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Working Paper 30746
http://www.nber.org/papers/w30746

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
December 2022

Glaeser and Gorback acknowledge support from the US Department of Transportation under NSF grant SES1559013 to the NBER. The authors thank David Austin, Elaine Buckberg, Dorian Carloni, Gilbert Metcalf, Clifford Winston, and participants at the NBER Environmental and Energy Economics Summer Institute and Tax Policy and the Economy conference for helpful comments and guidance. Poterba is the president of the NBER, which receives unrestricted corporate support from firms in both the energy and automotive industries. Any views expressed are those of the authors and should not be interpreted as representing the views of the USDOT or the NBER.

At least one co-author has disclosed additional relationships of potential relevance for this research. Further information is available online at http://www.nber.org/papers/w30746.ack

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JEL No. H23,R48

ABSTRACT

Pigouvian taxes and user fees can address environmental externalities and efficiently fund transportation infrastructure, but these policies may place burdens on poorer households. This paper presents new evidence on the distributional consequences of the gasoline tax, bus and light rail charges and a vehicle miles traveled (VMT) tax. Gas taxes have become more regressive over time, partially because of environmentally-oriented technological change, although the share of expenditures on gas taxes declines with expenditures much less than the share of income spent on gas taxes declines with income. Replacing the gasoline tax with a household-level VMT tax would increase the average tax burden on households in the top income and expenditure deciles, because of their greater use of hybrid-electric and battery-electric vehicles. This progressive shift would be small given current levels of hybrid and electric vehicle ownership, but will be larger in the future if such vehicles continue to be more common among higher than lower income households. An expanded commercial VMT would place a larger burden, as a share of expenditures, on lower income or expenditure households, because better-off households consume more non-tradable goods that do not require transportation. User charges for airports, subways and commuter rail are progressive, while bus fees loom much larger for lower income households.

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Introduction

Consumption of transportation services is replete with externalities such as carbon emissions, traffic congestion, and motor vehicle fatalities. Economists have long embraced user fees to address these externalities. In *The Wealth of Nations*, Adam Smith wrote that user fee financing would promote efficient investment decisions, for if transportation infrastructure is "made and supported by the commerce which is carried on by means of them, they can be made only where that commerce requires them, and consequently where it is proper to make them." William Vickrey (1952) called for taxes and time-varying charges for subways to address congestion externalities, and Small, Winston and Evans (1989) were early advocates of a commercial Vehicle Miles Traveled (VMT) tax to charge truckers for the marginal damages they impose on roads. Yet Pigouvian mobility charges such as highway tolls and gas taxes remain politically unpopular because they are salient and seen as regressive. When President Biden called for a gas tax holiday on June 22, 2022, he justified this policy by arguing that "high gas prices pose a significant challenge for working families."[1]

Transportation infrastructure in the U.S. is funded through a combination of user fees, such as tolls and gasoline taxes, and general government resources. User fees play a significant role in funding airports and public transportation. When purchasing an airline ticket, for example, a consumer will pay a variety of user fees to different government entities, including taxes or fees to the Federal Aviation Administration (FAA), the Environmental Protection Agency (EPA), the Department of Homeland Security (DHS), and the local airport.

But gasoline and diesel taxes at the federal level have declined in real value over time, since nominal tax rates have been fixed since 1993 and total fuel consumption has plateaued for the last 15 years. The U.S. Energy Information Agency reports that total U.S. consumption of gasoline reached 3.39 billion barrels in 2007, and was at roughly the same level – 3.40 billion barrels in 2019, before a pandemic-related drop to 2.95 billion barrels in 2020.[2] As electric vehicles replace cars and light trucks powered by internal combustion engines, the revenue from gasoline and diesel taxes, which currently fund the Highway Trust Fund, will

[1] Available at https://www.whitehouse.gov/briefing-room/statements-releases/2022/06/22/fact-sheet-president-biden-calls-for-a-three-month-federal-gas-tax-holiday/

[2] See "Finished Motor Gasoline" dispositions available at the U.S. EIA: https://www.eia.gov/dnav/pet/pet_sum_snd_d_nus_mbbl_a_cur-1.htm

grow more slowly and eventually decline. The gas tax will also become more regressive, because higher income households disproportionately own hybrid-electric vehicles (HEVs) and battery-electric vehicle (BEVs), which we collectively refer to as BHEVs. Owners of these vehicles pay much less - nothing, in the case of BEVs - in gasoline taxes per mile than the drivers of internal combustion engine (ICE) vehicles. The Energy Information Administration reports, based on the 2017 National Household Travel Survey, that 42% of the households owning a plug-in hyrbid or electric vehicle have household income of more than $150,000, while only 14% of all households are in this income range.[3] The gap between transportation-related revenues and expenditures and the increasingly regressive nature of the gas tax, has generated interest in new funding sources, including a VMT tax which can be levied on both households and commercial drivers. At the same time, there is new attention to expanding transportation infrastructure, which is often financed in part with user fees. The Infrastructure Investment and Jobs Act of 2021 (IIJA) provides grants for states and localities to build vehicle charging infrastructure, to replace or update public buses with low- or no-emission vehicles, and to explore options for electrification of commercial trucking at U.S. ports. This paper considers the distributional impact of mobility-related user fees, including charges for airports, subways, commuter rail, and buses, with particular attention to gasoline taxes and Vehicle Miles Traveled (VMT) taxes.

We begin by presenting information on the distribution of outlays on current user charges that support transportation infrastructure such as public transportation user fees and the federal gasoline tax. Like Chernick and Reschovsky (1997) and Poterba (1991), we compare payments relative to income, the more common test of regressivity, with payments relative to household expenditures. The logic of the permanent-income hypothesis suggests that household expenditure may provide a better measure of long-term well-being than current income. Consequently, we focus more on the expenditure-based measure but we also report income-based measures for completeness.

The share of expenditure devoted to public transportation declines with total expenditure over much of the expenditure distribution, although it rises at high expenditure levels as a

[3] Stone, David. "Electrified vehicles continue to see slow growth and less use than conventional vehicles," *Today In Energy*. U.S. Energy Information Administration. May 22, 2018.

result of commuter rail and air travel usage. Bus trips are far more frequent for low income individuals. Commuter rail and air travel usage increase with expenditure. In areas with developed subways systems, subway trips are relatively independent of total expenditures.

Households in the highest income or spending category devote a smaller share of their budget to gasoline expenditures than do less-well-off households. Gasoline spending accounts for close to 5 percent of total expenditures, among those spending less than $30,000, and less than 2 percent of spending among the highest-expenditure households. Take for example, a household with two cars, each delivering 24 miles per gallon, that drives a total of 18,000 miles per year purchases 750 gallons of gasoline annually. With an 18.4 cent per gallon federal gasoline tax, and an average state gasoline tax of 26 cents per gallon, this household would pay $333 in gasoline taxes, which could be one percent of a poorer household's total expenditure. Not only would these tax payments represent a much smaller share of a wealthy household's annual expenditure, such a household could avoid these taxes altogether by replacing both vehicles with BEVs. Imposing a VMT would eliminate the implicit tax benefit given to hybrid-electric and battery-electric vehicles and charge drivers for their impact on road wear and tear.

BHEVs currently account for only about three percent of the US auto fleet, so even with the skew toward higher income owners, the distributional pattern of payments for a VMT tax would be very similar to that for an equal-revenue gasoline tax. However, the share of BHEVs in the fleet is rising, particularly among well-to-do households. In the fourth quarter of 2021, the Energy Information Agency reports that 6.1% of new sales were hybrids, 3.4% were electrics, and 1.4% were plug-in hybrid electrics (PHEVs).[4] In addition to considering the current setting, we therefore also consider the relative distribution of burdens from a gasoline and a VMT tax in a future year in which BHEVs account for one third of the vehicle fleet. If the new BHEVs are distributed across the households in roughly the same way as current ones, the distributional burdens of the gasoline tax and VMT tax will diverge, with substantially lower burdens for gasoline taxes than for VMT taxes at high income or expenditure levels.

[4] Dwyer, Michael. "Electric vehicles and hybrids surpass 10% of U.S. light-duty vehicle sales," *Today in Energy.* U.S. Energy Information Administration. February 9, 2022.

We also consider a commercial VMT (CVMT) tax. Four states, Kentucky, New York, Oregon and- New Mexico, have already adopted such taxes. Under the assumption that trucking costs are fully passed through to consumers of tradable goods, and that CVMT tax charges are added to trucking costs, a household's burden from a commercial VMT tax depends on the share of its budget share that is spent on tradable goods that need to be transported. Our estimates suggest that as a share of household expenditures, the current diesel tax and any expanded commercial VMT tax fall more heavily on less-well-off households than on those in the upper strata of the income or expenditure distribution. Better-off households consuming more services, which do not require much transportation, and devote a smaller budget share to tradable goods.

This paper builds on a long literature on the distributional impacts of transportation-related Pigouvian taxes. Metcalf (1999) noted that environmental taxes meant to mitigate the social damage of pollution tend to be regressive, and Levinson (2019) found that regulating fuel efficiency was more regressive than imposing fuel taxes to reduce consumption. The closest antecedent to our study is Metcalf's (2022) comparison of the distributional impact of a VMT tax and a gasoline tax. It relies on data from one of the two surveys that we analyze, and reaches similar conclusions about the progressivity of the VMT-for-gas tax swap. Our study makes different assumptions in forecasting the future growth of EVs in the vehicle fleet and takes a less parametric approach to summarizing distributional burdens, so the two studies are complementary. Our study also builds on earlier studies of the VMT tax including Davis and Sallee (2020), Fox (2020), Langer, Maheshri and Winston (2017), van Dender (2019), and Weatherford (2012). Our analysis focuses exclusively on tax burdens, and does not consider the distribution of transportation related externalities, such as pollution, that may be reduced by a gasoline tax or a VMT tax. Banzhaf, Ma and Timmins (2019) find these externalities to disproportionately burden low-income households. Jacqz and Johnston (2022) investigate the effect of current patterns of BHEV adoption in reducing environmental and other externalities, and observe that these effects would be larger if there was higher BHEV penetration in lower-income communities.

The remainder of this paper is divided into six sections. Section 1 introduces the two main data sets, the Consumer Expenditure Survey (CEX) and the National Household Travel

Survey (NHTS), that underlie our analysis. The next presents our core findings on the distributional impacts of current public transportation user fees. Section 3 summarizes current gasoline expenditure and gasoline tax burdens and highlights changes in the characteristics of the U.S. vehicle fleet over time. Section 4 considers the difference in the distribution burden of a VMT tax and a gasoline tax, both with the current level of HEV penetration in the vehicle fleet and a higher level designed to reflect a future year. Section 5 examines the impact of a CVMT tax on the prices paid by consumers for various final goods, and presents estimates of the distribution of burdens associated with this tax. There is a brief conclusion in Section 6.

1 Data Sources on Consumer Transportation Outlays: NHTS and CEX

Our household travel and expenditure analysis draws on two primary datasets. One is the National Household Travel Survey (NHTS), which includes information on transportation utilization by mode, vehicle characteristics, and driving behavior. It also includes information on household income. The NHTS is conducted every 8 years to study household travel patterns, and is a key input into national, state, and regional infrastructure planning. The survey recruits households and asks them about their trips in a 24 hour period, including mode, purpose, trip length, time of day, among other characteristics. These surveys are then linked to a suite of demographic and socioeconomic, vehicle, and location characteristics. We use data from three 2017 NHTS products: the household survey, the trip level survey, and the vehicle survey. This survey covers roughly 139,000 households who use 256,000 distinct vehicles and make nearly 925,000 trips on the survey date. The data are collected at the person-level, and then aggregated to households. The survey also provides weights used to aggregate households to population level statistics. We use this data set to estimate the number of households in various income ranges who are using each mode of transportation, to calculate their driving behavior, and examine vehicle characteristics. We focus on data from the 2017 NHTS, but in some cases we also draw on comparative data from the 2001 survey.

We use data on trips to study outlays on infrastructure user charges of various types. We focus on private vehicle, bus, subway, commuter rail, and airplane. The NHTS also includes data on the vehicles owned by each household, including their age, fuel type, and annual miles traveled. The NHTS has information on travel mode utilization, but not on travel expenditure, or total expenditures.

The second data set that we utilize, the Consumer Expenditure Survey (CEX), is a nationwide survey conducted quarterly by the Bureau of Labor Statistics. It provides estimates of annual expenditures on a variety of consumer goods and services, as well as total household expenditure and income. We convert CEX data from the 2019 survey, the primary focus of our analysis, to real 2017 dollars for comparability with the NHTS data. We verify, and report in Appendix Table B1, that aggregate measures computed from the public use microdata version of the CEX are comparable to the published tabulations from the Bureau of Labor Statistics.

The CEX reports tax-inclusive expenditures on gasoline, but it does not distinguish tax payments from the retail cost of gasoline. To calculate how many gallons of gasoline households have purchased and back out total federal plus state taxes paid on them, we complement the CEX sample with annual data on state gasoline prices and taxes. State motor fuels tax rates data come from the Brookings-Urban Tax Policy Center. Our focus is on the total federal gasoline user fee levied in each state in each year. To estimate gasoline costs per gallon, we use the "all grades all formulations" retail price average as reported by the Energy Information Administration (EIA). The EIA reports annual data for nine states. For the other 41 states and Washington, D.C., we use the averages that EIA reports for each of seven regions assigned by the EIA.

Most studies of household spending on gasoline and other transportation-related outlays report expenditures as a share of income. In the lowest decile of the household income distribution, reported income is substantially below household expenditure. This likely reflects the omission of some transfer program receipts in the measure of income, transitory fluctuations in income that render current income below permanent income, which is more likely to drive expenditures, and measurement error. At the highest income levels, the transitory income fluctuations may also be important, leading reported income to overstate permanent income, for example if a household realizes substantial capital gains in a particular year. These issues with reported income suggest that scaling outlays on transportation by total expenditure, rather than total income, as in Poterba's (1991) study of excise tax incidence, may provide a more informative measure of relative burdens than scaling by income.

The first panel in Figure 1 shows the ratio of expenditures to income for households in the 2017 CEX, with households grouped into deciles based on total household income. This ratio is nearly three in the lowest income decile, dropping to 1.5 in the second decile and declining smoothly to less than 0.6 in the top decile. To provide some context for the distribution, households in the lowest income decile have annual incomes below $12,158 ($2017), those in the fifth decile have incomes up to $52,147, and those in the top decile have incomes of at least $160,044.

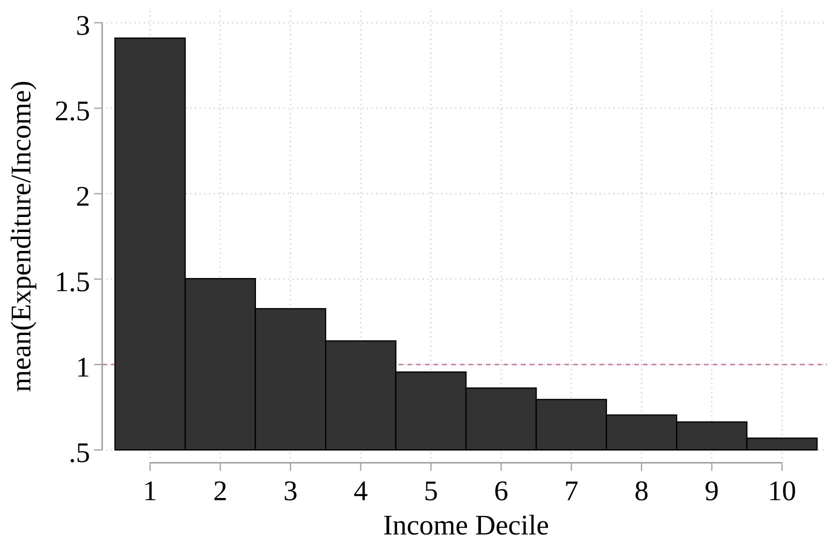
The second panel shows the expenditure-to-income ratio when households are ranked by total expenditures. It is much more stable, ranging from between 1.25 and 1.5 at the lowest two deciles, to values just above one in the middle of the distribution, and rising again at the highest expenditure decile. This may reflect the presence of infrequent outlays, such as car purchases, at the top of the expenditure distribution. Households in the lowest expenditure decile report total spending of less than $16,620. Those at the median (just above the fifth decile) report expenditures of up to $39,774, while those in the top decile have expenditures of at least $107,256. These break points for the deciles make clear that the gradient in expenditure is not as steep as the gradient in income.

Table 1 shows the distribution of CEX households across income and expenditure deciles. Nearly half of the households in the bottom income decile are in the bottom expenditure decile, and vice versa. The same is true for the top decile of each distribution. However, one third of those in the bottom income decile are in the third or higher expenditure decile, while almost one fifth of those in the highest income decile are in the eighth or lower decile of expenditures. In the middle of both the income and expenditure distribution, the share of households in the same decile of both distributions is lower, in part reflecting the narrower band of incomes or expenditures that correspond to each decile.

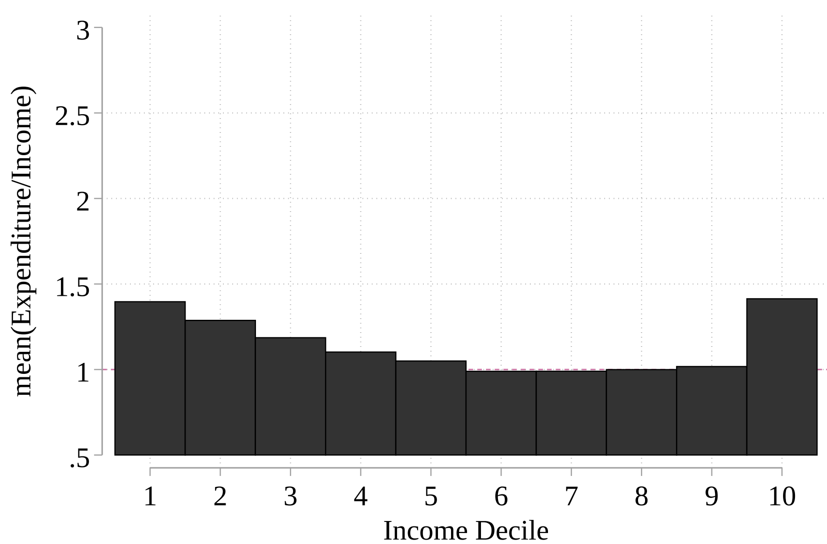
We compare expenditures for various transportation services to total household expen-

Figure 1: *Expenditure/Income* by Income and Expenditure Decile, 2017 CEX

(a) Income Deciles



(b) Expenditure Deciles



Notes: Data from the Survey of Consumer Expenditures, 2017. Panel (a) shows the average *Expenditure/Income* ratio within income deciles. Panel (b) shows the same ratio, averaged within expenditure deciles. All ratios winsorized at the 5^{th} and 95^{th} percentiles, for ease of inspection.

