# Do Car Buyers Undervalue Future Fuel Savings?

## Post-Purchase Evidence

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Draft: February 12, 2020
(Updated version: ariklevinson.georgetown.domains/CarMistakes.pdf)

**Abstract**

Regulators attest that tightened automotive fuel efficiency standards save drivers money. The more efficient cars cost more upfront but reduce drivers' annual fuel expenses by more than enough to pay for those upfront costs. That claim implies a market failure or irrationality: absent the regulation, drivers would underinvest in fuel economy. We use survey data on 180,000 American cars and their drivers to examine whether each individual driver would in fact have been better off in a more expensive but more fuel efficient car, given their actual annual miles of driving and local gasoline prices. We find the regulators' claim to be true only on average. Many drivers could have been better off financially by paying less upfront for less fuel efficient cars. Our use of post-purchase survey data allows us to classify those choices by driver demographics. The differences across groups vary depending on how we compare efficient and inefficient cars. Drivers that are older, male, and college-educated are more likely to be overinvesting in fuel economy, driving hybrid gas-electric models of vehicles that also come with standard gasoline engines, even though they do not save enough annually to pay for the extra upfront cost. But when we look at all cars, not just the pairs with gas and hybrid gas-electric versions, those same older, male, educated drivers appear more likely to be underinvesting in fuel economy.

**Acknowledgments**

The authors thank Georgetown University's McCourt School of Public Policy Massive Data Institute and the Georgetown Environmental Initiative for research funds, Antonio Bento and Mary Ann Bronson for constructive suggestions, and Kevin Ankney for research assistance. Sager gratefully acknowledges financial support by the Grantham Foundation for the Protection of the Environment and the UK's Economic and Social Research Council.

# Do Car Purchasers Undervalue Future Fuel Savings?
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US regulators attest that fuel efficiency standards for automobiles save drivers money. The Corporate Average Fuel Economy (CAFE) standards for vehicles sold in 2012 through 2016 were expected to raise the average cost of a new car by $950, but promised to save drivers enough gasoline to pay for that incremental cost in just the first three years of driving.[1] The CAFE standards for model years 2017 through 2025 were expected add another $1,800 to the cost of a new vehicle, but to save more than $5,000 in gasoline costs over the life of the car.[2] Even ignoring benefits from reduced pollution, the stricter fuel economy standards pay for themselves.

For that story to be true—obliging manufacturers to sell more fuel efficient cars benefits their drivers—cars sales must involve some type of market failure. If more efficient cars would save money, buyers should be willing to pay more for them than their incremental manufacturing cost. Carmakers in turn should be glad to manufacture and sell those more efficient cars at a profit. No regulation would be necessary. The fact that regulations are needed in order for carmakers to produce vehicles that buyers should prefer indicates that the new car market is not working efficiently.

What's the market failure? Proffered explanations include car buyers' borrowing constraints, information asymmetries, and behavioral-economics examples such as inattention or present bias.[3] All of these share a common empirical implication. Drivers would be better off financially driving cars with higher upfront purchase prices but lower annual fuel expenses. And evidence for those lost opportunities for savings should be apparent in data.

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[1] US EPA "EPA and NTSA Finalize Historic National Program to Reduce Greenhouse Gases and Improve Fuel Economy for Cars and Trucks" EPA-420-F-10-014, April 2010. Link here.

[2] US EPA "EPA and NHTSA Set Standards to Reduce Greenhouse Gases and Improve Fuel Economy for Model Years 2017-2025 Cars and Light Trucks" EPA-420-F-12-051, August 2012. Link here.

[3] See, for example, Allcott andWozny (2014), Busse et al. (2013), Leard et al. (2017), Sallee et al. (2016), Allcott (2011), Sallee (2014), Allcott and Knittel (2018), Ankney (2020), and Gillingham, et al. (2019).

Here’s an example, a respondent to the US National Household Travel Survey (NHTS). For reference, call him Albert. He was in his 50s, lived in the Southeast, and had annual household income between $40,000 and $45,000. In 2009 he had one car, a new(ish) gasoline-powered Honda Civic, which he drove nearly 25 thousand miles. If Albert had purchased a hybrid gas-electric version of his same Honda Civic, he would be spending $790 less per year on gas to drive those same 25 thousand miles.

Did Albert make a mistake purchasing the less expensive, less fuel efficient, gas-powered model? Perhaps. The Hybrid cost about $5,000 more than the least expensive gas-powered Civic, so he would have recouped the extra expenditure in a bit over six years. That’s more than the three-year payback promised by the Environmental Protection Agency (EPA) and the National Highway Traffic Safety Administration (NHTSA), but still respectable. Albert’s failure to buy the hybrid might be just the type of mistake EPA and NHTSA used to justify the CAFE regulations.

However some car buyers appear to have made the opposite choice, driving efficient cars when the energy savings don’t compensate for the extra upfront costs. Betty (another pseudonym) drives the hybrid version of Albert’s Honda Civic. In 2009 she was in her 50s, lived in the South, and had household income between $45,000 and $50,000. She only drove 4,600 miles. Had she been driving the standard Civic, those miles would have cost her $165 more per year. At that rate it will take her 30 years to recover the extra $5,000 cost to purchase her hybrid. Buying the hybrid could be seen as a mistake, at least from her own, self-interested, purely financial perspective.

Of course, these two car owners might not be making “mistakes” in the literal sense. They might have good reasons, unrelated to fuel expenditures, for preferring the gasoline or hybrid versions of their cars. Some drivers might like the quiet of the electric engine; others might worry that it poses a danger to pedestrians or bicyclists. Betty—the hybrid driver in our example—might be planning on driving more in coming years, and Albert the gas powered car driver might be about to cut back. Or their commute distances or gas prices might have changed since they purchased their cars, so that their vehicle decisions were financially optimal ex ante but not ex post. These decisions are only mistakes in a personal, purely financial, ex post sense.

Those other external, non-financial, ex ante considerations are also omitted from the analyses behind regulators’ claims about the US fuel efficiency standards. By noting that the typical driver could save money by purchasing a more expensive but more fuel efficient car, those regulatory analyses find that, from the perspective of private fuel expenses alone, US car buyers choose insufficiently efficient vehicles. If that's true, in the data we should expect to see more people like Albert who could benefit from more fuel efficiency than people like Betty who could have saved money by purchasing less fuel efficiency.

These two drivers represent more than just an anecdote. In the 2009 and 2017 rounds of the NHTS, there are 24,592 drivers of vehicles that come with either a gasoline or hybrid engine. For each of those, we can calculate the annual fuel cost difference between the two alternative versions of that driver's car:

$$\text{Annual fuel cost difference} = \left( \frac{1}{\mu_n} - \frac{1}{\mu_e} \right) m \cdot p_g \, , \tag{1}$$

where $\mu_n$ is the fuel economy in miles per gallon (mpg) of the car that is not efficient (gas powered), $\mu_e$ is the mpg for the efficient car (hybrid), $m$ is miles driven per year, and $p_g$ is the price of gasoline. Equation (1) differs for every driver depending how far they drive ($m$), the gas prices they pay ($p_g$), and the difference between the gas and hybrid fuel economies for their particular car ($\mu$). For hybrid cars, (1) represents the driver's annual savings, relative to driving the same number of miles in the gas powered version. For gas powered cars, (1) represents unrealized annual savings from switching to a hybrid.

Figure 1 plots two distributions of these annual fuel cost differences in (1). The outlined unshaded columns plot the distribution for drivers of the 22,124 gasoline powered vehicles in the 2009 and 2017 NHTS data. Cars further to the right in that distribution are more likely to represent (personal, purely financial, ex post) mistakes. They are gas-powered car owners who miss out on large annual savings of driving the hybrid version of their cars. The shaded columns plot the distribution of (1) for drivers of the 2,468 hybrids. Cars further to the left there are more likely to represent mistakes. Those drivers own hybrids but do not drive much or face high gas prices. Accordingly, we should expect to see the shaded histogram (hybrids) to the right of the outlined histogram (gas-powered). And that is exactly what Figure 1 shows.

Two points need to be made here. First, the shift of the hybrid distribution to the right of the gas-powered distribution could represent decisions by car purchasers based on their pre-purchase expected driving. People expecting to drive more miles purchase the hybrids. Or, that shift could also represent post-purchase reactions to the relative differences in driving costs. Even if we randomly assigned cars to drivers, the recipients of hybrids would find driving less expensive and might drive more, realizing more savings. In other words, drivers facing higher costs could choose to buy hybrids, or hybrid owners could respond to the lower cost by driving more miles. Either way, hybrid owners will exhibit greater annual savings in Figure 1.

The post-purchase reaction to the different price of driving represents the “rebound” effect (Gillingham et al. 2016). Purchasers of efficient cars will drive them more, making their investment in the efficiency appear smarter. Purchasers of less efficient cars will drive them less, making them seem smart not to have invested in the costlier efficient version. Any analysis we do based on estimated savings, with savings calculated based on actual miles driven given the cars people have chosen to drive, will be a conservative measure of mistakes. Drivers’ post-purchase driving behavior will rationalize their vehicle choices.

The second point we need to make here involves the complex set of assumptions necessary to figure out which drivers could be saving money in a different vehicle. In order to know whether an efficient hybrid car is worth the upfront investment, we need to compare the annual fuel savings in equation (1) to the annualized difference in the fixed costs of the two cars. That, in turn, depends on three things: (i) the difference in sales prices, net of any rebates or subsidies for buying an efficient car, (ii) the discount rate used to annualize the price difference, and (iii) the depreciation rate of the extra expenditure on the fuel efficient version.

Because that calculation is so complex, and requires so many assumptions, we take a simple and intuitive approach. Whatever the values of the key variables, for each pair of car models there is some level of annual cost differences that would justify the investment in fuel economy. Think of it as a vertical line drawn in Figure 1. Any driver to the right of that line in a standard gas powered car has underinvested in fuel efficiency. Any driver to the left in a fuel efficient car has overinvested. We pick a value for that line for each car model, and examine the demographics of drivers on either side.

To frame that empirical approach, we develop that intuition in a simple model in which cars differ only in their price and fuel economy. The model incorporates the tradeoff between upfront efficiency costs and future gasoline savings. And the model helps us to develop two straightforward empirical tests of car buyer mistakes. Both empirical tests are designed to overcome the chief obstacle to assessing drivers’ car choices: cars differ along many dimensions that are correlated with fuel efficiency. So any empirical test needs to control for car characteristics missing from the theoretical model. Our two empirical tests represent alternative approaches to controlling for those other characteristics.

The first test controls for car characteristics correlated with price and fuel economy by examining only those car models that can be purchased in two alternative versions: a standard gasoline powered engine or a hybrid gas-electric engine, like the two Honda Civic models in our introductory example. We assume those pairs differ only in their fuel economy, as in the theory model, and we compare the fraction of drivers in the gasoline powered versions who would have been better off paying more for the hybrids, to the fraction in the hybrids who could have saved money by purchasing the gas versions.

Our second empirical test uses all of the cars in the 2009 and 2017 NHTS surveys and controls for other car characteristics statistically, rather than by picking similar vehicles like the gas-hybrid pairs. We estimate the average fuel economy premium, the incremental upfront cost of purchasing a vehicle with an extra mpg of efficiency, controlling statistically for other observed car characteristics correlated with efficiency and price. We then calculate each driver's actual annual driving costs, given the gas prices they face and their annual mileage, and what they would save annually in a slightly more fuel efficient car with one extra mpg. If those annual savings exceed the fuel economy premium (annuitized appropriately), the driver would have been better off choosing a more efficient vehicle. If those savings are less than the fuel economy premium, the driver would have been better off paying less up front for a less efficient car. As with the gas-to-hybrid comparison, we calculate the proportion of drivers making both types of personal, purely financial, ex post mistakes.

Both empirical tests rely on assumptions. We assume we have controlled for other car characteristics, either in our gas-to-hybrid comparison or statistically. We follow the EPA and NHTSA regulatory analyses, which assumes the cars last 14 years and discounts future fuel savings at 3 and 7 percent. And we assume drivers pay the manufacturer suggested retail price (MSRP) for their vehicles, adjusted for inflation. We test the robustness of our results to all of those assumptions.

