Who Values Future Energy Savings? Evidence from American Drivers

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Abstract: Regulators attest that energy efficiency standards save consumers money. More efficient light bulbs, appliances, and vehicles would cost more up front but reduce energy expenses by enough to compensate. Using data on American drivers and cars, we show this to be true, but only on average. Many drivers could save money in less fuel-efficient cars. In fact, we find little correlation between mileage and fuel economy. A driver's income, sex, age, and education are far more closely associated with their vehicle's fuel economy. Rich drivers are not more sensitive to fuel costs, undermining claims that borrowing constraints explain the mismatch.

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US REGULATORS ATTEST that energy efficiency standards—for light bulbs, appliances, buildings, and vehicles—save consumers money. The products cost more but pay for themselves in energy savings. The Corporate Average Fuel Economy (CAFE) standards for cars sold in 2017 through 2025 were expected to add $1,800 to the cost of a car but save more than $5,000 in gasoline costs over its useful life (in 2007 dollars;

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US EPA 2012). The 2020 rollback of the same standards was projected to reduce vehicle costs by $800 but add $900 to $1,200 in discounted lifetime gas costs.[1] And the 2022 reversal of that rollback is now projected to increase up-front costs by $1,087 but save $1,377 in gas costs (in 2018 dollars; US EPA 2022). Across administrations, regulators have projected that even ignoring external costs from pollution, congestion, and accidents, fuel economy standards pay for themselves.

If efficient appliances or cars would save their owners money, buyers should be willing to pay for them and manufacturers to produce and sell them. The fact that regulations are needed suggests that these markets do not work efficiently. Proffered explanations for that market failure include consumers' borrowing constraints, information asymmetries, and behavioral factors such as inattention, present bias, and mistaken estimation of future energy expenditures.[2] All of these share a common empirical implication. Consumers would be better off paying higher up-front prices in exchange for lower annual energy expenses.

That is the explicit claim in the regulatory analyses. Requiring carmakers to manufacture cars that are more costly but more efficient will save drivers money. But the claim also implies that, given the range of available vehicles, car buyers could have saved money by purchasing higher-priced more efficient cars. We look for evidence for those lost opportunities in the US National Household Travel Survey (NHTS), asking whether individual drivers' car choices represent forgone savings, given how much they drive. We also examine used-car prices, asking whether drivers would be better off exchanging their current cars for ones that are more or less efficient. And we examine time-of-purchase data to ask whether car buyers' decisions originally made sense, given the prices they paid and the distances they expected to drive.

Because car buyers cannot purchase efficiency separately from other car attributes, we take two approaches to separating the price of fuel efficiency from other vehicle characteristics. The first approach compares car models sold in hybrid and gas-powered versions that are otherwise similar, so the price differences represent the cost of purchasing the hybrids' fuel savings. The second approach uses all cars and relies on regulatory estimates of how much it costs to increase fuel efficiency. Those regulatory estimates are somewhat lower than those in published economics papers and tilt the analysis toward finding personal savings from fuel economy.

It does not matter whether we compare hybrids and their gas-powered equivalents or rely on regulatory cost estimates, whether we value cars using manufacturer's suggested retail prices (MSRPs), transaction prices, or used car prices, whether we estimate annual mileage using self-reported expected future mileage, last year's mileage, or odometer readings, whether we use self-reported or official regional gas prices, or

1. In 2018 dollars; US EPA (2020). Bento et al. (2019) discuss these analyses.

2. See, e.g., Allcott (2011), Busse et al. (2013), Allcott and Wozny (2014), Sallee (2014), Sallee et al. (2016), Allcott and Knittel (2018), Gillingham et al. (2019), and Leard et al. (2023).

whether we discount future savings at high or low rates. In each case, we do find a majority of drivers who could have saved money in higher-priced, more fuel-efficient vehicles. But we also find many drivers who could have saved money in less expensive, less efficient cars. Observed car choices seem only weakly related to fuel expenditures. Drivers' characteristics such as income, sex, age, and education are far more closely associated with their vehicles' fuel economy than their mileage.

Consider one respondent to the 2017 NHTS. Albert (our pseudonym) was in his 40s, lived in the Southeast, and had annual household income between $35,000 and $50,000. He drove a new(ish) gasoline-powered Toyota Camry nearly 30,000 miles a year. If Albert drove a hybrid gas-electric version of the same Camry, he would have saved $650 per year on gas. The hybrid cost about $3,800 more than the gas-powered Camry, a cost he could have recouped in a bit less than six years, ignoring discounting and fuel price changes. Albert's failure to buy the hybrid might be just the type of forgone future savings used to justify the CAFE regulations.

Others made the opposite decision. Betty (another pseudonym) drove the hybrid version of the Toyota Camry. She was in her 70s, lived in the West, and had household income between $25,000 and $35,000. She drove 4,500 miles a year. In the standard Camry, that would have cost her $120 more per year, so it will take her 30 years to recover the extra cost of the hybrid. Buying the hybrid meant forgoing savings in a different way, because her up-front costs likely exceeded her reduction in future fuel expenses.

