Effects of Redistributive Tax Policies on Fuel Demand

By

Loan Tricot

Submitted to the MIT Sloan School of Management in Partial Fulfillment of the Requirements of the Degree of

Master of Science in Management Studies

at the

Massachusetts Institute of Technology

June 2023

Authored by: Loan Tricot
MIT Sloan School of Management
May 12th, 2023

Certified by: Jing Li
William Barton Rogers Career Development Professor of Energy Economics
Thesis Supervisor

Accepted by: Jacob Cohen
Senior Associate Dean for Undergraduate & Masters' Program

Abstract

The objective of this study is to evaluate the efficiency of policies aimed at reducing fuel demand. A model is developed to illustrate the channels through which policies — such as fuel taxes and electric vehicle subsidies — affect fuel demand. The model is based on a consumer theory framework at the household level. I model consumption of fuel and vehicles simultaneously and study the consumer's choice between a combustion vehicle and an electric vehicle. The study underlines the role of income elasticity of vehicle miles traveled in consumers' vehicle choice, and explores the policy implications of this role. The National Household Travel Survey's data is used to uncover stylized facts of fuel demand, which I compare with those exhibited by my model. Studying this subject is crucial for understanding and enhancing the effectiveness of policies aimed at reducing fuel demand, which is key to addressing climate change by promoting sustainable transport options.

Contents

List of Figures

List of Tables

1 Introduction

The critical intersection of environmental sustainability and energy security has brought emissions from the transport sector into sharper focus in recent decades. Countries worldwide are grappling with the need to transition from fossil fuel-dependent modes of transportation to those relying on more sustainable energy sources. The urgency is amplified by the volatile nature of fossil fuel prices, which have profound implications for economies and societies. Thus, it becomes imperative to understand how public policy instruments, such as fuel taxes and electric vehicle subsidies, influence emissions in the transportation sector.

However, the understanding of how these policy measures affect fuel demand is incomplete without a detailed consumer behavior analysis at the household level. Such an analysis necessitates a model that can simultaneously capture consumption of fuel and vehicles, as well as the consumers' choice between combustion vehicles and electric vehicles. Moreover, the heterogeneity of consumers in terms of preferences and income levels cannot be overlooked. This heterogeneity is crucial for decomposing the effects of changes in price and income on fuel demand, which can yield insights into the change in behavior and size of each consumer group.

Previous studies have provided valuable insights into fuel consumption and demand patterns. Yet, they often fall short in integrating a comprehensive consumer theory framework that would help in predicting the consumers' responses to changes in policy measures. This gap in the literature is what motivates the current study.

Using data from the National Household Travel Survey, this study seeks to uncover the stylized facts of fuel demand and draw comparisons with the proposed model's outcomes.

The subsistence driving hypothesis suggests that lower-income groups, who largely drive for essential needs, show a stable fuel demand, less influenced by price fluctuations or minor income adjustments. Understanding the subsistence driving hypothesis is crucial for this study as it provides a nuanced perspective on fuel demand patterns across different income groups. Such insights are instrumental in shaping effective policies. For instance, traditional measures like fuel taxes may not significantly impact these groups' fuel consumption, and alternative strategies such as enhancing public transportation accessibility could be more fruitful. Furthermore, recognizing the income range where this stable demand becomes more elastic can help identify target demographics for various policies. Overall, the subsistence driving hypothesis offers valuable insights into consumer behavior, enabling the formulation of more efficient policies.

Section 2 is dedicated to reviewing past studies price and income elasticities of fuel demand. The subsistence driving hypothesis is examined in detail in section 3, where I present evidence from the Consumer Expenditure Survey and the National Household Travel Survey in support of it. I present several modelling ideas in section 4. The structure of the model is justified by qualitative observations, one of which is the subsistence driving hypothesis. In section 5, the implications of the model are explored in terms of policy, considering both utilitarian and Rawlsian perspectives.

2 Literature review

2.1 Automobile fuel demand: a critical assessment of empirical methodologies

2.1.1 Review

Basso and Oum [1] comprehensively review the methodology of various fuel demand studies, offering a categorization of papers based on methodology and providing a summary of insights from each approach. One significant variance in methodology they discuss is the use of aggregate or disaggregate (household) data. Some studies opt to study average individual behavior using aggregate data, while others prefer a granular view using disaggregate household data. Studies also differ in terms of utilizing either time series data, which reveals patterns over time, or cross-sectional data, which provides a snapshot at a specific point in time. The choice between static or dynamic models is highlighted, with dynamic models explicitly incorporating the dependence of fuel demand on time. The authors also draw attention to the implicit short run and long run modeling found in many studies. These time frames are often subtly embedded within the methodology, which can make it ambiguous what time horizon a particular model is best suited for. In this context, Basso and Oum praise Error Correction Models that uniquely address both short and long run dynamics. The treatment of fuel efficiency is noted as another dimension of differentiation: some studies treat fuel efficiency as an endogenous factor, such as in Gallini's [2] framework where fuel efficiency innovation is endogenous, while others consider it an exogenous factor. Finally, Basso and Oum distinguish between direct and indirect (structural) models. Indirect models allow for a decomposition of price and income elasticities, providing more detailed insights into the various factors affecting fuel demand.

Basso and Oum argue that, although demand models based on aggregate data (normalized to be per capita) have been the more popular approach due to data availability, household level models should provide valuable insight. They justify this position by observing that most decisions relevant to fuel demand are made at the household level. Income elasticities uncovered through household level models are lower than through aggregate models. As more variables are considered (notably, the amount of licensed drivers in the household, the amount of cars owned...), estimates of income elasticities fall.

Time series or cross-sectional models often materialize as linear models on log-transformed demand, price and income data (among other variables of interest). The appeal of these models is that coefficients have obvious economic interpretations. The most popular fuel demand model is a static log-linear model which takes the following shape:

$$\ln g_i = \beta_0 + \beta_1 \ln p_i + \beta_2 \ln m_i + \epsilon_i$$

Where g_i, p_i and m_i are respectively fuel demand, fuel price and individual income. Elasticities appear explicitly as parameters: β_1 is price elasticity and β_2 is income elasticity. Basso and Oum call the model static as it has no dependence on time (though i can represent time if the data is a collection of time series). The simplest way to incorporate time is by modelling fuel demand as an autoregressive process. A possible drawback of simple linear models is that the dependent and independent variables are likely non-stationary, which could lead to spurious correlations. Co-integration approaches deal with this by looking for an integrating vector relating the variables. The authors praise a particular approach called Error Correction Models, which separate long run and short run effects explicitly. Effectively ECMs model long run demand first, and model short run demand as a dependence of the change in demand on the long run "error" (the lagged residual of the long run model).

$$\Delta g_t = \alpha_0 + \alpha_1 \Delta p_t + \alpha_2 \Delta m_t + \alpha_3 \left(g_{t-1} - \beta_0 - \beta_1 p_{t-1} - \beta_2 m_{t-1}\right) + \epsilon_t$$

Where g_t, p_t, and m_t are respectively fuel demand, fuel price and individual income at time t. Short run price and income elasticities depend respectively on the α and the β parameters. The variables can be log-transformed prior to the analysis. Price elasticities estimated with these methods are lower.

2.1.2 Implications for the study

Our paper develops a structural model of fuel demand at the household level. According to Basso and Oum, this in line with my goals of decomposing the effect of price and income changes on a household's fuel demand, in order to understand the implications of redistributive tax policies.

Quoting Basso and Oum directly: “In the long-run, the largest fraction of the response to changes in fuel price comes from changes in car fuel efficiency, whereas the majority of the response to changes in income comes from changes (increase) in car stock”. This supports the idea that reductions in fuel consumption will come not through driving less, but through the transition to electric vehicles. The model I later develop decomposes price elasticity into the choice between combustion and electric vehicles and the demand for miles driven. I attempt to support the same conclusion.

Another important conclusion of household level models, according to Basso and Oum, is that demographics matter. Demographic variables such as access to public transportation, and whether a household is located in a rural or urban area, and of course income, are relevant to price and income elasticities. This supports one of the assumptions which motivates me: fuel taxes have a highly non uniform impact on consumers.