Despite the sometimes strong assumptions underlying our analysis, the approach we take has two advantages over existing work. The first is that we assess the actual, realized, *post-purchase* fuel savings by specific drivers. Until now, all of the evidence for whether drivers appropriately value future fuel savings has come from expected savings of typical drivers. Some researchers using that strategy have found the fuel economy premium to be less than the present discounted value of expected future savings, suggesting that on average, car buyers make mistakes by purchasing insufficiently fuel-efficient cars (Allcott and Wozny 2014; Grigolon et al. 2018; Gillingham et al. 2019). Others find the premium approximately equal to the discounted future savings, suggesting that on average, buyers are not mistakenly purchasing too little or too much fuel efficiency (Sallee et al. 2016; Busse et al. 2013).

All of those prior analyses compare the fuel economy premium to the expected fuel savings at the time of purchase. At best those expectations are based on miles driven by the average driver of particular car models. In no cases do the researchers know the driving habits of particular drivers. As Bento et al. (2012) note, some individual drivers will put a lot more miles on their cars each year than the average, and others will put less. The high-mileage drivers should be willing to pay more for fuel economy than low-mileage drivers, and that heterogeneity will bias the results towards suggesting that consumers undervalue future savings.

Our approach instead compares the premium paid for fuel efficient cars to the actual realized fuel savings of those cars' drivers, based on how far they drive each year and the gasoline prices they pay. That's our first and most important advantage. We find lots of drivers who could have saved money by purchasing more efficient cars. Those drivers undervalued future savings, as in Allcott and Wozny, Grigolon, and Gillingham et al., and as suggested by US regulators. But we also find nearly as many drivers who could have saved money by purchasing *less* efficient cars, spending less to buy the cars initially, and more each year to drive them.

Our analysis also has a second important advantage. Because we use household survey data from the NHTS, we know many details about the demographics of the drivers. We can assess which particular groups are more likely to undervalue or overvalue future savings: male or female, rich or poor, educated or less educated, old or young.

Whether we compare cars using the hybrid-gas pairs or by controlling statistically for other car characteristics, we find that drives do appear to undervalue fuel savings, but only on average. Many could be saving money in a more expensive, more fuel efficient vehicle. But nearly as many could have saved money paying less for the car but more for their annual fuel costs. But when we examine these differences across different types of drivers, the approaches we take lead to different results. When we control for car characteristics by limiting the analysis to hybrid-gas model pairs, male, older, and college educated drivers appear more likely to be overinvested in fuel economy, driving hybrids even though the savings are too small to cover the incremental upfront car cost. But when we control for car characteristics statistically, those same male, older, educated drivers appear underinvested in fuel economy. To be precise, these groups do own vehicles that are more fuel efficient on average, but not nearly enough to account for the fact that they also tend to drive more. In either analysis, demographic characteristics play a much larger role in predicting car fuel economy that fuel costs. Individual drivers' cost-saving potential appears to have close to no influence on investments in fuel economy.

Before describing those analyses in detail, we describe the evidence on these issues so far, and then sketch a theory that frames our thinking as well as some comparative statics that demonstrate normative implications derived from the analyses.

## I. Evidence to date comparing fuel economy premiums to expected annual savings

Our paper is not the first—by a large margin—to model the tradeoff between upfront costs and future energy savings or to try to measure consumers' willingness to pay for future energy savings empirically. Much of that research studies cars, in part because good data are available and in part because vehicle fuel economy has been the focus of regulatory attention. Allcott and Greenstone (2012) synthesize that literature in a model that frames the key issues. In their model, relabeled here for consistency with our terminology, consumers choose among durable goods, such as cars, with different energy intensities, labeled μ. Think of cars with two different mpg ratings, efficient $\mu_e$ and inefficient $\mu_n$, where $\mu_e > \mu_n$. Efficient cars cost more to purchase, all else being equal. Label that incremental upfront capital cost $p_\mu$. A driver will be better off buying the efficient car if that incremental cost is less than the discounted energy savings:

$$p_\mu < \gamma p_g \left( {}^{m}\!/_{\mu_n} - {}^{m}\!/_{\mu_e} \right) F . \tag{2}$$

In equation (2), $p_\mu$ represents the price difference between the equivalent efficient and inefficient cars, $m$ is consumption of the energy service (miles driven), $p_g$ is the price of energy (gas), and future cost savings are collapsed into present values by factor $F$.[4]

The ad hoc parameter $\gamma$ in equation (2) describes the weight consumers appear to assign to discounted future energy costs. If $\gamma=1$, consumers make rational tradeoffs between current costs and future energy savings. If $\gamma<1$, some behavioral anomaly or market failure impedes consumers from purchasing cars or appliances that would save them money.

Estimating $\gamma$ requires knowing the price of incremental fuel efficiency, mileage, fuel prices, discount rates, and vehicle lifespans. And, importantly, it requires comparing cars that are identical in all respects other than efficiency. Finding that buyers undervalue fuel savings could simply mean that car buyers have disutility from some unobserved characteristics of the efficient cars.

That difficulty—separately identifying preferences for fuel economy from other car attributes—is the biggest challenge faced by this work. Many car characteristics, like size and power, are associated with more expensive, less fuel efficient vehicles. As a result, more fuel efficient vehicles are not typically more expensive; they are cheaper. Only after controlling statistically for other observable car characteristics does the relationship between price and fuel economy become positive. But that leaves open concern about other car characteristics omitted from the analysis.

Five recent studies have taken creative steps to address the omitted variables problem.[5] Allcott and Wozny (2014) use monthly data on new vehicle registrations in the United States. They test whether more fuel efficient cars command higher prices when gasoline prices rise. Because their results are identified by price changes for specific car models, fixed effects can account for unobserved model characteristics. Allcott and Wozny estimate moderate undervaluation of future fuel savings ($\hat{\gamma} = 0.76$).

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[4] For example, applying NHTSA's assumption that cars last for 14 years, if future savings are then discounted at 3 percent, $F$ is 11.3. If savings are discounted at 7 percent, $F$ is 8.7.

[5] Greene (2010) and Helfland and Wolverton (2011) contain thorough reviews of earlier papers.

Sallee et al. (2016) examine used car auctions in the US. Cars with fewer miles on their odometers have more expected remaining useful years and therefore a higher payoff to fuel efficiency. When gasoline prices increase, the price of fuel efficient used cars increase, and increase more for used cars with lower odometer readings. Sallee et al.'s estimates suggest that vehicle prices move approximately one-for-one with discounted future fuel savings, or that $\hat{\gamma} \approx 1$ . As with Allcott and Wozny, the identification is within model type, so unobserved differences between models pose less of a problem.

Grigolon et al. (2018) use European car sales data. They compare different variants of the same model, in the spirit of our hybrid-gasoline example. These variants differ in their suggested retail prices and fuel economies. Grigolon et al. exploit variation in the market shares of new vehicle registrations of these variants. Their main estimate is that $\hat{\gamma} = 0.91$, implying that consumers only moderately undervalue discounted fuel savings.

Busse et al. (2013) take a different approach. They estimate the discount rate (*r*) that would justify the price premium consumers pay for efficient cars. If that rate is implausibly large, it would suggest consumers undervalue future savings (i.e. that $\gamma<1$). Busse et al. find implied discount rates in line with market interest rates for car loans, and that therefore consumers do fully value future savings.

Gillingham et al. (2019) exploit the fact that in 2012 Hyundai and Kia corrected labels that had previously overstated the fuel economy for 13 car models. They find little decline in willingness to pay for the cars, suggesting a value of $\gamma$ in the range of 0.16-0.39. Their result amounts to a joint test of consumers' willingness to pay for future savings and the degree to which consumers' get their information about savings from vehicle labels.

All of these papers calculate future savings based on the typical miles driven by the average driver. But Bento et al. (2012) remind us that that heterogeneity in mileage will result in underestimates of the value of future fuel savings ( $\hat{\gamma}$ ). Grigolon et al. (2018) attempt to estimate the size of this bias by simulating the distribution of driving patterns based on actual mileage data from the United Kingdom in 2007. Their main result ($\hat{\gamma} = 0.91$) accounts for heterogeneity. However, their simulation only partially addresses the problem. Their analysis remains at the level of car models, not individual consumers, and their results are identified by fluctuations in market shares of variants of similar models.

Our approach differs from all of the prior work in that we explicitly examine the realized, post-purchase mileage for each driver. We don't ask whether drivers of Honda Civics pay a premium for hybrid versions of the car that is worthwhile given the average annual mileage for all drivers, or even the average for Honda Civic drivers. Rather, we examine the actual annual miles driven and gas prices paid to see whether each individual driver would have been better of paying more up front for a more efficient car, or paying less for a less efficient car.

To help frame the empirical analysis, we start with a simple model.

## II. A theoretical sketch

Consider a representative consumer or household, with utility over two goods: miles driven, $m$, and a numeraire good, $x$. Consumers don't purchase miles directly, but instead purchase cars and gasoline, $g$. Miles driven is the product of gasoline and the car's energy efficiency, $\mu$, expressed as miles per gallon or mpg: $m=\mu g$. Utility is then

$$U(m,x)=U(\mu g,x)\,. \tag{3}$$

Driving requires two expenditures: gasoline $g$ at price $p_g$ and a vehicle at price $P_v$. For simplicity, assume the car price is annuitized, or equivalently that the car is leased and $P_v$ represents the annual rental cost. More efficient cars with higher $\mu$ cost more to buy or lease. Call that premium $p_\mu$, as in equation (2). Here $p_\mu$ is the cost of one extra mile per gallon of fuel economy. A car owner's budget constraint is thus

$$Y = x + p_g g + P_v + p_\mu \mu\,. \tag{4}$$

This budget constraint can be represented by a plane in three dimensions: $x$, $g$, and $\mu$. Those are the three purchases: the numeraire ($x$), gallons of gasoline ($g$) and fuel economy for the car ($\mu$). But that's not the most instructive representation, because miles $m$ are in the utility function, not gasoline $g$.

For a clearer view of the tradeoffs, rewrite (4) replacing $g$ with $m/\mu$, and in a more familiar form with the numeraire on the left:

$$x=\left(Y-P_v\right)-p_g\left(\frac{m}{\mu}\right)-p_\mu \mu\,. \tag{5}$$

That's a budget surface in which two of the dimensions are goods in the utility function: the numeraire $x$ and miles $m$. The third dimension is fuel economy, $\mu$. Figure 2 plots an example of the budget surface in equation (5).

For any given fuel economy ($\mu$), there's a linear tradeoff between miles travelled ($m$) and the numeraire ($x$). That can be seen by envisioning a vertical slice through Figure 2 at any level of $\mu$. Figure 3 plots two such slices, one for an inefficient car with mpg $\mu_1$ and a second, dashed budget line for an efficient car with mpg $\mu_2$. The slope of each budget line is $p_g/\mu$, the cost of driving an additional mile.

Maximizing utility in (3) with respect to the budget constraint (4) results in two first-order conditions:

$$\begin{aligned} &(i) && U_m/U_x = p_g/\mu \\ &(ii) && U_m/U_x = p_\mu/g\,. \end{aligned} \tag{6}$$

The first condition in (6) indicates that the marginal rate of substitution between the two goods in the utility function, miles and the numeraire, should equal the cost of going one more mile by purchasing more gasoline. That cost is $p_g/\mu$, the price of gas divided by the car's mpg. The second condition in (6) indicates that the same marginal rate of substitution should also equal the cost of going one more mile by purchasing a more efficient car. That cost is $p_\mu/g$, the price of fuel economy divided by the number of gallons being used.

The intuition is simple. Drivers have two ways to travel an extra mile. They can buy more gasoline at price $p_g$ for a car with any fixed fuel economy $\mu$. That first order condition is represented in Figure 3 by a tangency between an indifference curve (with slope $U_m/U_x$) and a budget line (with slope $p_g/\mu$). Or they can buy more fuel economy at price $p_\mu$ for a fixed amount of gasoline $g$. That represents a move along the $\mu$ axis in Figure 2 and a lowering of the vertical axis in Figure 3, as from $\mu_1$ to $\mu_2$.

