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ABSTRACT

The Effect of Diesel Tax Rates on the Daily Commuting of US Workers: An Effective Instrument to Promote Sustainable Mobility?*

In this paper, we analyze whether diesel fuel taxes can be an effective tool to boost the daily commuting of US workers towards the use of green modes of transport. To that end, we use data from the American Time Use Survey 2003-2019 and explore the factors influencing commuting time and the proportion of commute using alternative modes of transport, including walking and cycling. Our results indicate that diesel fuel taxes are linked to a reduction in the total time devoted to commuting, and to the proportion of commuting by private car, and to an increase in the proportion of commuting done by green modes of transport such as public transport and walking. This relationship is not homogeneous in the urban dimension, as the effects on total commuting time and the percentage of commuting by public transport is present in urban areas only. In a context where many countries are implementing policies aimed at increasing the use of sustainable modes of personal mobility, our results indicate that taxing fuels used for personal mobility may be an efficient way to decrease the use of more polluting modes of transport and encourage more eco-friendly alternatives while commuting.

JEL Classification: D1, Q4, R4

Keywords: commuting time, green mobility, state diesel taxes, American Time Use Survey

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1. Introduction

In this paper we analyze the daily commuting of workers in the United States, with a focus on the influence of diesel tax rates on the total time devoted to commuting and the proportion of daily travel to work by several transportation modes. Millions of individuals travel every day, and commuting to and from the workplace is one of the most important routines of the daily lives of workers (Prakash et al., 2020). How workers commute to and from their workplaces is very important in the current context of greenhouse gas (GHG) emissions and global warming, as commuting and modes of travel have significant environmental consequences such as damage from crashes, congestion, and pollution (Buehler, 2011; Morris and Zhou, 2018). For instance, in the US the private car is the most frequent method of transport chosen by workers to travel to/from work (Giménez-Nadal and Molina, 2019; Molina et al., 2020), which leads to an unsustainable transport system, and which could explain why GHG emissions from the transportation sector are the largest source of emissions in the US, accounting for 27.2 percent of the total in 2020 (EPA, 2022).[1]

Within this framework, a process of decarbonisation has been initiated in developed countries, and to that end it is important to check whether specific policies have the intended effects.[2] In the case of commuting of workers, public policies should aim to reduce the use of the car and boost the use of green modes of transport, such as public transport, or zero-carbon alternatives such as walking or cycling (Chapman, 2007; Gössling and Choi, 2015). Given that commuting implies costs – monetary and time – one of these policies could be to increase the cost of using cars. Thus, in this paper we address how workers change the amount of their driving to work in response to changing diesel fuel tax rates.

Given its importance, we link diesel fuel tax rates with the commuting of workers to analyze the effects of pricing/taxing policies on the use of the different modes of transport.

[1] The most prominent GHG from transportation is carbon dioxide (CO_2) from burning fossil fuel, specifically petroleum (primarily gasoline and diesel), by cars, trucks, ships, trains, and airplanes (EPA, 2022). Consequently, the transport sector is a key factor in meeting the environmental protection goals (Silsbe, 2003; Greening, 2004; Yang et al., 2009; Frank et al., 2010) established by international commitments, such as the United Nations Framework Convention on Climate Change (UNFCC) and the Paris Agreement (PA) (UNFCCC, 2015, 2016; UN, 2015) and to reduce the contribution of the US, the current second-largest world CO_2 emitter after China (IEA, 2021), to global climate change.

[2] In the US, policy makers have devoted a great deal of effort to reduce emissions with several measures, including the Corporate Average Fuel Economy (CAFE) standards, the Zero Emissions Vehicle (ZEV) mandate, the Renewable Fuel Standards (RFS) and the Low Carbon Fuel Standards (LCFS).

To that end, we analyze the daily commuting of US workers in two ways: total amount of time devoted to commuting in their daily trips to work, and the proportions of commuting done by four different modes of transport (private car, public transport, walking, and cycling). We link this data to monthly data at the state level for diesel tax rates from 2003 to 2019. Our findings suggest that diesel tax rates are a key predictor of daily travel to and from work in the US. More specifically, results show that state diesel tax rates are negatively related to the commuting time of workers and to the percentage of commuting by private car, and positively related to the percentage of time spent commuting by public transport and walking, relatively less polluting modes of transport. Furthermore, we find differences in this relationship according to the urban status of workers, which affects the commuting time and commuting done by public transport. Those who have secondary education and live as a couple travel less by public transport or walking, while the number of children is negatively related to commuting by public transport, and age has a negative linear relationship with commuting by walking.

Our work contributes to the analysis of commuting behavior of workers in the US, focusing on modes of transport while commuting, and analyzing the influence of diesel tax rates on the daily minutes spent commuting and the mode of transport chosen for daily commutes. We complement prior literature by focusing on both private vehicle, public transport, walking, and cycling. To the best of our knowledge, no previous work has studied the potential link between daily commuting, travel choices, and diesel fuel tax rates. Our results have significant implications for current fuel tax policy. We find that the relationship between commuting and state diesel tax rates is negative, and the results suggest a substitution from more polluting modes of transport, private car for instance, to greener alternatives, such as public transport and walking. This relationship is not homogeneous across the urban/rural continuum.

The remainder of the paper is organized as follows: Section 2 presents an overview of diesel fuel consumption and taxation in the US. Section 3 shows the data and provides sample statistics, and Section 4 sets out our empirical strategy. The discussion and interpretation of the results are contained in Section 5, and Section 6 presents a summary of our main empirical findings and policy implications.

2. Diesel fuel taxation in the US

Carbon taxes on diesel and gasoline have acquired worldwide importance as a policy instrument to correct externalities associated with the transportation sector and to raise government revenues. Consequently, their incidence is crucial to mitigate carbon emissions and generate fiscal revenues. Hitherto, the main objection to the fuel taxation policy has concentrated on its redistributive impact, as it is a clearly regressive instrument: lower-income households spend a higher percentage of their income on fuel than do higher-income households (i.e., this policy disproportionately burdens the poor). Although gasoline is the most common fuel in passenger vehicles, diesel is also widely used in the US: the EIA calculations (U.S. Energy Information Administration, Monthly Energy Review April 2021) show that diesel is the second-dominant transport fuel in the United States, with an average diesel fuel consumption of about 122 million gallons per day (EIA, 2021). In addition, recent years have shown a significant increase in diesel vehicle registrations (U.S. Department of Energy).

