2018. That analysis finds that a federal VMT tax of 1.2 cents per mile for light-duty vehicles would raise $35 billion per year, equivalent to our estimate for the share of revenue needed from household vehicles (Section 2.3.2). This lower estimate reflects the static nature of the analysis, which assumes no changes in driving behavior when a VMT tax is implemented. In our modeling, drivers respond to the VMT tax (and other changes in driving costs) by driving less, which implies that a higher tax rate is needed to achieve the revenue target.

The C scenario levies a per-mile tax for accidents and congestion and a per-gallon tax for CO_2 and air pollution based on the external damages from driving. It is not a fully efficient tax because it averages costs within each county and across time (rather than applying taxes that vary based on precise location and time of driving), and it does not account for any spatial and temporal variation in accident externalities. Nonetheless, it draws on the best information available for our modeling tools, and it updates past estimates from the literature.

On average across the country, the tax is 16 cents per mile, five times higher than the level in B3 that maintains highway performance. This suggests that current and proposed tax rates on vehicles focused on funding infrastructure are far below external damages, especially from ICE vehicles. The revenue raised from this scenario averages $310 billion per year between 2025 and 2035, or 2.5 times higher than the target revenue in the B scenarios. In theory, revenue raised from these externality taxes could be used to reduce other, more distortionary taxes (e.g., Parry and Small 2005).

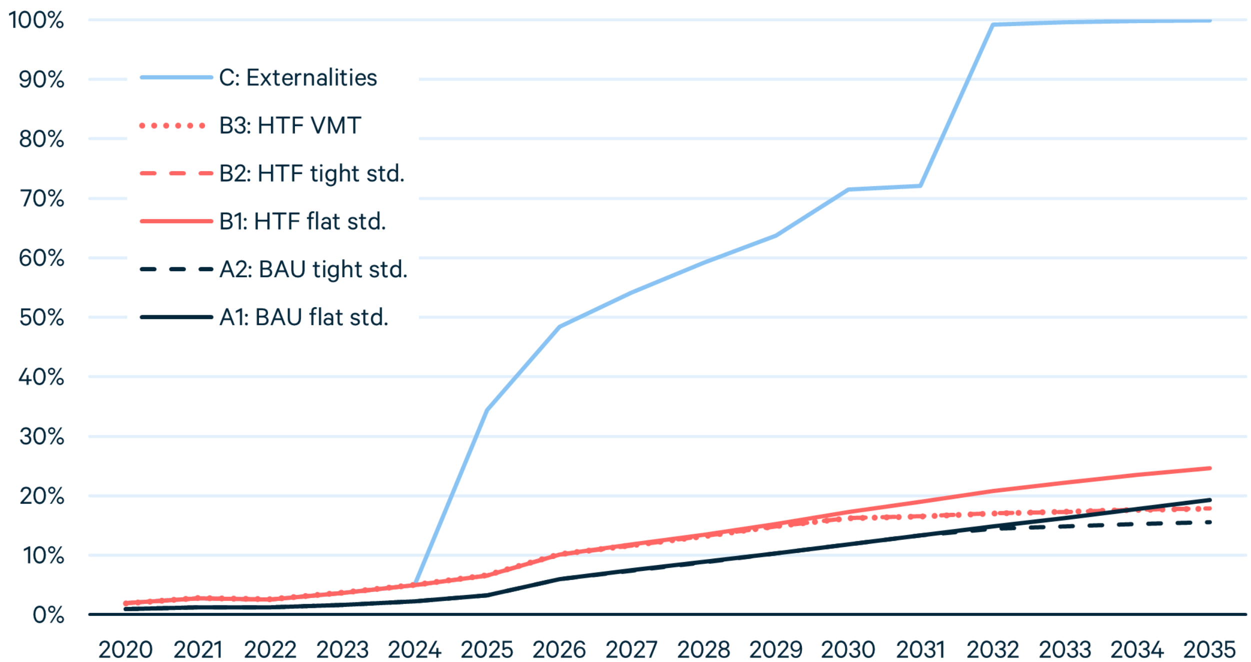
Revenues in the C scenario are roughly four times higher than those in the B scenarios in 2026 (the first year the full VMT tax takes effect), but then they fall to roughly three times the revenues in the B scenarios by 2035, as fewer ICE vehicles pay the pollution portion of the VMT tax (all drivers pay the accident and congestion portions). Although tax revenues are very high under the C scenarios, they would decline over time as EV penetration rises, which could create new revenue gaps if VMT tax revenues are used for specific purposes (e.g., reducing payroll taxes).