To see that second way of driving an extra mile, by purchasing more fuel economy, Figure 4 sketches two different vertical slices through Figure 2, drawn for two particular mileages, $m_1$ and $m_2$. A driver can minimize the cost of driving $m_1$ miles by purchasing fuel economy $\mu$ until the cost of an extra unit of fuel economy $p_\mu$ equals the savings from that extra efficiency. The savings is just the derivative of the total cost of driving, $mp_g/\mu$, with respect to $\mu$. So in the optimum, the cost of that extra mpg, $p_\mu$, equals those savings:

$$p_\mu = \frac{mp_g}{\mu^2}. \tag{7}$$

That is just another way of writing the combined first order conditions in (6), replacing gallons $g$ with $m/\mu$. The optimum is depicted in Figure 4 as $\mu^*$ for a car owner driving $m_1$ miles per year. A car owner driving $m_2$ miles per year will be along a different slice through Figure 2, with lower possible expenditures on the numeraire $x$ and higher optimal fuel economy.[6]

The two first order conditions in (6), and their representations in Figure 3 and Figure 4, motivate our two empirical tests. Given a choice between two cars with efficiencies $\mu_1$ and $\mu_2$, drivers choices will depend on their willingness to trade off miles traveled for other goods in the numeraire. Given the indifference curve depicted in Figure 3, the driver would be best served choosing the inefficient car and driving $m^*$ miles. A driver with a flatter indifference curve, however, might be better off given those same budget constraints choosing the efficient car and driving more than $m^0$ miles. Because we cannot observe utility, we cannot identify all of the cases where a driver would be better off in a more or less efficient vehicle. A different driver might be making a mistake choosing to drive $m^*$ miles in the inefficient car.

We can, however, identify some cases that are mistakes—purely personal, financial, ex post mistakes—even without knowing utility. In Figure 3 any car owner driving more than $m^0$ miles per year in a vehicle with efficiency $\mu_1$ ,the solid budget line, is making a mistake. Albert in our introduction may be in that position. He could drive that same number of miles at lower total cost, including the upfront price of the car, in the more efficient vehicle $\mu_2$. Similarly, anybody

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[6] Or, consider a third way of looking at the tradeoffs. For any given expenditure on the numeraire, there's a quadratic relationship between miles ($m$) and mpg ($\mu$). Envision horizontal slices through Figure 3. A household can spend more on energy efficiency to travel more miles, up to a certain point, holding the total budget and expenditures on $x$ constant. Beyond that point, purchasing more efficiency doesn't pay off and results in fewer miles travelled. At the optimum $\mu = (Y - x)/2p_\mu$.

driving fewer than $m^0$ miles per year in a vehicle with efficiency $\mu_2$, the dashed budget line, is making a mistake. That may be Betty in our introduction. She could have saved money by purchasing the less efficient car.

Our first empirical test examines pairs of cars that come in standard gas or hybrid gas-electric versions, and looks for people with low annual gas expenses who have purchased the hybrids, and people with high annual expenses in the standard models. Our second empirical test focuses on the second first order condition in (6) and on Figure 4. For each driver in our sample, we can calculate the annual gas savings from purchasing a slightly more efficient car, with one more mpg: $mp_g / \mu^2$. If that is higher than the cost of an extra mpg, the driver has underinvested in fuel economy and could be saving money in a more efficient car. If that annual savings is lower than the the cost of an extra mpg, the driver has overinvested in fuel economy, and would have been better off purchasing a less expensive, less efficient car.

To reiterate, the mistakes identified by both approaches are only errors in that the upfront costs of fuel efficiency can or does not exceed the associated future fuel savings. Drivers may care about externalities such as pollution, or other vehicle attributes correlated with efficiency, or drivers' expected mileage may change. That's why we keep referring to the mistakes as personal, purely financial, and ex post. But these mistakes are the same behavior that the EPA and NHTSA implicitly identify when they report that fuel economy standards will save drivers money. And so in the next section we turn to the data to assess which drivers in practice are driving more miles in cars that could be saving them money if they had spent more on fuel efficiency, and how many are driving relatively few miles in cars that could have saved them money had they spent less on fuel efficiency.

## III. Identifying mistakes in practice: Comparing hybrid and gas powered cars

For post-purchase evidence of the annual miles people drive, and the cars in which they do that driving, we rely on the 2009 and 2017 waves of the National Household Travel Survey. It includes household demographics, the annual number of miles driven in each vehicle, and the make, model, and model year of those vehicles. We match that information with WardsAuto data for each make and model year to get vehicle characteristics, in including size, engine power, and the EPA estimated combined city/highway fuel economy.

Table 1 presents some summary statistics. The first two columns contain data for only those vehicle models that come in both a gasoline and hybrid version. Drivers of hybrid cars get more miles per gallon of gasoline and travel more miles, as expected. The mileage difference translates to a 7 percent increase (relative to the midpoint of the two values). The fuel economy difference translates to a 30.4 percent drop in the cost of traveling each mile. If we could convert those two numbers into a price elasticity—and we cannot, due to the selection by drivers into gas and hybrid cars—that elasticity would be 0.23. For comparison, Labandeira et al's (2017) meta-analysis of studies has an average short run price elasticity of demand for gasoline of 0.20 and an average long run elasticity of 0.53. In other words, if we randomly assigned drivers to hybrid and gas cars, the mileage difference we see in Table 1 is at the low end of what we should expect to see.

To examine the choices households make, we start with the simplest strategy that matches the introductory intuition, comparing hybrid and standard gasoline powered versions of the same make and model as in the first two columns of Table 1. For each driver with a car that comes in both gas and hybrid versions, we calculate the annual value of the fuel cost difference between the hybrid and gasoline powered versions of that driver's car. That cost difference is in equation (1), and differs for every driver, depending on their miles (*m*), gas prices $\left(p_g\right)$, and the difference between the gas and hybrid fuel economies for their particular car. It is plotted in Figure 1 for two groups: the black outlined bars for drivers of gasoline powered vehicles, and the shaded bars for hybrids.

As a way of comparing the two distributions in Figure 1, we note that there is some benchmark value of annual fuel savings for which the share of hybrids to the left of that amount equals the share of gas-powered cars to the right. Those are the apparent mistakes: gas cars for which the savings are large and hybrids for which the annual fuel savings are small.

Figure 5 sketches these distributions as frequencies rather than densities, to emphasize that the hybrid market share is smaller. For each car model that comes in both gas and hybrid versions, there's an annual cost difference that would justify purchasing the more expensive hybrid. Figure 5 depicts that benchmark as a starred vertical line. Drivers of standard gas cars spending more than the benchmark could be saving annual expenses in the hybrid. The share of gas drivers in that position in Figure 5 is B/(A+B). Drivers of hybrids spending less could have saved money by purchasing the gas car. That share is C/(C+D).

Finding the true benchmark annual cost difference is difficult. It requires knowing all the various parameters of equation (2), including the price premium for the hybrid, the cars' live expectancies, and consumers' intertemporal discount rates. Accordingly, we take two contrasting approaches.

Our first approach is completely ad hoc but has the advantage of being transparent and straightforward. We find the annual cost difference for which the share of gas drivers whose missed savings are larger than the benchmark, B/(A+B) equals the share of hybrid drivers whose realized savings are smaller than the benchmark, C/(C+D). We calculate this cutoff value separately for each make, model, and year. And we call that the mistake-equalizing annual savings.[7]

As a second approach, we calculate the benchmark annual cost difference by assuming that the hybrid price premium for each model pair is the difference in the two cars' MSRPs. That may overstate the cost of fuel economy if consumers receive tax incentives or other rebates for purchasing the fuel efficient versions. And that overstatement may be different for different model pairs. So each approach has different strong assumptions, and we will show that our main conclusions with regard to the demographics of drivers making different fuel economy choices do not differ across our approaches.

### *Mistake-equalizing annual savings.*

Start with the simplest, ad hoc definition of the benchmark annual savings, the one for which the share of gas car drivers who would be better off in a hybrid equals the share of hybrid drivers who would have been better off driving a gas car, or B/(A+B)=C/(C+D) in Figure 5. Once we set that benchmark annual fuel savings for each make, model, and year we report two types of (personal, purely financial, ex post) mistakes. The first is the share of drives with high

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[7] For this mistake-equalizing approach, we restrict the analysis to a slightly smaller sample of 22,493 vehicles in the NHTS which belong to model-year pairs with at least 5 drivers with a hybrid version and 5 drivers with a gas powered one.

annual potential savings from being in a hybrid, but who are driving gas cars. That fraction of our drivers is B/(B+D) in Figure 5. The other group of potential mistakes is the share of drivers with low annual savings but who are driving gas cars. That's C/(A+C) in Figure 5.

Figure 6 illustrates how the proportions of drivers who would likely be better off in different versions of their same vehicles differ by household income, given their annual miles and the gas prices they face.[8] The upper line depicts the share of households who have annual expenses above the cutoff but are driving gas powered cars, B/(B+D) in Figure 5. That is the mistake used to motivate fuel economy regulations: people don't invest enough in efficiency. Higher-income households are less likely to fit that pattern. The lower line in Figure 6 depicts the share of drivers with annual expenses below the cutoff but who drive hybrids, C/(A+C) in Figure 5. That's the opposite mistake: these people are likely to have overinvested in fuel efficiency. Higher-income households are more likely to have made that apparent mistake.

Note that our ad hoc cutoffs for high and low annual fuel expenses ensures that equal proportions of hybrid and gas vehicle drivers make apparent mistakes, even though the market shares of gas and hybrid cars are quite different. Ten percent of our sample drive hybrids, which is why the lower line in Figure 6 centers on ten percent and the upper line on 90 percent. What's interesting is not the levels, but how those shares differ by income. So to normalize for the different market shares, we subtract from each group's share the average market share for that vehicle type.

Figure 7 plots the market-share-adjusted versions of the two lines from Figure 6.[9] The left axis reports the difference between the share of the group likely to be making the particular mistake—under or over-investing in fuel economy—and the overall market share of that style of car. The differences in Figure 7 by income are based entirely on the propensity of different income groups to choose hybrids or gas powered cars, conditional on their annual mileage and gas prices, and factoring out aggregate market shares of vehicle types. Poorer households are

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[8] The categories of household income in the 2009 and 2017 NHTS data are not directly comparable, because they are based on current dollar values. We use the 2017 NHTS for this example.

[9] In the context of Figure 5, the top line in Figure 7 is B(B+D)−(A+B)/(A+B+C+D). The bottom line is C(A+C)−(C+D)/(A+B+C+D).

relatively more likely to be missing out on annual fuel savings from driving hybrids, and richer households are more likely to have spent too much upfront for hybrids.

Note that Figure 7 does not suggest that poor or rich households systematically make more mistakes. Rather, they make different types of mistakes. Poorer households are more likely to have chosen a gas powered car when a hybrid would be saving them money, and richer households are more likely to do the opposite.

Why is this important? That depends on how we interpret the apparent mistakes. If the choices reflect underlying unobserved preferences, then richer people have a higher willingness to pay for hybrids for some reason unrelated to fuel savings. A public policy that that subsidizes hybrids would be an inframarginal transfer to rich drivers. A public policy that penalizes gas powered cars would be a regressive burden on poorer drivers.

The policy conclusions are the same if poorer households have higher discount rates, and that is why they choose gas powered cars even if hybrids would save future fuel expenses. A hybrid subsidy would benefit rich drivers who already choose hybrids, and a gas-powered car tax would burden poorer drivers who don't value the future savings.

But if the interpretation of Figure 7 is that poorer households face liquidity constraints (Ankney, 2020), then the policy implication is different. A hybrid subsidy may enable poorer households to afford the upfront costs of hybrids that would save them future fuel expenses.

In Figure 8 we conduct the same exercise for other household characteristics: sex, age, rural/urban, and education. We calculate the shares of apparent mistakes for each demographic group, normalized by the market shares for the two types of cars. The open circles represent the shares of drivers with high expenses who drive the gas powered versions of their vehicles. They could be saving money in a hybrid. The solid diamonds represent the opposite mistake, drivers with low annual expenses who drive the hybrid version. They could have saved money by purchasing the gas powered version.

At the top of Figure 8, among drivers with high annual expenses, men are less likely than women to make the apparent mistake of choosing a gasoline powered car. But among drivers with low annual expenses, men are *more* likely than women to make the opposite apparent mistake, driving hybrids.

For drivers younger than 40, a higher proportion with high annual expenses drive gas cars even though they would be better off in hybrids. For drivers older than 40 that pattern is reversed.

Drivers who have not been to college look like the younger drivers. Fewer drive hybrids but would likely be better off in standard gas powered cars, and more drive gas cars that would likely be better off in hybrids.

One final distinction in Figure 8 is worth noting. Rural and urban drivers appear equally disposed to make each type of apparent mistake. Our analysis controls for miles driven and gas prices, so those distinctions should not matter here. If the car choice differences are determined by preferences, and if rural and urban drives have different preferences, we would have expected there to be significant differences between rural and urban drivers.