Table 1: Joint Distribution of Expenditure and Income Deciles

Income Decile	Expenditure Decile 1	2	3	4	5	6	7	8	9	10
1	49	18	11	7	5	3	3	2	1	2
2	32	28	15	9	5	4	3	2	1	1
3	12	25	20	15	11	6	4	3	2	3
4	4	14	22	18	15	9	6	4	3	3
5	2	8	16	20	18	15	9	5	4	3
6	1	4	10	15	18	18	14	9	6	5
7	0	1	4	9	15	20	20	15	8	7
8	0	1	2	5	8	15	22	23	17	8
9	0	0	1	2	4	9	16	23	29	18
10	0	0	0	0	1	2	5	11	28	51

Expenditure Decile	Income Decile 1	2	3	4	5	6	7	8	9	10
1	50	31	11	4	2	1	0	0	0	0
2	19	28	25	14	8	4	1	1	0	0
3	12	15	19	22	16	10	4	2	1	0
4	7	9	15	19	20	15	9	5	2	0
5	5	4	11	15	18	18	16	8	4	1
6	3	3	5	9	14	18	20	15	9	2
7	3	3	4	6	9	13	20	23	15	5
8	2	2	3	5	5	9	16	24	23	12
9	1	1	2	3	4	6	8	17	29	28
10	2	1	2	3	3	5	7	8	17	51

Notes: Entries in each panel denote the percentage of customer units in the income or expenditure decile listed in the row that are found in the income or expenditure decile in the column, as in Poterba (1990). Calculations based on the 2017 Consumer Expenditure Survey.

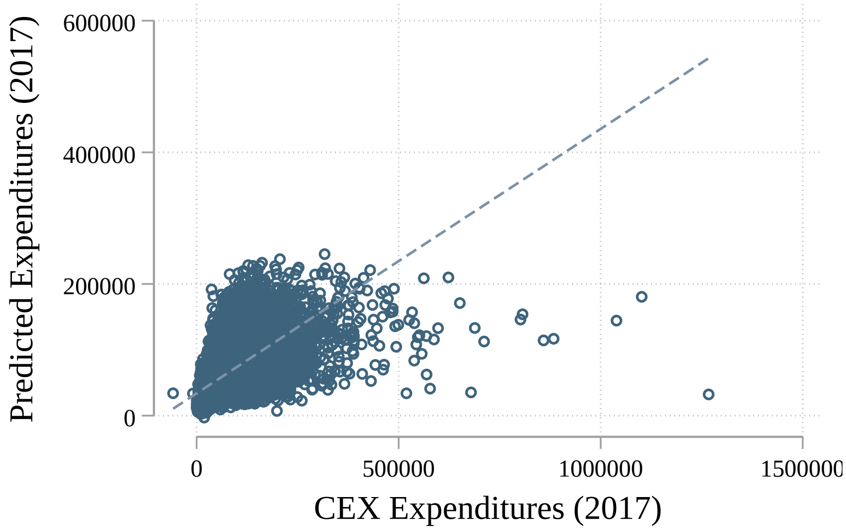
ditures, rather than reported income. We group households into deciles based on their total expenditure levels; we do not make any adjustment for household size. For transportation outlays reported in the CEX, we can compute the expenditure share directly. For transportation outlays or utilization measures drawn from the NHTS, we need to impute total expenditures; the NHTS records household income in intervals, but it does not report expenditures. We use variables other than expenditure that are observed in both the CEX and NHTS, as well as the full range of expenditure data in the CEX, to predict total expenditures in the CEX, and we then use the resulting model to impute total expenditures to NHTS households.

We impute total expenditures as a function of reported household characteristics using data from all CEX surveys for 2000 through 2019. We estimate Engel curves for total expenditure using weighted regression, with population weights in the CEX, of total expenditure on state and year fixed effects, a fourth order polynomial in household income, indicators for the household head's race, Hispanic status, employment, retirement, student status, gender, and homeowner status. We include information on education level and age by grouping households into five-year age bins, and interact the education categories with each of the age bins. We include indicator variables for families with each number of household members, along with indicators for number of children, the head of household's marital status, and the interactions between marital status and number of children. The R^2 for total expenditure in our estimating equation is 0.41, so the correlation between actual and fitted outlays is about 0.64. Figure 2 shows the scatterplot of actual and fitted total expenditure in the CEX.[5]

We predict total expenditures for NHTS households using the estimated Engel curves by harmonizing variables between the NHTS and CEX. For example, we define the income for each NHTS household as the income value at the midpoint of the income ranges in that survey. As one way of judging the similarities between the imputation of total expenditures across income classes in both the CEX and the NHTS, we regressed predictive expenditures on reported income in the CEX, and on our measure of income (midpoint of intervals) in the

[5]The estimated Engel curve appears to under-predict expenditures for high expenditure households. In 2017, for a CEX household with income of $73,590, the sample average, our estimated Engel curve implies a marginal propensity to spend out of income of 0.33. This is substantially below the average propensity to spend.

Figure 2: Model Fit: Actual and Predicted Expenditures in CEX (2017)



Notes: This figure shows the model fit for predicting total expenditures in the CEX. The horizontal axis measures observed expenditures for one year in our data, 2017. The vertical axis shows the expenditures predicted from our model. The dots each map to one household, and the dashed line shows the linear fit, weighted by each households respective population weight.

NHTS. The coefficient on reported income in the CEX is 0.41 and in the NHTS it is 0.41, suggesting some broad similarity between the two fits. The expenditure shares on gasoline from actual expenditure in the CEX and imputed expenditure in the NHTS exhibit a similar pattern, shown in Appendix Figure C1; this provides some validation for our exercise.

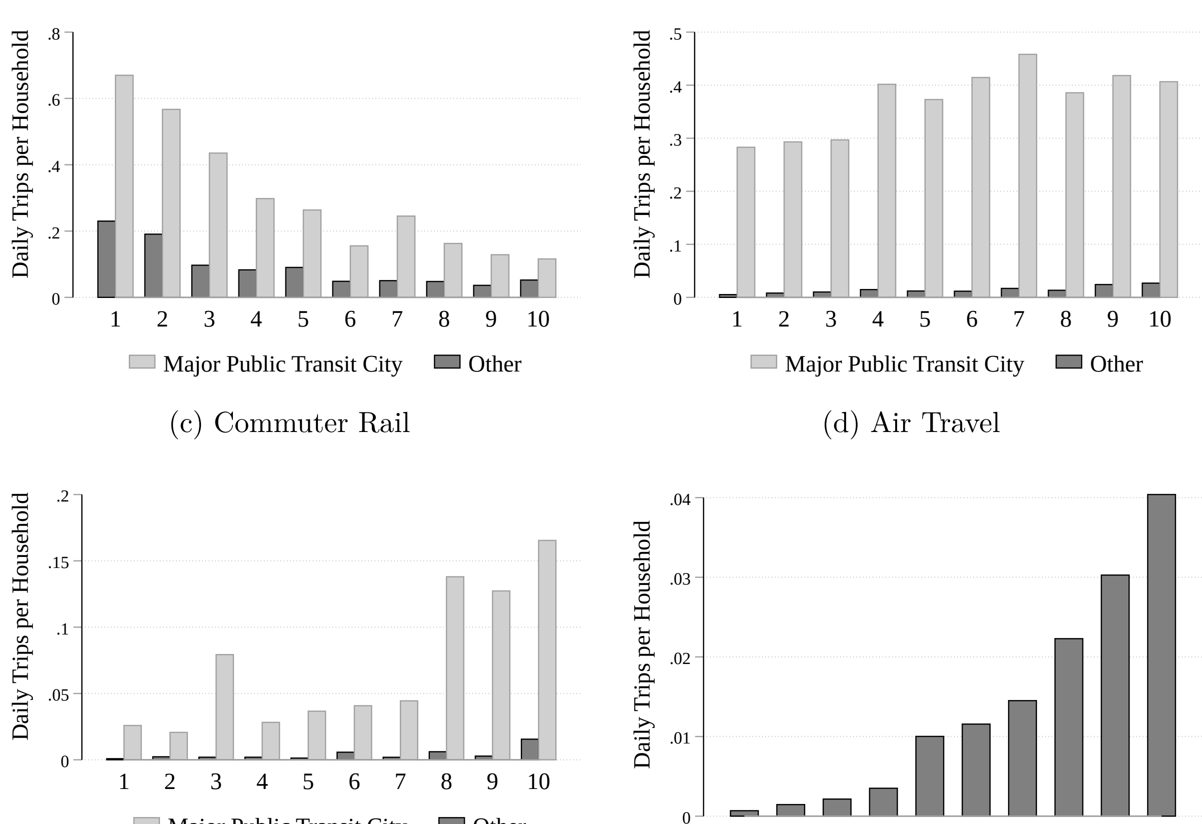
2 Heterogeneity in the Use of Public Transit and Airports

We report utilization and outlays for a number of public transportation modes. Information on utilization is essential to assessing the potential distributional impacts of levying increased fees on the use of these transport modes. While the CEX documents expenditure on public transportation, it does not differentiate modes. Detailed utilization information by mode is reported in the NHTS. As such, our baseline results focus on NHTS households classified by predicted total expenditures. The NHTS reports the number of trips taken on different modes of transportation, not the charges associated with these trips. Trip counts are, however, a key determinant of the distribution of potential burdens from user fees.

Figure 3 panels (a), (b), and (c) reports the average number of trips taken each day per household for three types of public transit - bus, subway, and commuter rail - as reported in the NHTS. We plot two bars in each case. The lighter corresponds to cities with at least 10% of the population commuting by public transit (New York, Chicago, Washington, Boston, Philadelphia and San Francisco), while the darker bars correspond to all the other major metro areas and sub-metro areas in the NHTS.

Figure 3: Public Transit Utilization in the NHTS, by Expenditure Decile

(a) Bus (b) Subway



Notes: Data from the National Household Travel Survey, 2017, trip level dataset aggregated to households. Figures do not include households with negative expenditure. Panel (a) shows the distribution of daily household trips by bus, panel (b) by subway, panel (c) by commuter rail, and panel (d) by air. Figures do not include households with negative expenditure. Figures (a), (b) and (c), split by a city's status as a major public transit city: New York City, Chicago, Boston, Washington, DC, Philadelphia and San Francisco.

Bus utilization declines as total household expenditure rises, reflecting a substitution of private for public transit. Households in the lowest expenditure decile use the bus approximately 0.7 times each day in high public transit cities, and about 0.2 times per day in other locations. In contrast, households in the highest expenditure decile use the bus only about 0.1 times each day in the high public transit cities, and about half that often elsewhere.

In contrast to riding the bus, using the subway is very popular for households in all expenditure deciles in major public transit cities, and subway use increases with expenditure. This reflects the combination of reliance of low-income inner city neighborhoods on public transit and the use of subways in many high-income neighborhoods, for example in Manhattan, where proximity to a subway is highly valued.

Commuter rail use is the most progressive of the various forms of land-based public transit. In high public transit cities, utilization is sharply higher, averaging about 0.15 trips per day, for households in the top three deciles of the expenditure distribution than for other households, for whom the average is less than one third this level. Commuter rail tends to be co-located with wealthy suburbs surrounding dense cities, and fare costs are higher than public bus or subways.

The National Transit Database (2019) reports that for the 50 largest transit authorities in the US, passenger fares cover only about 40 percent of operating costs. Thus even before considering capital costs, which are critical in public transportation, these systems are not covering costs. Increased user fees offer one potential means of closing the funding gap, and at least for commuter rail, it may be possible to raise revenues without placing disproportionate burdens on households lower in the economic distribution.

In addition to bus, subway, and commuter rail, where many of the services providers are public authorities, we also consider the distribution of airline trips across households, in Figure 3(d). Air travel involves substantial use of public infrastructure in the form of airports and air traffic control, even though airlines in the U.S. are private firms. The infrastructure services are partially funded by various taxes on airline tickets and airport utilization. The consumption of air travel is even more progressive than commuter rail use. Households in the highest expenditure decile report roughly 22 times as many trips as those in the lowest deciles, where utilization is negligible. Households in the top decile report roughly one airline trip each month. Households in the top two expenditure deciles are about twice as likely to use air travel as those in the next two deciles. These four deciles account for most airline trips. This provides guidance on the potential incidence of higher user fees for airlines, or ticket taxes for airline travel.

3 Gasoline Tax Burdens by Expenditure and Income Groups

The transportation-related user charge that attracts the most attention is the gasoline tax, and it is the focus of the balance of this study. The CEX has information on household outlays on gasoline. We impute gasoline taxes based on gasoline expenditure by converting expenditures to gallons based on average per-gallon prices, and then applying the average federal or federal plus state gasoline tax rate.

3.1 The Distribution of Gasoline and Gasoline Tax Outlays

Figure 4(a) shows outlay shares on gasoline for households across expenditure deciles. For households in the lowest expenditure decile in 2017, gasoline accounts for about four percent of total expenditures, while for those in the highest expenditure decile, it accounts for about 2 percent. The expenditure share for gasoline is highest in the middle of the expenditure distribution, where it rises to five percent, more than twice the level of the highest decile.

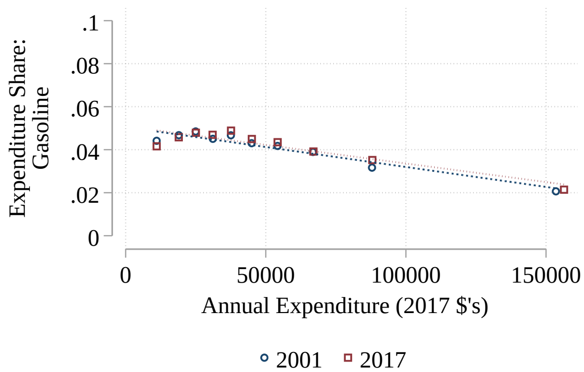
The figure shows the expenditure shares for 2001 and 2017.[6] The two years are similar in the real ($2017) price of a gallon of gasoline: $2.27 and $2.14, respectively. Higher gasoline prices reduce gasoline demand. Levin, Lewis and Wolak (2017) suggest that a price elasticity of about -0.30 as a middle-range value based on many studies. While the expenditure share does not rise or fall in exact proportion to movements in gasoline prices, but higher gasoline prices are associated with higher expenditure shares.

One factor that has limited the increase in the expenditure share of gasoline, despite rising miles driven, is the rising fuel efficiency of vehicles. The average fuel economy of the light duty vehicle fleet was 22.3 miles in 2017, up from 20.2 miles in 2001 or 19.2 in 1994,

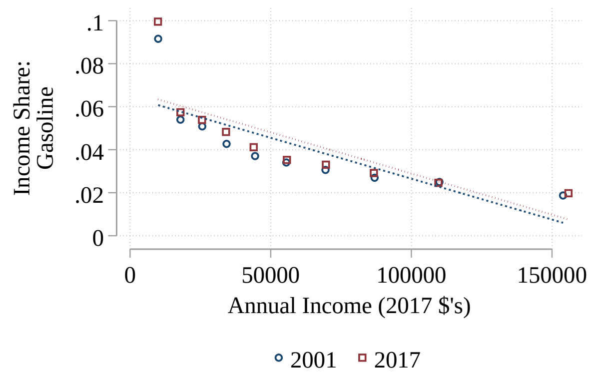
[6] In the 2001 CEX, gasoline and motor oil spending equals 3.2% of total expenditure, while in the 2017 CEX, the comparable value is 3.3%. In 2020, the expenditure share for gasoline and motor oil was 2.6%, presumably lower than in the past because of both low gasoline prices and low driving during the pandemic.

Figure 4: Gasoline and Tax Expenditures in the CEX

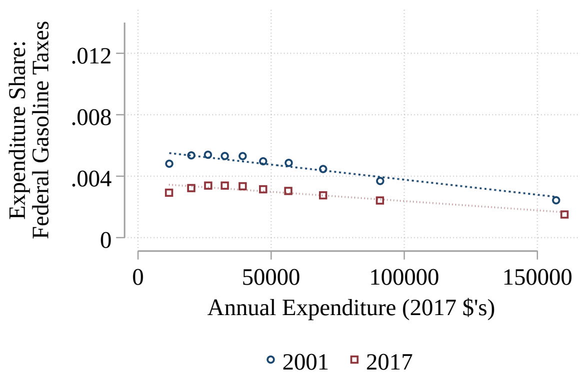
(a) Gasoline, by Expenditure Decile



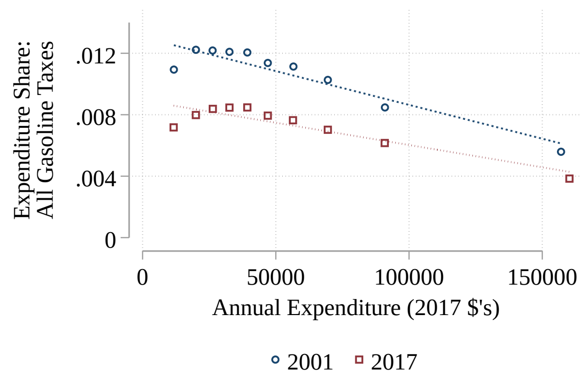
(b) Gasoline, by Income Decile



(c) Federal Taxes, by Expenditure Decile



(d) All Taxes, by Expenditure Decile



Notes: Data from the 2001 and 2017 CEX waves. The figure plots binned scatters and their associated linear fits. Panel (a) shows the average expenditure share devoted to gasoline by expenditure decile. Panel (b) shows the average income share devoted to gasoline expenditures by income decile. Panel (c) and (d) plot expenditure share on federal gasoline taxes, or on total taxes (state and federal), by expenditure decile. Expenditure is winsorized at the 1^{st} and 99^{th} percentiles prior to binning, for positive values of expenditure. Income is trimmed at the 5^{th} and 95^{th} percentiles prior to binning, for positive values of income. Data on annual fuel prices by state or region from the Energy Information Administration's "all grades all formulations" retail price average. State motor fuels tax rates data come from the Brookings-Urban Tax Policy Center.

when the current federal gasoline tax rates was set.[7] Thus the amount of gasoline needed, on average, to drive a mile declined by about 14 percent between 1994 and 2017. The average fuel economy for new vehicles is currently much higher than for the existing stock. Hula et al. (2021) report that for 2021, the EPA estimates that the realized MPG - the fuel efficiency achieved in actual driving - was 28-32 for cars, and 19-24 for trucks. This suggests that the average fuel economy of the light duty fleet is likely to continue to rise in future years, as newer vehicles continue to replace older ones. Data from the 2017 NHTS show that the average household drives about 12,000 miles per year or about 33 miles per day. There is substantial heterogeneity, with the 25th percentile driving 15 miles per day, and the 75th nearly triple that at 42 miles per day. Higher expenditure households tend to drive more per annum than their low-expenditure counterparts; this is a factor pushing toward progressivity in the distribution of gasoline tax burdens. However, the expenditure share on gasoline depends not only on how many miles households drive, but also on how many gallons are needed per mile. On average, lower-expenditure households drive older and less fuel efficient vehicles. This counterbalances the pattern of miles driven per household, and in extreme cases - when the high-expenditure household owns an electric vehicle - can result in no gasoline tax burden at all. We revisit the ownership of electric vehicles when we consider VMT taxes below.