3.2. New vehicle market for households

This section discusses how fuel and VMT taxes affect EV market shares. Overall, the EV market shares vary relatively little across the A and B scenarios, largely because the ZEV standards are driving EV sales in ZEV states. Under our A scenarios, new EV sales grow from 1 percent near the beginning of the projection period to almost 20 percent by 2035, assuming fuel economy standards remain unchanged after 2026 (A1 scenario). When these standards are tightened (A2 scenario), the financial benefits of increased fuel economy push more purchases to ICE vehicles, reducing EV sales to 16 percent in 2035. A similar dynamic holds for our B1 and B2 scenarios, but EV penetration is higher than in the A scenario counterparts because of higher fuel taxes on ICE vehicles. This suggests that tighter fuel economy standards create a dilemma, especially if gasoline is being taxed well below its marginal social cost. The standards push more ICE vehicles into the market over EVs, but less gasoline is used overall. For the B3 scenario, in which all drivers are required to pay a VMT tax and fuel economy standards are extended, the EV sales share is unaffected, reaching 18 percent by 2035.

Imposing the full cost of driving on all household vehicles (scenario C) pushes sales of new EVs to nearly 100 percent by 2032, as the costs of greenhouse gas emissions and pollution make purchasing a new ICE vehicle uneconomic for almost all consumers (Figure 5). This provides a rough estimate of how high pollution taxes might have to be to convert all new light-duty sales to electric by the early 2030s, although many ICE vehicles would remain on the road for years to come.