2.2 Gasoline demand and car choice: estimating gasoline demand using household information

2.2.1 Review

Kayser [4] wrote one of the studies reviewed by Basso and Oum. They model vehicle choice and fuel demand simultaneously. The model is based on production theoretic concepts: “Together with the household’s automobile stock and time, gasoline enters as an input into the production of the economic good of transportation services”; my model is based on a similar idea. Kayser fits the following model of short run gasoline demand:[1]

$$\ln g_i = \beta_0 + \beta_1 \ln p_i + (\beta_2 + \beta_3 \ln m_i) \ln m_i + \beta_4 \ln p_i \ln m_i + \epsilon_i$$

[1]There are other terms related to “taste” but these are less relevant for my analysis

Where g_i is household fuel demand, p_i is the price of gasoline, and m_i is the household income. Price elasticity appears as β_1. Income elasticity is affine in the log-transformed income and appears as $\beta_2 + 2\beta_3 \ln m_i$. Kayser finds that income elasticity is higher at lower income, and estimates average income elasticity at 0.49. Price elasticity is estimated to be low in the short run, at -0.23. Kayser also studies demand for "miles driven" and does not find significant price elasticity. They also find that price elasticity is higher for higher income consumers. Indeed, although lower income consumers need to budget more, they have less options to cut demand (this supports the hypothesis of subsistence driving). Higher income households have more options to cut demand: they can cut leisure trips, use their more fuel efficient vehicle more often than their less fuel efficient vehicle, etc... Unsurprisingly, Kayser also finds that higher income consumers drive more fuel efficient vehicles.

2.2.2 Implications for the study

Kayser's results support the assumptions which motivate the study. The income effect dominates, especially for lower income households, which is problematic for tax policies with a redistributive component. Indeed, sensible policy should redistribute tax revenue to lower income groups to avoid impoverishing them, but this may negate the effectiveness of the pollution tax if the redistributed tax is large enough.

2.3 Modelling fuel demand for different socio-economic groups

2.3.1 Review

Wadud, Graham and Noland [5] separate households into five quintiles and fit the same model for each. This is essentially a non-parametric model of the dependence of elasticities on income. Their main result concerns price elasticities across income groups: they observe a U pattern, so that price elasticities are lowest for middle income groups, and the highest for the most extreme quintiles. The authors fit the following model:

$$\ln g_i = \beta_0 + \beta_1 \ln p_i + \beta_2 \ln m_i + \beta_3 \ln e_i + \beta_4 \ln s_i + \epsilon_i$$

Where e_i represents fuel efficiency, p_i is the price of fuel, m_i is income, and s_i is the vehicle stock of the household.

The authors find the income elasticity of low and high income groups is statistically insignificant. This is at odds with Kayser's results, which purport that low income households have the highest income elasticity. This may be due to a difference in model horizon.

2.3.2 Implications for the study

Kayser's result that income elasticity decreases with income isn't validated by other studies. Indeed, the authors review various papers with incompatible results. It is difficult to state a hypothesis with any confidence.

2.4 Demand for gasoline in canada

2.4.1 Review

Gallini's [2] paper is quite old and I review it mostly to appreciate the model Gallini formalized. Their model uses aggregate data (and therefore analyzes the individual rather than the household). It is dynamic and structural.

Gallini's first result is a collection of estimates of price elasticities in Canada for the short, intermediate and long run. As stated in their abstract: "The short run price elasticities range from -0.3 to -0.4; the five-year intermediate run estimates range from -0.6 to -0.8; the ten-year long-run estimated price elasticity reaches -0.7 to -0.9."

Gallini's works in a utility maximization framework. The consumer optimizes a portfolio of miles driven and a composite good. Utility is a function of both of these goods. The consumer "produces" miles driven from fuel and speed. Fuel efficiency is a parameter of the production function, which depends on the vehicle the consumer owns. The vehicle choice is accounted for through a discrete choice model. The car fleet is endogenous and evolves through time: manufacturers' choices are modeled as well.

2.4.2 Implications for the study

Gallini's model shares certain similarities with my own. Firstly, both models adopt a utility maximization framework. However, there are distinctions in terms of the utility functions and budget constraints employed. Gallini incorporates time and labor into the budget constraint, whereas my model takes a simpler approach. Secondly, in Gallini's model, fuel efficiency is not treated as a separate good, as it is considered a characteristic of vehicles. Finally, while Gallini addresses the choice of vehicle, their model does not simultaneously consider fuel consumption and the choice of vehicle. Rather, the fuel consumption problem is contingent upon the chosen vehicle.

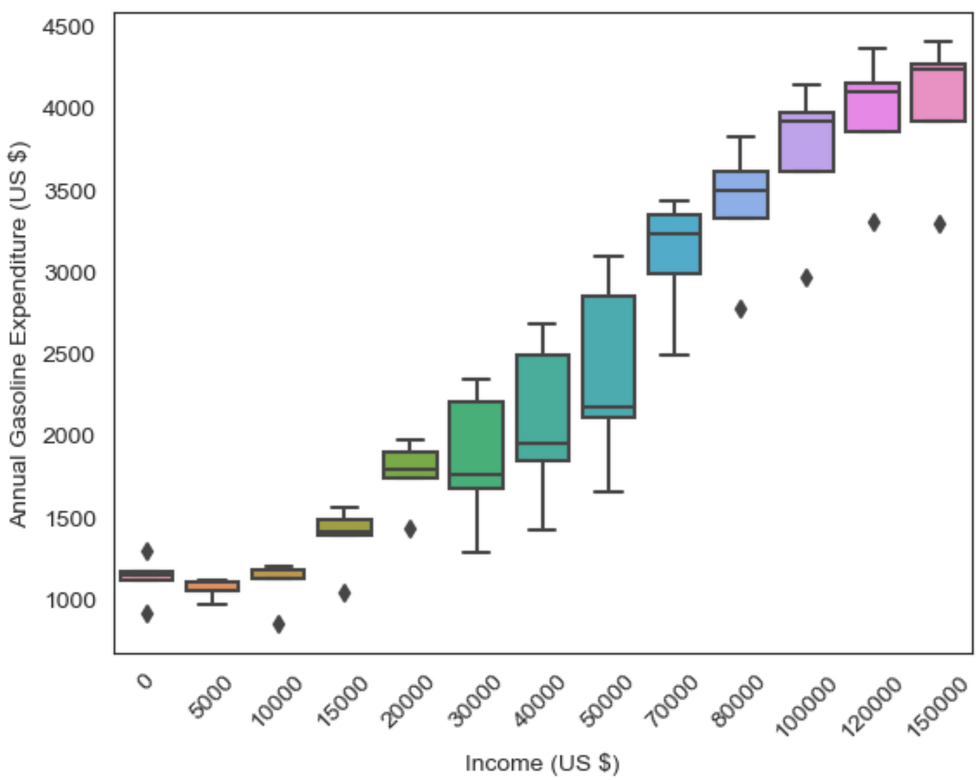
Gallini formalized their model before the time of electric vehicles. The innovation which comes with electric vehicles is a discontinuity in fuel efficiency. This discontinuity must come with a qualitative change in the formalization of a fuel consumption model which considers fuel efficiency.

3 Travel spending across income groups and the subsistence driving hypothesis

The subsistence driving hypothesis purports that many low income consumers drive only for necessary trips, such as going to work and shopping for groceries. This should make them insensitive to price: consumers will not stop eating or working when gas prices go up, and they won't suddenly stop budgeting when gas prices go down. It should also make them insensitive to relatively small increases or decreases in income. It's important to acknowledge there is a certain income level below which individuals neither own a car nor engage in any driving. This implies the presence of some elasticity in both income and price with regards to gasoline demand. Nevertheless, if the subsistence driving hypothesis is correct, there should be an income range within which consumers' demand for fuels exhibits very few income or price elasticity. This section compiles evidence towards the subsistence driving hypothesis.

3.1 Evidence from the U.S. Consumer Expenditure Survey

Figure 1: Annual gasoline expenditures across income groups. Gasoline expenditures are aggregated within income bins and over 2011 to 2015 included. The horizontal and vertical axes are in U.S. dollars. Each box is labeled with the lower bound of the income bracket it describes.