So far, our comparison of gas and hybrid cars has relied on an arbitrary cutoff for fuel savings—a combination of gas prices and annual miles such that the share of hybrid drivers with lower expenses equals the share of gas powered car drivers with higher expenses. As an alternative, we calculate a cutoff fuel savings based on the cars' MSRPs and the discount rates and vehicle depreciation assumptions used by the EPA and NHTSA in their analyses of the national fuel economy standards.

### *Calculating mistakes using the assumptions behind the CAFE analyses.*

In 2012, the US EPA and NHTSA issued new fuel economy rules for cars to be produced in model years 2017 through 2025. That ruling was accompanied by a Regulatory Impact Analysis (RIA) predicting that the new rules would add $1,800 to the cost of a new vehicle and to save more than $5,000 in gasoline costs over the life of the car.[10]

The EPA and NHTSA analyses hinge on vehicle depreciation rates and discount rates. They assume various lifespans for cars based on model-specific calculations. The average of those is 14 years, and we apply that average vehicle life to all the cars in our sample. The EPA

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[10] See footnote 2.

and NHTSA then apply either a 3% or a 7% discount rate to future fuel savings, following standard US government guidance.[11]

Our version of that analysis can be found in Table 2. The 2009 and 2017 NHTS data contain 24,592 cars that come in hybrid or gas powered versions, 2,468 of which are hybrids. We assume those cars all sell for their MSRP and last for 14 years. If we discount future fuel savings at 3 percent, then 4,213 of those drivers would be saving money in the hybrid version of their car-model pair. Given their driving mileage and gas prices, their discounted future fuel savings would more than cover the price premium for the hybrid version of their car. But of those 4,213 drivers, only 554 (13 percent) are actually driving hybrids. The other 3,659 are making the apparent mistake of underinvesting in fuel economy.

If we discount future fuel savings at 7 percent, 2,493 would be better off in the hybrid, and only 346 (14 percent) of them actually are driving the hybrids. Increasing the discount rate reduces the number of drivers predicted to be better off in a hybrid, but doesn’t significantly change the share of those that actually do so.

Table 2 also reports the other type of mistake—overinvestment in fuel efficiency. Of the 20,379 drivers predicted to be saving money in the gasoline-powered cars, discounting future savings at 3 percent, 18,465 are driving gas powered cars. The other 1,914 are making an apparent mistake by driving hybrids. That’s 9 percent of low-expense drivers who would be better off in less fuel efficient gas powered cars.

And again, if we discount future fuel savings more, at 7 percent rather than 3 percent, the proportions are roughly the same. More would drivers save money in the gas powered cars, 22,099. Of those, 90 percent do choose the gas versions. The other 2,122, or 10 percent, are making the apparent mistake of driving hybrids, overinvesting in fuel efficiency. Raising the discount rate from 3 to 7 percent only barely reduces the share of hybrid drivers estimated to be overinvested in fuel efficiency, from 87 to 86 percent.

Why don’t the shares of apparent mistakes change much, even though the discount rate substantially cuts the value of driving a hybrid? Because drivers’ gas-hybrid decisions do not seem to reflect their potential annual fuel savings. Look again at Figure 1. The two distributions

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[11] US Office of Management and Budget, Circular A-4, 68 FR 58366, October 9, 2003.

mostly overlap. Raising the discount rate from 3 to 7 percent shifts to the right the cutoff annual fuel savings that would make choosing the hybrid worthwhile. That shrinks share of drivers for which we consider choosing a hybrid to be optimal. But it also shrinks the share of drivers who have chosen to drive a hybrid by almost the same amount.

More concretely, if cars were randomly assigned to drivers in our sample, regardless of gas prices or annual miles. Then changing the discount rate would have no effect on observed apparent mistakes in car choice. That, in fact, is nearly the case. Table 2 is just one more way of demonstrating the key takeaway from Figure 1. Drivers' choices of fuel efficient cars seem mostly unrelated to annual fuel savings.

### *Regression-based approach to demographic analysis—Hybrid Pairs.*

The demographic analyses in Figure 7 and Figure 8 examine the sample according to single demographic characteristics, one at a time: income, gender, age, location, education. However, these characteristics may covary significantly. We cannot be certain, for example, whether differences between education groups are really due to differences across income levels, or vice versa.

To examine how all of these five demographic characteristics together are associated with the fuel economy of the cars people drive, we take a regression approach. Table 3 regresses the likelihood of driving a hybrid vehicle (1 for hybrid, 0 for gas powered) on the cumulative discounted value of future fuel savings (in $1000s) from the hybrid relative to the gas powered version of their car model, given their individual annual miles driven and fuel price. The regressions also include the upfront investment cost of the hybrid car. It controls for all five demographic characteristics, vehicle characteristics that affect fuel economy, and a full set of make and year-by-type fixed effects. We again mirror the assumptions from the CAFE analysis, summing annual fuel savings over 14 years and discounting them at 3% and 7% respectively. And as before we restrict the analysis to the 17,586 drivers in the 2017 wave of the NHTS for which income groups are comparable and who drive vehicles which come in both a hybrid and a gas powered version.

To create bounds for our analysis, we calculate two extremes. The first pairs the lower discount rate of 3% with a low estimate of the upfront investment cost, using half of the difference in MSRPs between the two vehicles in each model pair. That combination is most favorable to choosing a hybrid. The other extreme pairs the higher discount rate of 7% with a high estimate of the upfront investment cost, twice the MSRP difference.

Column 1 of Table 3 suggests that an additional $1000 in discounted fuel savings is associated with an increase in the probability of driving a hybrid by 0.43%. A $1000 increase in the incremental cost of the hybrid is associated with a 2% reduction in the probability of driving a hybrid. In other words, a dollar of upfront investment cost has a greater association with observed choices than a dollar of future fuel savings. If consumers would fully value future energy costs, i.e. if $\gamma=1$, the two coefficients should be equal. But our estimates in column 1 suggest significant undervaluation of future fuel savings relative to upfront investment cost $(\hat{\gamma}=0.2)$.

Demographic characteristics of drivers are highly associated with the probability of driving a hybrid, even after controlling for fuel savings potential, upfront investment cost and vehicle specifications. Drivers with higher incomes are more likely to own hybrids. This could be for many reasons. Perhaps high-income drivers prefer fuel efficient cars for reasons other than personal financial cost, such as altruistic concern for the environment or signaling environmental credentials to neighbors. Perhaps they have less trouble affording or borrowing to buy the more expensive hybrids. Or perhaps they are more likely to “do the math” and get closer to choosing their optimal level of fuel economy.

Column (2) of Table 3 tests this last hypothesis, that richer drivers are more likely to make the right financial decision, purchasing a hybrid when it the gas savings justify the investment. The specification in column (2) includes an interaction between the cumulative fuel savings and an indicator for households with annual incomes above $100,000. The small and insignificant coefficient (0.001) suggests that high-income drivers’ propensity to own a hybrid is only marginally more responsive to fuel savings potential, if at all. Higher-income drivers are on average more likely to own a hybrid, but evidently not for reasons of economic cost. Their estimated conversion rate between future fuel savings and upfront investment costs is only marginally higher than for households with lower incomes $(\hat{\gamma}=0.22$ compared to $\hat{\gamma}=0.16)$. That suggests that rich households are not more likely to do the math, and that poor households are not more likely to be credit constrained. Some other reason must explain the income effect: rich households' altruism or environmental virtue signaling.

The regressions in Table 3 also show that some demographic traits are significantly more powerful predictors of observed vehicle choice than are the economic elements that we would have expected to motivate the decision—fuel savings potential and upfront investment cost. Possessing a graduate degree or being above 60 years of age are associated with increases in the probability of owning a hybrid that are respectively 8 times and 7 times larger than from a $1000 increase in fuel savings potential, even after controlling for households' incomes. Column (3) of Table 3 controls for car model-specific fixed effects. There, the estimated responsiveness to future fuel savings is even smaller $(\hat{\gamma} = 0.1)$.

Columns (4) through (6) of Table 3 use the other extremes of our assumptions, a 7 percent discount rate, and a price premium for hybrid vehicles equal to twice the MSRP difference. This makes purchasing a hybrid less financially worthwhile. The implications are identical: fuel costs do not predict very much of the hybrid choice $(\hat{\gamma} = 0.26)$; richer drivers are no more likely to take fuel costs into account; and having a graduate degree has 6 times the predictive power for hybrid ownership as $1000 of future fuel savings.

In general, the results so for demonstrate that drivers' choice of fuel economy does not seem to be determined by future fuel savings. One possible explanation is that the hybrid-gas model pair distinction is not the best way of controlling for other unobservable differences between less efficient and more efficient cars. Some hybrid vehicles clearly identify themselves as such, perhaps signaling the environmental virtue of their drivers. Battery life may limit the resale value of hybrid vehicles. Hybrids may have less interior room or cargo space. And the on-the-road performance of the hybrid and gasoline powered vehicles may differ. For those reasons, in second overall approach we expand the sample to include all cars, not just the models that come in gas and hybrid versions.

## IV. Identifying mistakes in practice: A regression approach using all car models

Instead of controlling for other car characteristics with a simple hybrid-to gasoline comparison, in this section we use all cars, and a calculation of the incremental costs and benefits of purchasing a more fuel vehicle. A car owner $i$ who drives $m_i$ miles each year could save a little money on gasoline each year by purchasing a slightly more fuel efficient car, with higher mpg ($\mu$). Annual gas costs are

$$C_i = m_i \left( \frac{1}{\mu_i} \right) p_g . \tag{8}$$

And the savings from buying a more efficient car, given $m_i$, are

$$\frac{\partial C_i}{\partial \mu_i} = -\frac{m_i}{\mu^2} p_g \ . \tag{9}$$

That right hand side of (9) is the same as the right hand side of the first order condition in equation (7). That incremental benefit from fuel economy is easy to calculate for each driver in the data, because we know how much they drive ($m$), what they pay for gas ($p_g$) and their car's mpg ($\mu$).

Figure 9 plots those values of $\partial C_i / \partial \mu_i$ . A rational, informed car purchaser, will purchase fuel economy until the present discounted savings in (9) are equal to the capital cost of purchasing a vehicle with an additional mpg, $p_\mu$. So in equilibrium,

$$p_\mu = \left( \frac{m}{\mu^2} p_g \right) F \tag{10}$$

where $F$ is the multiple that translates annual fuel savings into a present discounted value. Any car owner for whom the right-hand side of equation (10) is larger than the left-hand side will be making a (person, financial, ex post) mistake and should have purchased a more efficient car, with higher mpg ($\mu$). Any owner for whom the price of fuel economy is larger than the marginal savings will be making the opposite mistake and should have purchased a less efficient, less expensive car.

The annual savings—the bracketed term in (10)—is simple to calculate using the NHTS, but the other two terms $p_\mu$ and $F$ are mostly unknown. In a way it doesn't matter. As in our hybrid-to-gas comparison, there is some benchmark value for savings, $mp_g / \mu^2$ . All drivers in Figure 9 with annual savings greater than that benchmark will be more likely to have underinvested in fuel efficiency, and all drivers with savings smaller than the benchmark willl be more likely to have overinvested. We will test the robustness of our findings to the choice of the benchmark savings level, but we are primarily interested in the demographic characteristics of drivers that tend to the be on the right or left side of the benchmark savings, and those turn out not to be sensitive to the choice of benchmark.

What is $p_\mu$? The current US CAFE standards are projected to raise fleetwide fuel economy from 35.5 mpg in model year 2016 to 54.5 in 2025, at an average cost of \$2017 per vehicle.[12] That is \$106 per mpg. The previous round of CAFE standards raised the fleetwide fuel economy from below 30 mpg to 35.5 mpg by 2016, at a projected cost of \$1,140 per vehicle, or \$207 per mpg.[13]

To get a sense for what $p_\mu$ might be in the NHTS data, we regress car prices on car characteristics, using the MSRP from the Wards car price data:

$$MSRP_{tmk} = a + r \times m_{tmk} + \mathbf{bX}_{tmk} + y_{mk} + e_{tmk}. \tag{11}$$

The price of trim *t* of model *m* and make *k* is a function of its fuel economy $\mu_{tmk}$ as well as a range of other vehicle characteristics $\mathbf{X}_{tmk}$. We also include either make or model fixed-effects.