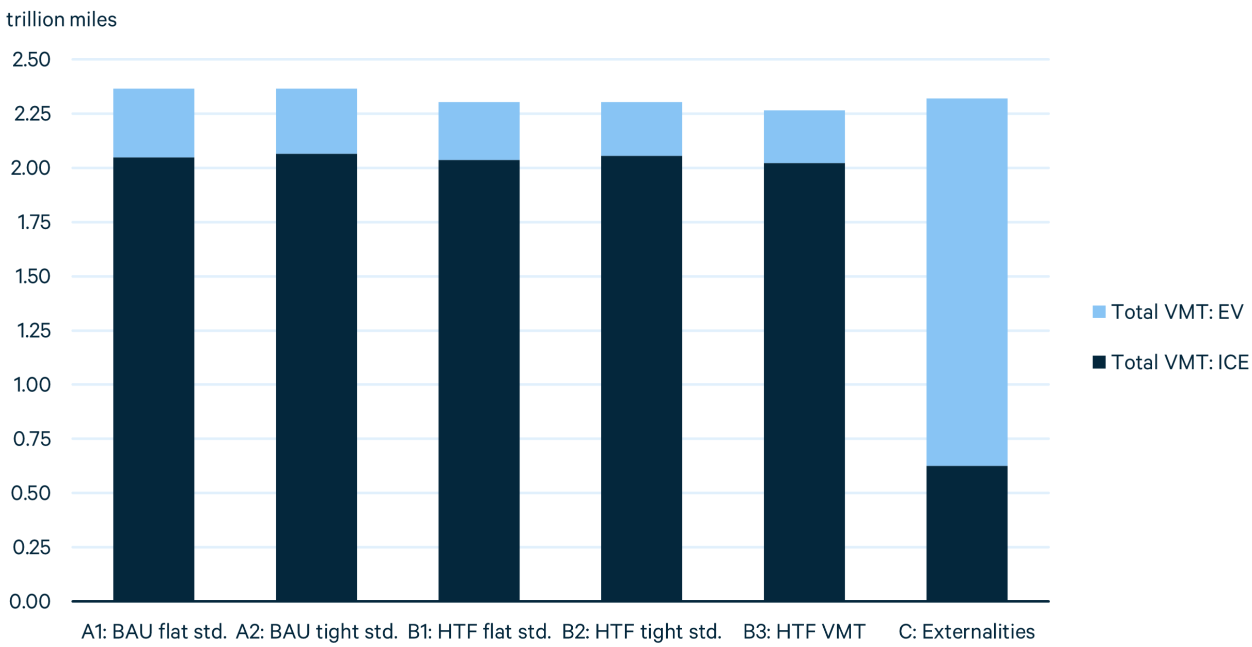
Figure 5. EV Share of New Vehicle Sales



3.3. VMT and gasoline consumption

For the most part, fuel taxes and VMT taxes have modest effects on VMT. Total VMT for ICE vehicles remains virtually unchanged in the A and B scenarios, with the exception of scenario B3, which imposes a VMT tax on all vehicles and reduces driving by 1.6 percent in 2035 for ICE vehicles. EVs, which pay a VMT tax in all the B scenarios, demonstrate a more substantial response to this policy, reducing VMT in 2035 by 16 to 20 percent relative to the A scenarios. Under the C scenario, the composition of the vehicle fleet and VMT shift heavily to EVs, but the total amount of VMT across the fleet differs little from that in the A or B scenarios (Figure 6).

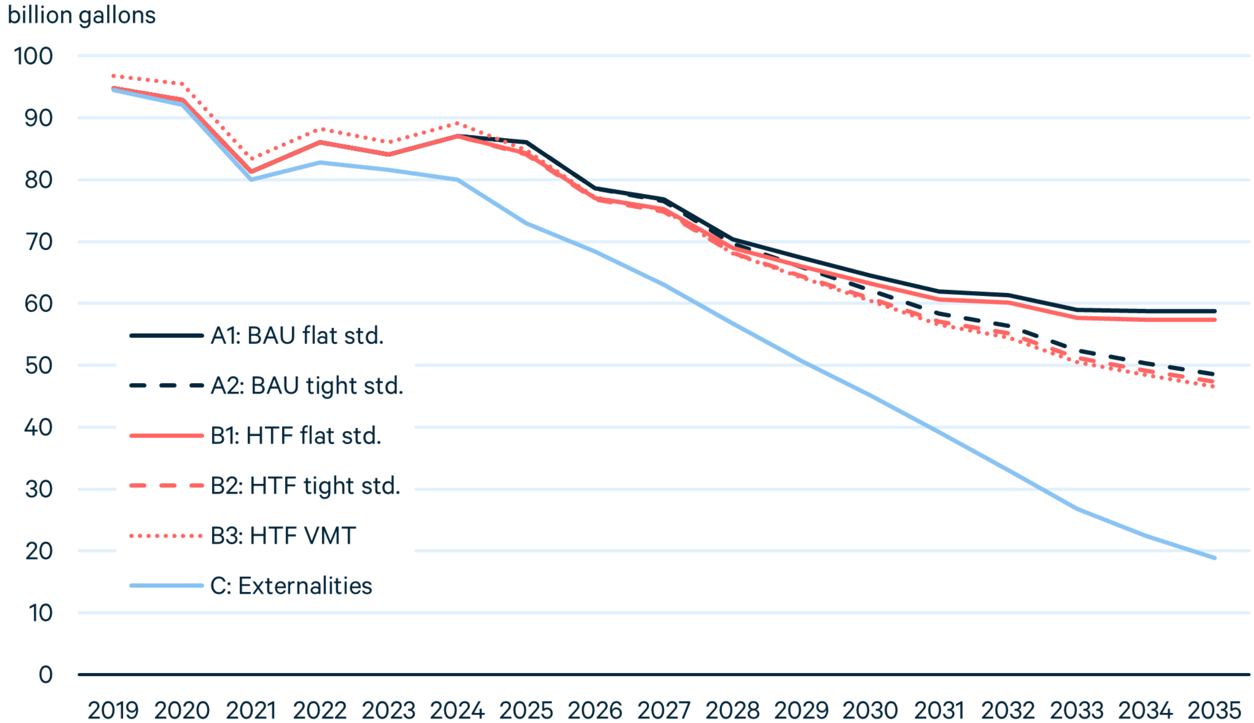
Figure 6. Total Vehicle Miles Traveled in 2035 by Vehicle Type



This result is somewhat surprising because, unlike the A and B scenarios, the C scenario fully prices congestion and accidents, and we would expect this price signal to reduce VMT, all else equal. However, EV driving costs under the C scenario are lower than ICE driving costs under the B scenarios, which causes a large shift in VMT from ICE vehicles to EVs in the C scenario. Total VMT is similar for the B and C scenarios, reflecting the relatively inelastic demand for VMT with respect to driving costs.