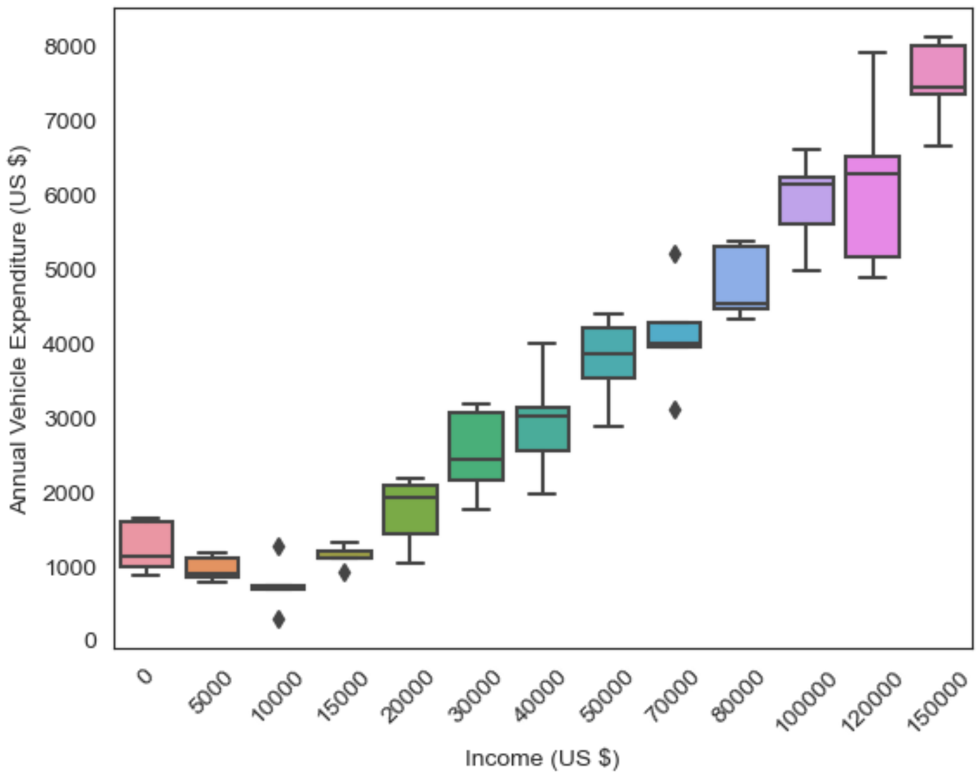
The Consumer Expenditure Survey contains data about the annual expenditures on gasoline and vehicles across income groups.

The box plot in figure 1 illustrates the annual expenditures of consumers on gasoline across income groups in the U.S. from 2011 to 2015 included. There are several noticeable trends. Unsurprisingly, consumption increases with income. The effect is however less noticeable for the first income brackets: the association between income and fuel expenditures seems flat for the lowest income groups. This supports the subsistence driving hypothesis, under which some income groups drive only when it is necessary, notably to go to work. Another noticeable effect is the difference in variance of demand throughout the period across income groups. This suggests middle income groups, which exhibit the greatest variance, react to changes in their environment by increasing or reducing their consumption of gasoline. These same effects do not change the behavior of the first 4 income groups, and seem to be weaker for higher income groups. This is consistent with the U-pattern of price elasticity of gasoline demand observed by Wadud, Graham and Noland [5]. I believe the variance in middle income groups' spending comes from their higher price elasticity.

There are some drawbacks to the data. One could argue income groups are chosen somewhat arbitrarily, with lower income groups describing smaller ranges that larger income groups. Additionally, I discuss the variance of spending through time, but the sample size is small across time.

The same pattern is observed with vehicle spending across income groups, though there is more variance. The box plot in figure 2 was generated with vehicle purchase data from the Consumer Expenditure Survey. While the gasoline expenditure data exhibited variance in a U-pattern, there is no such pattern in the vehicle expenditure data, which is consistent with the hypothesis. It seems likely that modeling gasoline consumption simultaneously with vehicle choice is appropriate.

Figure 2: Annual vehicle expenditures across income groups. What is meant by "vehicle expenditures" is the net outlay of vehicle purchases. The net outlay of vehicle purchases refers to the total amount of money spent on acquiring a vehicle, taking into account any deductions, trade-ins, or rebates. It represents the actual expenditure made by a respondent to obtain the vehicle, considering any offsets or adjustments that reduce the total cost (such as, for example, a trade-in allowance for the respondent's old vehicle). Repair costs and financing costs are not included in this figure. The respondents' net outlays of vehicle purchases are aggregated within income bins and over 2011 to 2015 included.

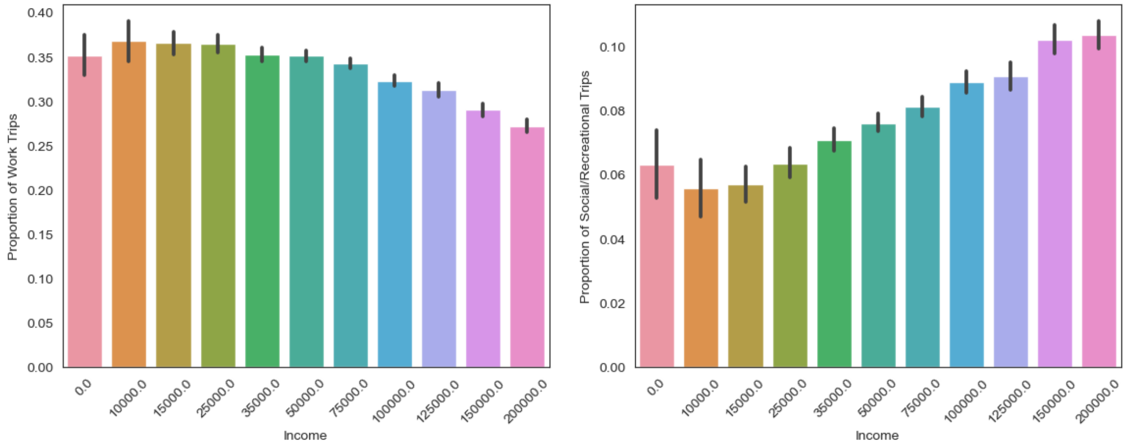


3.2 Evidence from the National Household Travel Survey

The National Household Travel Survey's data provides more evidence towards to the subsistence driving hypothesis. Comparing the proportion of trips for work and social / recreational purposes among full time workers across income groups reveals the expected trend. Figure 3 illustrates this trend.

The proportion of all trips which are work trips is higher for low income groups than high income groups. Additionally, the proportion of all trips which are social or recreational is lower for low income groups than high income groups.

Figure 3: Work (left) and recreational (right) trips among full time workers of different income groups



4 Modeling fuel demand

This section is dedicated to understanding and modeling fuel demand. The goal of the model is to illustrate stylized facts of fuel demand. The subsistence driving hypothesis notably shows up as an implication of the model. The main conclusion of the model concerns the relevance of the income elasticity of vehicle miles traveled for the choice of vehicle. This is explored in subsection 4.3.2. I aim to make reasonable assumptions so as to have some amount of confidence in the model.

4.1 A consumer theoretic model

The consumer optimizes a portfolio of a composite good, fuel, and fuel efficiency. Their utility is a function of miles driven and the composite good. I assume the utility of the consumer is quasilinear, so that the composite good can be interpreted as a numeraire:

$$U(x, y) = u(x) + y$$

Where x denotes miles driven and y is the numeraire. Miles driven are a function of fuel f and fuel efficiency e so that:

$$x = ef$$

I assume u is concave. Miles driven are a resource spent by the consumer. A rational consumer will spend their first miles on the tasks which provide the most utility, such as traveling to buy essentials and going to work. I can now state the consumer's problem:

$$\begin{aligned} \text{maximize} \quad & u(x) + y \\ \text{subject to} \quad & p_0 f + p_1 e + y \leq w \\ & x = ef \\ & f, e, y \geq 0 \end{aligned}$$

By substituting x/e for f in the budget constraint, one finds the marginal cost of x to be p_0/e. This intuitive result means that fuel efficiency decreases the marginal cost of miles driven.

It is fruitful to interpret x as a good produced with 2 inputs e and f. With this point of view, the production function of x is Cobb-Douglas with both coefficients equal to 1:

$$x = q(e, f) = ef$$

The defining characteristic of Cobb-Douglas production functions is that a fixed proportion of income is spent on each input. In this case, one finds that the consumer should spend as much on fuel efficiency as on fuel.[2] It is straightforward to prove this by considering the

[2] Raising the price of fuel has two effects on the demand for fuel efficiency: the substitution effect increases demand for efficiency, and the income effect decreases demand for efficiency. Because fuel demand is rather inelastic, it is possible that the income effect dominates and raising fuel price decreases demand for fuel efficiency!

Lagrangian of the problem:

$$\mathcal{L}(e, f, y, \lambda) = u(ef) + y + \lambda\,(w - p_0 f - p_1 e - y)$$

Setting to 0 the derivative with respect to y yields $\lambda = 1$. Setting to 0 the derivatives with respect to e and f, and substituting in $\lambda = 1$, yields $u'(ef) = p_1/f$ and $u'(ef) = p_0/e$, so that $p_0 f = p_1 e$.

Figure 4: Ratio of vehicle expenditures to gasoline expenditures. Vehicle expenditures represent the net outlay of vehicle purchases, and account for all characteristics of the purchased vehicle, rather than strictly its fuel efficiency.