Figure 4(a) shows annual expenditure on gasoline, not gasoline taxes, as a share of total expenditure. To place the tax burden in perspective, in 2017 the federal gasoline tax was 18.4 cents per gallon, when average gasoline prices were $2.53, so federal taxes were approximately seven percent of the total cost of gasoline. The average state gasoline tax in 2017 was $0.28. The total tax burden therefore represents about 18 percent of the retail, tax-inclusive price of gasoline. Figures 4(c) and 4(d) present our estimates of expenditures on gasoline taxes by expenditure decile. These are estimates because we calculate gallons of gasoline purchased from the amount spent on gasoline, divided by the mean state gasoline price provided by the EIA, and then multiply by the federal and state tax rates to compute expenditure on gasoline taxes.

[7] Bureau of Transportation Statistics 2022
`https://www.bts.gov/content/average-fuel-efficiency-us-light-duty-vehicles`

If the federal gasoline tax had been indexed for inflation when it was set in 1993, today it would be over 34 cents per gallon. Brooks and Liscow (2019) and Mehrotra, Turner and Uribe (2021) find that inflation in the cost of building new highways has outpaced general inflation, so even had the tax kept up with overall inflation, its buying power would have diminished. There is a growing gap between federal gasoline tax revenues, which are dedicated to the Federal Highway Trust, and federal highway outlays. In 2021, the former was $43.4 billion, while the average expected outlay for the FY2021-25 period was $60.4 billion (Kirk and Mallett, 2020). If the federal gasoline tax rate were increased to a level that would cover average expected federal highway revenues, it would be approximately 26 cents per gallon, and the expenditure shares for federal taxes would be about one third greater than those shown in Figure 4(c).

To illustrate the importance of focusing on annual expenditure rather than annual income as the denominator when measuring gasoline expenditure burdens, Figure 4(b) presents the share of gasoline expenditures relative to reported income in the CEX for 2001 and 2017. Gasoline expenditures account for almost ten percent of income in the lowest decile, compared with only two percent in the highest groups. For those in the second lowest decile, however, gasoline expenditure as a share of income falls to about six percent. Gasoline tax burdens appear regressive in both Figures 4(a) and 4(b) , but the relative burden on less-well-off relative to better-off households is greater in Figure 4(b), in part because the income measure for those in the lowest income decile may not be a complete measure of economic well-being.

Rural households travel longer distances than their urban and suburban counterparts, and are more likely to drive larger vehicles, so they can face heavier burdens from gasoline taxes. Figures 5(a) and 5(b) compare the expenditure share and income share distributions for households by local area population. In the 2017 CEX, 25% of sample households live in cities with populations higher than 5 million, 28% in cities with between 1 and 5 million, and 48% in communities with fewer than 1 million residents, including rural areas.[8] In both the income and expenditure share distributions, those living in smaller cities spend higher shares

[8] Our CEX sample includes fewer rural households than the population. While the 2017 CEX has 8% "rural" and 92% "urban" households, the 2020 Census estimates that 20% of the US population lives in rural areas.

on gasoline. Metcalf (2022) presents complementary findings on urban/rural differences in gasoline expenditures as a share of income using 2017 NHTS data; his findings also suggest greater expenditure by rural households.

In the bottom half of the expenditure or income distribution, and especially in the bottom decile, gasoline expenditures are significantly greater - close to three percent of either income or expenditure in the bottom decile - for rural households than for those in large cities. At the top of both distributions, there are almost no urban-rural differences. when households are ranked by total expenditure the disparity between urban and rural households at the bottom of the distribution is larger than when households are ranked by income, in part reflecting that the denominator in the share calculations - expenditure - is smaller than income. Prospectively, rural households may have some advantages in BHEV adoption, notably because they are more likely to live in stand-alone dwellings that can be configured to support at-home charging.

3.2 Technological Change, Vehicle Ownership Patterns, and Distributional Burdens

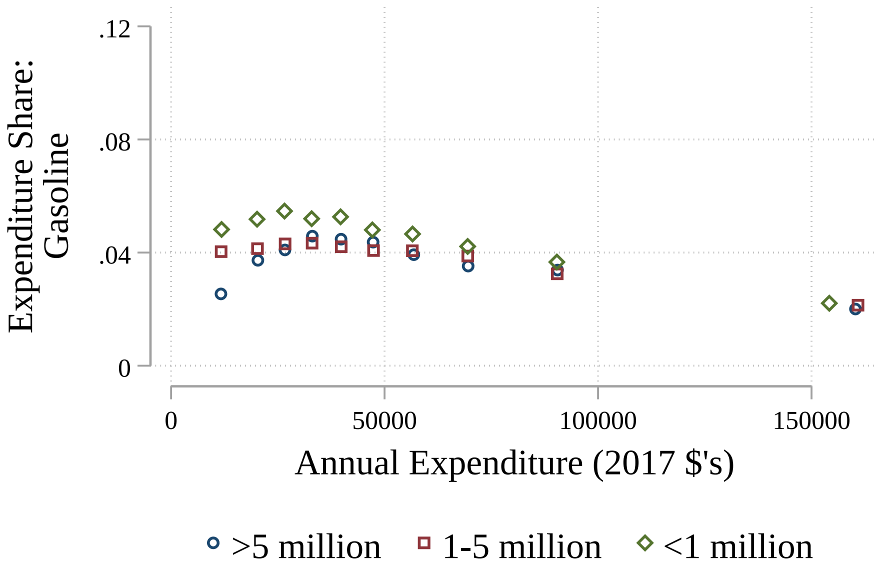
Technological change will respond to Pigouvian taxes in any setting, and if new technologies are used disproportionately by the rich, then Pigouvian taxes will become more regressive over time. When all vehicles were powered by internal combustion engines (ICEs), the central question was how average fuel economy varied across deciles. More recently, as BHEVs have entered the market, some better-off households have reduced their gasoline expenditures to zero while still driving. Technological change - the advent of BHEVs - has made a Pigouvian tax less progressive over time.

The first reason why technological change may lead Pigouvian taxes to become more regressive over time is that most durable goods, including cars, refrigerators, and houses, depreciate in quality over time. Higher income households tend to own newer durable goods than their lower income counterparts, who either keep their durable goods longer or purchase used durable goods. Lowry (1960) labeled this “filtering” in the housing context.

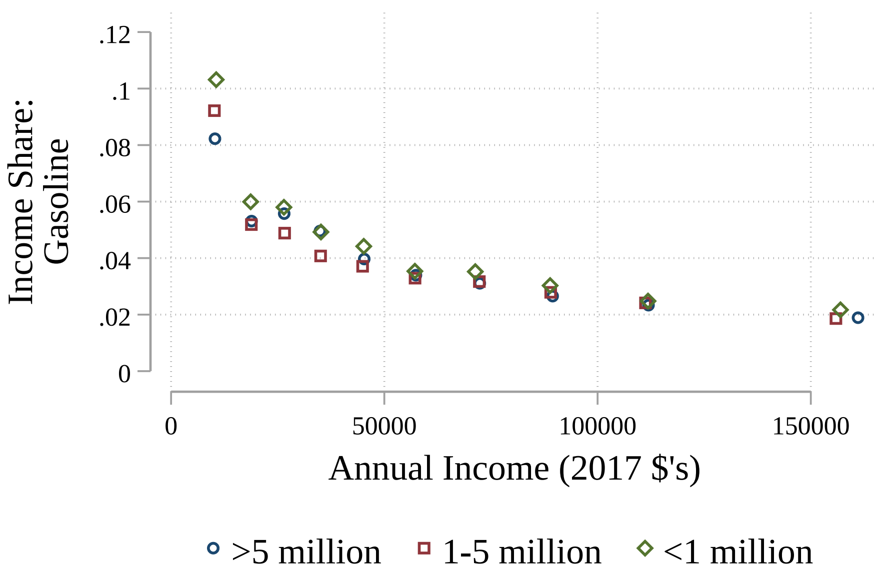
Table 2 shows that in 1977, the average household earning more than fifty thousand dol-

Figure 5: Gasoline Expenditure and Income Shares, by City Size

(a) Expenditure Share



(b) Income Share



Notes: Data from the 2017 CEX. All panels plot binned scatters and their associated linear fits. Panel (a) shows the gasoline expenditure share, by expenditure decile and city size. Panel (b) shows gasoline income share, by income decile and city size. Expenditure is winsorized at the 1^{st} and 99^{th} percentiles prior to binning, for positive values of expenditure. Income is trimmed at the 5^{th} and 95^{th} percentiles prior to binning, for positive values of income.

Table 2: Vehicle Characteristics by Income

	1977 Nationwide Personal Transportation Survey		
Income (1977 $'s)	Average Vehicle Age	Average MPG	Average Curb Weight
<$5,000	8.38	19.7	3,469
$5,000–$9,999	7.23	19.1	3,572
$10,000–$14,999	6.54	18.9	3,630
$15,000–$24,999	6.04	19.0	3,639
$25,000–$34,999	5.56	19.1	3,728
$35,000–$50,000	5.32	18.4	3,796
>$50,000	4.56	16.8	3,835
Average	6.4	19.0	3,640
	2017 National Household Travel Survey		
Income (2017 $'s)	Average Vehicle Age	Average MPG	
<$10,000	12.99	21.38	
$10,000–$14,999	12.96	20.97	
$15,000–$24,999	12.19	21.49	
$25,000–$34,999	11.38	21.41	
$35,000–$49,999	11.07	21.49	
$50,000–$74,999	10.34	21.55	
$75,000–$99,999	9.48	21.73	
$100,000–$24,999	9.28	21.89	
$125,000–$149,999	8.57	22.18	
$150,000–$199,999	8.38	22.17	
>$200,000	7.82	22.52	
Average	10.11	21.73	

Notes: Data in the top panel from the 1977 Nationwide Personal Transportation Survey "Household Vehicle Ownership: Report 2," 1980. Data in the lower panel based on author's calculations using the 2017 NHTS vehicle survey, for vehicles with positive miles driven.

lars owned a car that was 4.5 years old while the average household earning less than $10,000 owned a car that was over 8 years old. Introducing a Pigouvian tax induces innovation that creates products that generate less of the taxed externality. Since better-off households buy more new products than the poor, externality-reducing innovation will mean that the they pay less of the Pigouvian tax.

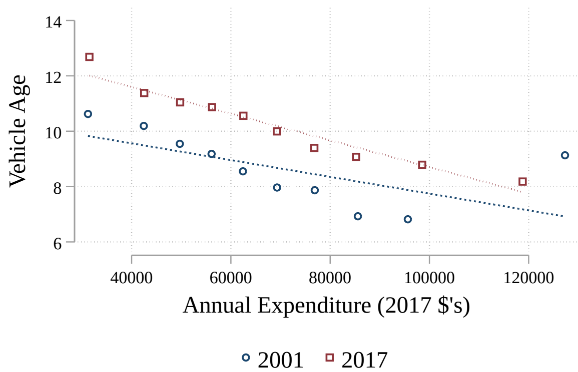
A second reason Pigouvian taxes may become less progressive over time is that the interest groups that supported the adoption of the tax may also try to create a sense of moral obligation to avoid generating the externality in question. For decades, environmentalists have tried to both tax and regulate environmental harms and to spread environmental consciousness through books, such as Rachel Carson's (1962) Silent Spring, advertisements, and environmental education in school curricula (Carlton and Hug, 2010, Glaeser, 2020). Persuasion in the classroom and through the written-word may be more effective with more educated individuals, who also tend to have higher incomes. In a March 2021 Gallup poll, 46 percent of American college graduates identified themselves as environmentalists, compared with only 37 percent of those who had not completed high school. Wang et al. (2022) find that arguably exogenous shifts in education due to compulsory schooling law changes in China lead to increases in pro-environmental attitudes and behavior. Even if persuasion generates an equal taste for environmentalism in all income strata, if that taste is a normal good, then it will tend to have a larger impact on the behavior of higher income households.

Finally, innovation related to the Pigouvian tax may be directed towards more luxurious consumer products that are disproportionately demanded by higher-income households. If richer customers generate higher profit margins, then technological change, green or otherwise, will be targeted towards products consumed by the rich. This effect suggests that even within the set of new products, those targeted to the top income strata may benefit from faster innovation and greater externality avoidance.

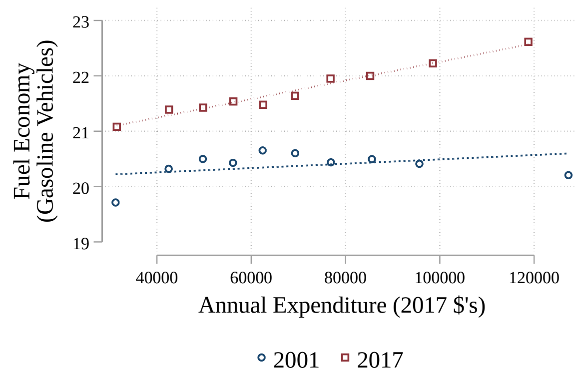
Figure 6(a) shows the vehicle age distribution, based on data from the NHTS, in 2017 for households ranked by expenditure class. Panel (b) plots the average miles per gallon (MPG) for the vehicles owned by households in each part of the expenditure distribution. Improvements in productin technologies have extended vehicle lives, and today,vehicles last longer than they did in the past. In 2017, the average vehicle had been owned by its current owner for two years longer than the average vehicle in 2001. Additionally, fuel efficiency rose at every point in the expenditure distribution, especially so at higher expenditure deciles. In 2001, the MPG-expenditure profile was nearly flat, with both the highest and lowest deciles owning cars that ran around 20 miles per gallon. By 2017, the highest expenditure households drove cars that were 1.5 MPG more efficient than the lowest decile households. Figure 6(a) shows one puzzling finding - the jump in of more than two years in average vehicle age between the second-to-highest, and highest expenditure decile. This may reflect purchases of more durable luxury models by those at the top of the distribution; the pattern is present in 2001 but not 2017.

Figure 6: Vehicle Characteristics in the NHTS, by Expenditure Level

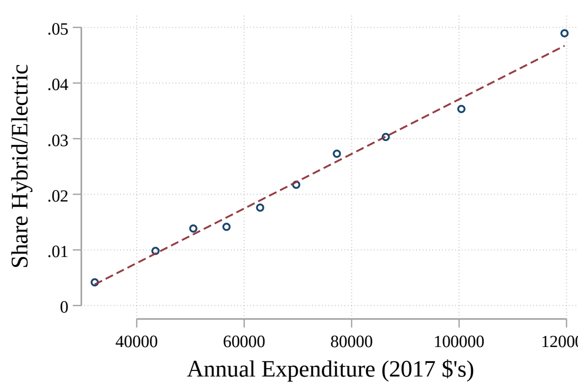
(a) Vehicle Age



(b) Fuel Economy



(c) HEV Share



Notes: Data from the NHTS waves from 2001 and 2017, only vehicles that run on gasoline are considered, including hybrid vehicles. All panels plot binned scatters and their associated linear fits. Panel (a) shows vehicle age by expenditure decile. Panel (b) shows mean fuel economy, calculated as observed miles driven divided by gallons purchased, by expenditure decile. Panel (c) shows the binned scatter and associated linear fit for the share of hybrid and electric vehicles. Expenditure is winsorized at the 1^{st} and 99^{th} percentiles prior to binning, for positive values of expenditure.

In the 1977 National Personal Travel Survey (NPTS), higher income households owned less fuel efficient vehicles.[9] On average, households in the top income bracket - more than \$50,000, about \$250,000 with CPI adjustment to 2022 - owned cars that averaged 2.9 fewer miles per gallon than those in the lowest income group, which was less than $5,000 in 1977 or about$25,000 today. The lowest income group owned cars on average that were four years older than those in the highest income group.

The relationship between vehicle age and income is similar in the 2017 and the 1977 data. In 2017, the average age of a vehicle owned by a household with income of less than \$25,000 was 13.0 years. It was 11.5 for income \$25,000-49,999, 10.7 for \$50,000-74,999, 9.9 for \$75,000-99,999, and 8.9 for households with incomes above \$100,000.[10] But the pattern of fuel economy was very different in the two years.[11] The 2017 NHTS data show that the highest income households own vehicles that run, on average, 1.5 more miles per gallon than those in the lowest income categories, consistent with the expenditure results in Figure 9. This pattern offsets the tendency of better-off households to drive more miles than their less-well-off counterparts.