The reduction in petroleum consumption associated with decreased ICE driving would substantially reduce air pollution and greenhouse gas emissions, particularly if the carbon intensity of the electricity mix continues to decline. By 2035, fleetwide gasoline consumption falls to 19 billion gallons under the C scenario, compared with a range from 47 to 59 billion gallons under the A and B scenarios. However, gasoline consumption and related emissions decline considerably under all scenarios, falling from 2019 levels by 38 percent under scenario A1 and as much as 80 percent under scenario C (Figure 7).

Figure 7. Gasoline Consumption of Household Vehicles



4. Conclusions

Our results illustrate the challenge for transportation funding: as demand for petroleum-based fuels declines in the United States, policymakers will need to find alternative funding sources to sustain transportation infrastructure. Under current policies, revenues will continue to decline as vehicles become more efficient and motorists switch to EVs. Revenue gaps will grow further if policymakers adopt policies to reduce greenhouse gas emissions and other pollutants by boosting fuel economy standards and adoption of EVs.

Recognizing this challenge, state and federal governments have begun experimenting with pilot programs that tax VMT. Our results suggest that a VMT tax of $0.03 per mile could provide sufficient funding to maintain transportation infrastructure. However, governments seeking to adopt and implement such a policy will face substantial technical and political challenges. Establishing and operating a VMT tax program will be costly, especially during the transition away from the established practice and existing infrastructure of taxing gasoline. Improving technologies over time will likely reduce implementation costs and improve compliance rates. Public opinion on VMT taxes is mixed, but compliance and acceptance by the public will likely improve if programs are phased in gradually and include options for fee collection that reduce privacy concerns.

A VMT tax has a variety of desirable attributes. It could, in theory, be adjusted to account for the weight of the vehicle and the location and time of driving, better reflecting the external costs associated with air pollution, congestion, and accidents. In our scenario that fully prices these externalities, government revenues are double or triple the levels needed to maintain highway infrastructure, potentially allowing policymakers to reduce other, more distortionary taxes. However, our results suggest that pricing these externalities into a VMT tax may have relatively little effect on the number of miles driven, so it may have limited effect on congestion- and accident-related externalities (though it would have large environmental and public health benefits).

From a climate change perspective, gasoline consumption and associated GHG emissions can be reduced through multiple channels. Today both major federal policies that reduce GHG emissions in the transportation sector—fuel economy standards and incentives to purchase EVs—widen the gap between tax revenues and funding needs to maintain highway performance. Our results indicate that a VMT tax could plug this gap while further incentivizing the shift away from ICE vehicles. Indeed, our simulations show that adopting a VMT tax for EV drivers exclusively would have little effect on EV adoption and only a moderate effect on driving behavior.

Future research can build on this analysis by incorporating additional scenarios, sensitivities, and analysis of the distributional consequences of different policies. We see the distributional consequences of changes to transportation tax policy as particularly salient for several reasons. First, increased attention to equity issues in the fields of energy and environmental economics highlights the importance of carrying out such analyses before implementing major policy changes that could differentially affect households. Second, policymakers have increasingly focused on equity issues when considering future energy and environmental policies, and informing their decisionmaking will require analyses of the distributional consequences of policies. Third, the idea of a VMT tax has raised concerns that rural households would bear a disproportionate burden due to longer driving distances, and research can help demonstrate the extent to which this concern may play out under different policy designs.

Along with examining distributional consequences, future research could evaluate alternative policy scenarios, which could include allowing the VMT tax to vary depending on when and where the vehicle is driven, vehicle weight, or other factors. Sensitivity analysis could also be conducted on key parameters of the tax rate, such as externalities from congestion, greenhouse gas emissions, and more. Researchers could also estimate the effects of different approaches to phasing in a VMT tax and the potentially large variation in implementation costs under different assumptions for technologies and consumer acceptance.

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6. Appendix

A.1. Developing revenue estimates

To generate our revenue target in the B scenarios, we estimate the portion of total federal and state revenues that come from household vehicles. Because these data are not collected or estimated by state or federal agencies, we take the following approach.

We begin with data from the US Energy Information Administration (EIA), which provides transportation sector energy use by fuel type in Table 36 of its *Annual Energy Outlook* (EIA 2021). Although the *Annual Energy Outlook* is known primarily for its projections, it also includes historical data, which we extract for years 2015 through 2020. These data are provided in British thermal units and are broken down into the amount of energy used by various vehicle and fuel types. Vehicle types include light duty, commercial light trucks, freight trucks, and buses. Fuel types include motor gasoline, E85 (a gasoline-ethanol blend containing more than 50 percent ethanol), diesel, compressed natural gas, liquefied natural gas, propane, electricity, and hydrogen.