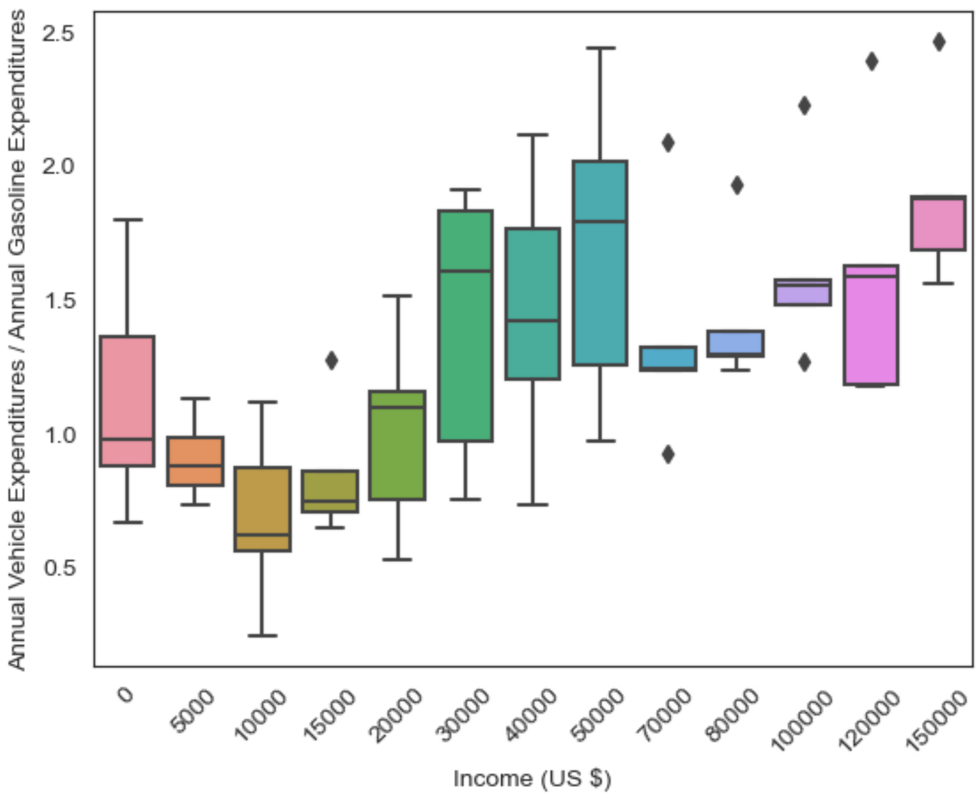


Figure 4 gives the ratio of vehicle expenditures to gasoline expenditures. The higher income groups consider more characteristics than fuel efficiency when buying a vehicle. These other characteristics, which explain the larger ratio for higher income groups, show up in the numeraire of our model. Nevertheless, consumers with more income tend to buy vehicles which are slightly more fuel efficient. The National Household Travel Survey contains data about the fuel efficiency of households, which corresponds to the ratio of miles driven to gallons of gasoline consumed for the household. This is estimated using the EPA's https://fueleconomy.gov data, which documents an estimate of the fuel efficiency of all vehicle models on the U.S. market. I estimate the following regression model to verify wealthier consumers own more fuel efficient cars:

$$\ln e_i = \beta_0 + \beta_1 \ln m_i + \epsilon_i$$

Where e_i corresponds to the fuel efficiency of household i, m_i corresponds to the upper bound of their income bin, and ϵ_i is the error term. The estimate of β_1, which corresponds to the income elasticity of fuel efficiency demand, is statistically significant at 0.0254 ± 0.002, where I use a 5% confidence interval. Though the effect seems small, it's important to keep in mind the data I used only reflects the demand for fuel efficiency, rather than the expenditures on fuel efficiency. These two quantities would only be comparable if the marginal price of fuel efficiency was constant, which it is not.

Spending as much on fuel efficiency and gasoline is only possible if fuel efficiency is unbounded, which is untrue. Additionally, the marginal cost of fuel efficiency is not constant: the last units of fuel efficiency are the most expensive. The model is appropriate as a first order approximation. Another option is to consider more general Cobb-Douglas production functions:

$$x = q(e, f) = e^\alpha f$$

With $0 < \alpha < 1$. This production function accounts for the decreasing marginal value of fuel efficiency. I call the term e^α real fuel efficiency. Setting this form of production function is equivalent to letting the price of e increase with e. Indeed, consider the derivative of e^α, which is $\alpha e^{\alpha-1}$. Its inverse describes the cost of increasing e^α linearly: it is the marginal cost of real fuel efficiency.

$$\frac{e^{1-\alpha}}{\alpha}$$

The property that consumers spends as much on real fuel efficiency as on fuel remains true.

Modeling fuel efficiency as a good has the advantage that the choice of vehicle and fuel consumption is in some sense simultaneous: fuel efficiency is the only vehicle characteristic I consider in this study, so consumption of fuel efficiency determines vehicle choice. It also establishes the model as one of medium run demand (the car fleet doesn't change every time gas prices change). Though vehicle models are inherently discrete, treating fuel efficiency as a continuous variable isn't necessarily problematic, so long as fuel efficiency innovation is relatively incremental. This is the case if one only considers internal combustion vehicles. The model cannot deal with electric vehicles, which are an important consideration of any tax policy aimed at reducing fuel demand: the literature suggests that fuel demand reduction will not come from driving less, but through the transition to more fuel efficient modes of transportation.

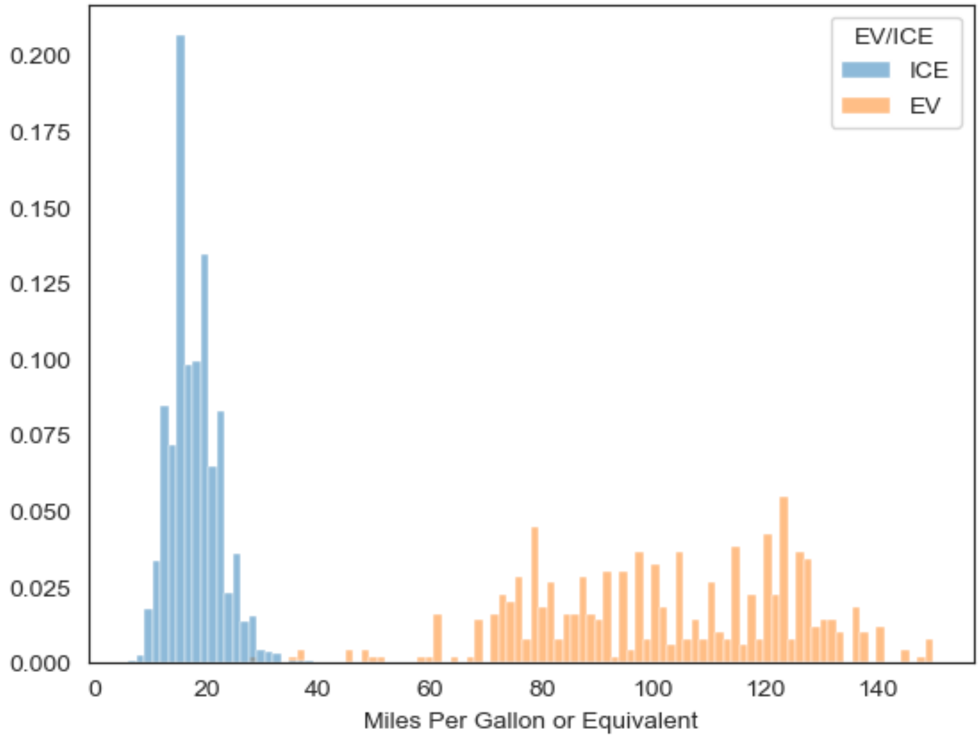
4.2 Fuel efficiency of existing vehicles

The objective of this subsection is to evaluate the hypothesis put forward in the preceding section, concerning the discontinuity in fuel efficiency between electric vehicles and internal combustion engine vehicles. The Environmental Protection Agency provides data on the fuel efficiency of vehicles sold in the U.S.[3] Fuel efficiency is in units of miles per gallon (MPG). Electric Vehicles' fuel efficiency is measured in miles per gallon equivalents (MPGe). The definition of MPGe is obtained by fixing a rate of conversion of heat energy into electrical energy.

Figure 5 gives the distribution of the fuel efficiency of vehicles sold in the U.S. Each data

[3]Found at https://www.fueleconomy.gov/feg/download.shtml

Figure 5: Fuel efficiency of vehicle models available on the U.S. market



point corresponds to a vehicle model and make. Filtering to exclude older vehicles does not significantly change the visualization. There is an observable discontinuity between the fuel efficiencies of Internal Combustion Engine Vehicles and the fuel efficiencies of Electric Vehicles. The fuel efficiency measured by the EPA corresponds to the real fuel efficiency e^{α} in the model presented in the preceding section.

4.3 Internal Combustion Engine vehicles and electric vehicles

To better represent the discontinuous innovation in fuel efficiency electric vehicles represent, one can constrain e to be binary. One case represents combustion vehicles, the other electric vehicles.