Table 4 presents estimates of (11) for the 14,789 cars in the WardsAuto dataset. Column (1) has means and standard errors. Column (2) just regresses price on fuel economy alone, without other characteristics, demonstrating the omitted variable problem. Cars with an extra mile per gallon sell for \$1,381 less on average, not more. In column (3) all we do is control for other car characteristics. In that specification, each extra mile per gallon is associated with an extra \$197 in upfront vehicle costs. Column (4) adds make fixed effects, and column (5) adds make and model fixed effects.

We start by using two estimates of $p_\mu$, \$115 and \$340 from columns (4) and (5) of Table 4. Those are respectively slightly smaller and larger than the back-of-the-envelope calculations based on NHTSA’s analysis of recent CAFE standard changes. But again, all we really care about is showing the demographic differences between drivers with savings larger and smaller

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[12] Converted from 2010 dollars used in the RIA to 2017 dollars using the Consumer Price Index. See footnote 2.

[13] Converted from 2007 dollars. See footnote 1.

than the benchmark, and as we show below those demographic differences are not sensitive to the choice of $p_\mu$.[14]

The next step is to choose the discount and depreciation rates. We again follow the assumptions used in the EPA and NHTSA regulatory impact assessments, discounting future fuel savings for 14 years at 3 and 7 percent, which is equivalent to multiplying savings by $F$=11.3 and 8.75 in equation (10). We construct two cutoffs, one favorable to fuel economy investments, one less favorable. The first uses the low discount rate (3%) paired with the low price for fuel economy ($115); the second uses the high discount rate (7%) paired with the high price for fuel economy ($340). That leads to two benchmark annual fuel savings level cutoffs, above which it would make sense for drivers to purchase more energy efficiency: $10 and $39 per year.[15] For comparison, the mean annual savings from one extra mpg in Figure 9 is $56, and the median is $42.

We use these benchmark annual savings, $10 and $39, to classify all drivers as either having purchased too little fuel economy—because the marginal discounted lifetime savings from one more unit of mpg outweighs the cost—or too much fuel economy. This classification is shown in Table 5.

When we discount future fuel savings at 3 percent and impose the low fuel economy price of $115 per mpg, the analysis in Table 5 suggests that 168,168 (92%) of the 183,465 drivers in our sample bought too little fuel economy. Their discounted lifetime savings from one more unit of mpg would have outweighed the cost. The other 15,297 drivers (8%) overinvested in fuel savings. More than ten times as many underinvest as overinvest. The fact that most drivers would benefit financially from investing more in fuel efficiency supports the claims in the benefit-cost analyses done for the US fuel economy rules. Those rules purportedly pay for themselves, by requiring manufacturers to sell more cars that cost more but save fuel.

But when we discount future fuel savings by 7 percent and impose the high fuel economy price of $340 per mpg, Table 5 suggests that the two types of mistakes are about equally likely:

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[14] For context, the average annual savings from a 1 mpg increase in fuel economy, in Figure 9, is $55. Discounted at 3% for 14 years, that's $618. At 7% that's $479.

[15] For the first cutoff, $10=$115/11.3. For the second, $39=$340/8.75.

54 percent underinvest and 46 percent overinvest. But again, that will be dependent on our relatively high estimate of $p_\mu$, and we are more interested in the types of people likely to under or overinvest in fuel efficiency.

Figure 10 begins to describe these distinctions, plotting the share deemed to have underinvested in fuel efficiency as a function of household income. It uses the high cost combination: 7% discount rate and \$340 per mpg. Interestingly, this works in the opposite direction as our hybrid-to-gas comparison. Here the probability that a household underinvests in fuel efficiency *increases* with income, whereas the probability that a high-expense driver purchases a gas car *decreases* with income (Figure 6).

In this case, however, we are concerned that most of the distinction in Figure 10 results from the fact that richer households drive more miles. In our hybrid-to-gas comparison, we controlled for driving by examining the share of high-expense drivers who drive the gas or hybrid cars, compared with those shares for low-expense drivers. We cannot do that in this case, because we are classifying all drivers as likely to make one of the two mistakes, depending on whether their annual potential savings from an extra mpg are larger or smaller than our benchmark values.

Instead, we calculate a version of Figure 10 in which we assign to each driver the median fuel economy (mpg) for their survey wave. We then calculate each driver's annual savings—the right-and-side of equation (10)—given that driver's actual miles, actual price of gas, but the imposed median mpg. Finally, we calculate the fraction of each income group that could save money in a more fuel efficient car, and subtract that fraction from the true fraction depicted in Figure 10. Those differences are plotted in Figure 11. Just as in the hybrid-to-gas comparison, this approach should eliminate group differences in mileage and gas price.

Figure 11 shows that the share deemed to have too little fuel economy, given their driving expenses, does not vary with income except for the very richest households. For most households, after we control for their driving and gas expenses, the shares with driving expenses higher than would justify investing in more fuel economy are approximately the same. Recall that the shares are a function of our assumed price of fuel economy ($p_\mu$) and discount and depreciation rates. So we aren't focused on the level of mistakes, per se, only how they change with income. The highest-income households are distinctly more likely to choose cars that could be more cost-effective. Presumably those households focus on other costly car features.

In Figure 12 we do the same exercise for other characteristics of drivers. We calculate the share of households in each demographic group deemed likely to be driving cars with too little fuel efficiency, given their annual expenses and our assumptions about $p_\mu$ and depreciation and discount rates. We then calculate the counterfactual shares for each group if every driver were assigned the median fuel economy. Finally, we subtract the two and report the difference.

Figure 12 shows that men are more likely than women to be driving vehicles where, given their annual mileage and gas prices, they could be saving money in more fuel efficient cars. Again, this is the opposite result from our hybrid-to-gas comparison, which found high-expense men to be more likely to be driving hybrids than high-expense women. Similarly, people younger than 40, with graduate degrees, and living in urban areas are less likely, given their miles and gas prices, to be driving cars with too little fuel efficiency.

The hybrid-to-gas comparison and the regression based analysis of all cars lead to somewhat different results. For education groups and location, we find similar results across the two approaches. Those with less education and those living in rural areas are more likely to be choosing a vehicle with too little fuel economy, after controlling for group-level differences in mileage and gas prices. They are also more likely to choose the gas powered version of a model available as a hybrid when they have high gas expenses.

But the two analyses yield different results with regards to gender and age groups. In the hybrid-to-gas comparison, men are less likely than women to choose a gas powered version when they have high individual fuel savings potential. In the regression-based analysis involving all types of cars, men are now significantly more likely to have underinvested in fuel economy. Similarly, younger households were more likely to own a gas powered version of a model available as hybrid despite driving enough to justify the investment in a hybrid. Considering all vehicle types, we find that drivers under 40 are the least likely to underinvest in fuel economy. Of course, the two analyses are based on very different samples. Owners of vehicles with both hybrid and gas powered versions represent a small subset of all drivers.

### *Regression-based approach to demographic analysis—All Vehicles.*

As with the gas-hybrid comparison, this analysis so far has examined single demographic characteristic one-by-one. To examine how all of these five demographic characteristics together are associated with the fuel economy of the cars people drive, we take a regression approach in Table 6. We again restrict our analysis to the 118,259 drivers in the 2017 wave of the NHTS for which income groups are comparable.

Start by calculating the optimal fuel economy for each driver, given their gas prices and annual miles, as represented in theory by equation (7) or Figure 4. Rewrite equation (10) to include the multiple γ capturing the degree to which consumers value future fuel savings:

$$p_\mu = \gamma\left(\frac{m}{\mu^2}p_g\right)F\ . \tag{12}$$

Equation (10) is just the all-cars version of the gas-hybrid comparison in equation (2). Solve (12) for μ:

$$\mu = \sqrt{\gamma\frac{mp_g}{p_\mu}F}\ . \tag{13}$$

The optimal choice of fuel economy, $\mu^*$, is just the $\mu$ in (13) where $\gamma=1$.

The first column of Table 6 regresses each driver's car's actual fuel economy ($\mu$) on the optimal fuel economy for driver ($\mu^*$), given their miles driven and gas price. It controls for all five demographic characteristics, vehicle characteristics that affect fuel economy, and a full set of make and year-by-type fixed effects.[16] We find a statistically significant by tiny positive association $\mu$ and $\mu^*$. For each additional mpg that drivers should purchase, based on mileage and gas prices, their cars have actual mpg that are only 0.008 higher. We find almost no economically meaningful relationship between drivers' optimal level of fuel economy and the observed fuel economy of their vehicles.

We can again interpret these regressions results as evidence for the significance of future fuel savings relative to the upfront cost of fuel efficiency. The regressions in Table 6 estimate $\mu$ as a function of $\mu^*$, so the coefficient on $\mu^*$ can be interpreted as an estimate of $\sqrt{\gamma}$ from equation (13). Or, $\hat{\gamma} = \hat{\beta}^2$. The $\hat{\beta}$ in column (1) of Table 6 is 0.008. If we square that, it shrinks to irrelevance,

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[16] The optimal fuel economy, $\mu^*$, is just level of μ that solves the equation $p_\mu = F\,mp_g / \mu^2$, where F is the multiplication factor 8.75 corresponding to cumulative savings over 14 years, discounted at 7%.

suggesting that drivers all but ignore fuel savings when choosing the energy efficiency of their vehicles. Or to be more precise, drivers appear to ignore the degree to which their individual cost savings from fuel efficiency may differ from others. Maybe drivers act in a way akin to internalizing the cost savings for the average driver, but certainly not their own. We find close to no sorting into fuel economy levels based on individual miles driven.

Meanwhile, demographic characteristics of drivers are clearly associated with observed fuel economy levels, even after controlling for optimal fuel economy levels and vehicle specifications. Drivers with higher incomes own more fuel efficient cars. This is could be for many reasons. Maybe high-income drivers prefer fuel efficient cars for reasons other than personal financial cost, such as altruistic concern for the environment or signaling environmental credentials to neighbors. Maybe they have less trouble affording or borrowing to buy the more expensive, more fuel efficient vehicles. Or maybe they are more likely to "do the math" and get closer to choosing their optimal level of fuel economy.

Column (2) of Table 6 examines whether high-income households are more responsive to their optimal fuel economy. It includes in the regression an interaction between the optimal level of fuel economy $(\mu_i^*)$ and an indicator for households with annual incomes above \$100,000. The small and insignificant coefficient (0.003) suggests that observed fuel economy choices of high-income drivers are only marginally more responsive to the economically optimal level, if at all. Rich households are not significantly more likely to choose a vehicle's fuel economy based on financial calculations of mileage and gas prices. Higher-income drivers do on average choose higher levels of fuel economy, but evidently not for reasons of economic cost. There is close to no meaningful association between the cost-minimizing level of fuel economy and observed choices for either rich or poor households. As with the gas-hybrid comparison, rich households are not more likely to do the math, and poor households are not more likely to be credit constrained.

In Column (3) of Table 6 we ask a related, but different question: Which households end up with a level of fuel economy that is further away from the level that would be economically optimal given their driving? We replace the dependent variable of our regression with the difference between observed mpg and optimal mpg, $(\mu_i^* - \mu_i)$. The coefficients for income and education flip in sign. We estimate that drivers with higher incomes and more education own vehicles that are on average further below the levels of fuel economy that would be economically optimal. For example, a driver from a household with annual income exceeding $150,000 will on average own a car that is about 1.0 mpg further below what would be economically optimal than a driver in the lowest income group. The same is true for highly educated drivers, drivers below 40 years of age, male drivers, and drivers living in rural areas. Column (4) confirms these findings in an additional specification that controls for model fixed effects as well as for the choice of light trucks and hybrid vehicles. Estimates are very much in line with Column (3).

These results are largely shaped by differences in driving between these groups. High-income drivers, educated drivers, male drivers and rural drivers do on average have higher mileages, and hence higher levels of economically optimal fuel economy. Since economic incentives appear to not influence fuel economy choices for drivers across the board, it is exactly those groups that we find fall further below their optimal levels of fuel economy.