To convert the energy usage of various vehicles to government revenues, we use the Department of Energy (DOE) Alternative Fuels Data Center's fuel properties comparison chart (Putzig et al. 2021). From these data, we convert energy consumption for each vehicle and fuel type into gallons, pounds for natural gas and hydrogen, or kilowatt-hours for electricity.

Having converted all fuel use data into their taxable units (e.g., gallons of gasoline), we can then calculate the federal and state taxes per gallon, pound, and kilowatt-hour sold. The current federal excise tax rates for gasoline, gasohol (E90 ethanol), and diesel can be found in the federal *Highway Statistics Series* (FHWA 2021, Table FE-101A). For state taxes, we use annual state gas and diesel excise tax estimates from the same source, where an average state tax is constructed as a weighted average on gross gallons taxed (FHWA 2021, Table MF-205). We average state tax rates from 2015 to 2020. The *Highway Statistics Series* also documents state tax rates on liquefied petroleum gas (propane) and gasohol (FHWA 2021, Table MF-121T). Finally, we apply a federal excise tax rate for compressed natural gas (CNG) based on a summary from the DOE (AFDC 2022b). The tax rate is given in units of gasoline gallon equivalents (GGE), and the summary provides the conversion factor from pounds of CNG to GGE. We compute an average state CNG tax from the same source and only for the states with laws taxing CNG (30 states, according to the database).

Using these methods, we estimate that 66.2 percent of federal and 70.9 percent of state tax revenues come from light-duty vehicles. The remaining revenue is from motorcycles, commercial light trucks, freight trucks, buses, and other vehicles. To validate our findings, we check the *Highway Statistics Series*, which reports that all private and commercial vehicles used an average of 70.25 percent of all motor fuels from 2015 to 2020 (FHWA 2021, Table MF-21). Additionally, using the average dollars-per-gallon prices of the fuels in our analysis for those same years (AFDC 2022a), we calculate an overall expenditure of 71.03 percent from light-duty vehicles. These values are similar enough to our results to give us confidence in our tax revenue estimates.

A.1.1. Fuel consumption from fleet vehicles

To arrive at our revenue target for household vehicles, we next need to estimate the fuel consumed by light-duty vehicles that are owned by households (relative to fleet vehicles such as publicly owned vehicles, taxis, or rental cars). DOE's *Transportation Energy Data Book* shows that on average from 2015 through 2019, 3.6 and 3.5 percent of cars and light trucks, respectively, were part of commercial or government fleets (Davis and Boundy 2021, Table 8.1 for fleet vehicles, Tables 4.1 and 4.2 for all vehicles). However, commercial vehicles were driven considerably more than the national average. Across all US vehicle ownerships, cars averaged 13,000 and trucks averaged 11,000 VMT per year (Davis and Boundy 2021, Tables 4.1 and 4.2). Commercial vehicles, however, averaged 22,000 VMT per year for cars and trucks (Davis and Boundy 2021, Table 8.3). Government vehicles were driven less, averaging roughly 9,000 VMT per year for cars and 7,000 for trucks (Davis and Boundy 2021, Figure 8.2).

Fuel economy data for fleet vehicles were not available, but if we assume that commercial and government fleet vehicles achieve the same fuel economy as the nationwide average, fleets would account for 5.5 percent of total fuel consumption in cars and 4.8 percent for light trucks (Davis and Boundy 2021, Tables 4.1 and 4.2).

For cars and light trucks, we estimate that fleets account for 5.1 percent of light-duty fuel consumption. From this, we estimate that household vehicles contribute 94.9 percent of all fuel tax revenues from light-duty vehicles. Combining this with our estimates of the light-duty vehicle share of revenue for state (70.9 percent) and federal (66.2 percent) fuel taxes, we estimate that household vehicles contribute 67.3 and 62.8 percent of state and federal fuel tax revenues, respectively.

A.1.2. Estimating revenue levels

After calculating the *share* of revenue that household vehicles would need to contribute, we need to determine the appropriate *level* of revenue. There are multiple approaches for choosing a level of revenue. For our B scenarios, we rely on analysis conducted by the Congressional Budget Office (CBO). In testimony from April 14, 2021, CBO director of microeconomic analysis Joseph Kile stated, based on CBO analysis of data from the FHWA, that federal and state highway spending would need to be $99 billion annually from 2023 through 2031 to maintain highway performance at 2014 levels.