In the United States, federal diesel taxes remained constant at 4 cents per gallon from 1981 to 1993, when nominal federal diesel tax grew sharply to 24.4 cents per gallon. During those almost thirty years, the US Congress has not increased the federal diesel tax of 24.4 cents per gallon. By contrast, the nominal federal gasoline tax was 4 cents per gallon in 1983 and has remained at 18.4 cents per gallon since January 1997. Nevertheless, each state imposes an additional excise tax on diesel fuel and during recent decades there have been important changes in some states, but not in others.[3] For information on tax rates at the state level, we use monthly data for the state tax rate on diesel (50 states plus District of Columbia) available from the Federal Highway Administration, expressed in cents per gallon. More specifically, in 2019 the weighted average state diesel tax was 29.357 cents per gallon vs 19.414 cents per gallon in 2003. In 2019, Pennsylvania had the highest diesel tax in the United States (74.1 cents per gallon) followed by Indiana (50 cents per gallon) and Washington (49.4 cents per gallon). The lowest diesel taxes are in Alaska (8 cents per gallon), Hawaii (16 cents per gallon), and Missouri (17 cents per gallon). By contrast, in 2003 diesel taxes ranged from a low of 7.5 cents per gallon in Georgia to 30.8 cents per gallon in Pennsylvania.

[3] The EIA (2022) estimates that 47% of diesel prices are explained by the crude oil price, 25% by refining, and 17% by distribution and marketing. By contrast, diesel taxes represent 10% of total remaining diesel fuel prices (Energy Information Administration (EIA), 2022. Gasoline and Diesel Fuel Update, available in https://www.eia.gov/petroleum/gasdiesel/).

To further illustrate these variations, Figure 1 displays the average (unweighted) diesel tax and the number of states (50 states plus District of Columbia) that have modified their diesel taxes during the period 2003-2019. The mean diesel state tax rate has risen continuously, and several states have changed their taxes on diesel fuels during the same period. More specifically, from 2003 to 2019, state diesel taxes changed in 82.35 percent of the states (only 9 states have maintained constant levels of diesel taxes during the period).[4] In addition, states vary substantially in the frequency with which they change diesel tax rates; Florida changed its duties most often during the period, changing its rates fourteen times, followed by North Carolina, which changed its rates twelve times. Arkansas, District of Columbia, Hawaii, Illinois, Kansas, Massachusetts, Michigan, New Hampshire, New Jersey, New Mexico, North Dakota, Oklahoma, South Dakota, and Wyoming only changed their diesel fuel taxes once.

Figure 2 shows the diesel tax rates standard deviation across states (50 states plus District of Columbia) and over time (2003-2019). There are substantial cross-state variations in diesel taxes during the period and the differences have increased over the analyzed period.

3. Data and variables

The data come from the American Time Use Survey (ATUS) 2003-2019, which contains information on the daily activities of respondents, including commuting. The ATUS database is an annual, nationally representative time use survey conducted continuously since January 2003 by the US Census Bureau and the Bureau of Labor Statistics (BLS).[5] The respondents in this survey fill-in a time use dairy, in which they report their main activity from 4 a.m. of the assigned day to 4 a.m. the following day. This detailed information allows us to compute the total time devoted to commuting by workers.

The ATUS collects the start and stop times of activities, which allows us to identify the time devoted to any given activity, such as commuting or market work, the main time

[4] The data in nominal terms allows us to identify policy tax changes.

[5] We accessed the data using the American Time Use Survey Extract Builder (https://www.atusdata.org/atus/), a collaboration between the Integrated Public Use Microdata Series (IPUMS) of the Institute for Social Research and Data Innovation of the University of Minnesota and the Maryland Population Research Center at the University of Maryland that simplifies the use of the rich, complex data in the ATUS.

use categories of our analysis (Table A1 in the Appendix provides a detailed description of the activity codes included in each of the categories of time use). For most activities, the ATUS also collects information about who else was with the respondent during the activity, and the location where the activity took place. Furthermore, the ATUS collects information about a range of respondent and household characteristics, both socio-demographic and geographic characteristics of a household and a personal interview.

We restrict the sample to full-time employees aged 21-65 who completed their diaries on working days, defined as days when respondents worked for at least one hour, excluding commuting time (Giménez-Nadal et al., 2018a, 2018b, 2020). We omit workers who filled-in their diaries during holidays, in order to avoid atypical or strange days. From these restrictions, our final sample is 54,962 workers (from the original 210,586 pooled diaries) for the period between 2003 and 2019.

The dependent variables are the commuting of workers in minutes per day (activity code 180501 'travel to/from work') and the proportion of commuting time by modes of transport. The ATUS gathers information about the mode of transport, asking the question "Where were you?" (location of activity), which is especially useful for our approach regarding the use of sustainable and healthy modes of transport while commuting. There are twenty-six different locational coding categories, but here we focus on the following answers: 'car, truck, or motorcycle (as driver or passenger)', 'walking', 'bus', 'subway/train', 'bicycle', 'boat/ferry', 'taxi/limousine service', and 'airplane'.[6] From these transport mode alternatives, we define the following groups of transport modes: private vehicle (car, truck, or motorcycle, both as driver or passenger), public transport (bus, subway/train, boat/ferry, taxi/limousine service, or airplane), walking, and cycling (bicycle). We calculate the total time devoted to commuting and the sum of the commuting time using each mode of transport, obtaining the proportion of commuting by car, public transport, walking, and cycling.

We merge the information on commuting time and the proportion of commuting done with the various modes of transport, with monthly data for the state tax rate on diesel (50 states plus District of Columbia) that are available from the Federal Highway

[6] These modes of transport represent 97% of the total commuting time.