Let a_0, a_1 denote the costs of ICE and electric vehicles. Let b_0, b_1 denote the costs of fuel and electricity, normalized so that they represent an equal distance traveled using the corresponding vehicles. Let w denote the consumer's income. Let x represent distance traveled and y the numeraire, which represents consumption of other goods when the consumer is otherwise satiated. The numeraire's price is normalized to 1. I assume the consumer's utility function u is concave and strictly increasing. This assumption is justified by the nature of fuel as a good. In some sense, the consumer secures a budget of miles to drive. They will use their miles first on the most vital trips, such as going grocery shopping and going to work. The more miles the consumer can drive, the more the consumer will drive on less useful trips. The consumer's problem is to choose a vehicle as well as quantities of fuel and the composite good to consume. The sub-problem of the consumer, contigent on the choice of vehicle i, is:

$$\begin{aligned} v_i = \text{maximize} \quad & u(x) + y \\ \text{subject to} \quad & b_i x + y \leq w - a_i \\ & x, y \geq 0 \end{aligned}$$

The consumer chooses an electric vehicle or an internal combustion engine vehicle depending on which problem has the higher value. Crucially, their choice depends on their preferences u and their income w. Write the Lagrangian as:

$$\mathcal{L}(\lambda, \mu_0, \mu_1) = u(x) + y + \lambda(w - a_i - b_i x - y) + \mu_0 x + \mu_1 y$$

The following conditions on x_i^* and y_i^* are necessary for optimality:

$$\begin{aligned} \partial_x \mathcal{L} &= u'(x_i^*) - \lambda b_i + \mu_0 = 0 \\ \partial_y \mathcal{L} &= 1 - \lambda + \mu_1 = 0 \\ \partial_\lambda \mathcal{L} &= w - a_i - b_i x_i^* - y_i^* = 0 \end{aligned}$$

Complementary slackness implies that $y_i^* \neq 0 \Rightarrow \mu_1 = 0$ so that λ, the marginal value of income, is 1 when the composite good is consumed. The composite good is only consumed when driving is consumed to satiation, that is $u'(x_i^*) = b_i$. Assuming $u'(0) > b_i$, μ_0 is always 0. This is hardly a restrictive assumption: it only means that the consumer drives more than 0.

I divide my analysis in two cases. In the first case, the consumer cannot cover their traveling needs (this is mostly treated for the sake of completeness). In the second case, the consumer is wealthy enough to cover their traveling needs. This means the satiation point x_i^*, which is the optimal demand for fuel defined by $u'(x_i^*) = b_i$, is feasible for at least one of the vehicle types.

4.3.1 Destitute consumer

I treat this case for the sake of completeness. Consumers do not spend the totality of their income on traveling needs. This is verified in the U.S. Consumer Expenditure Survey.

In this case, the choice of the consumer depends on both their preferences u and their income w. It was shown in the preceding section that some consumers will choose the ICE vehicle no matter their wealth. This section focuses on those who would select an electric vehicle if their income allowed it. So long as the consumer is not satiated ($u'(x_i^*) > b_i$), one has $y = 0$ so the first order conditions imply

$$x_i^* = \frac{w - a_i}{b_i}$$

u is increasing so the arguments may be directly compared. The following cutoff describes when a consumer is wealthy enough to switch to an electric vehicle.

$$\frac{w - a_0}{b_0} > \frac{w - a_1}{b_1} \iff w > \frac{a_1 b_0 - a_0 b_1}{b_0 - b_1}$$

4.3.2 Normal consumer

The consumer chooses the option which maximizes their utility. Assume x_0^* and x_1^* are the optimal demand for fuel for each of the consumer's problems, given income w. The value of each problem is given by:

$$w - a_i - b_i x_i^* + u(x_i^*)$$

leading to the following inequality, which represents the consumer's decision:

$$u(x_1^*) - u(x_0^*) > a_1 + b_1 x_1^* - a_0 - b_0 x_0^* \tag{1}$$

The consumer compares the added utility from traveling x_1^* (which is at least as large as x_0^*) to the cost in terms of the numeraire. If the consumer is only looking to satisfy travel needs ($x_0^* = x_1^*$), the above inequality reduces to a cost comparison. Indeed, suppose a given consumer is only looking to satisfy travel needs. The marginal utility of driving presents a discontinuity for this consumer. It is large early on and becomes 0 at x^*, when the consumer's travel needs are met. Assuming the consumer is not destitute, they will necessarily travel x^*, and choose the cheapest option to do so. Setting $x_0^* = x_1^* = x^*$ above and solving for x^* yields the threshold at which the consumer is indifferent between buying the internal combustion vehicle and the electric vehicle:

$$\frac{a_1 - a_0}{b_0 - b_1}$$

I believe this represents the situation of low income consumers. As the gap $u(x_1^*) - u(x_0^*)$ grows, the consumer is more likely to choose the electric vehicle over the internal combustion engine vehicle, as the former will allow their to drive more. Understanding this gap is especially relevant to the design of subsidies for electric vehicles. This is explored in subsection 6.4 of the section on empirical results. Of central importance is the relation between the gap and the income elasticity of vehicle miles traveled. This is best understood by varying the cost of the electric vehicle, a_1. By reducing a_1, the income of the consumer for the electric vehicle subproblem is increased. Then, if their elasticity of miles traveled is high with respect to income, x_1^* will increase, and so will the gap.

4.4 Driving as an economic input to the production of other goods

A major assumption of the model presented in the preceding section is that utility derived from driving and from the composite good are entirely separable. This does not reflect reality: consumers drive to places where they consume other goods. In this sense, driving is a economic input to the production of other goods. Introducing z as another input, one can denote the good produced from driving and z by $q(x, z)$ and modify the budget constraint to include z. y now represents the collection of goods unrelated to driving (for example, watching television). Letting p denote the price of z, and v the utility of the good produced from x and z, the consumer problems for each i are:

$$\begin{aligned} \text{maximize} \quad & v(x, z) + y \\ \text{subject to} \quad & b_i x + pz + y \leq w - a_i \\ & x, y, z \geq 0 \end{aligned}$$

Where $v(x, z)$ subsumes q by being of the form $f(q(x, z))$. In what follows, I denote $v_x(x, z)$ the partial derivative of v with respect to x at x, z. I similarly use $v_z(x, z)$ for the partial derivative with respect to z. Write the Lagrangian as:

$$\mathcal{L}(\lambda, \mu_0, \mu_1, \mu_2) = v(x, z) + y + \lambda(w - a_i - b_i x - pz - y) + \mu_0 x + \mu_1 z + \mu_2 y$$

Necessary conditions for optimality are:

$$\partial_x \mathcal{L} = v_x(x_i^*, z_i^*) - \lambda b_i + \mu_0 = 0$$
$$\partial_z \mathcal{L} = v_z(x_i^*, z_i^*) - \lambda p + \mu_1 = 0$$
$$\partial_y \mathcal{L} = 1 - \lambda + \mu_2 = 0$$
$$\partial_\lambda \mathcal{L} = w - a_i - b_i x_i^* - p z_i^* - y_i^* = 0$$

Complementary slackness ensures that $\mu_0 = \mu_1 = \mu_2 = 0$. Solving for λ, I find $\lambda = 1$, and substituting this value in the first and second conditions yields:

$$v_x(x_i^*, z_i^*) = b_i$$
$$v_z(x_i^*, z_i^*) = p$$

4.5 Drawbacks of the model

The model described in subsection 4.3 has several drawbacks.

Firstly, as addressed in the preceding section, the model fails to account for the positive income elasticity of middle income consumers. Each consumer has a satiation point which they reach unless they are destitute. Beyond this satiation point, consumers have 0 elasticity of travel demand with respect to income.

Secondly, the price elasticity of demand for fuel is independent from income. This is problematic, because the differences in price elasticity of demand for fuel across income groups are relevant for tax policies with distributional concerns.

Thirdly, the model does not consider other features of vehicles. Because of this, there is no opportunity to consider taxing different vehicles differently. The government could for example tax heavy vehicles to finance an electric vehicle subsidy. The idea would be to target richer consumers which value this feature and buy large internal combustion engine vehicles rather than electric vehicles. My model cannot be used to study such a policy.

4.6 Conclusion on modelling fuel demand

In my model, fuel demand is influenced by several factors: the price of vehicles and their fuels, the wealth of consumers, and their traveling needs. Curiously it may be sometimes be better to convince users to travel *more* so that they are incentivized to switch to electric vehicles. It is however generally more desirable that the consumer travel less.

Changing consumers' travel habits or changing the redistributive properties of a nation's tax code are difficult policies to enact. I consider policies that are relatively more realistic, such as taxes and subsidies which rely on the elasticity of demand for travel with respect to price and income, and the dependence of these on income level, to reduce fuel demand without disproportionately affecting the lowest income groups.