The rise of hybrid-electric and battery-electric vehicles accentuates the declining fuel use of better-off households. Figure 6(c) shows the BHEV fraction of the light duty vehicle fleet by household expenditure category in 2017. The emergence of BHEVs, which allow the driver to avoid paying gasoline taxes, is an example of a setting in which, in the presence of two technologies, the distributional burden of a tax on an input to one of them will depend both on the nature of the two technologies and the resulting pattern of use across income classes. When better gas mileage meant reducing car weight and power, then the low-income households were more likely to take advantage of that possibility, so in the 1970's, gas taxes were paid disproportionately by high-income households driving heavy, low-MPG cars. When better mileage means buying a relatively expensive electric vehicle with higher up-front capital costs than an ICE-powered car, then gas taxes become a disproportionate burden on the poor, who may not be able to afford – even with access to credit markets

[9] US Department of Transportation, Federal Highway Administration, 1977 Nationwide Personal Transportation Study, Household Vehicle Ownership (Report 2), Table 28.

[10] See https://www.eia.gov/todayinenergy/detail.php?id=36914

[11] The NPTS, like the NHTS, only provides reports based on income, so we are unable to compare vehicle characteristics by expenditure across the two datasets.

– the greater upfront cost of the cleaner technology. Appendix A presents a simple model illuminating the interplay between household income and the adoption of an energy-saving technology. When well-to-do households demand more transportation services which use energy than less-well-off households, a tax on energy inputs will place greater burdens on them, but that can be reversed if the well-do-to are more likely to adopt the greener, and less-heavily-taxed, alternative technology.

4 The Distributional Impact of a Gasoline Tax vs. a Household VMT Tax

All-electric vehicle sales alone have grown from 0.1% of all sales in 2011, to 1.7% in 2020, according to Davis and Boundy (2019). As the BHEV market has grown, it has sparked discussion of a vehicle miles traveled (VMT) tax, which would tax drivers based on their road usage rather than their gasoline consumption. With a VMT tax, both BHEV drivers and those driving internal combustion engine (ICE) vehicles would contribute to the costs of infrastructure maintenance. Because BHEVs are typically between 10 and 40 percent heavier than ICE vehicles, there is a case for charging them even more per mile driven. In this section, we compare the distribution of the 2017 federal gasoline tax with an equal-revenue VMT tax applied to households. We also consider the distribution of both taxes at a hypothetical future date when BHEVs represent one third of the stock of light-duty vehicles. In the next section, we consider a commercial VMT tax levied on vehicles that burn diesel fuel.

4.1 Modeling the Driving Response to a VMT Tax

Shifting from a gasoline tax to an equal-revenue VMT tax would change the pricing of driving services. Households with BHEVs would experience an increase in their cost-per-mile, while those driving ICE-powered cars would experience a decrease because some taxes would now be collected from BHEV drivers. To estimate the distribution of taxes paid with a VMT tax, we must model how the miles driven by different households would change if such a tax were adopted.

We assume that each household i has a quasi-linear separable utility with the utility from travel in miles, T_i, generated through a power function:

$$U_i(T_i) = Y_i - pT_i + AT_i^\sigma \tag{1}$$

Households earn income Y_i, and purchase T_i at price per mile, p. The first order condition $\frac{\partial U_i}{\partial T_i} = 0$ can be rewritten as

$$ln(T_i) = \frac{1}{1-\sigma} ln(A\sigma) - \frac{1}{1-\sigma} ln(p) \tag{2}$$

The price elasticity of demand for travel miles is $\varepsilon_g = -\frac{1}{1-\sigma}$. We assume a value for this parameter of $\varepsilon_g = -0.31$ based on Levin, Lewis, and Wolak (2017). The authors use high frequency data on credit card swipes at gas stations to measure how gasoline demand responds to price changes; importantly their model can accommodate drivers substituting expenditure across days, allowing current price changes to impact expenditure more flexibly across time.

The -0.31 value is an elasticity of gasoline consumption with respect to the price of gasoline, but the elasticity that is relevant for our analysis is that of miles traveled with respect to the cost per mile of travel. Using data from the 1997-2001 period, a period when there were no BHEVs, Small and van Dender (2007) estimate a long run elasticity of vehicle miles traveled with respect to fuel cost per mile of between -0.11 and -0.15. This long run elasticity allows for vehicle changes. In the short run, they estimate an elasticity of between -0.02 and -0.03. We have explored the robustness of our distributional analysis with respect to alternative elasticities; in general, the results are not substantially affected by assuming zero or by assuming higher values, such as -0.20, for this elasticity.

We estimate that the average current price per mile driven, inclusive of the gasoline tax, is \$0.12. This price varies across households. It is lower for households with fuel-efficient vehicles, and for those who live in areas with low gasoline prices, than for those who live in states with high gasoline prices and drive gas guzzlers. Each household is assigned a gas price per mile, p_i, and a tax rate per mile, τ_i. The former is calculated using the miles per gallon for each vehicle and our estimate of the tax-inclusive price of gasoline in the household's area. For example, a household driving a 30 MPG vehicle in 2017, paying \$2.53 per gallon, would have $p_i = 0.084(= 2.53/30)$. A household driving a 20 MPG vehicle would pay 0.127 per mile, more than fifty percent more. Adopting a VMT tax eliminates the heterogeneity in the per-mile cost across households.

Table 3: Tax per Mile (\$'s), by Tax Scheme

Proposal	τ/gallon (cents)	τ/mile (cents)
Baseline Federal Gas Tax	18.4	μ=0.89*
Match Current Effective Tax/Mile (τ_1)		0.89
Future Fleet: Gasoline Tax (τ_2), 60/40 EV/HV	25.8	μ=1.15*
Future Fleet: VMT (τ_3), 60/40 EV/HV		0.93

Notes: Top two rows use data from the National Household Travel Survey, 2017, vehicle level dataset. Future fleet forecast using NHTS panel. This table summarizes the taxes used in the proposals outlined in section 5. *mean τ/mile only calculated for hybrid and gasoline vehicles as electric do not pay the tax.

Table 3 shows that a VMT tax of \$0.0089 (0.89 cents per mile) would raise as much revenue as the current gasoline tax. For ICE-powered cars, this would make the price per mile driven with a VMT tax equal to the original per-mile cost of gasoline, gas price per mile paid at the pump, P_i, less the original gas tax per mile, τ_i, plus the proposed VMT tax per mile, t.

Hybrid vehicle drivers pay relatively little, and BEV drivers no, federal gasoline tax. To calculate the cost per mile for BEVs, p_e, we assume a BEV travels 3 miles per kWh at the average cost of 11.7 cents per KWh (Advanced Vehicles Testing Activity, 2011). This yields a fuel cost of 4 cents per mile, about $\frac{1}{3}^{rd}$ the current price per mile driven. For HEVs, we assume an average gasoline price of \$2.41/gallon, taken from the NHTS sample, and an efficiency of 45 mpg, which yields yielding a hybrid cost per mile of $p_h = \$0.055$ (5.5 cents). We use these prices for all households with BEVs or HEVs. We calculate miles driven under a VMT tax as initial miles driven, T_i, plus the change in miles associated with and increase or decrease in the price per mile relative to the status quo gasoline tax:

$$T_i^{'} = T_i + T_i \left(\frac{t - \tau_i}{p_i} \right) \varepsilon_g \quad (3)$$

The tax revenues collected by the VMT tax equal $R^{VMT} = t \times \sum_i T_i^{'}$. To find the VMT tax rate that will raise the same revenue as the current gasoline tax we solve for the value t that equates $R^{ICE} = \sum_i \tau_i T_i$, where R^{ICE} refers to the revenue collected by the current gasoline tax and $\sum_i T_i^{'}$ is the total number of miles driven if the VMT tax is levied at rate t. We can calculate the distribution of tax payments under various alternative policies by using Equation 3.

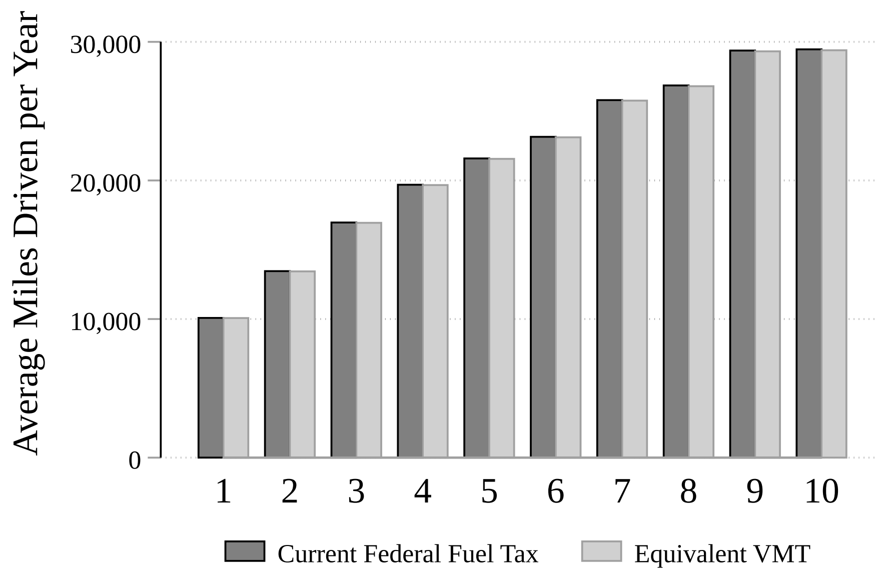
Figure 7 illustrates the impact of a gas tax-to-VMT tax swap. It shows the distribution of burdens from the current federal gasoline tax as well a revenue-neutral federal VMT tax. The average number of miles driven per household is almost identical under the gasoline tax and the VMT tax. The average tax payment by households in the top expenditure virtually unchanged under this policy, staying around 250 on average. Because of the distribution of BHEV ownership, the average tax payment by those in the top three deciles of the expenditure distribution increases under the VMT tax plan, while the average tax burdens on those in the lower deciles decline.

Figure7 shows that at current levels of BHEV penetration of the light duty vehicle fleet, the distributional patterns of the gasoline excise tax and the VMT tax are very similar.[12] This reflects the relatively small number of BHEVs in the current vehicle fleet: only 2.1% of the US light duty vehicle fleet in 2017, the year we use as our benchmark. Even if all of these vehicles were owned by households in the top decile of the expenditure distribution, the impact would be modest, because households in the top decile own 13% of all vehicle. By comparison, households in the lowest expenditure decile own 4% of all vehicles. If all BHEVs currently in the US fleet were owned by households in the top expenditure decile, that would leave a residual 84% ownership share for vehicles in the top expenditure decile. In Appendix Figure C2, we explore results shutting down the behavioral response to price increases by

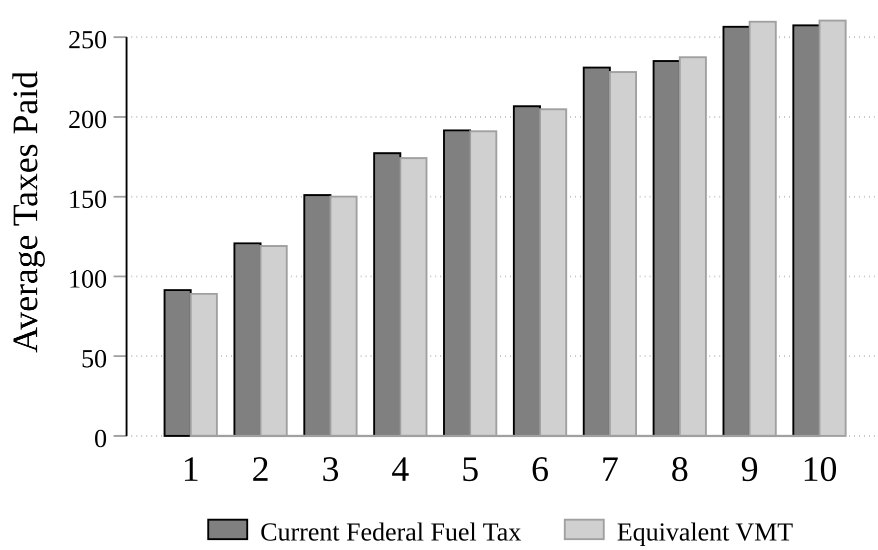
[12]These findings are broadly consistent with Metcalf's (2022) analysis of the 2017 NHTS data. He estimates the income elasticity of fuel intensity across the income distribution, and finds that a revenue-neutral VMT tax-for-gas tax swap is progressive at all but the highest income levels.

Figure 7: Baseline (2017) vs. Revenue Neutral VMT (2017)

(a) Mean Miles



(b) Mean Federal Taxes Paid



Notes: Data from the 2017 NHTS. Panels show the mean miles traveled and mean federal taxes paid per household, comparing the current gasoline tax and proposed revenue-neutral vehicle miles tax (VMT). All results conditional on having positive predicted expenditures.

setting $\varepsilon_g = 0$ in Equation 3. This requires households to drive the same number of miles under our counterfactual tax policies. Similar to the results in Figure 7, average taxes paid change very little, marginally increasing in the top three deciles, and marginally declining in the bottom 7.

4.2 Projecting a Future Vehicle Fleet with Higher BHEV Penetration

Although the current differences between the distribution of a gasoline tax and a VMT tax are small, hybrid and electric vehicles are entering the vehicle fleet at a rising rate. By the next decade, the comparison between the two taxes could look quite difference. To explore this, we create a counterfactual future scenario in which BHEVs account for $\frac{1}{3}^{rd}$ of the stock of light duty vehicles. Some forecasters expect this vehicle mix by the mid-2030s. A key issue in determining how such a vehicle fleet would affect the difference between the distribution of the VMT tax and the gasoline tax is whether drivers in high- or low-income and expenditure strata will switch from ICE vehicles to BHEVs as the composition of the fleet evolves. The number of miles driven by BHEV versus ICE drivers, an issue considered by Davis (2019) and Burlig et al. (2021), is also a relevant consideration, although one that we do not consider in our projections.

There is substantial uncertainty about the prospective distribution of household BHEV buyers across expenditure or income strata. It depends on model introduction decisions by manufacturers, who will make choices about offering high-end versus less expensive BHEV models, as well as public policies such as tax incentives which may affect the net-of-tax purchase price.[13] Muehlegger and Rapson (2018) estimate a substantial price elasticity, around -3, for BHEV purchases.[14] The Inflation Reduction Act of 2022 (IRA) significantly altered the pattern of tax incentives for HEV purchase across households, eliminating tax credits for single-person households with incomes above $150,000 and for married couples

[13] Ewing and Eavis (2022) describe ways in which auto manufacturers may be shifting their product line-ups to target BHEVs to middle-income households in future years.

[14] Other studies that describe the demand for BHEVs and the challenges of predicting future adoption patterns include Archsmith, Muehlegger, and Rapson (2022), Holland, Mansur, and Yates (2020), and Rapson and Muehlegger (2021).

with incomes above $300,000.[15] In addition, the IRA introduced a tax credit for purchase of used vehicles, which may encourage lower income households to acquire these vehicles. These factors, along with potential changes in the supply of BHEV models by manufacturers, suggest caution in using the BHEV penetration patterns of the last few years as a guide to the next two decades.

To illustrate how the growing share of BHEVs in the fleet would affect the distribution of tax burdens, we develop a calculation that is grounded in the recent purchase patterns for these cars. We project purchases of BHEVs across household groups, vehicle retirements, and trickle-down of ICE vehicles across groups. IHS Markit (2022) reports that the average age of US cars in 2022 was 13.1 years. This underscores the slow impact of changes in the composition of new car sales on the vehicle stock.

We fit a time trend to light duty vehicle sales and registrations for the 2000-2020 period (Davis and Boundy (2019)). Vehicle registrations grew at an annual average rate of 0.7% over this period. We use the fitted trends to project both data series forward. The projected change in annual registrations yields the net change in the vehicle fleet, after accounting for sales and retirement.

There are a range of commercial forecasts of the share of future auto sales that will be accounted for by HEVs. For example, Deloitte predicts 27% of sales will be BHEV by 2030, Ford predicts 40%, and KPMG predicts 52%. We fit a logistic curve to the data on the growth of the HEV share of new vehicle sales over the 2000-2020 period, and to calibrate the intercept, we assume that 50 percent of light duty sales are HEV by 2032.[16] These shape and endpoint parameters define a unique logistic curve, which we show in the first panel of Figure 8. It implies that BHEV sales outstrip gas vehicle sales after 2032 and sales of ICEs

[15] U.S. Internal Revenue Service (2021) data on the 157.8 million tax returns filed in 2019 can provide some guidance on the impact of these limits. Using information on the Adjusted Gross Income (AGI) of tax returns by filing type, and assuming that within the $100-200,000 and $200-500,000 AGI brackets tax filers are uniformly distributed by income – an assumption that is likely to overstate the number of returns above the $150,000 and $300,000 income limits – indicates as many as 3.05 million single filers, 0.76 million heads of household, 0.11 million married filing separately, and 5.55 million married joint filers, a total of 9.47 million households – could be ineligible for BHEV tax credits after 2022. Even if the actual number of ineligible households is only two thirds this large, it represents a significant group. Most of these households would have been in the top two income or expenditure deciles.

[16] The logistic curve is takes the form $SalesShare_t^{BHEV} = \dfrac{1}{1 + e^{-0.25(t-2032)}}$

nearly vanish by the mid 2040's. The second panel shows the changes in both the fraction of new car sales accounted for by HEVs and the share of these vehicles in the car fleet. While sales of BHEVs pass 50% in 2032, the stock of vehicles is less than 20% BHEV at that point. It takes another five years for BHEVs to reach one third of the vehicle stock, and by the time that happens, BHEV sales comprise 80% of all sales.

We accumulate the number of BHEVs sold in each year between 1999 and 2017 and estimate that there were 5.35 million BHEVs in the US fleet in 2017, compared with 243.54 million ICE-powered cars. We compute vehicle retirements from projected total sales, BHEV sales, and net new registrations:

$$Retire_t = Sales_t^{BHEV} + Sales_t^{ICE} - \Delta Registrations_{t+1,t} \tag{4}$$

We assume that all retirements from 2017 through 2037 are ICE-powered vehicles. While there are some aging BHEVs in the 2017 fleet, most are relatively young and the BHEVs in particular may have longer lives than ICE-powered cars. By assuming that there are no BHEV retirements, we likely overstate the BHEV share of the future fleet.