Administration, expressed in cents per gallon.[7] The ATUS includes information on the month and year in which respondents were interviewed, so for each respondent we are able to match the state diesel tax rate for the state in which the participant lives at the time of the interview. The use of monthly data for diesel fuel taxes allows for a more accurate assessment of the variations across states in the timing of diesel tax changes (Alm et al., 2009). We use the over-time and across-state variations in diesel tax rates to identify the effects of these rates on the commuting behavior of workers.

Table 1 presents summary statistics of the total commuting time and the proportion of commuting made by each mode of transport. The average commuting time in the sample is 38.32 minutes per day, with a standard deviation equal to 40.01 minutes, and the dominant method of travel to work in the US is the private car, with an average 94.66% of commuting done that way. The proportion of time by public transit while commuting is, on average, 2.28%, while the proportion of commuting done by walking and bicycle is about 2.53% and 0.53%, respectively. The average state diesel tax rate during the period 2003-2019 has been 23.51 cents per gallon.

The ATUS also contains rich information about respondents, which allows us to define several variables to control for socio-demographic characteristics, aimed at accounting for the observed heterogeneity of individuals, both at the individual and household level, that may affect the time spent commuting. We include controls for age, gender (ref.: male), the maximum level of education achieved (ref.: primary education), a dummy for the presence of a partner (either married or cohabiting), the family size and the number of children under 18 years old in the household. Table A2 in the Appendix shows the descriptions of these variables.

Table 1 presents summary statistics of the set of socio-demographic characteristics for our sample. The average age of workers is 42 years, and around 59% of workers are males. Regarding the maximum level of education achieved, 6.8% of workers have primary education, 27.1% secondary education, and 66.1% of the sampled workers have achieved at least some college. Finally, regarding family composition, 66.6% of workers live with a married/unmarried partner, the average family size is 3 members and the number of children under 18 in worker's household is 0.80.

[7] Information from ATUS is available until 2020, but that survey year was not collected for the entire year due to the COVID-19 shutdown. Data on tax rates is abtained from the following page, https://www.fhwa.dot.gov/policyinformation/motorfuelhwy_trustfund.cfm, accessed on 28th March.

A first descriptive analysis based on correlations shows that the relation between total commuting time and diesel tax rates equals -0.007, but it is not statistically significant at standard confidence levels. On the other hand, the correlation between diesel tax rates and the proportion of commuting time done by car is -0.023 and is statistically significant at the 99% confidence level. By contrast, the correlation between the diesel tax rate and the proportion of commuting time by public transport is 0.017 and the correlation with the proportion of commuting time walking equals 0.019. Both correlations are statistically significant at the 99% confidence level. When we compute the coefficient of correlation between diesel taxes and the proportion of commuting time by bicycle, we obtain a coefficient equal -0.002, although it is not statistically significant. Hence, this preliminary analysis suggests a possible negative relationship between the state diesel tax rates and the proportion of commuting by car, while it appears that the relationship is positive between diesel tax rates and the proportion of commuting by public transit and walking. Thus, the higher the diesel taxes, the smaller the proportion of commuting by car, and the greater the proportion of commuting by public transport and walking. We will explore these associations in more detail in the following sections, controlling for the observed heterogeneity of workers.

4. Empirical strategy

We use two types of models to analyze the daily commuting of US workers, with a special focus on total daily commuting and travel mode while commuting. We estimate the following linear models by Ordinary Least Squares (OLS):[8]

$$\log(1 + C_{i,jmt}) = \alpha + \beta_D \log(DieselTax_{jmt}) + X'_{ijt}\beta_X + FE_t + FE_d + \varepsilon_{ijt} \quad (1)$$

$$\log(1 + p_{i,jmt}) = \alpha + \beta_D \log(DieselTax_{jmt}) + X'_{ijt}\beta_X + FE_t + FE_d + \varepsilon_{ijt} \quad (2)$$

where i indexes individuals, j indexes states ($j = 1, 2, \dots, 51$), m indexes months ($m = 1, 2, \dots, 12$), and t indexes years ($t = 2003, 2004, \dots, 2019$). The dependent variables, $\log(C_{i,jmt})$ and $\log(p_{i,jmt})$, are the natural logarithm of the time spent on commuting measured in minutes per day and the natural logarithm of the proportion of

[8] Previous studies comparing OLS and Tobit models in the study of time allocation conclude that the results are qualitatively similar and conclusions are equivalent (Frazis and Stewart, 2012; Gershuny, 2012; Foster and Kalenkoski, 2013; Stewart, 2013). As a consequence, we rely on OLS models for the sake of simplicity. The Tobit estimates are reported in Table A3.

commuting done by car, public transport, walking, and cycling for individual i at state j in month m at year t, respectively. We aggregate a value equal to one in order to retain those workers who report zero commuting time or do not use some modes of transport while commuting.[9] $\log(DieselTax_{jmt})$ is the natural logarithm of the diesel tax rate of state j in month m at year t, X'_{ijt} represents a number of observable demographic and household controls of individual i correlated with commuting time, including age, gender, education level (indicators for secondary and University education), cohabitation status, family size, and the number of children aged 0-17 years old in the household. FE_t are year fixed effects (2019 is the reference survey year), FE_d are weekday fixed effects (Sunday is the reference weekday), and ε_{ijt} is the error term for random variables that capture unmeasured factors in the model. β_D is the coefficient of interest, representing the estimated relationship between diesel tax rates and commuting, and β_X is a vector of coefficients to be estimated.

Commuting time exhibits right-hand skewness (Figure A1), and we opt to log-transform it to correct for positive skew. As the state diesel tax rates have been log-transformed too, this allows us to treat the coefficient of interest β_D as an elasticity: the percentage of change in the commuting time or the proportion of commuting by mode of transport due to an increase of one percent in the state diesel tax rate.