5 Welfare considerations for transportation policy

The aim of this section is to study the optimal tax to correct an externality, under varying assumptions. The assumptions will be related to the distribution of wealth among consumers and the welfare function optimized by the government. The conclusions will be applied to the case of the externality generated by the consumption of fuel.

5.1 Single consumer

I begin by studying the most simple version of this problem. Assume the consumers can be aggregated into a single consumer. I focus on a single good: denote $x(p)$ the demand of the consumer when price is p. Denote as well $v(p)$ the indirect utility function of the consumer. I consider an externality $e(x)$ generated by the consumption of x, which affects the social welfare function of the government. Although each consumer should perceive the externality, I assume the externality is negligible for any single consumer in the group which will be taxed. Let p be the current price and t be the tax chosen by the government. The social welfare function of the government is:

$$v(p+t) - e(x(p+t))$$

Which can be expressed as a function of $x(p+t)$ by considering the direct utility $u(x(p+t))$. The government's problem is:

$$\begin{aligned} &\text{maximize} \quad u(x(p+t)) - e(x(p+t)) \\ &\text{subject to} \quad t^T x(p+t) \geq T \end{aligned}$$

T appears in the budget constraint of the government and represents the minimum revenue of the government. Denoting w the wealth of the consumer, recall $x(p+t) = \arg\max_x \{u(x) : (p+t)^T x \leq w\}$. The government problem is more simply understood by introducing the demand x as a decision variable and solving the consumer's problem within the government's problem. Denoting λ the marginal utility of wealth, the optimality conditions for the consumer are:

$$\begin{aligned} &u'(x) = \lambda(p+t) \\ &(p+t)x = w \end{aligned}$$

But the government wishes the consumer to act as if their utility function were $u(x) - e(x)$. This would give the following optimality conditions:

$$u'(x) = \lambda p + e'(x)$$

$$px = w$$

If the government imposes a tax $t = e'(x)/\lambda$, the first condition for the consumer and the government are the same. This result is the familiar idea that the tax should reflect the cost of the externality.

The most restrictive assumption of this model is that it deals with a social welfare function without any distributional concerns and so the externality is perceived the same way by all consumers, which are aggregated into a single consumer.

5.2 Rawlsian welfare

A Rawlsian version of the social welfare function considered above is only concerned with the consumer whose indirect utility is the lowest. Assuming each consumer has their own indirect utility and perceives the externality differently, the indirect utility of each consumer takes the shape:

$$v_i(p) = u_i(x_i(p)) - e_i(x_i(p))$$

Where $u_i(p)$ is the part of the direct utility which does not account for the externality. The social welfare function of the government is:

$$\min_i u_i(x_i(p)) - e_i(x_i(p))$$

So that only the consumer with the lowest utility, including the effect of the externality, determines the value of the social welfare function. Some immediate observations can be made. Externalities affecting only the most well off consumers have no effect on the social welfare function and will therefore not be eliminated. Externalities which have a particularly strong effect on the least well of consumers will justify the spending of a larger amount of resources under rawlsian welfare than under a social welfare function which considers all consumers uniformly. A tax which affects all consumers will see its size determined to fix the effect of the externality for a single consumer.

Under the social welfare function $\sum_i v_i(p)$, without any externality, there is no need to distort prices. This is not the case under a rawlsian welfare function. Goods consumed by well off consumers will be taxed to subsidize goods consumed by the least well off consumers. Without a constraint on the size of price distortion, all consumers will end up equally well off.

5.3 The effect on welfare of policies aimed at reducing fuel consumption

The externality generated by carbon emissions is generally considered to have the greatest effect on lower income consumers. However, the proportion of income spent on fuel is greater for low income consumers than for high income consumers. Under a Rawlsian social welfare function, the first observation justifies an outsized tax on fuel, while the second observation justifies a smaller tax on fuel. Because of this, it is possible that subsidizing electric vehicles, thus redistributing income from all consumers to well off consumers, is better than taxing fuel.

Under the setting of subsection 4.3, consider the case of two consumers. One is poorer than the other, but both prefer to buy the electric vehicle given their current income. The Rawlsian welfare is simply the poorer consumer's indirect utility v_0. To increase the poorer consumer's utility, is it better to tax fuel to reduce the richer consumer's consumption, or to subsidize electric vehicles enough to encourage the richer consumer to consume no fuel at all?

If the poor consumer has negligible elasticity, the loss in welfare when taxing fuel at rate t is tx_0, where x_0 is the poor consumer's fuel consumption. Let now β denote the price elasticity of demand for fuel for the richer consumer. It is expected their demand for fuel change by $\beta x_1 t/b_0$, where x_1 is the poor consumer's fuel consumption. If the fuel consumption of the rich consumer affects the poor consumer by $e(x_1)$, the welfare change after taxing is

$$-tx_0 - e(x_1(1 + \beta t/b_0)) + e(x_1)$$

Or expressed differentially,

$$\frac{\partial v_0}{\partial b_0} = -x_0 - \frac{\beta x_1}{b_0}\frac{de}{dx_1}$$

Because $\beta < 0$ and $e(x_1)$ grows with x_1, the second term is positive. This describes the trade-off between reducing the poor consumer's utility by making their fuel more expensive, and increasing the poor consumer's utility by making the rich consumer's fuel more expensive.

The goal of subsidizing the electric vehicle is to encourage the rich consumer to switch to an electric vehicle. This occurs at the threshold discussed in subsection 4.3. The change in welfare is simply $e(x_1)$. It is obviously better to subsidize the electric vehicle without considering budget constraints and distributional concerns. One way to compare both approaches is to constrain both policies to be budget neutral by redistributing tax revenue and financing subsidy budgets. It is then necessary to decide how to redistribute and finance: which consumers benefit from the redistribution, and which consumers finance the subsidy?

The effectiveness of electric vehicle subsidies is explored in more detail in subsection 6.4. The parameter most relevant to the design of electric vehicle subsidies is the income elasticity of vehicle miles traveled. It will be shown there is a way to reduce the the consumption of fuel, and therefore reduce the externality borne by lower income consumers, by targeting electric vehicle subsidies at middle income consumers.

6 Elasticity of miles driven with respect to income and fuel price

The object of this section is to study the income and prices elasticities of demand for driving. The first subsection describes the National Household Travel Survey (NHTS) data. The following subsection applies log-linear regression models to the household level data to decompose the income elasticity of demand for driving into several explanatory factors. It outlines three progressively enriched models that estimate annual miles driven using variables such as income bracket, household size, number of workers, number of drivers, and metropolitan and urban area classifications. The results of these models are discussed, emphasizing the significant impact of various variables on income elasticity. The next subsection moves on to discuss the estimation of price elasticities using the trip-level data from the NHTS. It presents a log-linear regression model that incorporates miles driven, annual income, and the gas price at the time of reporting. The last subsection investigates the dependence on income of the income elasticity of demand for driving. The goal is in part to evaluate once again the subsistence driving hypothesis.

6.1 The National Household Travel Survey

The NHTS data offers a comprehensive look into the travel habits of U.S. households. This data is categorized into four distinct tables. Firstly, the vehicle level table provides detailed information about the vehicles that each household owns. This includes specifics such as the vehicle model, the annual miles it is driven, and its fuel efficiency. Secondly, the household level table focuses on the characteristics of each household that has responded to the survey. This table features information about household income, size, the number of drivers, employment status, and whether the household is located within an urban or rural area. The last two tables are person level and trip level, which further delve into the individual and travel aspects of the data.

There is no way to study the behavioral changes of a household across time, as gasoline prices evolve. Trip data is only collected for a single day per household. Other data is aggregated through time: it is impossible to infer which miles were driven when simply from the annual miles driven data.

6.2 Household level log-linear regression

By joining the household and vehicle level tables, I extract a variety of variables for each household. These include the annual miles driven, represented as d_i and the annual income bracket, which is transformed into an upper limit and denoted as m_i. The household size (s_i) is also noted, along with the number of workers within the household (w_i), the number of drivers (r_i), and the number of vehicles owned by the household (v_i).

In addition to these variables, the Metropolitan Statistical Area (MSA) is also considered, indicated by a set of dummy variables. The categories include an MSA of 1 million or more with rail (M_i^1), an MSA of 1 million or more not in the first category (M_i^2), an MSA less than 1 million (M_i^3), and households not in an MSA.

The final category of variables corresponds to the urban area classification. These classifications encompass being in an urban area (U_i^1), in an urban cluster (U_i^2), and being in an area surrounded by urban areas. However, given that the latter category only accounts for 51 instances out of 129,696 data points, I do not introduce a dummy variable for it. The last group represents households not in an urban area.