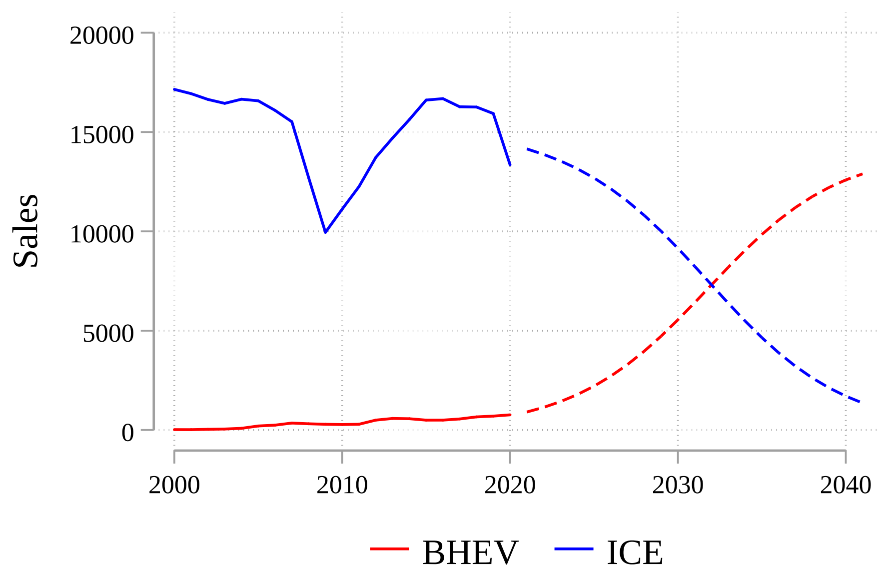
Appendix Table B2 reports our projected evolution of the vehicle fleet from 2000 to 2037. Our analysis implies that 92.4 million BHEVs and 205.7 million ICE-powered vehicles will be added to the fleet, while 260.7 million vehicles will be retired.

We project that the vehicle fleet will grow by 15 percent, from 248.9 million to 286.3 million, between 2017 and 2037, and that the BHEV fleet will grow from 5.4 to 97.8 million. The ICE-powered vehicle fleet contracts from 243.5 million in 2017 to a projected 188.5 million in 2037. BHEVs represent just over 34 percent of the projected 2037 vehicle fleet.

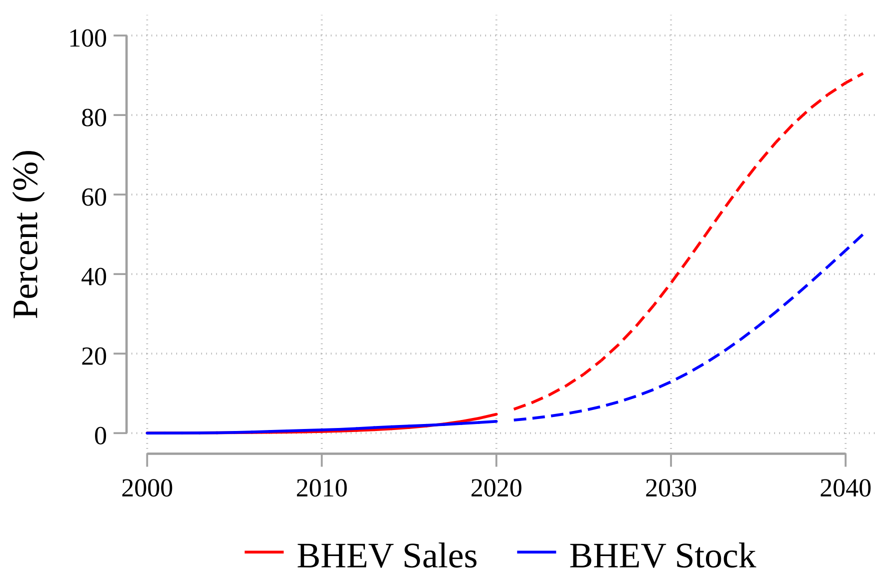
Only about 90 percent of vehicles in the light duty fleet are driven in a given year. In 2017, for example, when there were 248.9 million vehicles, the NHTS reported 229.3 million, 92.1 percent of the fleet, with positive miles. Only vehicles that are driven in a given year expose their owners to gasoline taxes or VMT. We limit our analysis to vehicles with positive miles driven, and assume that the fraction of vehicles driven in 2037 will be the same as in 2037. This implies 263.7 million driven vehicles in 2037. We assume that driven vehicles are 34 percent BHEVs, with 27% hybrid and 7% electric (reflecting a 60/40 BEV/HEV mix of

Figure 8: Hybrid and Electric Vehicle Adoption Curves

(a) Sales



(b) Share



Notes: Data on vehicle registrations and sales by fuel type from *Transportation Energy Data Book, Edition 39* produced by Oak Ridge National Laboratory for the Department of Energy. Sales and share hybrid/electric based on data up to 2020; registration data through 2019. Additional years authors' forecast. Registrations, sales, and retirement in 1000's. Solid lines denote observed data, while dashed lines denote forecasts.

new adoptions), and 66 percent ICE-powered. By comparison, in 2017, 97.5% of the vehicle fleet was gasoline-powered, 2.3% hybrid, and 0.1% electric.

A critical question for the comparative distribution of future gasoline and VMT taxes is where, in the income or expenditure distribution, new BHEV purchases will take place. Different assumptions in this regard will result in different outcomes. Metcalf (2022), for example, reports some counterfactuals in which he adjusts vehicle ownership in the 2017 NHTS by assuming that the most recent ICE vehicle purchases were replaced by BHEVs. In our projection, we assume that the greater propensity for high than for low income households to purchase BHEVs, which has been observed in the last two decades, will continue. This reflects both the tendency for new cars to be purchased by higher rather than lower income households, and the relatively expensive pricing, particularly of EVs, to date. In light of recent changes in eligibility for BHEV tax credits at high incomes, the strong tilt toward BHEV purchases at higher incomes may attenuate over the next fifteen years. Our results may therefore be seen as an upper bound for the disparity in future distributional differences between the gasoline and the VMT tax.

Appendix Table B3 reports the 2017 NHTS vehicle composition by expenditure decile. The share of vehicles owned by households in an expenditure decile that are BHEVs rises monotonically with expenditure level. In 2017, about 27% of all BHEVs were owned by households in the highest expenditure decile, while only 1% of these vehicles were owned by those in the lowest decile. We apply these shares to the number of BHEVs that we project in the 2037 vehicle fleet, thereby predicting $BHEV^{2037}$ by decile, and then we compute the number of ICE-powered vehicles by decile as $ICE^{2037} = Vehicles^{2037} - BHEV^{2037}$.

To determine which households within a decile are net purchasers of additional vehicles between 2017 and 2037, we proceed in three steps. First, for every vehicle that is owned in the 2017 NHTS, we assign a 15 percent probability that the owner will have one more vehicle in 2037. This randomly assigns an increase in the vehicle fleet of 15 percent across households that currently own vehicles. We do not assign any of the net increase in vehicle ownership to households that did not own cars in 2017. Second, when we assign a net new vehicle to a household, if the 2017 vehicle being "cloned" was an BHEV, we assume the new vehicle will also be an BHEV. If the 2017 vehicle was ICE-powered, we assign the new vehicle either BHEV or ICE status based on the fraction of net new vehicles that need to be HEV in order to achieve the overall share of BHEVs in the expenditure decile. This means that the probability that a new vehicle is assumed to be an BHEV varies across expenditure deciles. Finally, after we have allocated all net new vehicles, if the share of BHEVs in the vehicle fleet for a decile is still below the share of BHEVs that result from our aggregate projections, we randomly reassign a fraction of the ICE-powered vehicles in the 2037 fleet to HEV status. Some such "swapping" of ICE-powered cars for BHEVs is required in each of the top seven expenditure deciles, but it is particularly prevalent in top two.

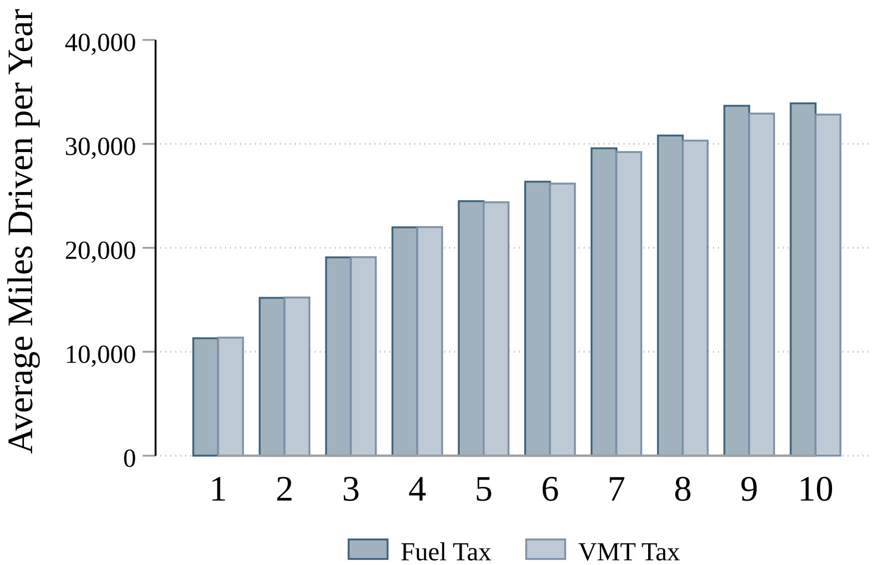
4.3 Comparing Gasoline Tax and VMT Tax Burdens

We compare the distributional burden of the current gasoline tax with a gasoline tax that would raise the same revenue per vehicle in our future scenario, allowing for the change in fleet composition between 2017 and that date. In 2017, we estimate that the federal gasoline tax raised about $20 billion. With the 15% increase in the vehicle fleet, we adjust this target to a tax that can raise $23 billion in revenues. This involves setting the future gasoline tax to 25.8 cents per gallon, roughly 40% higher than the current federal tax. This tax rate corresponds to an average tax of 1.15 cents per mile. We also consider the effect of using the VMT tax to raise $23 billion, and calculate that the required VMT tax rate is 0.93 cents per mile.

Figure 9 shows the distributional results of adopting a VMT tax vs. adjusting the gasoline tax. Panel (a) shows drops in mileage in the top six deciles of the expenditure distribution under a VMT tax relative to a gasoline tax. The average decline is about 1.2%. Panel (b) shows the average taxes paid by household, by tax scheme. The first through six deciles pay significantly less under the VMT tax than under the fuel tax. Taxes even out in the seventh expenditure decile, and increase through the rest of the distribution. At the lowest decile, households save on average of $32 per year in federal fuel taxes with the VMT tax, while the average tax burden on households in the highest expenditure decile rises from $191 to $305. Again, we show in Appendix Figure C3 that these results are driven primarily by changes in the vehicle fleet composition rather than the specific elasticity governing households' driving responses to increases in travel costs.

Figure 9: Raising Constant Revenues with Gas Tax vs. VMT (Future Fleet)

(a) Mean Miles



(b) Mean Federal Taxes Paid

Notes: Data from the 2017 NHTS. Panels show the mean miles traveled and mean federal taxes paid, comparing a gasoline tax and a vehicle miles tax calibrated to match current revenues inflated by 15% in line with the vehicle fleet expansion. The figures use the forecast vehicle fleet, assuming a 60/40 split of new non-gasoline vehicles by electric and hybrid. All results conditional on having positive predicted expenditures.

We also explore average taxes paid by drivers of each type of vehicle – gasoline, hybrid, and electric – under the VMT tax with the future fleet. Table 4 shows the annual average taxes paid per household, by expenditure decile and vehicle type. The first column presents payments under the 2017 composition and baseline taxes. The second column shows payments using the future fleet VMT proposal without allowing for the behavioral response described in Equation 3, i.e. this calculation sets the price elasticity of travel demand to 0. The third column shows payments using the full behavioral model under the future VMT tax proposal.

Under the current tax policy, hybrid and electric vehicles pay significantly less or even no gasoline tax relative to households with gasoline vehicles. Comparing the second and third columns, for gasoline vehicles the increase in per mile costs under the future VMT tax induce an increase in taxes paid, with little adjustment due to behavioral response, on account of the low relative change in the price paid before and after policy adoption. In contrast, we estimate that the group with the largest increase in per mile costs, electric vehicle owners, would pay about 8% more in driving-related taxes if they did not adjust their driving behavior in response to the per-mile price increase.

None of these calculations include the potential benefits of reducing other taxes that are currently levied to fund highway maintenance, or the lower driving externalities, such as reduced congestion and emissions, that might be associated with higher taxes. We note that a VMT tax would not be levied at the gas pump, but rather might be paid in a few installments each year. This could affect price salience and might change the price elasticity of demand for miles traveled.

5 Distributional Effects of a Commercial VMT Tax

The last section focused on a VMT tax levied on household vehicle use, but we can also consider a commercial VMT (CVMT) tax as a replacement for or addition to the current federal excise tax of $0.24 per gallon on diesel fuel. In addition to diesel fuel charges, commercial truckers also pay some per-truck fees for interstate highway use. This results in trucks often maximizing their loads, which can increase road damage because the marginal

Table 4: Mean Taxes Paid by Expenditure Decile: Future Fleet with VMT

	Gasoline Vehicles		
	Baseline ($'s)	Paid (no ΔMiles) ($'s)	Paid (ΔMiles) ($'s)
1	91	103	103
2	121	129	129
3	151	158	158
4	177	181	181
5	192	193	192
6	207	194	193
7	231	197	197
8	235	193	192
9	255	184	183
10	256	158	157
	Hybrid Vehicles		
	Baseline ($'s)	Paid (no ΔMiles) ($'s)	Paid (ΔMiles) ($'s)
1	29	88	82
2	67	99	92
3	57	106	98
4	71	119	110
5	54	143	133
6	59	153	142
7	59	161	149
8	58	157	146
9	66	165	154
10	70	178	165
	Electric Vehicles		
	Baseline ($'s)	Paid (no ΔMiles) ($'s)	Paid (ΔMiles) ($'s)
1	0	88	82
2	0	99	92
3	0	106	98
4	0	119	110
5	0	143	133
6	0	153	142
7	0	160	149
8	0	157	146
9	0	165	154
10	0	178	165

Notes: This table shows the mean amount of federal taxes paid per household, by vehicle type and expenditure decile, for three scenarios. In the first column, we present annual federal fuel taxes paid by vehicle type under the current federal gasoline tax. In the second column, we present annual taxes paid under our VMT proposal, assuming no change in driving behavior after the policy change. In the final column, we present annual user fees paid under our VMT proposal, allowing for driving behavior to respond to changes in per mile driving costs induced by the tax change. We calibrate the VMT tax to match current revenues inflated by 15%, use the 2037 forecast vehicle fleet, with a 60/40 BEV/HEV breakdown of new vehicles. For households with multiple types of vehicles (i.e. a gasoline vehicle and a hybrid vehicle), total payment is split across the categories.

damage function rises sharply in weight per axle. In most states, the majority of trucking taxes paid are fuel taxes, registration fees, and tire taxes. Small, Winston and Evans (1989) note that in a handful of states, taxes have varied by miles traveled or by vehicle weight. New Mexico, New York and Oregon have adopted VMT taxes for commercial trucks that varies with the trucks' maximum load capacity.[17] These state taxes vary from 1 to 29 cents per mile, as a function of the weight of the truck. Kentucky has a flat rate CVMT of 3 cents per mile, regardless of truck weight.

Our analysis of the CVMT tax differs from that of the personal driver VMT tax in two ways. First, we consider the CVMT tax as an addition to, not a replacement for, the existing diesel tax. This allows us to start from the status quo costs-per-miles driven and add the new tax per mile. Second, because the CVMT tax is levied on intermediate goods – transport services – in order to describe the incidence on households, we need to determine how it would affect the end-user price of traded goods. This unifies our analysis of the commercial and personal VMT tax policies. For the CVMT tax, we first estimate the share of trucking service costs and indirect diesel taxes in household expenditure, and then explore how an add-on CVMT tax would impact household expenditures. We incorporate data from the Bureau of Economic Analysis' (BEA) Total Requirements tables, specifically the "Industry by Commodity/ After Redefinitions/ Producer Value" table for 2012, the most recent data available. These tables provide estimates of the inputs required, measured in dollars, to produce one dollar's worth of a given output. We focus on the trucking transportation inputs needed to produce various consumer products listed in the CEX Table 1203.[18]

[17] The experience of the four states that currently impose commercial VMT taxes can provide some guidance on the implementation of VMT taxes. These states primarily on self-reported odometer readings. Oregon also uses electronic logging devices (ELDs) to track miles traveled. These are on-board devices already utilized in over a quarter of commercial trucks, due to their requirement in interstate commerce. To extend this approach to the light duty fleet would require vehicle owners to purchase new devices, or vehicle makers to incorporate them into new production. Beider and Austin (2019) discuss enforcement costs related to VMT taxes, including the possibility of using radio-frequency identification readers placed on roads for some VMT tax implementation.

[18] For a breakdown of consumers' expenditure groups, please refer to `https://www.bls.gov/cex/tables/calendar-year/mean-item-share-average-standard-error/cu-income-before-taxes-2019.pdf`. We outline the crosswalk from the CEX to the Total Requirements table in Appendix Table B4, and show crosswalk coverage in Appendix Figure C4.

5.1 Current Distributional Burdens of the Federal Diesel Excise Tax

Before considering a CVMT tax, we examine the distribution of burdens associated with the current diesel fuel tax. This analysis proceeds in the spirit of several earlier studies of both current diesel taxes and prospective CVMT taxes, including Austin (2015), Carloni and Dinan (2021), and the Congressional Budget Office (2019). The total requirements tables list inputs and outputs by industry code, NAICS, or commodity code. We link these to CEX expenditure categories. When necessary, we average the trucking costs of various products in the BEA table that are aggregated within a given CEX category. This linkage matches between 70 and 88% of the expenditures of households in the bottom eight deciles of the spending distribution. The match rate in the highest spending decile is only 59% of spending, reflecting higher expenditure shares on non-tradable goods and services we were unable to crosswalk. If we exclude outlays on retirement saving and pensions – items that are included as expenditures in the CEX – our match rate rises to more than 90% for the bottom eight expenditure deciles, and at least 78% in the top two deciles. For consistency with our household VMT tax analysis, however, we continue to calculate tax burdens as a fraction of total CEX expenditure.