If the share of federal and state spending on capital improvements and maintenance remains constant, CBO estimated that maintaining performance at 2014 levels would require annual spending of $56 billion and $44 billion from the federal and state governments, respectively. If household vehicles provide 67.3 and 62.8 of state and federal tax revenues, respectively (Section A1.1), this would mean $35 billion in federal revenue and $29.3 billion in state revenues, for a total of $64.3 billion (Table A1).

Table A1. Annual Revenues Needed to Maintain Highway Performance at 2014 Levels (billions 2021$)

	Total	Household share
Federal	$55.7	$35.0
State	$43.5	$29.3
Total	$99.2	$64.3

A.2. Developing congestion cost estimates

A.2.1. Congestion in urban areas

The Federal Highway Administration's Highway Performance Monitoring System defines roughly 400 urban areas (UAs), which include metropolitan areas of about 500,000 population and up. The Texas Transportation Institute (TTI) has estimated congestion levels for each of these areas, finding the average number of extra hours lost in commuting on congested streets over and above the time that would be spent if roadways were not congested (Schrank et al. 2021). Examples of these additional annual hours due to congestion per driver range from 56 hours per year per driver in the New York–Newark, NY–NJ–CT Urban Area to 1 hour in the Alton, IL–MO Urban Area.

These are the five highest congestion regions, followed by the number of hours per year per driver:

- New York–Newark, NY–NJ–CT: 56
- Boston, MA–NH–RI: 50
- Houston, TX: 49
- Los Angeles–Long Beach–Anaheim, CA: 46
- San Francisco–Oakland, CA: 46

And these are the five lowest:

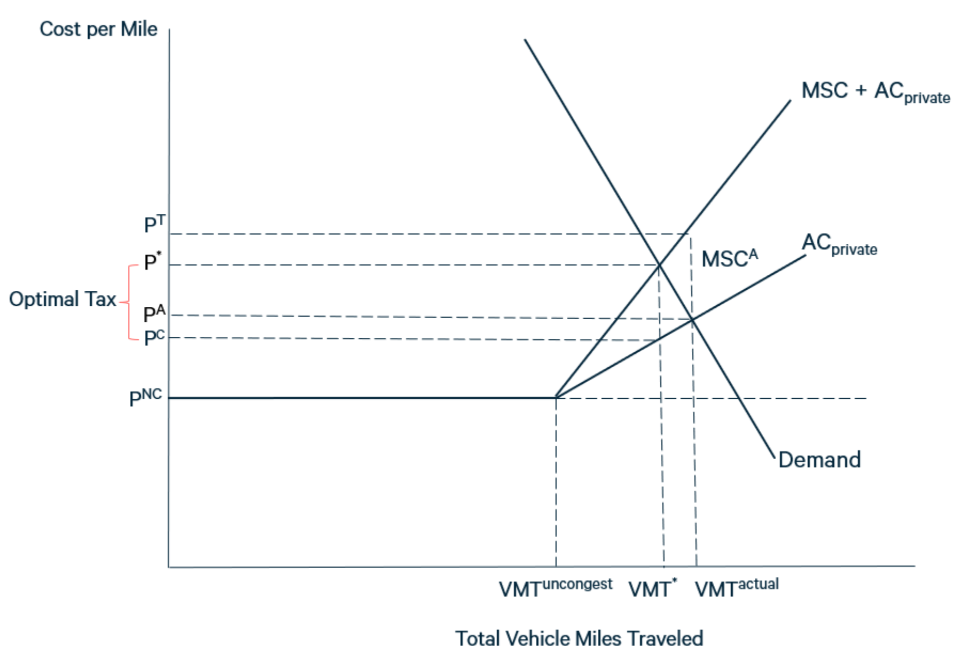
- Alton, IL–MO: 1
- Round Lake Bch–McHenry–Grayslake, IL–WI: 1
- Lake Havasu City, AZ: 2
- Ames, IA: 3
- Danville, IL: 3

A.2.2. Finding the optimal tax on congestion for the urban areas

We find the current costs per mile from congestion in each urban area by multiplying hours lost per driver by $12.86, which was half the US mean wage in 2019 (BLS 2020) and dividing by the number of miles driven in each area.