This econometric strategy permits us to examine the effect of diesel taxes imposed by each state on the commuting time and the proportion of commuting done by several methods of transport. Consequently, we estimate five different models where we separately include total commuting time, and the proportion of commuting by car, public transport, walking, and cycling. We include in all regressions robust standard errors to account for potential heteroskedasticity and all estimates are weighted at the individual level using survey demographic weights provided by the ATUS (the results are maintained with/without clusters and weights). Variance inflation factors (VIFs) reveal no multicollinearity problems (except the coefficient for age and age squared, as would be expected).

The ATUS database also contains information on the geographic location of the respondent, which allows us to check if workers respond differently to diesel fuel taxes

[9] The estimates when we replace the coefficient by 0.1 or 0.5 are qualitatively robust and available upon request.

according to their residence. For example, an increase in diesel fuel tax rates could be accompanied by a substitution from private vehicle to public transport in urban areas, due to its relatively higher dotation of those infrastructures, in comparison to rural areas. To create this variable, we use the information for the metropolitan/central city status gathered from the ATUS (variable coded 'metro'), indicating whether the household resides within a metropolitan area and, for households in metropolitan areas, whether the household resides within or outside of a central/principal city. This information has been compiled for all survey years. The potential responses to this question are: 'Metropolitan, central city', 'Metropolitan, balance of MSA', 'Metropolitan, not identified', 'Nonmetropolitan', and 'Not identified'. From these answers, we define a dummy variable 'urban' that takes value 1 if the answer is 'Metropolitan, central city', 'Metropolitan, balance of MSA', and 'Metropolitan, not identified', and 0 for 'Nonmetropolitan'.

We use this information to examine whether the relationship between diesel fuel taxes and commuting time differs depending on the location of residence. To do this, we estimate the following linear regressions:

$$\log\left(1+C_{i,jmt}\right)=\alpha+\beta_D \log\left(DieselTax_{jmt}\right)+\beta_{URBAN}Urban_i+\beta_I \log\left(DieselTax_{jmt}\right)*Urban_i +X'_{ijt}\beta_X+FE_t+FE_d+\varepsilon_{ijt} \quad (3)$$

$$\log\left(1+p_{i,jmt}\right)=\alpha+\beta_D \log\left(DieselTax_{jmt}\right)+\beta_{URBAN}Urban_i+\beta_I \log\left(DieselTax_{jmt}\right)*Urban_i +X'_{ijt}\beta_X+FE_t+FE_d+\varepsilon_{ijt} \quad (4)$$

where the variable $Urban_i$ is a dummy variable that takes the value 1 if the respondent lives in an urban area, and the interaction $\log\left(DieselTax_{jmt}\right)*Urban_i$ is included to test potential differences in the relationship between time devote to commuting and diesel fuel taxes, according to the urban status of the workers' residence.

5. Results

Column (1) of Table 2 shows the results of estimating Equation (1), while Columns (2) to (5) of Table 2 show the results of Equation (2) for the different modes of transport. Focusing on the coefficient associated with the natural log of state diesel tax rates, we observe statistically significant relationships between that and the natural log of the total commuting time and the natural log of the proportion of commuting done by various modes of transport. Table 2 shows elasticities statistically significant for the natural log of diesel tax rates, at the 99% confidence level. We find that the elasticity between diesel tax rates and total commuting is -0.094. Consequently, an increase of one percent in the state diesel tax rate is associated with a statistically significant reduction of -0.094 percent in the average daily time devoted to commuting by US workers.

Looking at the results by mode of transport (Columns 2-5), we see significant coefficients between state diesel tax rates and the proportion of commuting time done by car, public transit, and walking. More specifically, we find that an increase of 1 percent in state diesel tax rates is significantly correlated with a decrease of 0.131 percent in the proportion of daily commuting time by private vehicle (both as driver and as pasenger), the most unsustainable mode of transport and the predominant mode in the US. By contrast, an increase of 1 percent in state diesel tax rates is correlated with a statistically significant increase of 0.042 percent in the proportion of daily commuting time by both public transport and walking. However, the coefficient does not display a statistically significant coefficient for the proportion of commuting by bicycle (Column 5), the least common mode of transport in the US.

In summary, we find that the higher the diesel tax rate, the less time workers spend commuting and the lower proportion of commuting is done by car, whereas that the higher the diesel tax rate, the more time workers spend commuting by public transport and walking. These results suggest that the proportion of the unsustainable mode of daily travel to work (i.e., car) decreases when the diesel tax rates are higher, and higher diesel tax rates are associated with an increase in the proportion of daily travel to work made by greener alternatives, such as public transport or “zero-carbon” alternatives, such as walking.

Considering the set of socio-demographics, we find that being male is associated with commuting times that are 17.939% longer (Giménez-Nadal and Molina, 2016; Giménez-Nadal, Molina and Velilla, 2022), and with a 1.613% greater proportion of commuting by bicycle.[10] Being older is negatively related to the proportion of commuting done walking, as one additional year is associated with a decrease of 0.7 percentage points in

[10] $(e^{\gamma} - 1) \times 100$ is the percentage of change in commuting associated with a change in the indicator variable.

the proportion of walking. Having achieved the secondary education is negatively correlated with the total commuting time, and the proportion of commuting made by public transport and walking, in comparison with workers with low/primary education; those workers who have achieved secondary education commute -13.24% with respect to those with primary education, whereas the proportions of commuting by public transport and walking are 5.54 percent and 4.69 percent lower, respectively. University education is also negatively correlated with total commuting time and the proportion of commuting by private vehicle, in comparison with workers with low/primary education; those workers who have acquired the University qualification devote 19.26 percent less time to commuting and the proportion of commuting done by private vehicle is 20.94 percent lower than their counterparts with only primary education.