Of course, car owners might have reasons unrelated to fuel expenditures for preferring the gas or hybrid versions of their cars. Some might be concerned about local pollution or climate change, or want to display that concern to neighbors. Others might like the quiet hybrid engines or worry that they pose a danger to pedestrians. Some might be averse to the risk of new technologies or of being stuck with fuel-efficient cars if gas prices fall (Hassett and Metcalf 1993). They may have expected different fuel prices. Or their commutes or gas prices might have changed, so that their vehicles made financial sense at the time of purchase but not with hindsight. The US regulators' claims set all of those reasons aside and merely state that drivers could save money in more fuel-efficient cars.

If the claims are true, in the data we should see more drivers like Albert, who could benefit from more fuel efficiency, than like Betty, who could benefit from less.[3] In the 2009 and 2017 rounds of the NHTS, we identify 24,362 drivers of vehicles available in either a gas or hybrid version.[4] For each, we calculate the annual fuel cost difference between the two alternative versions of the car:

3. Duncan et al. (2019) show that buying a hybrid would be financially costly for the average car buyer. Here we examine the decision for particular car buyers, given individual annual gas costs.

4. This total is limited to those NHTS observations with complete data on household demographics.

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

where μ_n is the fuel economy in miles per gallon (mpg) of the less efficient gas car, and μ_e is the mpg for the more efficient hybrid car. Equation (1) differs for every driver depending on miles (m_i), gas prices (p_g), and the difference between the gas and hybrid fuel economies (μ). For drivers of hybrids, (1) represents their annual savings, relative to driving the same miles in the gas version. For drivers of gas cars, (1) represents unrealized annual savings from not driving a hybrid.

Figure 1 plots two distributions of the annual fuel cost differences in (1). The horizontal axis measures the annual fuel savings from choosing the hybrid over its gas equivalent. For the 22,025 owners of gas cars, shown by the unshaded bars, cases farther to the right forgo larger savings by not driving hybrid cars. For the 2,337 owners of hybrids, shown by the shaded bars, cases farther to the left are those whose choice of a hybrid results in small annual fuel savings, because they do not drive much or their gas

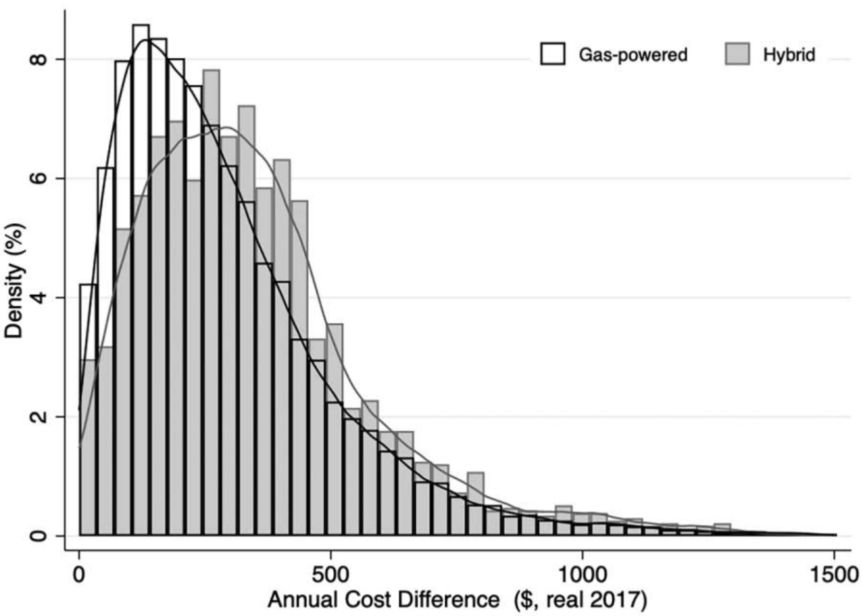

Figure 1. Annual fuel cost differences, gas versus hybrid. For each vehicle in the 2009 and 2017 National Household Travel Survey that comes in both gas and hybrid versions, we calculate the annual fuel cost difference between the two versions, given mileage and gas prices. The shaded bars represent the cost savings for hybrid drivers relative to driving a gas version of the same car; the outlined bars represent the extra annual costs borne by gas drivers. Color version available as an online enhancement.

prices are low. As we should expect to see, the shaded histogram (hybrids) lies to the right of the unshaded histogram (gas powered).

Two points need to be made. First, the hybrid distribution could be shifted right because people expecting to drive more miles purchase hybrids. Alternatively, the shift could be hybrid drivers' reactions to lower driving costs, called the "rebound" effect (Gillingham et al. 2016). Postpurchase behavior will rationalize vehicle purchases. Comparing drivers' actual costs with costs that would be incurred driving the same distance in an alternative car, as we do, will produce an underestimate of both types of forgone savings.

The second point involves the assumptions necessary to estimate which drivers could be saving money in different vehicles. We need to compare the annual fuel savings in equation (1) with the annualized difference in the fixed costs of the two cars. That, in turn, depends on (i) the difference in sales prices, net of any rebates or subsidies for buying an efficient car, (ii) the discount rate used to annualize that difference, and (iii) the depreciation rate.