[TO BE CONTINUED]

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## Table 1. Summary Statistics

| | Gas-Hybrid Model Pairs | | |
|---|---|---|---|
| | **Gas engines (1)** | **Hybrids (2)** | **All Cars (3)** |
| Annual miles | 12,350 | 13,251 | 12,403 |
| | (74) | (219) | (27) |
| Combined city highway mpg | 27.72 | 37.67 | 25.25 |
| | (0.023) | (0.15) | (0.014) |
| Household Income (2017 NHTS) | | | |
| Less than $25,000 | 0.0846 | 0.0348 | 0.0910 |
| $25,000 - $50,000 | 0.185 | 0.100 | 0.182 |
| $50,000 - $75,000 | 0.198 | 0.129 | 0.187 |
| $75,000 - $100,000 | 0.165 | 0.169 | 0.160 |
| $100,000 - $150,000 | 0.217 | 0.273 | 0.213 |
| More than $150,000 | 0.149 | 0.294 | 0.167 |
| Age | 52.74 | 54.44 | 53.27 |
| | (0.118) | (0.302) | (0.039) |
| Education: | | | |
| High School | 0.169 | 0.0980 | 0.193 |
| Some College | 0.544 | 0.485 | 0.539 |
| Graduate | 0.242 | 0.380 | 0.221 |
| Rural | 0.213 | 0.199 | 0.256 |
| | | | |
| Length | 186.4 | 186.0 | 188.0 |
| | (0.044) | (0.148) | (0.031) |
| Width | 71.63 | 71.59 | 72.82 |
| | (0.0136) | (0.0408) | (0.0088) |
| Height | 59.80 | 60.55 | 63.12 |
| | (0.0325) | (0.113) | (0.0155) |
| Weight | 3,279 | 3,630 | 3,565 |
| | (4.068) | (11.64) | (1.646) |
| Liters | 2.417 | 2.464 | 2.842 |
| | (0.0036) | (0.0180) | (0.0021) |
| Valves | 3.949 | 3.914 | 3.701 |
| | (0.0021) | (0.0084) | (0.0017) |
| Horsepower | 171.9 | 162.4 | 195.5 |
| | (0.230) | (1.025) | (0.139) |
| RPM | 6,014 | 5,850 | 5,861 |
| | (1.753) | (4.756) | (1.334) |
| | | | |
| Observations | 22,025 | 2,337 | 175,472 |

Standard errors in parentheses. The income variable is for the 2017 NHTS, 18,143 gas-hybrid models in columns (1) and (2), and 126,537 observations for all cars in column (3). The age variable has some missing values; there are 175,535 in column (3).

## Table 2. Two types of mistakes

| | Actual vehicle | Optimal vehicle (discount rate 3%, lifetime 14 years) | | Optimal vehicle (discount rate 7%, lifetime 14 years) | |
|---|---|---|---|---|---|
| | **Total (1)** | **Gasoline (2)** | **Hybrid (3)** | **Gasoline (4)** | **Hybrid (5)** |
| **Total** | **24,592** | **20,379** | **4,213** | **22,099** | **2,493** |
| **Gas-powered** | **22,124** | **18,465** | **3,659** | **19,977** | **2,147** |
| (*% of row*) | | (83%) | (17%) | (90%) | (10%) |
| (*% of column*) | | (91%) | (87%) | (90%) | (86%) |
| **Hybrids** | **2,468** | **1,914** | **554** | **2,122** | **346** |
| (*% of row*) | | (78%) | (22%) | (86%) | (14%) |
| (*% of column*) | | (9%) | (13%) | (10%) | (14%) |

Source: 2009 and 2017 NHTS. All cars in with complete data on prices and incomes, and that come in hybrid and gasoline powered versions. Model years 2005-2017. The shaded boxes represent “mistakes”—drivers who would be better off in the alternative version of the same vehicle. Calculations assume a 14-year lifetime with discount rates of 3 percent and 7 percent respectively.

Note: The 14-year lifetime roughly replicates the CAFE 2017-2025 RIA. EPA and NHTSA use model-year-specific lifetime estimates, but these average 14 years.

## Table 3. Characteristics of drivers with hybrid vehicles

| | | "Low" Cut-Off (discount rate 3%, 50% MSRP) | | | "High" Cut-Off (discount rate 7%, 200% MSRP) | | |
|---|---|---|---|---|---|---|---|
| Dependent variable = 1 if hybrid | | (1) | (2) | (3) | (4) | (5) | (6) |
| Cumulative fuel savings ($1000) | | 0.00428* | 0.00355* | 0.00240* | 0.00552* | 0.00458* | 0.00310* |
| | | (0.000503) | (0.000763) | (0.000481) | (0.000649) | (0.000985) | (0.000621) |
| Fuel savings×(Income>$100,000) | | | 0.00124 | | | 0.00160 | |
| | | | (0.000975) | | | (0.00126) | |
| Upfront investment cost ($1000) | | -0.0215* | -0.0215* | -0.0245* | -0.0215* | -0.0215* | -0.0245* |
| | | (0.00104) | (0.00104) | (0.00127) | (0.00104) | (0.00104) | (0.00127) |
| Income: | $25k – $50k | 0.0126 | 0.0128 | 0.00775 | 0.0126 | 0.0128 | 0.00775 |
| | | (0.00697) | (0.00697) | (0.00663) | (0.00697) | (0.00697) | (0.00663) |
| | $50k – $75k | 0.0162* | 0.0166* | 0.0104 | 0.0162* | 0.0166* | 0.0104 |
| | | (0.00693) | (0.00694) | (0.00659) | (0.00693) | (0.00694) | (0.00659) |
| | $75k – $100k | 0.0425* | 0.0384* | 0.0315* | 0.0425* | 0.0384* | 0.0315* |
| | | (0.00718) | (0.00785) | (0.00683) | (0.00718) | (0.00785) | (0.00683) |
| | $100k – $150k | 0.0490* | 0.0449* | 0.0379* | 0.0490* | 0.0449* | 0.0379* |
| | | (0.00696) | (0.00768) | (0.00663) | (0.00696) | (0.00768) | (0.00663) |
| | over $150k | 0.0867* | 0.0825* | 0.0660* | 0.0867* | 0.0825* | 0.0660* |
| | | (0.00747) | (0.00816) | (0.00712) | (0.00747) | (0.00816) | (0.00712) |
| Education: | Some college | 0.0119* | 0.0120* | 0.0122* | 0.0119* | 0.0120* | 0.0122* |
| | | (0.00476) | (0.00476) | (0.00452) | (0.00476) | (0.00476) | (0.00452) |
| | Graduate | 0.0343* | 0.0344* | 0.0341* | 0.0343* | 0.0344* | 0.0341* |
| | | (0.00544) | (0.00545) | (0.00518) | (0.00544) | (0.00545) | (0.00518) |
| Age: | 40 – 60 years | 0.0174* | 0.0173* | 0.0165* | 0.0174* | 0.0173* | 0.0165* |
| | | (0.00435) | (0.00435) | (0.00413) | (0.00435) | (0.00435) | (0.00413) |
| | over 60 years | 0.0301* | 0.0298* | 0.0223* | 0.0301* | 0.0298* | 0.0223* |
| | | (0.0237) | (0.00426) | (0.00427) | (0.00406) | (0.00426) | (0.00427) |
| Male | | 0.0257 | 0.00179 | 0.00175 | 0.00221 | 0.00179 | 0.00175 |
| | | (0.0190) | (0.00341) | (0.00341) | (0.00324) | (0.00341) | (0.00341) |
| Rural | | 0.00242 | -0.000500 | -0.000518 | -0.00198 | -0.000500 | -0.000518 |
| | | (0.0216) | (0.00423) | (0.00423) | (0.00402) | (0.00423) | (0.00423) |
| Implied $\hat{\gamma}$ | | 0.20 | | 0.10 | 0.26 | | 0.13 |
| ($\hat{\gamma}$ for income < $100,000) | | | 0.16 | | | 0.22 | |
| ($\hat{\gamma}$ for income > $100,000) | | | 0.22 | | | 0.27 | |
| Observations | | 17,586 | 17,586 | 17,586 | 17,586 | 17,586 | 17,586 |
| R-squared | | 0.365 | 0.365 | 0.427 | 0.365 | 0.365 | 0.427 |
| Year-by-Type FE | | yes | yes | yes | yes | yes | yes |
| Make FE | | yes | yes | no | yes | yes | no |
| Model FE | | no | no | yes | no | no | yes |
| Engineering Specs | | yes | yes | yes | yes | yes | yes |

Source: 2017 NHTS. All cars in with complete data on prices and incomes, and that come in hybrid and gasoline powered versions. Model years 2005-2017. Calculations for cumulative (and discounted) fuel savings assume a 14-year lifetime with discount rates of 3 percent (Columns 1-3) and 7 percent (Columns 4-7). Dependent variable is a binary indicator for hybrid vehicle choice. * p<0.05

## Table 4. Fuel economy and vehicle prices

| | Means | Regressions | | | |
|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) |
| MPG $\mu$ | 22.3 | -1,381* | 197.0* | 339.7* | 115.5* |
| | (5.5) | (31) | (37.3) | (33.1) | (37.6) |
| Length (ins.) | 200.7 | | -214.0* | -99.3* | 17.7 |
| | (27.3) | | (9.0) | (8.6) | (11.3) |
| Width (ins.) | 75.3 | | -231.6* | -214.1* | 227.0* |
| | (5.6) | | (58.4) | (52.7) | (70.0) |
| Height (ins.) | 67.0 | | -794.6* | -235.5* | -270.4* |
| | (9.5) | | (31.0) | (30.2) | (64.7) |
| Weight (lbs.) | 4,393 | | 9.50* | 6.02* | 5.06* |
| | (1,271) | | (0.42) | (0.39) | (0.43) |
| Liters | 3.98 | | -3,767* | -1,752* | -2,390* |
| | (1.60) | | (258) | (241) | (245) |
| Valves | 3.41 | | 271 | -1,295* | -1,889* |
| | (0.88) | | (221) | (224) | (262) |
| Horsepower | 272.4 | | 226.5* | 170.2* | 158.3* |
| | (88.1) | | (3.1) | (2.9) | (2.7) |
| Rpm | 5,539.9 | | -4.12* | -2.67* | -2.84* |
| | (884.8) | | (0.24) | (0.23) | (0.23) |
| | | | | | |
| Observations | | 16,982 | 14,789 | 14,789 | 14,789 |
| R-squared | | 0.106 | 0.587 | 0.712 | 0.811 |
| Make FE | | No | No | Yes | Yes |
| Model FE | | No | No | No | Yes |

Source. Authors' calculations from Wardsauto.com data. Prices are manufacture suggested retail (MSRP). MPG is the EPA's combined for city and highway driving. Each observation is a single make, model, year combination.

## Table 5. The influence of fuel economy on vehicle price (Wards)

| | | **Fuel Economy Level (discount rate 3%, lifetime 14 years, $115 per mpg)** | | **Fuel Economy Level (discount rate 7%, lifetime 14 years, $340 per mpg)** | |
|---|---|---|---|---|---|
| | **Total (1)** | **Too much (2)** | **Too little (3)** | **Too much (4)** | **Too little (5)** |
| NHTS 2009 | 56,928 | 3,423 | 53,505 | 20,463 | 36,465 |
| | | (6%) | (94%) | (36%) | (64%) |
| NHTS 2017 | 126,537 | 11,874 | 114,663 | 63,324 | 63,213 |
| | | (9%) | (92%) | (50%) | (50%) |
| **Total** | **183,465** | **15,297** | **168,168** | **83,787** | **99,678** |
| | | (8%) | (92%) | (46%) | (54%) |

Source: 2009 and 2017 NHTS. Model years 2005-2017. Calculations assume a 14-year lifetime with discount rates of 3 percent and 7 percent respectively. The cumulative (and discounted) monetary value of one more unit of MPG (according to equation 12) is compared to the marginal cost of mpg estimated in Table 2, Columns 4 and 5 ($115 and $340).

Note: The 14-year lifetime roughly replicates the CAFE 2017-2025 RIA. EPA and NHTSA use model-year-specific lifetime estimates, but these average 14 years.