Across all CEX categories, truck transportation services account for about 0.72 cents of each dollar of household expenditure. There is substantial variation in the trucking share across commodities. For example, rental dwellings have a low share, at 0.04 cents per dollar of expenditure, while gasoline and petroleum products are high-share goods, at 1.7 cents per dollar of household expenditure. To place the CEX values in context, we note that trucking contributes to 0.8% of GDP (Bureau of Transportation Statistics, 2018). Since our estimates from the Total Requirements analysis fall a bit below this, we inflate all our trucking shares upward by about 10 percent to match this GDP metric.

To calculate a household's indirect diesel tax burden, we combine the micro expenditures on trucking with macro data on revenue collected by diesel taxes. The Congressional Budget Office (2020) reports that in 2020, the federal government collected \$10.5 billion in diesel tax revenues. Bieder and Austin (2019) estimate that households spend, indirectly, between

0.02 and 0.06% of their income on diesel taxes. Our earlier estimates from the CEX suggest that spending of about 0.3% of income on the federal gasoline tax. These statistics would place the indirect diesel tax burden on households at about 15 percent of the gasoline tax burden, even though federal diesel revenues are about 40 percent of gasoline tax revenues. Our estimates thus suggest that households indirectly bear about one third of the diesel tax burden; this indicates that there are likely additional goods that indirectly use diesel fuel in their production chain but that are not well captured in our analysis.

To determine the burden of diesel taxes across the distribution of households, we allocate the diesel tax revenue to households based on our estimate of the trucking expenditures that they indirectly consume. This reflects in all cases indirect consumption. The diesel expenditure for household i is

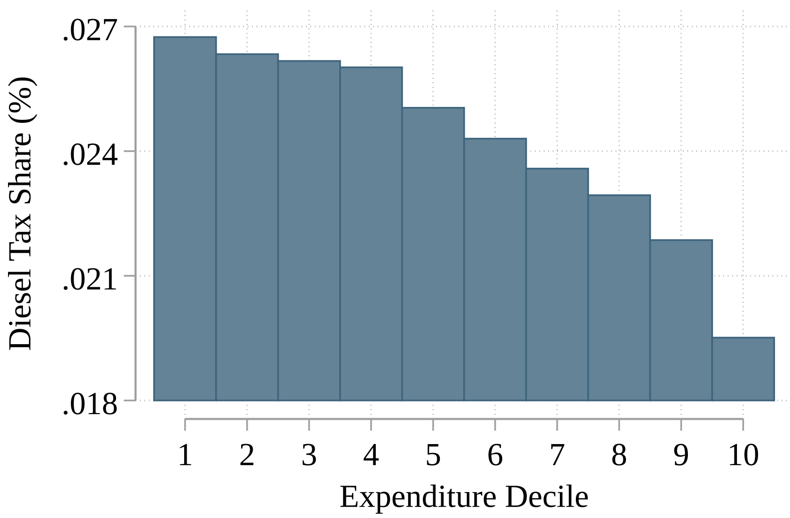
$$DieselExp_i = \frac{TruckExp_i}{\sum_i TruckExp_i} \times \frac{10.5 \times \frac{1}{3}^{rd}}{w_i} \tag{5}$$

where w_i denotes the household's sample weight. We also calculate indirect diesel share of expenditures as $DieselShare_i = \frac{DieselExp_i}{\sum_c Exp_{ic}}$, where we sum across all spending categories, c, within a household.

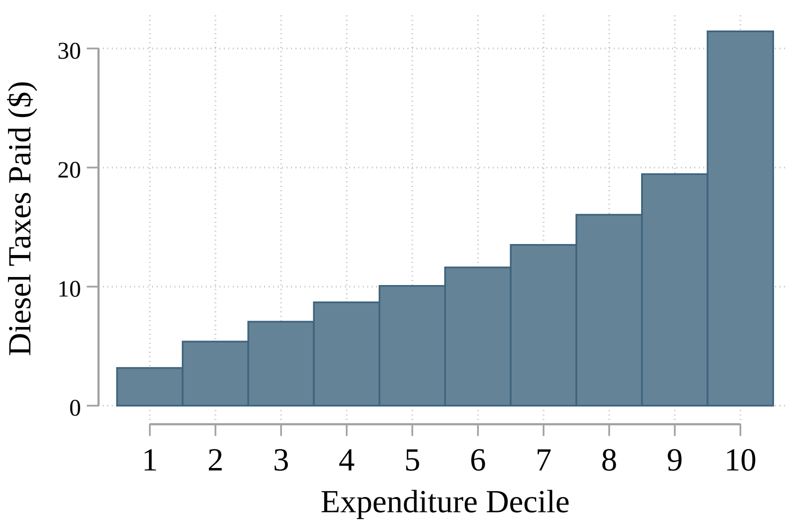
The two panels in Figure 10 provide information on average indirect diesel tax expenditure shares and diesel taxes paid by expenditure decile. The first panel shows that the total share of diesel taxes in the average household's expenditures ranges from 0.020% of total expenditure at the highest decile to 0.027% in the lowest decile. The share of imputed diesel taxes in total expenditures generally declines with total expenditures. The bottom panel shows that households in the lowest expenditure decile can expect to purchase goods each year that embody about $3 of federal diesel taxes each year. These households account for less than 3 percent of indirect diesel fuel consumption. The highest expenditure households consume goods, on average, that include $31 per year in embodied diesel taxes. These households collectively consume about one quarter of the indirect household sector use of diesel fuel.

Figure 10: Diesel Tax Shares and Amount Paid Annually, by Expenditure Decile

(a) Diesel Tax Share of Total Expenditures



(b) Diesel Tax Expenditures ($'s)



Notes: Data from the BEA's 2012 Input-Output tables, crosswalked to the CEX 2017 household expenditure categories. Panel (a) plots the diesel taxes paid indirectly as a share of household expenditure, by expenditure decile. Panel (b) shows the average annual indirect expenditures, in dollars, for households by expenditure decile.

5.2 Distributional Burdens of a Commercial VMT Tax

We consider a 3 cents per mile flat-rate CVMT tax similar to that currently in place in Kentucky. The tax rate is 3 cents per mile. To place this in context, assuming that the average diesel truck delivers a fuel efficiency of about 6.65 miles/gallons, the federal diesel excise tax of 24.4 cents per gallon translates to a per-mile charge of about 3.8 cents. Adding a 3 cent per mile CVMT tax would raise the total tax burden by about 81% increase.

To analyze the impact of adopting a commercial VMT, we calculate the change in expenditures needed to purchase a household's original consumption bundle under the assumption that the CVMT tax is fully passed forward in the prices of consumer goods. Final expenditure on any item c, e^t_{ic}, can be decomposed into expenditure on the good, and the expenditure on the diesel tax component necessary to ship the good to the purchaser: $e^t_{ic} = good^t_{ic} + tax^t_{ic}$. If each household, indexed by i, spends a portion of its consumption basket α^t_c on trucking-related diesel taxes, then the burden of the new CVMT tax can be computed from the difference between α^0_c (no CVMT tax) and α^1_c (CVMT tax in place). We can distribute the CVMT burden based on these patterns across households. In order to calculate how required expenditure changes, we need to estimate the impact of the CVMT tax on α^t_c.

We assume that the distribution of the CVMT tax across trucking service providers is the same as the distribution of the current diesel tax. Our estimates suggest that consumers spend \$12, on average, per year on indirect diesel taxes, while they spend \$312 on average on embodied trucking services. Diesel taxes therefore comprise about four percent 4% of trucking costs. Assuming that all other costs are constant, the increment to trucking costs from a CVMT tax that raises the tax burden on trucking by about 81 percent must be $\Delta TruckingCost^0_c = (0.81) \times (0.04) \times TruckingCost^0_c$. This expression implies that adoption of a 3-cent-per-mile CVMT tax would raise the total cost of trucking services by about 3.2%, with the sum of diesel and CVMT taxes accounting for just over seven percent of the trucking costs. In the language used above, this implies that $\alpha^0_c = 0.04 \times TruckingCost^0_c$ and $\alpha^1_c = 0.07 \times 1.0324 \times TruckingCost^0_c$ where $TruckingCost^0_c$ refers to the dollars of trucking required to produce final good c.

Figure 11 displays the results of implementing a CVMT tax on the required expenditures of households in different expenditure deciles. For those in the lowest expenditure decile, total expenditure needs to increase by 0.0245% in order to accommodate the near doubling of per-mile federal trucking taxes. This declines to 0.02% for the middle expenditure deciles, and falls further to 0.0195% for the top deciles. In dollar terms, the implied federal tax burden of product-embodied federal diesel and CVMT taxes rises from associated with taxes on trucking rises, for those in the lowest decile, from \$3.12 to \$5.65 per year. Those in the highest expenditure decile see their indirect payments rise from \$31.40 to \$56.75.

6 Conclusion

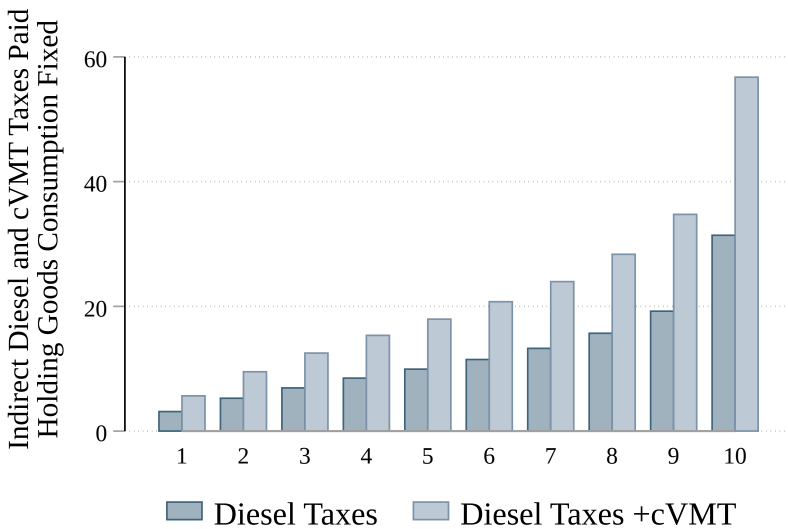
This paper studies the impact of imposing a vehicle miles traveled tax (VMT tax) on personal transportation services associated with the light duty vehicle fleet or on commercial trucking services that are intermediate inputs to household consumption. The analysis draws on data from the 2017 National Household Transportation Survey, and the Consumer Expenditure Survey for the same year, to examine the burden that these taxes would place on households in different strata of the income or expenditure distribution. Several findings emerge from this analysis.

First, with the current light-duty vehicle fleet, the distributional burden of a VMT tax is similar to that of a gasoline excise tax. Only 2 percent of the vehicle stock was hybrid or electric in 2017. Even though these vehicles are skewed toward the highest income and expenditure households, and households that own these vehicles pay less in gasoline excise taxes, the overall difference in the impact of a VMT tax - for - gasoline tax swap across income or expenditure deciles is small.

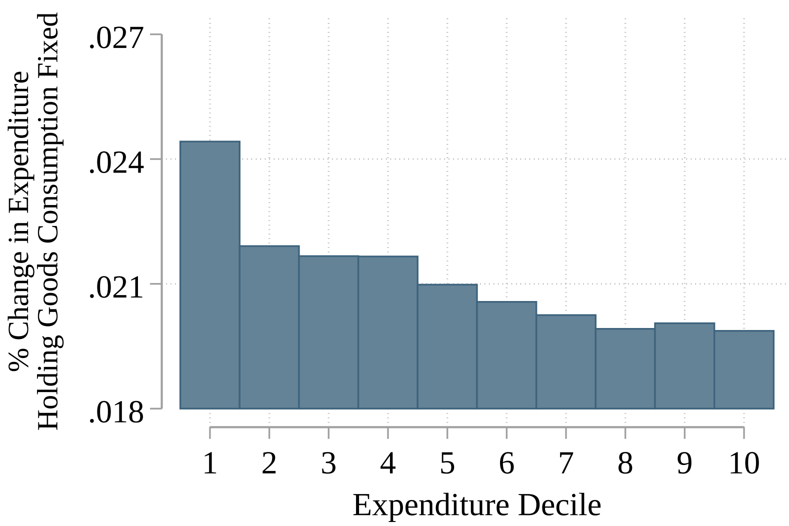
Second, in about 15 years, when current projections suggest that about one third of the vehicle fleet will be made up of battery-electric and hybrid-electric vehicles, the choice between a gasoline tax and a VMT tax is more important from the standpoint of tax burden distribution. If households at the top of the income and expenditure distribution continue to be the primary buyers of BHEVs, then the gasoline tax will become more regressive over time, and the VMT tax, by expanding the tax base to all vehicles, could both preserve the revenue stream associated with the current gasoline tax and distribute the burden of the

Figure 11: Change in Expenditure Needed to Maintain Original Consumption Basket, by Expenditure Decile

(a) $'s in Expenditure



(b) % Change in Expenditure



Notes: Data from the BEA's 2012 Input-Output tables, crosswalked to the CEX 2017 household expenditure categories. The figure presents the amounts of additional expenditure needed to purchase the original consumption bundle observed in the CEX, under the adoption of a new federal VMT of $0.03/mile. Panel (a) presents the results in dollars, comparing the baseline scenario (analogous to FIgure 15(b)) to the tax scheme with both diesel taxes and CVMT taxes. Panel (b) presents the percent change in expenditure needed to accomodate this change in indirect diesel tax exposure, in order to keep consumption bundles constant.

tax in a less regressive fashion. Whether the future distribution of BHEVs will skew as strongly toward high income households as the current distribution is an important source of uncertainty in our analysis, however, especially in light of limitations in the availability of tax credits for electric vehicle purchases that were enacted in the 2022 Inflation Reduction Act.

Third, a commercial VMT tax, levied on the trucking sector that currently pays the diesel fuel excise tax at a rate of 3 cents per mile for commercial trucking, and raising about $3 billion per year, if fully passed through to consumers in the form of higher goods prices for products that required truck transportation, would place burdens on households that vary with their total expenditures. The burden of the price increases associated with such a tax would vary from roughly $2.50 per year from households in the lowest expenditure decile, to about $26 per year in the highest decile. The burden as a share of total expenditures is modestly higher in the bottom half than the top half of the expenditure distribution, reflecting the larger budget share of tradeable goods (which are transported) relative to services in the budgets of low-income households.

There are many open questions on the distributional impact, and other economic effects, of VMTs that warrant future study. We have not considered potential differences in the average number of miles driven per year by BHEVs and gasoline-powered vehicles, although research on the current BHEV fleet suggests that they may be used less intensively than their internal-combustion-engine-powered counterparts. This may be due, in part, to the limited range of many first-generation battery-electric vehicles; driving patterns may change as new BEVs with longer range are introduced. We have not considered the economic determinants of vehicle scrappage decisions or the potential trickle-down of BHEVs from high-income initial buyers to middle and lower-income households, a prospect that may be accelerated by credits for used BHEV purchases by modest income households that was adopted in the Inflation Reduction Act of 2022. With regard to the commercial VMT, we have assumed complete pass-through of taxes to consumers, and we have not allowed for any product substitution at the household level in response to higher embodied transportation costs.

While the paper focuses on gasoline and VMT taxes, it also presents information on the distribution of various user fees that fund public transportation infrastructure. We find that different user charges have different distributional burdens. While buses are disproportionately used by low-income households, commuter rail ridership tilts toward higher income groups. Our analysis has not considered a number of special programs that may affect the progressivity of user fees. For example, many public transit authorities offer discounts for students or senior citizens, in line with reduced fare requirements that are a precondition for federal funding (CFR Title 49, Section 609). Some also offer low-income fare adjustments. These provisions have important effects in improving the progressivity of user fees for financing these transportation modes. The Infrastructure Investment and Jobs Act of 2021 includes more than $100 billion for public transportation, with equity and modernization highlighted as key policy goals. User fees financing could provide a way of expanding the revenue base for new public transit projects. We hope to consider in future work how various public transportation policies that create differentials in user fees across households in different income strata affect the distributional burdens of these fees.

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A Technological Adoption and the Progressivity of the Gas Tax

This appendix presents a stylized model that focuses onto inform the interplay between household income and adoption of an energy-saving technology, such as BHEVs. The model assumes that individuals choose one of two technologies and the number of miles they drive. The choice of technology determines the energy use per mile (denoted g_i), the fixed cost of purchase (denoted k$_i$) and the pleasure of driving (denoted α_i). Utility from using technology i is defined as

$$U = (Y - p_g g_i d - k_i)^{(1-\rho)} + \alpha_i d^{(1-\rho)}, \tag{6}$$

where Y is income, p_g represents the price of gas, d is the endogenous distance travelled and $\rho > 0$. We assume a benchmark technology "0" and an energy-saving technology "1", where $g_0 > g_1$. Conditional upon the choice of technology i, the total spending on energy equals $\frac{Y-k_i}{1+(p_g^{\rho-1} g_i^{\rho-1} \alpha_i)^{\frac{-1}{\rho}}}$. It increases with income and the composite term $\alpha_i g_i^{\rho-1}$, which captures the the combined impact on the technology's marginal parameter on driving. Energy use can decline with income if high-income households are more likely to adopt the energy saving technology. The following proposition describes the link between energy-saving technology adoption and income.

Proposition:

(a) If $k_0 > k_1$and $\alpha_1/\alpha_0 > (g_1/g_0)^{1-\rho}$, then all individuals adopt the energy saving technology and energy consumption rises with income. If $k_0 < k_1$ and $\alpha_1/\alpha_0 < (g_1/g_0)^{1-\rho}$, then no one adopts the energy saving technology and energy consumption rises with income.