I fit three regression models at the household level, to estimate income elasticity. The first is the simplest:

$$\ln d_i = \beta_0 + \beta_1 \ln m_i + \epsilon_i \tag{2}$$

To decompose the effect of income and do away with effects correlated with, but distinct from, income, I enrich the model with more variables incrementally. The next model considers the size of the household, its number of drivers as well as its MSA category and urban area classification. The dummy variables are added to compare with the conclusions of the literature.

$$\ln d_i = \beta_0 + \beta_1 \ln m_i + \beta_2 \ln s_i + \beta_4 \ln r_i + \sum_{j=1}^{3} \beta_6^j M_i^j + \sum_{j=1}^{2} \beta_7^j U_i^j + \epsilon_i \tag{3}$$

Finally, I add the number of workers and the amount of vehicles owned by the household. These are more closely related with income.

$$\ln d_i = \beta_0 + \beta_1 \ln m_i + \beta_2 \ln s_i + \beta_3 \ln w_i + \beta_4 \ln r_i + \beta_5 \ln v_i + \sum_{j=1}^{3} \beta_6^j M_i^j + \sum_{j=1}^{2} \beta_7^j U_i^j + \epsilon_i \tag{4}$$

All coefficients are statistically significant. The results for model (2) suggest an income elasticity for the demand of miles driven of 0.4206 on average, which seems in line with the rest of the literature. As I add more explanatory variables, the estimate of β_1 falls: the results of model (3) suggest a β_1 of 0.2654 while model (4) yields a β_1 of only 0.1410. Adding only the dummy variables has no effect on β_1. The household size, number of drivers, number of workers and amount of vehicles all contribute significantly to income elasticity. Together, they account for the majority of income elasticity.

It is useful to understand the income elasticity of miles driven, so as to better target tax and subsidy policies aimed at reducing fuel demand. I believe some the most useful parameters explored in this section are the dummy variables which concern the MSA and urban category of each household, as they are particularly adapted to targeted policies. I will explore the dependence on income of the elasticity of vehicle miles traveled with respect to income in a

Table 1: Estimated coefficients for models 1 through 3. Confidence intervals provided account for 2 standard deviations on both sides of the estimates.

	Model 1	Model 2	Model 3
Intercept	4.8107 ± 0.072	5.2833 ± 0.066	6.3115 ± 0.064
Log income	0.4206 ± 0.0066	0.2654 ± 0.006	0.1410 ± 0.006
Log household size	—	0.4122 ± 0.022	0.2792 ± 0.020
Log household workers	—	—	0.3845 ± 0.012
Log household drivers	—	1.1829 ± 0.030	0.1703 ± 0.030
Log household vehicles	—	—	1.1080 ± 0.018
MSA 1M & rail	—	-0.1790 ± 0.020	-0.1212 ± 0.020
MSA 1M no rail	—	-0.0699 ± 0.018	-0.0400 ± 0.016
MSA $<$ 1M	—	-0.0660 ± 0.016	-0.0520 ± 0.016
In urban area	—	-0.2102 ± 0.014	-0.1208 ± 0.012
In urban cluster	—	-0.1598 ± 0.018	-0.0850 ± 0.016
R^2	0.13	0.303	0.408
Number of observations	118908	118908	118908

later subsection, and will provide additional motivation for understanding income elasticities then.

6.3 Trip level log-linear regression

The NHTS dataset contains trip level data which can be used to examine the elasticity of miles driven with respect to gasoline prices. Each respondent recounted all the trips of their household over a period of 24 hours. The data contains the gas price of the day the respondent answered. By including the household's annual income, I fit the following model:

$$\ln d_i = \beta_0 + \beta_1 \ln m_i + \beta_2 p_i + \epsilon_i \tag{5}$$

Where d_i corresponds to miles driven during the day, m_i is the household's annual income (upper bound) and p_i is the price of gas the day the respondent reported their trips.

All coefficients are found to be statistically significant. Income elasticity is 0.0622 ± 0.01 and price elasticity is -0.3208 ± 0.045. The analysis in [3] indicates data whose main dependent variable is price should generate 0 income elasticity, which explains the difference in income elasticity found by model 5 and the preceding models. The price elasticity of miles driven demand appears in line with other estimates in the literature.

The price elasticity of vehicle miles traveled is relevant for the design of tax policies/ Though it is in the interest of policymakers to understand how this parameter varies with income, I did not find a strong relationship between income and price elasticity in the data, which is particularly noisy. This is a drawback of the study, which is in part built on the subsistence driving hypothesis.

6.4 Third order model for income elasticity

Earlier in the study, I discussed the subsistence driving hypothesis. I believe income elasticities should be low for the lowest income groups. Indeed, so long as a consumer owns a car, but has less income than the threshold under which they drive for subsistence, their income elasticity of miles driven should be close to 0. A bit more or a bit less income won't allow them to stop budgeting. Arguably, income elasticity for high income groups should also be very low: they can consume to satiation. Motivated by these observations and the shape of gasoline expenditures illustrated in figure 1, I fit a third order model of demand for log miles driven as a function of log income.

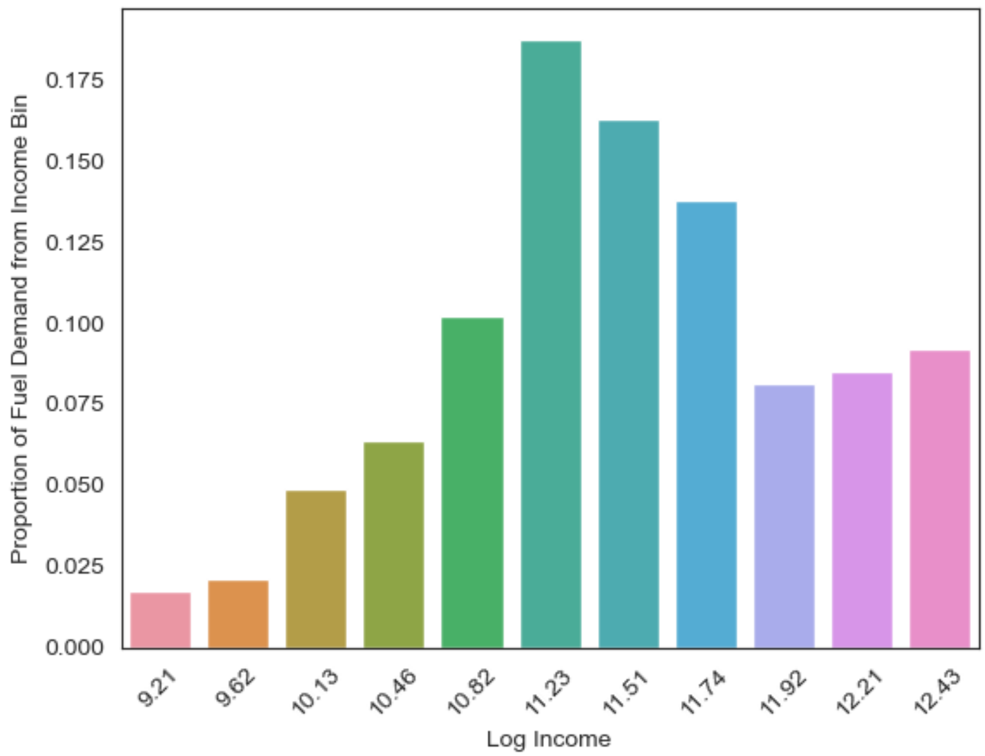
$$\ln d_i = \beta_0 + \beta_1 \ln m_i + \beta_2 (\ln m_i)^2 + \beta_3 (\ln m_i)^3 + \epsilon_i \tag{6}$$

Taking the derivative of the right hand side with respect to $\ln m_i$ reveals the elasticity of miles driven with respect to income:

$$\beta_1 + 2\beta_2 \ln m_i + 3\beta_3 (\ln m_i)^2 \tag{7}$$

The data used to fit this model is identical to the data used to fit models 2 through 4. Though the model predicts the elasticity of demand for miles driven with respect to income for each income bin, it does not do so by evaluating the behavior of households within a single bin, but rather by evaluating the differences in behavior of households in different income bins.

Figure 6: Proportion of total miles driven per income bin, as predicted by model 6. The middle income groups account for the majority of the demand for miles driven, largely because they claim more consumers than the high income bins.



Curves for expected log miles driven and income elasticity are given in figures 7 and 8. Observe the income elasticity of miles driven is estimated to be the lowest for high and low income groups, as hypothesized. The elasticity of miles driven with respect to income is the highest for middle income bins, at above 0.5.