## Table 6. Determinants of individual fuel economy choice

| | | Actual mpg: $\mu$ | | Actual – optimal mpg: $\mu - \mu^*$ | |
|---|---|---|---|---|---|
| | | (1) | (2) | (3) | (4) |
| Optimal mpg $\mu_i$* | | 0.00799* | 0.00641* | | |
| | | (0.000924) | (0.00132) | | |
| ($\mu_i$*) x (Income > $100k) | | | 0.00303 | | |
| | | | (0.00180) | | |
| Income: | $25k – $50k | 0.106* | 0.106* | -0.554* | -0.651* |
| | | (0.0362) | (0.0362) | (0.119) | (0.115) |
| | $50k – $75k | 0.190* | 0.190* | -0.798* | -0.989* |
| | | (0.0365) | (0.0365) | (0.120) | (0.116) |
| | $75k – $100k | 0.254* | 0.254* | -1.121* | -1.434* |
| | | (0.0584) | (0.0584) | (0.124) | (0.121) |
| | $100k – $150k | 0.341* | 0.341* | -1.274* | -1.671* |
| | | (0.0582) | (0.0582) | (0.121) | (0.118) |
| | over $150k | 0.492* | 0.492* | -1.060* | -1.584* |
| | | (0.0602) | (0.0602) | (0.131) | (0.127) |
| Education: | Some college | 0.116* | 0.116* | -0.901* | -1.007* |
| | | (0.0247) | (0.0247) | (0.0808) | (0.0782) |
| | Graduate | 0.404* | 0.404* | -1.049* | -1.431* |
| | | (0.0295) | (0.0295) | (0.0967) | (0.0937) |
| Age: | 40 – 60 years | 0.0248 | 0.0248 | 0.687* | 0.643* |
| | | (0.0237) | (0.0237) | (0.0778) | (0.0756) |
| | over 60 years | 0.0925* | 0.0925* | 4.271* | 4.193* |
| | | (0.0237) | (0.0237) | (0.0766) | (0.0752) |
| Male | | 0.0257 | 0.0257 | -0.660* | -0.707* |
| | | (0.0190) | (0.0190) | (0.0624) | (0.0607) |
| Rural | | 0.00242 | 0.00243 | -1.432* | -1.432* |
| | | (0.0216) | (0.0216) | (0.0706) | (0.0683) |
| Length (ins.) | | -0.0234* | -0.0234* | -0.0766* | -0.0251 |
| | | (0.00155) | (0.00155) | (0.00507) | (0.0143) |
| Width (ins.) | | -0.231* | -0.231* | -0.209* | -0.0138 |
| | | (0.00645) | (0.00645) | (0.0212) | (0.0343) |
| Height (ins.) | | -0.204* | -0.204* | -0.323* | -0.0410 |
| | | (0.00395) | (0.00395) | (0.0129) | (0.0440) |
| Weight (lbs.) | | 0.00110* | 0.00110* | 0.000963* | -0.000333* |
| | | (4.13e-05) | (4.13e-05) | (0.000135) | (0.000161) |
| Liters | | -2.098* | -2.097* | -1.630* | -2.342* |
| | | (0.0406) | (0.0406) | (0.133) | (0.190) |
| Valves | | 0.123* | 0.123* | -0.112 | -0.162 |
| | | (0.0246) | (0.0246) | (0.0807) | (0.130) |
| Horsepower | | -0.0225* | -0.0225* | -0.0169* | 0.00636* |
| | | (0.000527) | (0.000527) | (0.00173) | (0.00251) |
| Rpm | | -0.00174* | -0.00174* | -0.00178* | -0.000423* |
| | | (2.76e-05) | (2.76e-05) | (9.05e-05) | (0.000130) |
| Light Truck | | | | | 0.455 |
| | | | | | (0.489) |
| Hybrid | | | | | 9.621* |
| | | | | | (0.264) |

|  |  |  |  |
|---|---|---|---|
| Observations | 118,259 | 118,259 | 118,256 |
| R-squared | 0.733 | 0.240 | 0.292 |
| Year-by-Type FE | yes | yes | yes |
| Make FE | yes | yes | no |
| Model FE | no | no | yes |

Source: 2017 NHTS. Model years 2005-2017. Calculations for optimal MPG assume a 14-year lifetime with discount rates of 7 percent. The cumulative (and discounted) monetary value of one more unit of MPG (according to equation 12) is compared to the marginal cost of mpg estimated in Table 2, Columns 5 ($340). Dependent variable is observed MPG in Column (1) and difference between observed MPG and optimal MPG in Columns (2) and (3). * $p<0.05$