(b) If $k_0 > k_1$ and $(g_1/g_0)^{1-\rho} > \alpha_1/\alpha_0$, then individuals adopt the energy-saving if and only if $Y > Y^*$, where Y^* is a finite value of $Y > k_0$. Energy consumption rises continuously everywhere with Y, except at the point Y^*. At $Y = Y^*$, energy consumption increases discontinuously with Y if and only if $1 > \frac{Y^* - k_0}{Y^* - k_1} > \frac{\alpha_1 g_1^{\rho-1}}{\alpha_0 g_0^{\rho-1}}$.

(c) If $k_0 < k_1$ and $(g_1/g_0)^{1-\rho} < \alpha_1/\alpha_0$, then individuals adopt the clean technology if and only if $Y > Y^{**}$, where Y^{**} is a finite value of $Y > k_1$. Energy consumption rises everywhere with Y, except at the point Y^{**}. At $Y = Y^{**}$, energy consumption decreases discontinuously with Y if and only if $\frac{Y^{**} - k_0}{Y^{**} - k_1} > \frac{\alpha_1 g_1^{\rho-1}}{\alpha_0 g_0^{\rho-1}} > 1$.

The conditions $\frac{Y^{**} - k_0}{Y^{**} - k_1} > \frac{\alpha_1 g_1^{\rho-1}}{\alpha_0 g_0^{\rho-1}}$ and $\frac{Y^* - k_0}{Y^* - k_1} > \frac{\alpha_1 g_1^{\rho-1}}{\alpha_0 g_0^{\rho-1}}$ are equivalent to the condition $\frac{1 + (p_g g_1)^{\frac{\rho-1}{\rho}} \alpha_1^{\frac{1}{\rho}}}{(1 + (p_g g_0)^{\frac{\rho-1}{\rho}} \alpha_0^{\frac{1}{\rho}}} > \left(\frac{(p_g g_1)^{\frac{\rho-1}{\rho}} \alpha_1^{\frac{1}{\rho}}}{(p_g g_0)^{\frac{\rho-1}{\rho}} \alpha_0^{\frac{1}{\rho}}} \right)^{(1-\rho)}$, which is written only in terms of exogenous variables.

This proposition details three possible scenarios for energy-saving technologies and the relationship between income and energy use. In the parameter ranges covered in Part (a) of the Proposition, the green technology is either adopted for all values of Y or not adopted for all values of Y. As all individuals use the same technology, and hence richer people use more energy.

The parameters discussed in Part (b) seem relevant for the 1970s and 1980s. Energy-saving cars, such as the Honda Civic, were typically much smaller and less expensive, than gas-intensive cars, like Cadillacs. Energy saving arose from The energy saving was created primarily by having less weight and less power. Consequently, the green technology was adopted by lower- rather than higher-income households. Energy use rises with income almost everywhere, and it may jump up with income at the point of technology adoption, as long as the price gap between the two cars isn't too large. If the up-front cost of two technologies is similar, which is guaranteed by $\frac{Y^* - k_0}{Y^* - k_1} > \frac{\alpha_1 g_1^{\rho-1}}{\alpha_0 g_0^{\rho-1}}$, then the post-purchase parameter aggregate $\alpha_i g_i^{\rho-1}$ determine the change in energy use, and we have assumed $\alpha_0 g_0^{\rho-1} > \alpha_1 g_1^{\rho-1}$ in part (b).

If the up-front cost difference is larger, then this cost will have effectively an "income effect," which means that the Cadillac buyer is pushed to drive less. The condition that

$\dfrac{Y^* - k_0}{Y^* - k_1} > \alpha_1 g_1^{\rho-1} \alpha_0 g_0^{\rho-1}$ ensures that the "substitution effects" associated with the Cadillac (more fun to drive and more gas per mile) overwhelm that income effect.

The parameters discussed in Part (c) are oriented towards new expensive technologies that reduce energy use, but cost more. Expensive EVs such as Teslas reduce energy use, but they are also typically more powerful and quieter. The proposition predicts that if $k_0 < k_1$ and $\left(\dfrac{g_1}{g_0}\right)^{1-\rho} < \dfrac{\alpha_1}{\alpha_0}$, then the green technology is adopted by the rich. Again, energy use is rising almost everywhere with income, but in this case, energy use jumps downward with income at the point of adoption if k_0 is low relative to k_1, that $\dfrac{Y^{**} - k_0}{Y^{**} - k_1} > \dfrac{\alpha_1 g_1^{\rho-1}}{\alpha_0 g_0^{\rho-1}} > 1$ holds. In this case, price inequality is needed to generate the added income effect that pushes driving down for the Tesla driver. It is not enough for the expensive EV Tesla just to be gas efficient to satisfy this condition, given our functional form, because improvements in gas mileage are offset by extra driving.

Proof of Proposition:

(a) Conditional upon adopting technology i, the optimal level of driving satisfies $d_i^* = \dfrac{\alpha_i^{\frac{1}{\rho}}(Y - k_i)}{(p_g g_i)^{\frac{1}{\rho}} + p_g g_i \alpha_i^{\frac{1}{\rho}}}$, which implies that welfare is $(1 + (p_g g_i)^{\frac{\rho-1}{\rho}} \alpha_i^{\frac{1}{\rho}})^{\rho}(Y - k_i)^{1-\rho}$.
Consequently the net benefit of adoption technology 1 can be written as:

$F(Y) = (1+(p_g g_1)^{\frac{\rho-1}{\rho}} \alpha_1^{\frac{1}{\rho}})^{\rho}(Y-k_1)^{1-\rho} - (1+(p_g g_0)^{\frac{\rho-1}{\rho}} \alpha_0^{\frac{1}{\rho}})^{\rho}(Y-k_0)^{1-\rho}$, which is positive if and only if $\dfrac{1 + (p_g g_1)^{\frac{\rho-1}{\rho}} \alpha_1^{\frac{1}{\rho}}}{1 + (p_g g_0)^{\frac{\rho-1}{\rho}} \alpha_0^{\frac{1}{\rho}}} > \left(\dfrac{Y - k_0}{Y - k_1}\right)^{\frac{1-\rho}{\rho}}$.

If $k_0 > k_1$ and $\dfrac{\alpha_1}{\alpha_0} > \left(\dfrac{g_1}{g_0}\right)^{1-\rho}$, then $1+(p_g g_1)^{\frac{\rho-1}{\rho}} \alpha_1^{\frac{1}{\rho}} > 1+(p_g g_0)^{\frac{\rho-1}{\rho}} \alpha_0^{1\rho}$ and $(Y-k_1)^{1-\rho} > (Y - k_0)^{1-\rho}$ for all values of Y and consequently all income groups adopt.

If $k_0 < k_1$ and $\dfrac{\alpha_1}{\alpha_0} < \left(\dfrac{g_1}{g_0}\right)^{1-\rho}$, then $1+(p_g g_1)^{\frac{\rho-1}{\rho}} \alpha_1^{\frac{1}{\rho}} < 1+(p_g g_0)^{\frac{\rho-1}{\rho}} \alpha_0^{1\rho}$ and $(Y-k_1)^{1-\rho} < (Y - k_0)^{1-\rho}$ for all values of Y and consequently no income groups adopt.

(b) If $k_0 > k_1$ and $\dfrac{\alpha_1}{\alpha_0} < \left(\dfrac{g_1}{g_0}\right)^{1-\rho}$, then $0 < \dfrac{1 + (p_g g_1)^{\frac{\rho-1}{\rho}} \alpha_1^{\frac{1}{\rho}}}{1 + (p_g g_0)^{\frac{\rho-1}{\rho}} \alpha_0^{\frac{1}{\rho}}} < 1$, and the inequality can be written as $Y < \dfrac{(1+(p_g g_0)^{\frac{\rho-1}{\rho}}\alpha_0^{\frac{1}{\rho}})^{\frac{\rho}{1-\rho}}k_0 - (1+(p_g g_1)^{\frac{\rho-1}{\rho}}\alpha_1^{\frac{1}{\rho}})^{\frac{\rho}{1-\rho}}k_1}{(1+(p_g g_0)^{\frac{\rho-1}{\rho}}\alpha_0^{\frac{1}{\rho}})^{\frac{\rho}{1-\rho}} - (1+(p_g g_1)^{\frac{\rho-1}{\rho}}\alpha_1^{\frac{1}{\rho}})^{\frac{\rho}{1-\rho}}} = Y^*$.

Hence there is a value of Y, denoted Y^*, at which $\dfrac{1+(p_g g_1)^{\frac{\rho-1}{\rho}}\alpha_1^{\frac{1}{\rho}}}{(1+(p_g g_0)^{\frac{\rho-1}{\rho}}\alpha_0^{\frac{1}{\rho}}} = \left(\dfrac{Y-k_0}{Y-k_1}\right)^{\frac{1-\rho}{\rho}}$. For all values of Y>Y*, welfare is higher with technology 0. For all values of Y<Y*, welfare is higher with technology 1. Miles travelled and hence gas consumption is increasing continuously at all levels of Y other than Y^* (because within a technology $d = \dfrac{\alpha_i^{\frac{1}{\rho}}(Y-k_i)}{(p_g g_i)^{\frac{1}{\rho}} + p_g g_i \alpha_i^{\frac{1}{\rho}}}$), but at Y^*, gas consumption jumps from from $g_1 d_1^*$ to $g_0 d_0^*$, where $g_i d_i^* = \dfrac{(\alpha_i g_i^{\rho-1})^{\frac{1}{\rho}}(Y-k_i)}{p_g^{\frac{1}{\rho}} + p_g(\alpha_i g_i^{\rho-1})^{\frac{1}{\rho}}}$.

Using the fact that $\dfrac{1+(p_g g_1)^{\frac{\rho-1}{\rho}}\alpha_1^{\frac{1}{\rho}}}{1+(p_g g_0)^{\frac{\rho-1}{\rho}}\alpha_0^{\frac{1}{\rho}}} = \left(\dfrac{Y^*-k_0}{Y^*-k_1}\right)^{\frac{1-\rho}{\rho}}$, then inequality simplifies to $\dfrac{Y^*-k_0}{Y^*-k_1} > \dfrac{\alpha_1 g_1^{\rho-1}}{\alpha_0 g_0^{\rho-1}}$, or $\dfrac{1+(p_g g_1)^{\frac{\rho-1}{\rho}}\alpha_1^{\frac{1}{\rho}}}{1+(p_g g_0)^{\frac{\rho-1}{\rho}}\alpha_0^{\frac{1}{\rho}}} > \left(\dfrac{(p_g g_1)^{\frac{\rho-1}{\rho}}\alpha_1^{\frac{1}{\rho}}}{(p_g g_0)^{\frac{\rho-1}{\rho}}\alpha_0^{\frac{1}{\rho}}}\right)^{1-\rho}$.

(c) If $k_0 < k_1$ and $\dfrac{\alpha_1}{\alpha_0} > \left(\dfrac{g_1}{g_0}\right)^{1-\rho}$, then $\dfrac{1+(p_g g_1)^{\frac{\rho-1}{\rho}}\alpha_1^{\frac{1}{\rho}}}{1+(p_g g_0)^{\frac{\rho-1}{\rho}}\alpha_0^{\frac{1}{\rho}}} > 1$, and the inequality can be written $Y > \dfrac{(1+(p_g g_1)^{\frac{\rho-1}{\rho}}\alpha_1^{\frac{1}{\rho}})^{\frac{\rho}{1-\rho}}k_1 - (1+(p_g g_0)^{\frac{\rho-1}{\rho}}\alpha_0^{\frac{1}{\rho}})^{\frac{\rho}{1-\rho}}k_0}{(1+(p_g g_1)^{\frac{\rho-1}{\rho}}\alpha_1^{\frac{1}{\rho}})^{\frac{\rho}{1-\rho}} - (1+(p_g g_0)^{\frac{\rho-1}{\rho}}\alpha_0^{\frac{1}{\rho}})^{\frac{\rho}{1-\rho}}} = Y^{**}$.

Hence there exists a value of Y, denoted Y^{**} at which $\dfrac{1+(p_g g_1)^{\frac{\rho-1}{\rho}}\alpha_1^{\frac{1}{\rho}}}{(1+(p_g g_0)^{\frac{\rho-1}{\rho}}\alpha_0^{\frac{1}{\rho}}} = \left(\dfrac{Y-k_0}{Y-k_1}\right)^{\frac{1-\rho}{\rho}}$, and for all values of Y below Y^{**}, individuals choose technology 0 and for all values of Y above Y^{**}, individuals choose technology 1. Gas consumption will drop discontinuously down as income rises at the point if and only if $\dfrac{Y^{**}-k_0}{Y^{**}-k_1} > \dfrac{\alpha_1 g_1^{\rho-1}}{\alpha_0 g_0^{\rho-1}} > 1$ or $\dfrac{1+(p_g g_1)^{\frac{\rho-1}{\rho}}\alpha_1^{\frac{1}{\rho}}}{1+(p_g g_0)^{\frac{\rho-1}{\rho}}\alpha_0^{\frac{1}{\rho}}} > \left(\dfrac{(p_g g_1)^{\frac{\rho-1}{\rho}}\alpha_1^{\frac{1}{\rho}}}{(p_g g_0)^{\frac{\rho-1}{\rho}}\alpha_0^{\frac{1}{\rho}}}\right)^{1-\rho}$.

B Appendix Tables

Table B1: Replication of 2019 Consumer Expenditure Survey, Table 1203

Item	All	< $15,000	$15,000-$29,999	$30,000-$39,999	$40.000-$49,999	$50,000-$69,000	$70,000-$99,999	$100,000-$149,000	$150,000-$199,999	$200,000+
	Table 1203									
Number of CU's	132,242	15,848	19,856	12,991	11,208	17,470	19,119	18,225	8,266	9,260
Pre-Tax Income	$82,852	$7,574	$22,189	$34,772	$44,831	$59,328	$83,558	$121,433	$171,061	$343,498
Annual Expenditure	$63,036	$26,194	$34,201	$40,942	$47,299	$54,212	$66,801	$84,994	$109,020	$160,318
Gas, other fuels, motor oil	$2,094	$970	$1,170	$1,699	$1,864	$2,153	$2,496	$2,927	$3,181	$3,283
	Replication of Table 1203 using PUMD									
Number of CU's	132,242	15,742	19,720	12,910	11,145	17,432	19,044	17,885	7,477	10,815
Pre-tax Income	$82,451	$7,368	$22,048	$34,643	$44,679	$59,122	$83,592	$120,952	$170,183	$309,772
Annual Expenditure	$59,280	$24,716	$31,944	$39,308	$44,086	$50,980	$63,647	$79,859	$99,337	$142,784
Gas, other fuels, motor oil	$2,094	$961	$1,171	$1,701	$1,863	$2,142	$2,507	$2,911	$3,177	$3,223

Notes: This table replicates Table 1203 from the Survey of Consumer Expenditures annual release, for the year 2019. Replication errors occur due to sampling and adjustments made to the public use microdata in order to maintain consumer unit anonymity.

Table B2: Forecasting Vehicle Registrations, Sales and Retirement

Year	$\Delta Registrations_{t,t-1}$	$\widehat{Sales}_t$	$\widehat{share^{BHEV}}_t$	$Sales_t^{BHEV}$	$Sales_t^{ICE}$	$Retire_t$
2017	3249	16827	3.3	555	16272	13578
2018	673	16919	3.9	660	16259	16246
2019	2931	16630	4.2	698	15932	13699
2020	1768	14114	5.4	762	13352	12346
2021	1781	15055	6.6	995	14060	13275
2022	1793	15015	8.1	1215	13800	13222
2023	1805	14975	9.9	1483	13492	13169
2024	1818	14934	12.2	1810	13124	13117
2025	1830	14894	14.8	2210	12685	13064
2026	1843	14854	18.2	2697	12157	13011
2027	1856	14814	22.2	3293	11521	12958
2028	1869	14774	27.2	4019	10755	12905
2029	1882	14734	33.3	4906	9828	12851
2033	1936	14573	56.2	8193	6380	12638
2034	1949	14533	62.2	9046	5487	12584
2035	1963	14493	67.9	9843	4650	12530
2036	1976	14453	73.1	10566	3887	12476
2037	1990	14413	77.7	11203	3210	12422
		Totals		92,407	205,730	260,748

Notes: Data on vehicle registrations and sales by fuel type from *Transportation Energy Data Book, Edition 39* produced by Oak Ridge National Laboratory for the Department of Energy. Sales and share hybrid/electric based on data up to 2020; registration data through 2019. Additional years authors' forecast. Registrations, sales, and retirement in 1000's.

Table B3: Creating a Forecast for 2037 NHTS Data

Decile	(1) Vehicles^{2017}	(2) BHEV^{2017}	(3) ICE^{2017}	(4) P(Decile|BHEV)	(5) Vehicles^{2037}	(6) BHEV^{2037}	(7) ICE^{2037}	(8) $\Delta Vehicles$	(9) Δ BHEV	(10) Δ ICE
1	11013	41	10972	0.72	12665	646	12019	1652	605	1047
2	15093	113	14980	1.99	17357	1784	15573	2264	1671	593
3	18100	174	17926	3.05	20815	2735	18080	2715	2561	154
4	20072	251	19821	4.42	23083	3963	19120	3011	3712	-701
5	22312	356	21956	6.25	25659	5604	20055	3347	5248	-1901
6	25896	491	25405	8.63	29780	7738	22042	3884	7247	-3363
7	28177	713	27464	12.55	32404	11253	21151	4227	10540	-6313
8	28658	859	27799	15.11	32957	13549	19408	4299	12690	-8391
9	30005	1161	28844	20.44	34506	18328	16178	4501	17167	-12666
10	29998	1526	28472	26.85	34498	24075	10423	4500	22549	-18049
	229324	5685	223639	100.01	263723	89665	174056	34399	83990	-49591

Notes: Data in columns 1–4 based on 2017 NHTS vehicle level survey aggregated to households, by authors' household expenditure deciles. Data in columns 5–7 based on 2037 stock of BHEV and ICE vehicles according to authors' forecast, assuming constant distribution of BHEVs across expenditure deciles. Columns 8–10 difference the 2017 and 2037 findings.