Those living with a (married or unmarried) partner devote 3.66% minutes more to commuting, and their proportion of commuting by car is 11.74% higher, whereas the proportions of commuting by public transport and walking are 6.48% and 6.11% lower, respectively, than for those who do not have a partner. Thus, for those who cohabit there is a substitution from public and physical modes to private travel. Family size is positively correlated with commuting time, with each additional member of the family being associated with an increase of 4.1 percent in the daily work travel time. Finally, the number of children under 18 in the household is negatively correlated with the total commuting time (one additional child under 18 in the household is significantly associated with a decrease of 6.8 percent in the total commuting time) and the proportion of commuting done by public modes (one child more in the household is correlated with a decrease of 2.4 percent in the proportion of commuting by public transit).[11]

Table 3 shows the results of estimating Eqs. (3) and (4). The main coefficient of interest is that of the interaction effect between diesel fuel tax rates and urban area, together with the original tax rate coefficient. We observe no differential effects of tax rates on the proportion of commuting done by car and walking according to the urban/rural location of workers, indicating that the effect of this instrument is present in both urban and rural areas. Furthermore, we find that the negative relationship between diesel fuel tax rates and total commuting time, previously identified, is only present in

[11] We estimate other specification when we include the logs of hourly earnings, family income, and indicators for the presence of children aged 0-5 and 6-17 in the household. Since some of these additional covariates may lead to endogeneity problems, we exclude these results from the main results reported in the manuscript. Our main conclusions are similar, and the results are available upon request.

urban areas. We obtain a relationship equal to -0.119, statistically significant at the 95% confidence level, suggesting that an increase of 1% in diesel fuel tax rates is significantly associated with a decrease of 0.119% in the average daily time devote to commuting only in urban areas, whereas this association is not present in rural areas. Finally, we obtain that an increase of 1% in diesel fuel tax rates is associated with a statistically significant increase of 0.048% in the proportion of commuting by public modes only in urban areas.

To sum up, we do not identify heterogeneous effects between the proportion of commuting done by car and by walking by urban status, whereas we do find statistically significant associations between diesel fuel tax rates, and total commuting and the proportion of commuting made by public transport, according to the urban residence of workers. Our results suggest that substitution from more polluting modes of transport to greener alternatives is more intense in urban areas, possibly due to the greater quality of public transport infrastructures. The results suggest that higher diesel tax rates are only associated with a statistically significant reduction in the average daily time devote to commuting in urban areas. This latter result may be explained by the fact that in urban areas, car journeys may have to be made on the outskirts of cities using traffic belts, which implies having to travel a greater distance and therefore a greater time. On the other hand, the use of alternative means such as public transit or bicycle can make it possible to travel within cities, implying a shorter distance and less travel time.[12]

6. Concluding remarks and policy implications

In this paper, we analyze the relationship between diesel fuel taxes and the daily commuting behavior of workers in the US, for the period 2003-2019 and we analyze the influence of tax rates on the proportion of commuting done by different transportation modes. Using data from the American Time Use Survey for the period between 2003 and 2019, we find a statistically significant negative correlation between diesel tax rates and total daily commuting time, and identify a substitution during commuting trips from more

[12] Alternatively, we have included interaction effects between the natural log of state diesel tax rates and the MSA size, and the results suggest heterogeneous effects in the relationship between the proportion of commuting time by public transit and state diesel tax rates for metropolitan areas of over 5,000,000 population, in the relationship between the proportion of commuting time spent walking in metropolitan areas between 250,000-999,999 population,and in the relationship between the proportion of commuting by bicycle and state diesel tax rates for metropolitan areas between 2,500,000-4,999,999 population. The interaction effects are found to be positive for public transit and bicycles, whereas the estimated interaction effects display negative values for walking. These results are available upon request.

polluting modes of transport - private vehicles - to more eco-friendly alternatives such as public transport and walking, when diesel tax rates are higher. Nevertheless, the results obtained here suggest no relationship between the diesel tax rate and the proportion of commuting by bicycle. These findings are robust across a variety of specifications and estimation methods. Furthermore, the greater proportion of public transport use with higher tax rates is present in urban areas only, probably because there are more options for public transport in urban areas, in comparison to rural areas.

These results have important policy implications. However, during the period under consideration, the weighted average of state diesel tax rates has been falling in real terms across the US (a cumulative average annual growth rate equal to -13.30%, according to our own elaborations), and the federal diesel tax has stayed constant at 24.4 cents per gallon since 1993. In addition, the US is one of the countries with the lowest fuel taxes (European Comission, 2021). Nevertheless, diesel tax rates appear to be a suitable measure to change the travel behavior of US workers to meet the targets for GHG emissions reduction, stabilise CO_2 emissions, combat global warming, and achieve a much more sustainable transportation sector. Cheaper diesel hampers transportation sector emissions reductions and the transition to more energy-efficient modes of transport. Thus, planners should consider this instrument to change the daily transport patterns of their citizens and make green transportation modes more attractive, especially by promoting walking for commuting trips, ultimately improving the environment.

A limitation of this study is that we cannot control for unobserved individual heterogeneity due to the nature of the data, a cross-section of individuals, meaning that the relationship between commuting time and diesel tax rates could not be compared between different years for a given individual, and so we cannot talk about causality. Our analysis is limited to conditional correlations and the low R-squared statistics in the regressions suggest that this unobserved heterogeneity is important. Future research could use panel-data techniques, using for example the Panel Study of Income Dynamics (PSID), to control for this unobserved heterogeneity. In addition, extending this analysis to trips for other purposes, such as personal care, housework, childcare, sports, leisure, and market work is also a valuable future line of research.

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Figure 1. Diesel tax rates, by year