**Figure 1. Hybrid and Gas Powered Cars, All Models (NHTS 2009 & 2017)**

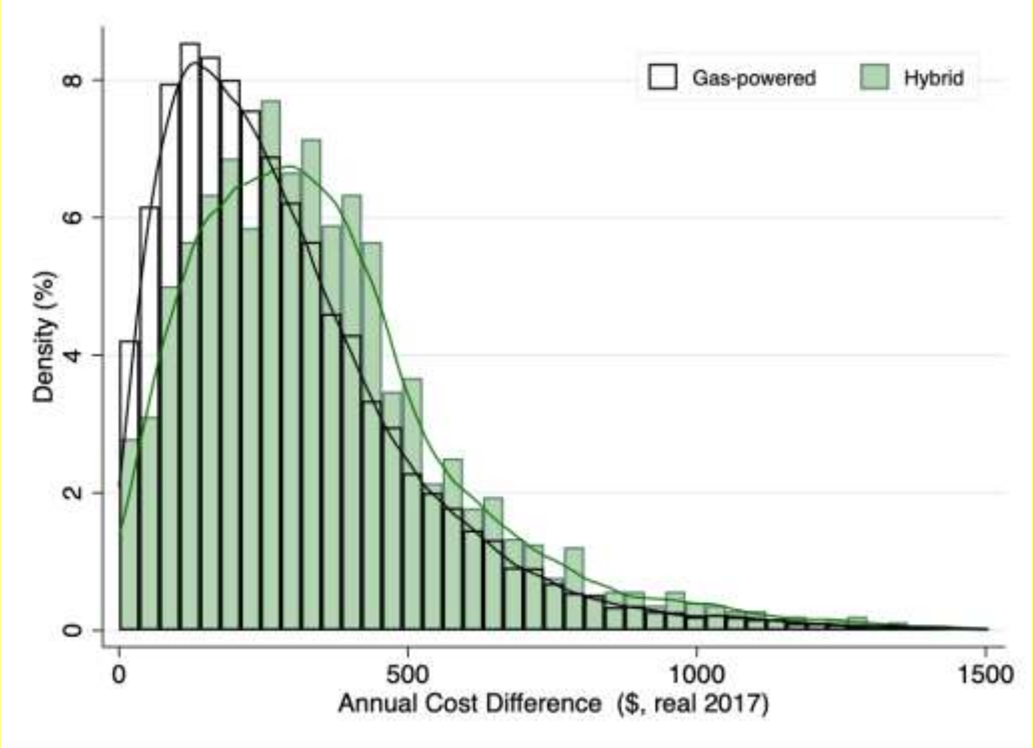

**Figure 2. A budget constraint**

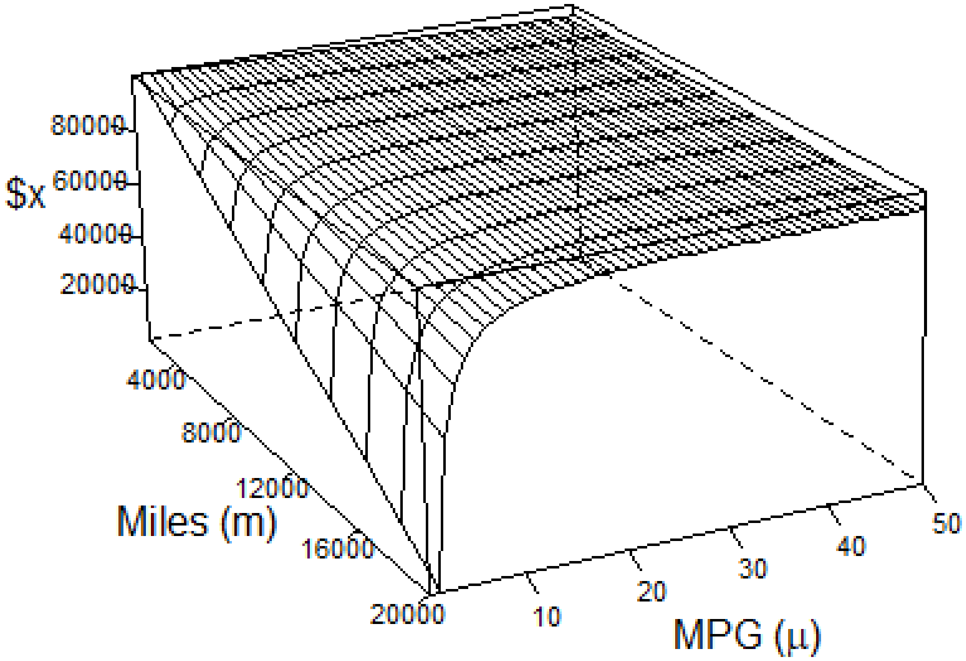

**Figure 3. A two-dimensional view of the same budget constraint**

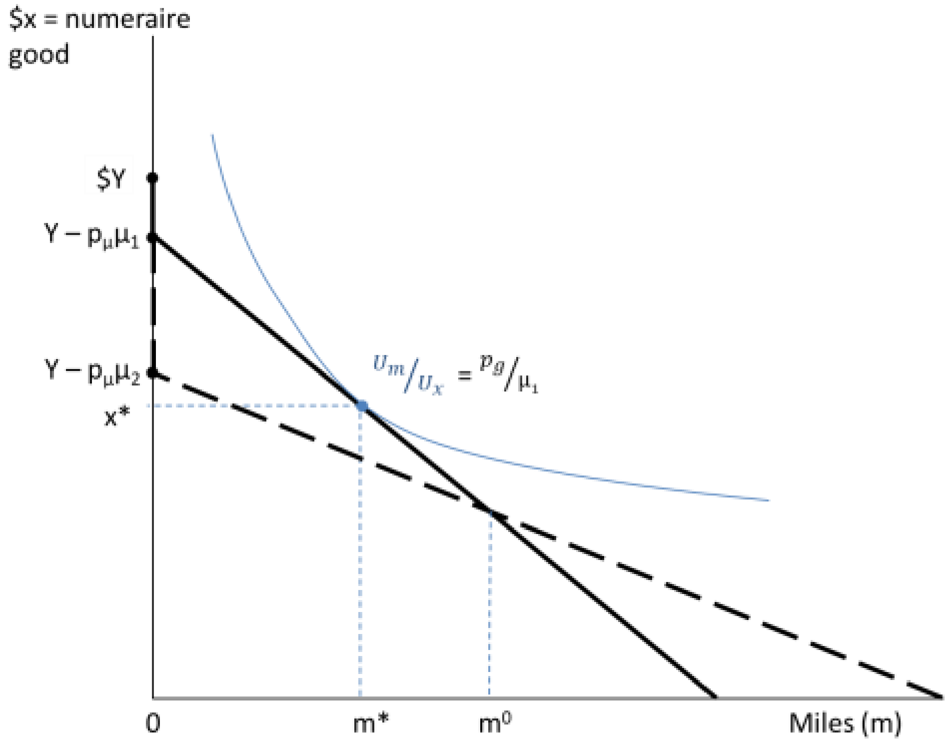

**Figure 4. A different view of the same budget constraint**

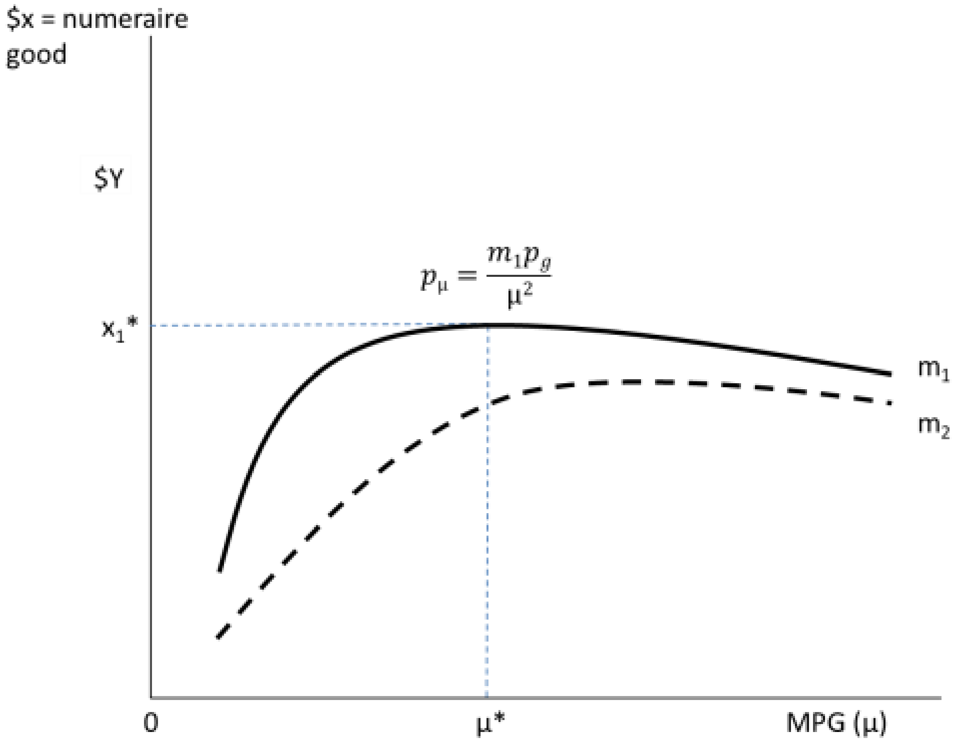

**Figure 5. Mistake equalizing cost differences**

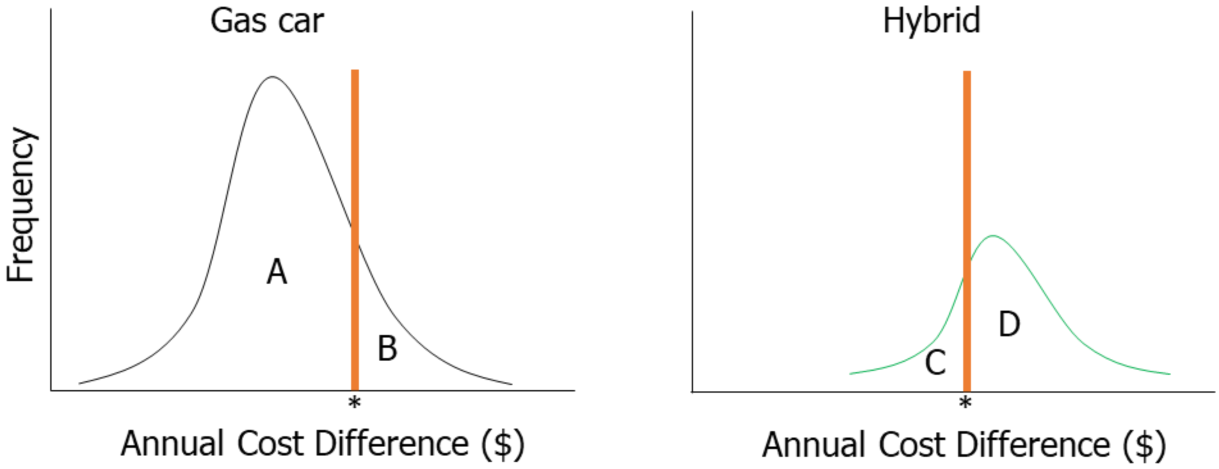

**Figure 6 Car buying mistakes by income – Actual vehicle (NHTS 2017)**

**Figure 7. Car buying mistakes by income – Difference (NHTS 2017)**

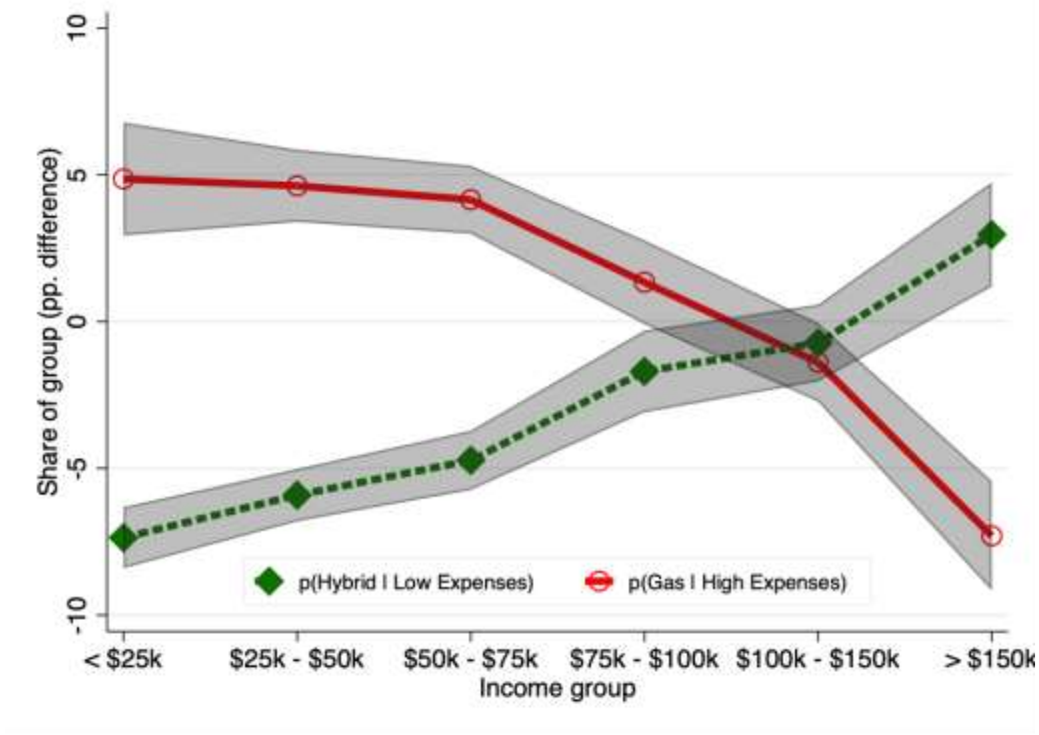

**Figure 8. Car buying mistakes by other demographics – Difference (NHTS 2009 & 2017)**

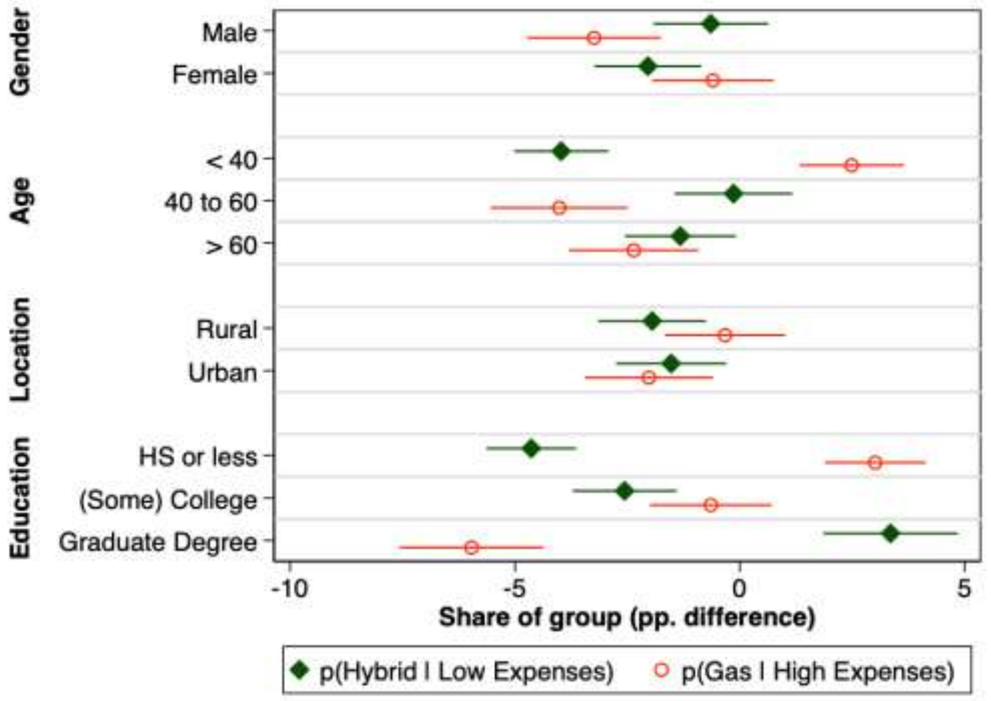

**Figure 9. Savings from one additional mpg**

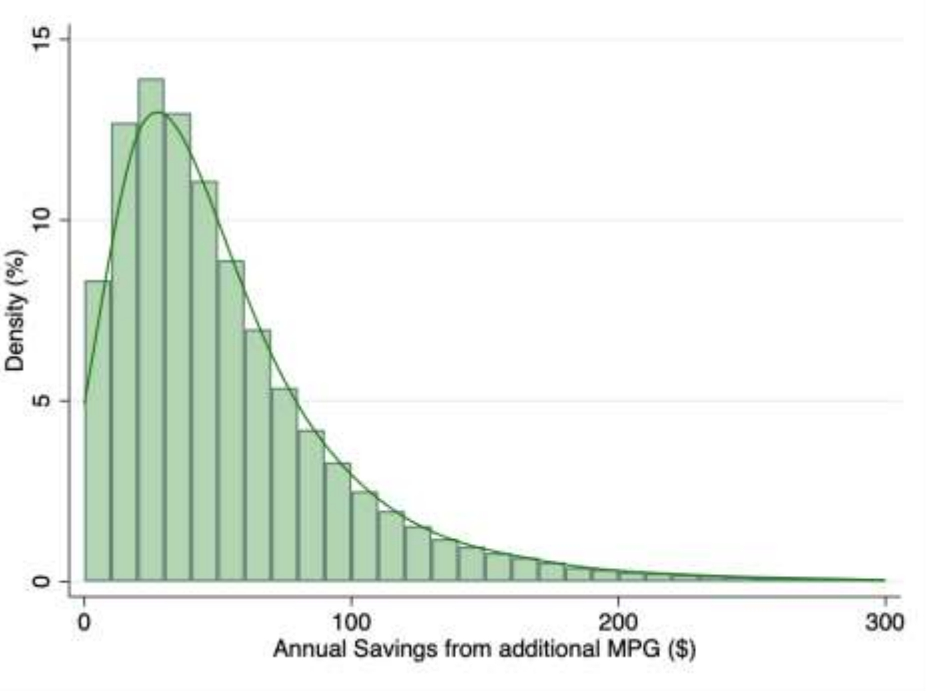

**Figure 10. Probability of having too little fuel economy, by income**

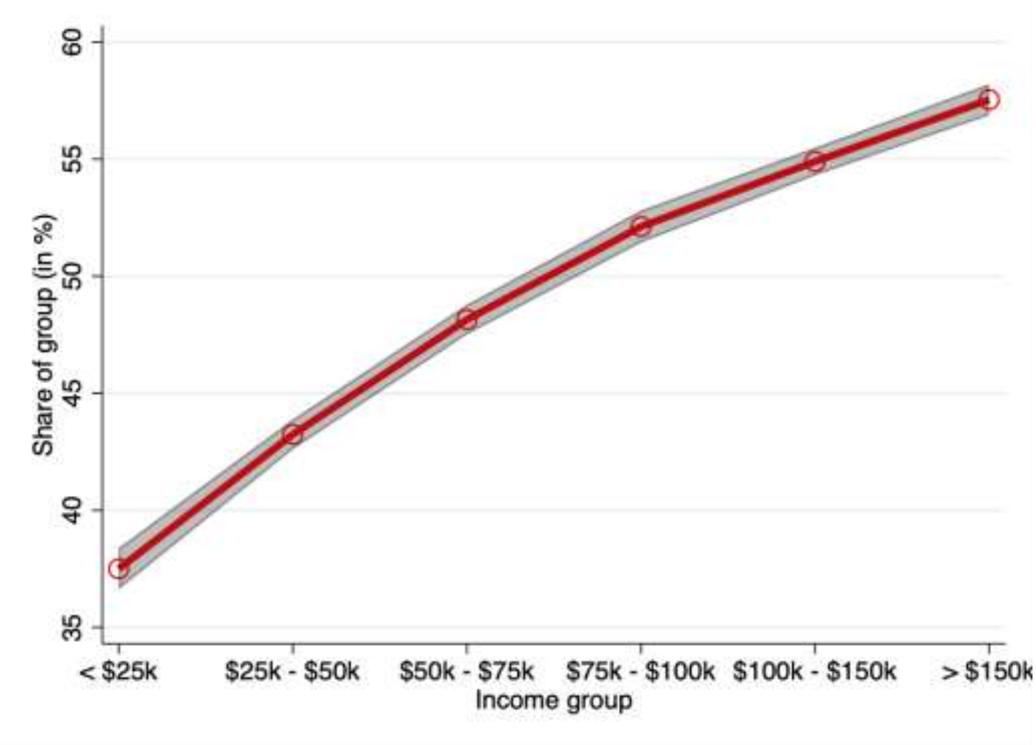

**Figure 11. Probability of having too little fuel economy, by income, difference from mean**

**Figure 12. Probability of having too little fuel economy, by income, difference from mean**