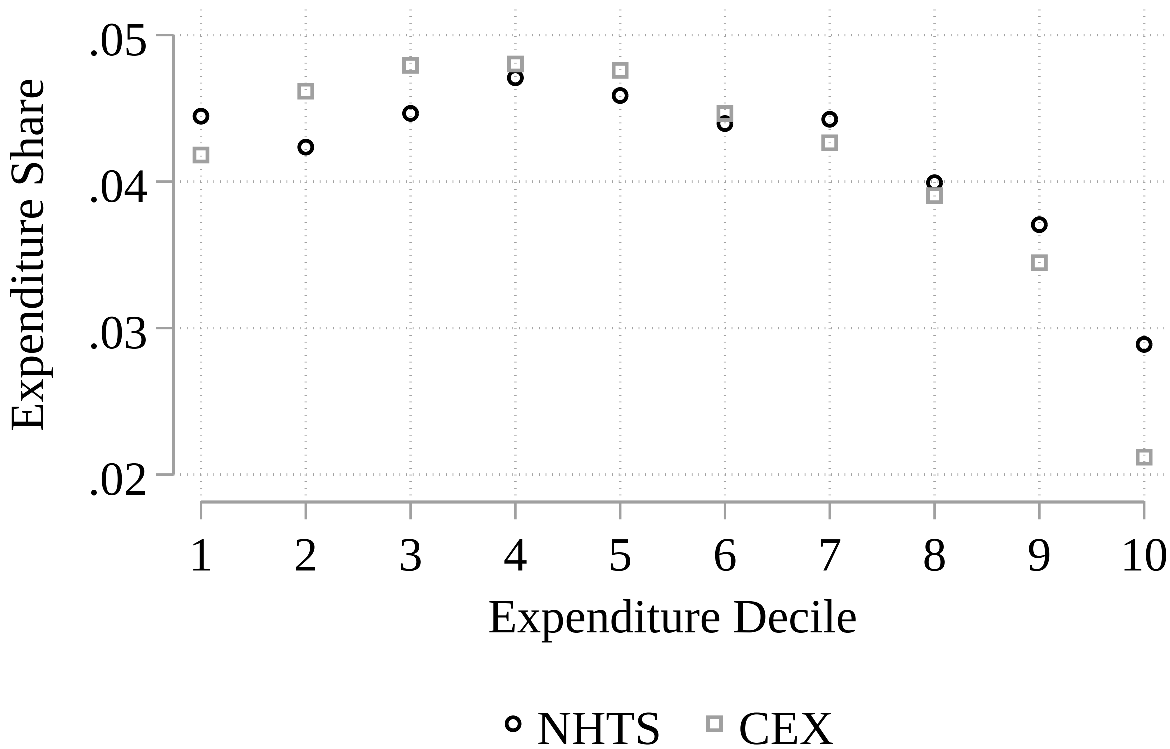
Table B4: Crosswalk from BEA's Total Requirements to CEX Expenditure Categories

BEA IO Commodity	CEX Category	Truck transportation Share
All other food and drinking places	food away from home	0.0070593
Amusement parks and arcades	fees and admissions	0.0090132
Automotive equipment rental and leasing	vehicle rental, leases, licenses and other charges	0.0043736
Automotive repair and maintenance	vehicle maintenance and repairs	0.0077437
Book publishers	reading	0.0110228
Child day care services	education	0.0078640
Civic, social, professional, and similar organizations	cash contributions	0.0070915
Clothing and clothing accessories stores	apparel and services	0.0090630
Direct life insurance carriers	life and other personal insurance	0.0009194
Dry-cleaning and laundry services	household operations	0.0094253
Elementary and secondary schools	education	0.0054672
Food and beverage stores	alcoholic beverages	0.0108911
Food and beverage stores	food at home	0.0108911
Full-service restaurants	food away from home	0.0093778
Gasoline stations	gasoline, other fuels, and motor oil	0.0154538
General merchandise stores	household operations	0.0099524
Grantmaking, giving, and social advocacy organizations	cash contributions	0.0048319
Health and personal care stores	personal care products and services	0.0055965
Health and personal care stores	drugs	0.0055965
Health and personal care stores	medical supplies	0.0055965
Home health care services	medical services	0.0052707
Hospitals	medical services	0.0072299
Independent artists, writers, and performers	fees and admissions	0.0008481
Insurance carriers, except direct life	vehicle insurance	0.0010972
Insurance carriers, except direct life	health insurance	0.0010972
Junior colleges, colleges, universities, and professional schools	education	0.0053413
Limited-service restaurants	food away from home	0.0116851
Medical and diagnostic laboratories	medical services	0.0050679
Motor vehicle and parts dealers	vehicle purchases	0.0112025
Museums, historical sites, zoos, and parks	fees and admissions	0.0070809
Newspaper publishers	reading	0.0065464
Nonstore retailers	household operations	0.0072482
Nursing and community care facilities	medical services	0.0067906
Offices of dentists	medical services	0.0048821
Offices of other health practitioners	medical services	0.0044240
Offices of physicians	medical services	0.0033476
Other ambulatory health care services	medical services	0.0080157
Other amusement and recreation industries	fees and admissions	0.0167363
Other educational services	education	0.0060345
Other personal services	household operations	0.0041878
Outpatient care centers	medical services	0.0050748
Owner-occupied housing	owned dwellings	0.0013106
Performing arts companies	fees and admissions	0.0044224
Periodical Publishers	reading	0.0080464
Personal and household goods repair and maintenance	household operations	0.0035449
Personal care services	personal care products and services	0.0053846
Religious organizations	cash contributions	0.0084143
Residential mental health, substance abuse, and other residential care facilities	medical services	0.0084259
Services to buildings and dwellings	natural gas	0.0091427
Services to buildings and dwellings	electricity	0.0091427
Services to buildings and dwellings	fuel oil and other fuels	0.0091427
Spectator sports	fees and admissions	0.0031418
Tenant-occupied housing	rented dwelllings	0.0004256
Veterinary services	pets	0.0130759
Waste management and remediation services	water and other public services	0.0307979
Wired telecommunications carriers	telephone services	0.0042030
Wireless telecommunications carriers (except satellite)	telephone services	0.0071040
Mean truck transportation cost share:		0.0072095

Notes: Data on total requirements from the BEA's total requirements table, for truck transportation industry (input) to all other commodities (output). Truck transportation share denotes the dollars of trucking industry input required, both directly and indirectly, to produce one dollar of the final BEA IO commodity for final use. Expenditure categories from the BLS's ***Table 1203.*** *Income before taxes: Annual expenditure means, shares, standard errors, and coefficients of variation, Consumer Expenditure Survey, 2019.* Crosswalked by authors.

C Appendix Figures

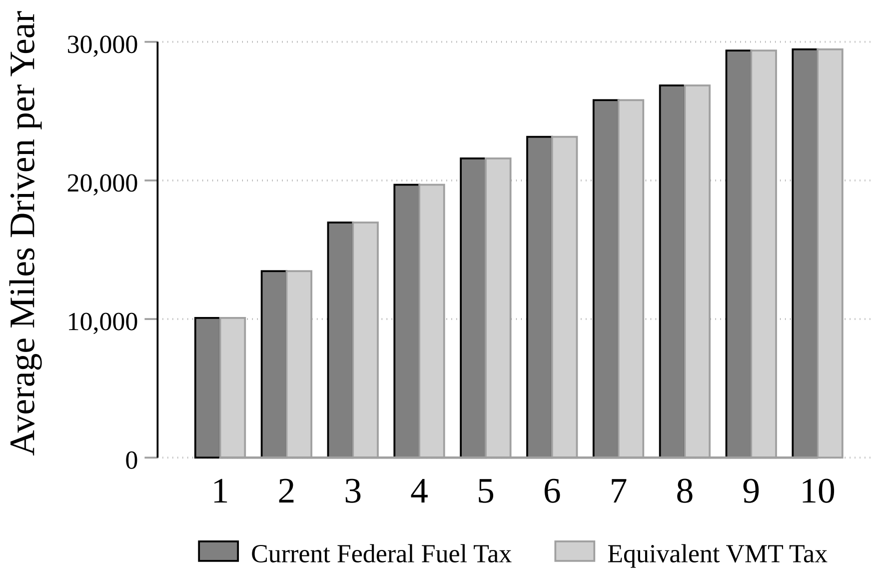
Figure C1: Expenditure Prediction Validation: Comparing Gasoline Expenditure in CEX with NHTS



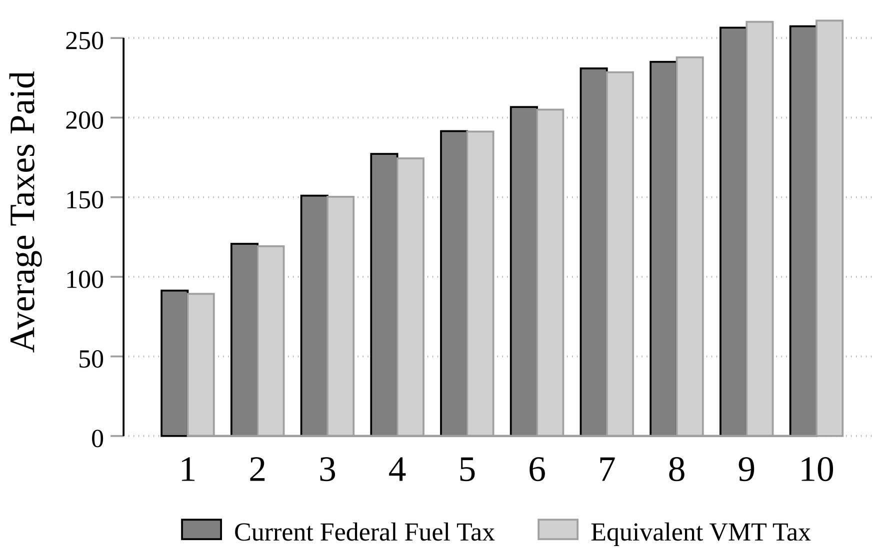
Notes: This figure compares the mean gasoline expenditure shares in the NHTS and CEX data. We use observed expenditures on gasoline, and observed total expenditures from the 2017 CEX. From the 2017 NHTS, we use imputed expenditures from our expenditure model. Gasoline expenditure in the NHTS comes from computing the gas cost per mile, based on fuel efficiency data from the NHTS and regional gas prices from the EIA, and multiplying by the observed miles traveled in the data. We then take the average gasoline shares, weighted by each survey's respective population weights.

Figure C2: Baseline vs. Revenue Neutral VMT (2017), No Behavioral Channel, $\varepsilon_g = 0$

(a) Mean Miles



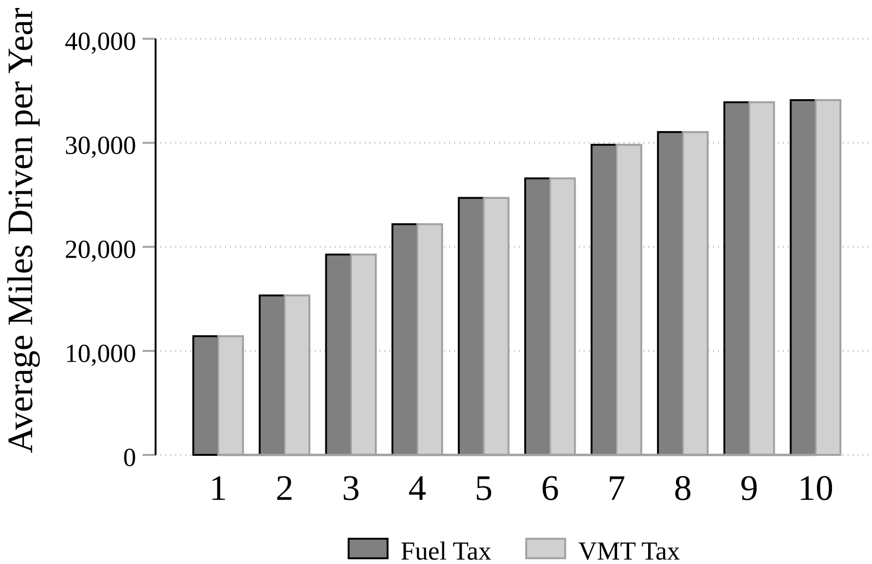
(b) Mean Federal Taxes Paid



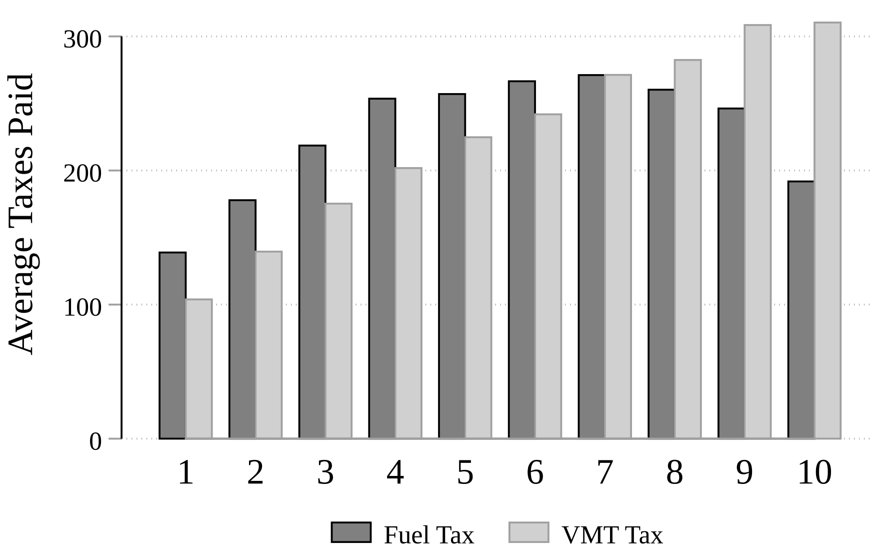
Notes: Data from the 2017 NHTS. Panels show the mean miles traveled and mean federal taxes paid, comparing the current gasoline tax and proposed revenue-neutral vehicle miles tax (VMT). All results conditional on having positive predicted expenditures.

Figure C3: Raising Constant Revenues with Gas Tax vs. VMT (Future Fleet), No Behavioral Channel, $\varepsilon_g = 0$

(a) Mean Miles



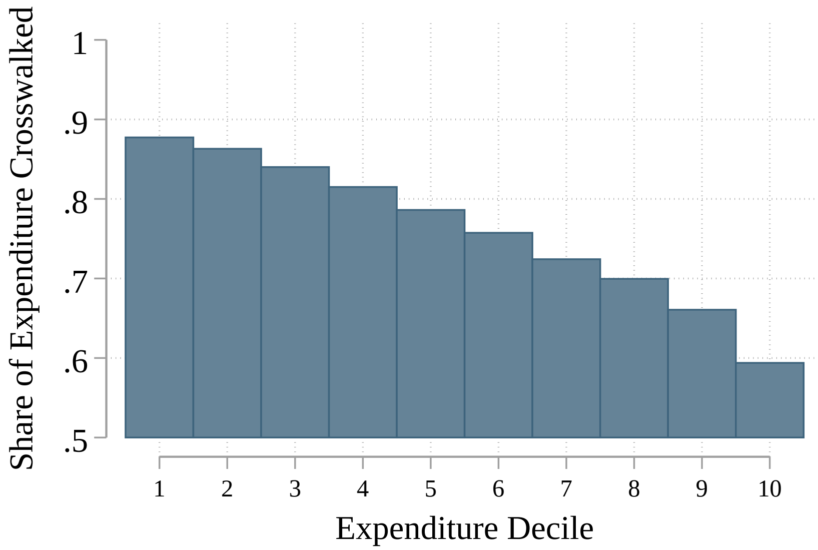
(b) Mean Federal Taxes Paid



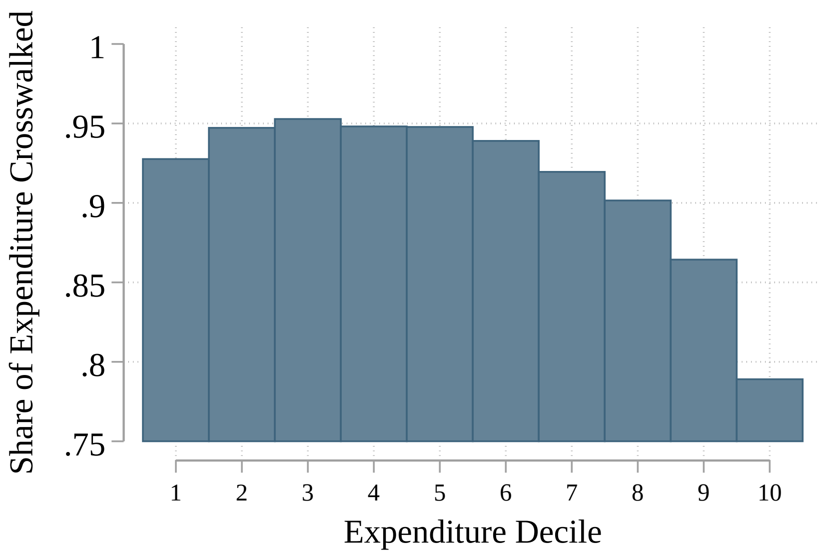
Notes: Data from the 2017 NHTS. Panels show the mean miles traveled and mean federal taxes paid, comparing a gasoline tax and a vehicle miles tax calibrated to match current revenues inflated by 15% in line with the vehicle fleet expansion. The figures use the forecasted vehicle fleet, assuming a 60/40 split of new non-gasoline vehicles by electric and hybrid. All results conditional on having positive predicted expenditures.

Figure C4: Fraction of Expenditures Covered by BEA–CEX Crosswalk

(a) All Expenditures



(b) Excluding Outlays for Pensions & Retirement



Notes: These figures plot the share of total expenditures we are able to account for with the crosswalk constructed from Table 9. Services that are not traded, such as pension outlays, do not crosswalk from the Input-Output tables to the CEX data. Panel (a) plots the share of expenditure we can link to trucking costs, by expenditure decile based on total expenditure, in line with the rest of the results in the paper. Panel (b) plots the share of expenditure we can link, by expenditure decile based on total expenditure less outlays for retirement and pension funds, as these could be classified as "savings," are a major component of outlays in higher expenditure deciles, and will not be impacted by a CVMT tax. Panel (b) shows that we do account for most of household expenditures, especially in the bottom 8 deciles, while at the top end, we continue to miss expenditure on other non-tradable services unrelated to our tax policy.