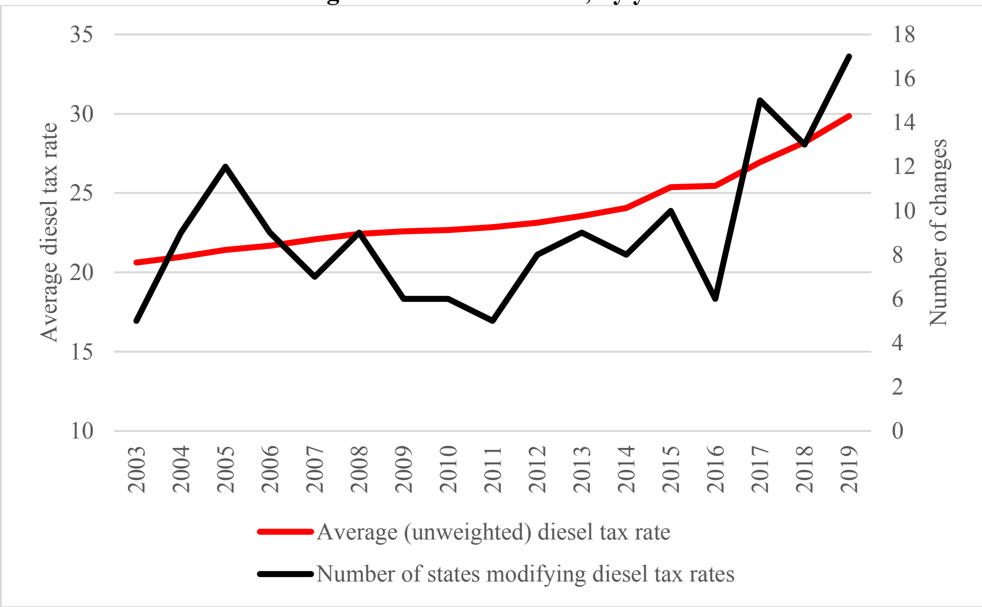


Figure 2. Standard deviation across states, by year

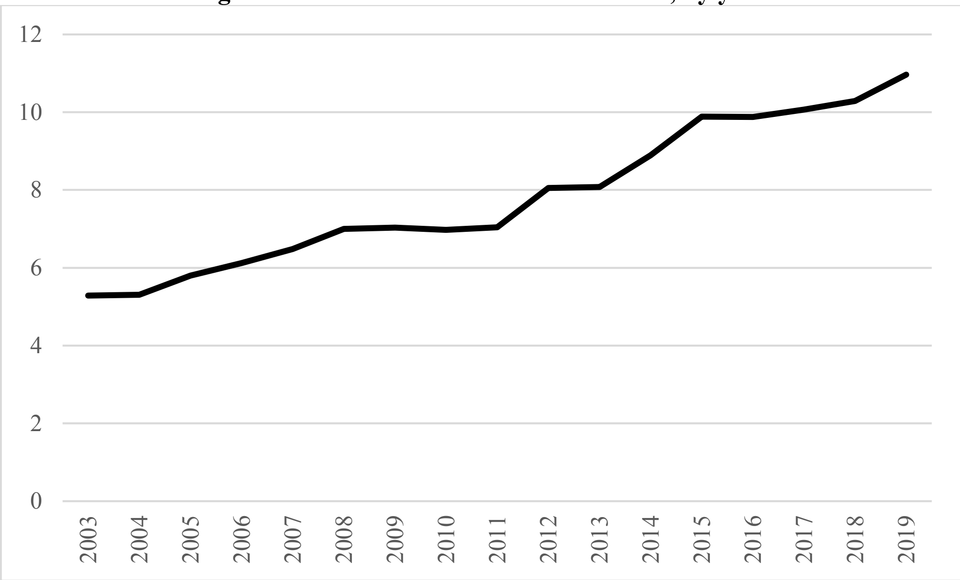


Table 1. Summary statistics

VARIABLES	Mean	Std. Dev.
Dependent variables		
Total commuting	38.324	40.007
% car	94.661	21.331
% public	2.278	13.716
% walking	2.528	13.737
% cycling	0.533	7.142
Independent variables		
State diesel tax rate	23.512	9.710
Age	41.616	11.726
Being male	0.588	0.492
Primary education	0.068	0.252
Secondary education	0.271	0.444
University education	0.661	0.473
Living in couple	0.666	0.472
Family size	3.031	1.489
Number of children	0.796	1.111

Notes: Sample is restricted to full-time workers on their working days, defined as days workers spent 60 minutes working excluding commuting. Statistics computed using survey demographic weights provided by the 2003-2019 ATUS.

Table 2. Commuting time, proportion of commuting by modes of transport, and state diesel tax rates

VARIABLES	(1) Total commuting	(2) % car	(3) % public	(4) % walking	(5) % bicycle
Log of state diesel tax	-0.094***	-0.131***	0.042***	0.042***	0.002
	(0.022)	(0.028)	(0.011)	(0.013)	(0.006)
Age	0.003	-0.010	0.001	-0.007**	-0.001
	(0.006)	(0.007)	(0.003)	(0.003)	(0.001)
Age squared	-0.010	0.005	-0.003	0.006*	0.000
	(0.007)	(0.008)	(0.003)	(0.004)	(0.001)
Being male	0.165***	-0.016	-0.001	0.017*	0.016***
	(0.016)	(0.020)	(0.008)	(0.009)	(0.004)
Secondary education	-0.142***	0.018	-0.057***	-0.048**	-0.012
	(0.034)	(0.042)	(0.017)	(0.020)	(0.008)
University education	-0.214***	-0.235***	0.001	0.005	0.005
	(0.032)	(0.039)	(0.017)	(0.019)	(0.008)
Living in couple	0.036*	0.111***	-0.067***	-0.063***	-0.009
	(0.019)	(0.024)	(0.011)	(0.011)	(0.007)
Family size	0.041***	0.004	0.013*	-0.012*	0.006
	(0.012)	(0.016)	(0.007)	(0.006)	(0.009)
Number of children	-0.068***	0.005	-0.024***	-0.001	-0.011
	(0.014)	(0.019)	(0.008)	(0.008)	(0.009)
Constant	2.625***	3.671***	0.022	0.232***	0.017
	(0.145)	(0.176)	(0.072)	(0.079)	(0.038)
Year F.E.	✓	✓	✓	✓	✓
Weekday F.E.	✓	✓	✓	✓	✓
Observations/Individuals	54,962	54,962	54,962	54,962	54,962
R-squared	0.063	0.056	0.007	0.007	0.004

Notes: Sample is restricted to full-time workers on their working days defined as days workers spent at least 60 minutes working excluding commuting, from the American Time Use Survey (ATUS) 2003-2019. Estimates calculated using survey demographics weights provided by the 2003-2019 ATUS. Robust standard errors reported in parentheses. *** Significant at the 1% level, ** significant at the 5% level, and * significant at the 10% level.