Figure A1 shows average traffic conditions and traffic costs to motorists for a representative city in our sample. Average costs of driving with no congestion include the costs of fuel, maintenance, insurance, and depreciation. In the graph, this cost is shown as P^{NC}. For all the urban areas in our sample, we use the AAA estimate of the average cost for a sedan, 50 cents per mile (AAA 2021). Travel on roads in the urban area occurs up to the point where there is congestion, shown in the graph as $VMT^{uncongest}$.

Figure A1. Average Traffic Conditions in Example Region



With greater total vehicle miles traveled on the roads, congestion increases and motorists face higher costs due to delays. These costs increase with traffic volume, as shown by $AC_{private.}$ For congested urban areas like the one shown in the graph, actual average traffic volume is VMT^{actual}, and the average cost per mile to motorists is P^{A}. The difference between P^{A} and P^{NC} is the average delay on a per-mile basis for the particular urban area. This is the cost of driving to the motorist. But there are external costs of congestion because each motorist who enters a roadway slows down traffic for all other motorists using the roadway. These external costs are shown by the addition of the marginal social cost (MSC) to the private cost of driving (Parry 2009). The full social costs (private plus external) are shown by the line MSC + ACp_{rivate}.

To internalize the cost of congestion, the congestion fee must reflect the MSC of congestion. But the optimal fee to charge for congestion will be less than the MSC of congestion at VMT^{actual}. This is because when the fee is levied, miles traveled will fall, and congestion will decrease. The optimal fee per mile is shown as the difference between P^{*} and P^{C} in Figure 1, and it is associated with total vehicle miles traveled, or VMT^{*}.

For each urban area, we calculate the optimal tax. From TTI data, we have uncongested and congested travel volumes. We also know actual congestion costs (hours lost for the average driver), from which we calculate average private costs including congestion, $AC_{private}$. MSC estimates evaluated at VMT^{actual} are taken from Parry (2009, equation 4), and we use the estimate of 1.07 for beta, the speed-density function, from Yang et al. (2020). However, as we have shown in the graph, this estimate of external congestion costs is too high. Using linear cost functions and a constant elasticity demand curve (following Yang et al. 2020), we can solve for the optimal congestion tax P^{*} for each urban area. We find that the optimal tax on congestion is, on average, 14 percent lower than congestion externalities at current traffic conditions.

A.2.3. Converting urban area congestion taxes to average county congestion taxes

TTI's estimates of congestion cannot be used directly in our model, which uses county-level data, because the UAs are defined over street networks and do not have the same boundaries as US counties. In many cases, the UAs overlap multiple counties or include portions of counties.

We use the UAs and county-level GIS files to find the areas of overlap and designate separate areas within each county that are UAs and non-UAs. TTI provides estimated hours lost to congestion for each of the UAs. We assume that the non-UA parts of counties have zero hours lost. (This is a reasonable assumption because the smallest of the UAs with estimated congestion have hours lost that are close to zero.) We have population data for each county from the 2020 US Census.

For counties that are wholly within a UA, we use the hours lost from congestion from the TTI estimates for that urban area. For counties that are only partly in one or more UAs, our approach is to find the share of population in the whole county that is within the UA boundaries. For example, Ventura County, California, has one UA that is wholly within the county, the Oxnard UA, and a small area that is within the Los Angeles UA. The county also includes a large non-urban area, which is assumed to have zero congestion cost. To get our estimate of the hours lost to congestion in Ventura County, we weight hours lost to congestion in each UA segment of the county by the population share of each segment. For Ventura County, it would be

$$HR_{VC} = HR_{LAUA*} Pop_{LAUA}/Pop_{VC} + HR_{OXUA} * Pop_{OXUA}/Pop_{VC}$$

where HR is hours lost, VC is Ventura County, LAUA is the Los Angeles Urban area of the county that is in VC, OXUA is the Oxnard urban area, and Pop is the population in different areas of the county.

To obtain the congestion cost per mile by county, we use the HR estimates by county and multiply by the average national hourly wage rate to get average annual congestion costs. We divide that by annual VMT to get $/mile in each county:

$$\$/mile_C = HR_C * w_C /VMT_i$$

where HR_C is annual hours lost per year due to congestion for average driver, W_C is average hourly wage rate, and VMT_i is average VMT a vehicle travels per year.

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