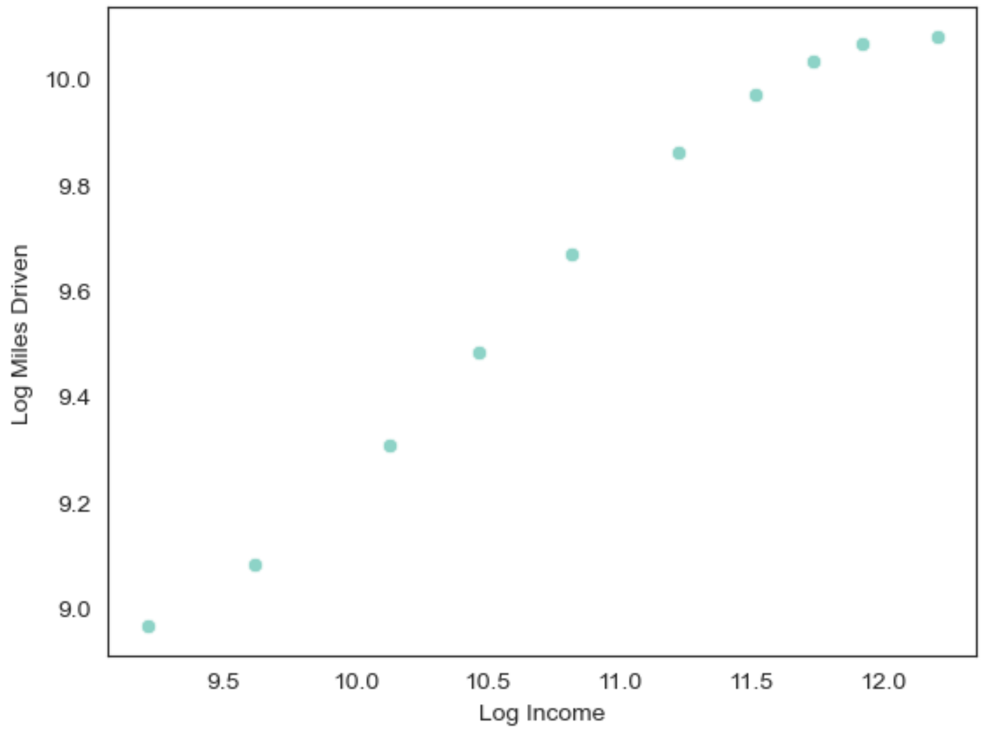
This is relevant for the design of subsidies for electric vehicles and alternative modes of transportation. Consider the case of an electric vehicle subsidy, when electric vehicles are beyond the financial reach of the majority of consumers. The subsidy is useful if two conditions are met. Firstly, the subsidy must cause some consumers to switch to electric vehicles. Secondly, these consumers should have relatively high demand for fuel (before the subsidy). Consumers' income elasticity of demand for miles driven is relevant for the first condition. As the subsidy grows, the income level at which consumers start to consider buying an electric vehicle decreases. Consumers whose elasticity of demand for miles driven with respect to income is very low will not switch to the electric vehicle until the latter is less expensive than an internal combustion vehicle. Consumers whose elasticity of demand for miles driven with respect to income is high will switch to the electric vehicle earlier, as this will allow them to drive more. This is best understood through the framework of section 4. A consumer with low income elasticity of demand miles driven will drive as much with an electric vehicle as they drive with an internal combustion vehicle. Therefore, the value of the electric vehicle subproblem will only surpass that of the internal combustion engine subproblem when the electric vehicle becomes cheaper. In equation 1, this is illustrated by $u(x_1^*) - u(x_0^*) \approx 0$. If the consumer exhibits high income elasticity of miles driven demand, the term $u(x_1^*) - u(x_0^*)$ is bigger and the price at which they will consider buying the electric vehicle is higher. Fortunately, the consumers which exhibit the largest elasticity of miles driven with respect to income are also those which are responsible for the majority of fuel demand in the U.S., as exhibited in figure 6.

7 Conclusion

This study offers important insights into the complex dynamics of fuel demand and the role of income and price elasticity therein.

The study suggest that the key demanded good is miles driven, not fuel itself. In essence, consumers seek to maximize their travel distance, choosing the most cost-effective option that takes into account both vehicle and fuel prices.

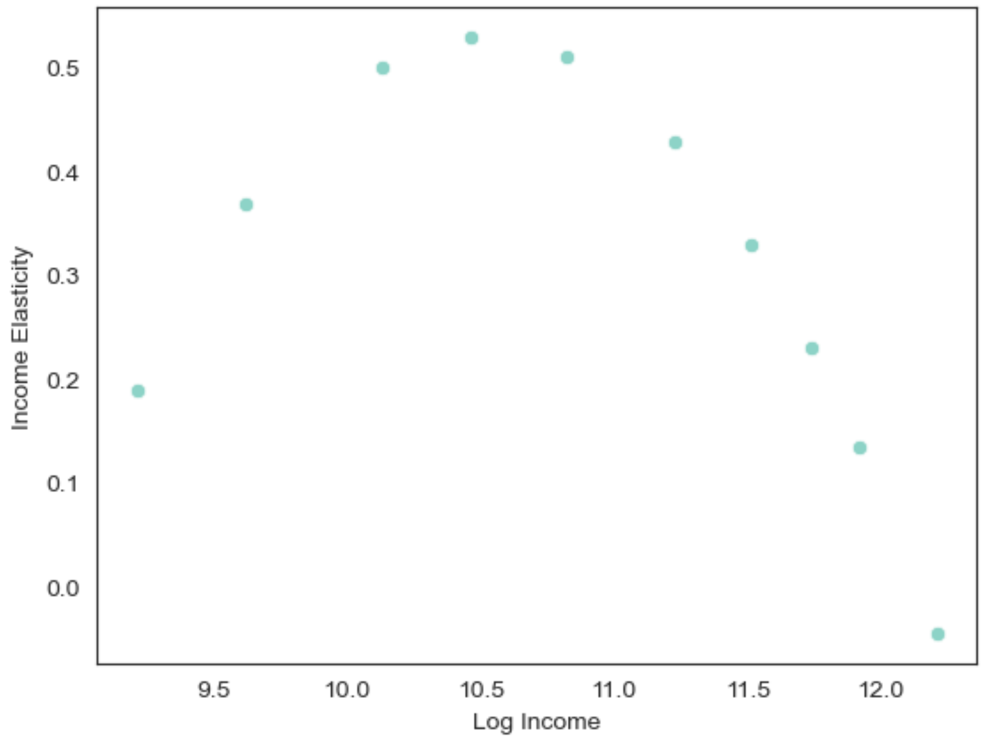
Figure 7: Log miles driven as a function of log income, as predicted by model 6



The findings underscore that elasticity of vehicle miles traveled and gasoline demand with respect to income varies across different income groups. This is a significant observation, highlighting that changes in income may not equally affect fuel demand across all income levels. As explained in the preceding section, this is especially relevant for the design of electric vehicle subsidies, which are most effective when they target consumers of higher income elasticity of miles driven. In short, studying the income elasticity of vehicle miles traveled is revealed to be as important as studying its price elasticity. This is the most important finding of this study. The income elasticity is largely decomposed into factors such as the number of workers and drivers in a household, the number of owned vehicles, and the location of the household (urban or rural).

Subsidizing electric vehicles could be a viable strategy for reducing fuel demand, but only if the subsidy's financial burden doesn't overshadow the benefits derived from the shift in vehicle preference among the wealthier consumers. This strategy could prove most effective

Figure 8: Income elasticity of demand for miles driven as a function of log income, as predicted by model 6



if many consumers are close to the threshold of switching to electric vehicles, particularly middle-class consumers which are responsible for the majority of fuel demand in the United States. A strategic decrease in the price of electric vehicles could encourage these consumers to switch, potentially leading to a significant decrease in fuel demand that would favorably impact the welfare of low-income consumers.

When evaluated in a Rawlsian context, taxing fuel proves effective only if it significantly curtails the consumption of higher-income groups. The price elasticity of high-income consumers would need to substantially outweigh that of low-income consumers for this to be feasible – a scenario that seems unlikely, based on the section on empirical results.

In conclusion, the study reveals the interplay of various factors influencing fuel demand, underlines the importance of the income elasticity of vehicle miles traveled, and offers valuable insights for policymakers in developing effective strategies for transitioning towards more sustainable modes of transportation.

References

[1] Leonardo J Basso and Tae Hoon Oum. Automobile fuel demand: a critical assessment of empirical methodologies. *Transport reviews*, 27(4):449–484, 2007.

[2] Nancy T. Gallini. Demand for gasoline in canada. *The Canadian Journal of Economics / Revue canadienne d'Economique*, 16(2):299–324, 1983.

[3] John C. Hause. The theory of welfare cost measurement. *Journal of Political Economy*, 83(6):1145–1182, 1975.

[4] Hilke A Kayser. Gasoline demand and car choice: estimating gasoline demand using household information. *Energy Economics*, 22(3):331–348, 2000.

[5] Zia Wadud, Daniel J Graham, and Robert B Noland. Modelling fuel demand for different socio-economic groups. *Applied Energy*, 86(12):2740–2749, 2009.