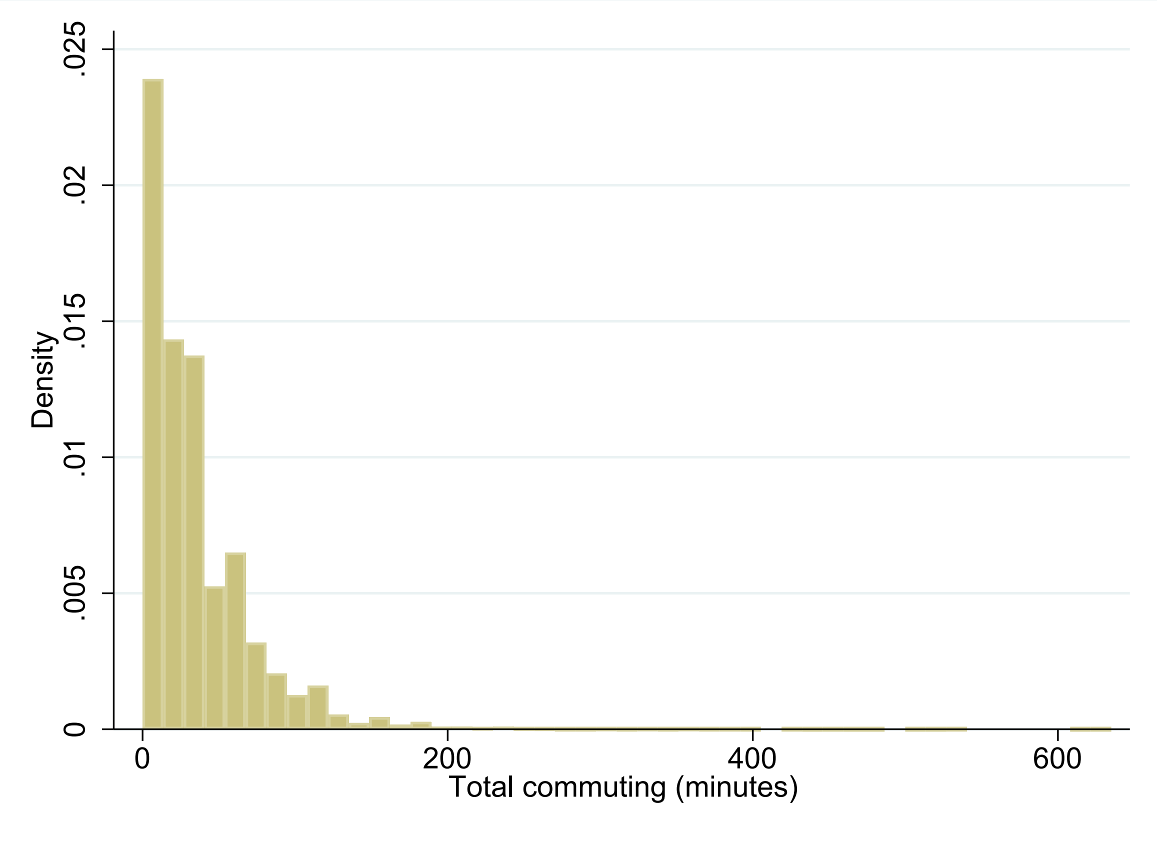
Table 3. Commuting time, proportion of commuting by mode of transport, state diesel tax rates and interaction effect

	(1)	(2)	(3)	(4)	(5)
VARIABLES	Total commuting	% car	% public	% walking	% bicycle
Log of state diesel tax	0.025	-0.122*	0.007	0.075**	-0.009
	(0.056)	(0.067)	(0.014)	(0.037)	(0.007)
Urban area	0.658***	0.005	-0.051	0.172	-0.037
	(0.187)	(0.225)	(0.059)	(0.119)	(0.031)
Log of state diesel tax*Urban	-0.119**	-0.012	0.048**	-0.036	0.013
	(0.060)	(0.073)	(0.020)	(0.039)	(0.010)
Age	0.001	-0.009	0.001	-0.007**	-0.001
	(0.006)	(0.007)	(0.003)	(0.003)	(0.001)
Age squared	-0.008	0.004	-0.002	0.007*	0.000
	(0.007)	(0.008)	(0.003)	(0.004)	(0.001)
Being male	0.164***	-0.015	-0.002	0.016*	0.016***
	(0.016)	(0.020)	(0.008)	(0.009)	(0.004)
Secondary education	-0.129***	0.018	-0.054***	-0.044**	-0.012
	(0.034)	(0.042)	(0.018)	(0.020)	(0.008)
University education	-0.231***	-0.233***	-0.005	0.003	0.005
	(0.032)	(0.039)	(0.017)	(0.019)	(0.008)
Living in couple	0.051***	0.112***	-0.063***	-0.060***	-0.009
	(0.019)	(0.024)	(0.011)	(0.011)	(0.007)
Family size	0.036***	0.005	0.011	-0.013**	0.006
	(0.012)	(0.016)	(0.007)	(0.006)	(0.009)
Number of children	-0.062***	0.003	-0.022***	-0.001	-0.011
	(0.014)	(0.019)	(0.008)	(0.008)	(0.009)
Constant	2.033***	3.645***	0.060	0.088	0.049
	(0.215)	(0.259)	(0.075)	(0.135)	(0.039)
Year F.E.	✓	✓	✓	✓	✓
Weekday F.E.	✓	✓	✓	✓	✓
Observations/Individuals	54,579	54,579	54,579	54,579	54,579
R-squared	0.069	0.057	0.010	0.008	0.004

Notes: Sample is restricted to full-time workers on their working days, defined as days workers spent at least 60 minutes working excluding commuting from the American Time Use Survey (ATUS) 2003-2019. Estimates calculated using survey demographics weights provided by the 2003-2019 ATUS. Robust standard errors reported in parentheses. *** Significant at the 1% level, ** significant at the 5% level, and * significant at the 10% level.

APPENDIX

Figure A1. Distribution of total commuting time



Notes: Sample is restricted to full-time workers on their working days, defined as day workers spent at least 60 minutes working excluding commuting from the American Time Use Survey (ATUS) 2003-2019.

Table A1. Definition of time use categories

Category	Activity description (Code in parenthesis)
Commuting	Travel to/from work (180501)
Market work	Work/main job (50101); Work, other job(s) (50102); Security procedures related to work (50103); Waiting associated with working (50104); Working, n.e.c. (50199); Socializing, relaxing, and leisure as part of job (50201); Eating and drinking as part of job (50202); Sports and exercise as part of job (50203); Security procedures as part of job (50204); Waiting associated with work-related activities (50205); Work-related activities, n.e.c. (50299); Income-generating hobbies, craft, and food (50301); Income-generating performances (50302); Income-generating services (50303); Income-generating rental property activities (50304); Waiting associated with other income-generating activities (2004+) (50305); Other income-generating activities, n.e.c. (50399); Job search activities (50401); Job interviewing (50403); Waiting associated with job search or interview (50404); Security procedures related to job search or interviewing (50405); Job search and interviewing, n.e.c. (50499); Work and work-related activities, n.e.c. (59999); Taking class for degree, certification, or licensure (60101); Taking class for personal interest (60102); Waiting associated with taking classes (60103); Security procedures related to taking classes (60104); Taking class, n.e.c. (60199); Extracurricular club activities (60201); Extracurricular music and performance activities (60202); Extracurricular student government activities (60203); Waiting associated with extracurricular activities (2004+) (60204); Education-related extracurricular activities, n.e.c. (60299); Research or homework for class (for degree, certification, or licensure) (60301); Research or homework for class (for personal interest) (60302); Waiting associated with research or homework (60303); Research or homework, n.e.c. (60399); Administrative activities: class for degree, certification, or licensure (60401); Administrative activities: class for personal interest (60402); Waiting associated with administrative activities (education) (60403); Administrative for education, n.e.c. (60499); Education, n.e.c. (69999); Teaching, leading, counseling, mentoring (150204); Travel related to work-related activities (180502); Travel related to income-generating activities (2004+) (180503); Travel related to job search and interviewing (2004+) (180504); Travel related to work, n.e.c. (180599); Travel related to taking class (180601); Travel related to extracurricular activities (ex. sports) (2005+) (180602); Travel related to research or homework (2005+) (180603); Travel related to registration or administrative activities (2005+) (180604); Education-related travel, not commuting (2003, 2004) (180605); Travel related to education, n.e.c. (180699)

Table A2. Description of socio-demographics set from 2003-2019 ATUS

Variable	Description
Age	Coded from age, measured in years
Being male	Coded from sex, 1 if male. Value 0 otherwise
Primary education	Coded from educ, 1 if educ equal to "Less than 1st grade", "1st, 2nd, 3rd, or 4th grade", "5th or 6th grade", "7th or 8th grade", "9th grade", "10 th grade", "11th grade", "12 th grade, no diploma". Value 0 otherwise
Secondary education	Coded from educ, 1 if educ equal to "High school graduate – GED", "High school graduate – diploma". Value 0 otherwise
University education	Coded from educ, 1 if educ equal to "Some college but no degree", "Associate degree - occupational vocational", "Associate degree - academic program", "Bachelor's degree (BA, AB, BS, etc.)", "Master's degree (MA, MS, MEng, MEd, MSW, etc.)", "Professional school degree (MD, DDS, DVM, etc.)", "Doctoral degree (PhD, EdD, etc.)". Value 0 otherwise
Living in couple	Coded from spousepres, 1 if spousepres equal to "Spouse present", "Unmarried partner present". Value 0 otherwise
Family size	Coded from hh_size: Number of people in household
Number of children	Coded from hh_numkids: Number of children under 18 in household

Table A3. Tobit estimates

	(1)	(2)	(3)	(4)	(5)
VARIABLES	Total commuting	% car	% public	% walking	% bicycle
Log of diesel tax rate	-0.094***	-0.131***	0.042***	0.042***	0.002
	(0.022)	(0.028)	(0.011)	(0.013)	(0.006)
Age	0.003	-0.010	0.001	-0.007**	-0.001
	(0.006)	(0.007)	(0.003)	(0.003)	(0.001)
Age squared	-0.010	0.005	-0.003	0.006*	0.000
	(0.007)	(0.008)	(0.003)	(0.004)	(0.001)
Being male	0.165***	-0.016	-0.001	0.017*	0.016***
	(0.016)	(0.020)	(0.008)	(0.009)	(0.004)
Secondary education	-0.142***	0.018	-0.057***	-0.048**	-0.012
	(0.034)	(0.042)	(0.017)	(0.020)	(0.008)
University education	-0.214***	-0.235***	0.001	0.005	0.005
	(0.032)	(0.039)	(0.017)	(0.019)	(0.008)
Living in couple	0.036*	0.111***	-0.067***	-0.063***	-0.009
	(0.019)	(0.024)	(0.011)	(0.011)	(0.007)
Family size	0.041***	0.004	0.013*	-0.012*	0.006
	(0.012)	(0.016)	(0.007)	(0.006)	(0.009)
Number of children	-0.068***	0.005	-0.024***	-0.001	-0.011
	(0.014)	(0.019)	(0.008)	(0.008)	(0.009)
Constant	2.625***	3.671***	0.022	0.232***	0.017
	(0.145)	(0.176)	(0.072)	(0.079)	(0.038)
Year F.E.	✓	✓	✓	✓	✓
Weekday F.E.	✓	✓	✓	✓	✓
Observations/Individuals	54,962	54,962	54,962	54,962	54,962

Notes: Sample is restricted to full-time workers on their working days, defined as days workers spent at least 60 minutes working excluding commuting from the American Time Use Survey (ATUS) 2003-2019. Estimates calculated using survey demographics weights provided by the 2003-2019 ATUS. Robust standard errors reported in parentheses. *** Significant at the 1% level, ** significant at the 5% level, and * significant at the 10% level.