We take a simple and intuitive approach. Whatever the values of those three variables, for each pair of car models there is some annual cost difference that would justify the investment in fuel economy. Think of it as a vertical line in figure 1. Any driver to the right of that line in a gas car has underinvested in fuel efficiency. Any driver to the left in a hybrid car has overinvested. We pick a value for that line for each car model-year, test the sensitivity of our findings to that value, and examine the demographics of drivers on either side.

To frame that empirical approach, we describe the intuition in a simple theoretical model, focusing on the trade-off between up-front efficiency costs and future gas savings. The model helps us to develop two empirical tests of forgone savings, designed to overcome the chief obstacle to evaluating car choices: cars differ in many ways that are correlated with price and fuel efficiency.

The first test controls for car characteristics by examining only those models, depicted in figure 1, available in both gas and hybrid versions. We assume that those pairs differ only in their fuel economy, and we compare the fraction of drivers in gas cars who would have been better off financially in the hybrids with the fraction owning hybrids who could have saved money in gas cars.

That gas-hybrid comparison depends on the assumption that the two versions do not differ in other respects, such as trunk space, acceleration, or maintenance costs (Lloro and Brownstone 2018). Because we know that assumption to be false in some cases, our second approach uses all cars, not just the ones in gas and hybrid pairs, and calculates what each driver would save annually in a car with one extra mile per gallon. We compare those annual potential savings to the estimated price increment for a car with one extra mile per gallon. If the potential savings exceed the price increment (annuitized appropriately), the driver would have been better off buying a more efficient car. If those savings are less than the increment, the driver could have saved money by purchasing a less efficient one. As before, we examine the proportions and demographics of drivers in each category.

Both approaches rely on assumptions. In each, we assume that we have isolated the fuel economy trade-off by holding other car characteristics constant, and we assume that we have correctly identified the financial trade-off between up-front cost and future savings. We follow the EPA and National Highway Traffic Safety Administration (NHTSA) regulatory analyses, which assume that cars last 14 years and discount future fuel savings at 3% and 7%.[5] And we assume that drivers paid the MSRP for their cars, adjusted for inflation. We demonstrate the stability of the results with used-car prices and prices paid at the time of purchase.

Until now, with few exceptions, analyses of fuel economy choices have studied expected savings for typical drivers. But as Bento et al. (2012) note, some drivers use their cars more than others, and that heterogeneity will bias the results toward suggesting that consumers undervalue future savings.

We take an entirely different approach, explicitly modeling the trade-off between up-front costs and future savings, based on individual drivers' miles and gas prices.[6] We find that lots of drivers could have saved money by purchasing more fuel-efficient cars, as suggested by US regulators and by some of the previous work using average mileage. But many other drivers could have saved money by purchasing less efficient cars, spending less to buy the cars but more each year to drive them. Even if the right share of drivers owns fuel-efficient cars, the wrong types of drivers own them.

In general, drivers' demographic characteristics play a much larger role in predicting vehicle choices than fuel costs. Women and younger drivers are less likely to underinvest in fuel economy in general, but men and older drivers are more likely to overinvest in hybrid cars relative to equivalent gas vehicles. Other groups that are less likely to underinvest are drivers living in urban areas and drivers with graduate degrees. After controlling for those demographic differences, individual drivers' cost-saving potential has little influence on fuel-economy choices. Before describing those analyses in detail, we recount the evidence on these issues so far and then sketch a theory that frames our thinking.

1. EVIDENCE TO DATE ON ENERGY EFFICIENCY CHOICES AND SAVINGS

Our study is not the first—by a large margin—to model the trade-off between up-front costs and future energy savings or to measure consumers' willingness to pay for those

5. For comparison, the real, inflation-adjusted, dealer-provided new-car loans studied by Busse et al. (2013) range from –0.9% to 9.0%.

6. We use annual average retail prices for regular gasoline in seven Petroleum Administration for Defense Districts (PADDs) (1A, 1B, 1C, 2, 3, 4, 5) provided by the Energy Information Administration. In the ex post analysis of purchase decisions, each vehicle is assigned the gas price in the year of vehicle production.

savings. Much of that research studies cars, in part because good data on usage—miles driven—are available and in part because vehicles have been a focus of regulatory attention.[7] Allcott and Greenstone (2012) synthesize that research. In their model, relabeled here for consistency with our terminology, consumers choose among durable goods with different energy efficiency levels, labeled μ. Think of cars with two different mpg ratings, efficient μ_e and inefficient μ_n, where $\mu_e > \mu_n$. Efficient cars cost more to purchase, all else equal. Holding other vehicle attributes constant, a driver will be better off in the efficient car if that incremental cost is less than the discounted energy savings:

$$p_\mu < \gamma p_g m\left(\frac{1}{\mu_n} - \frac{1}{\mu_e}\right)F\,. \tag{2}$$

In equation (2), p_μ is the price difference between the efficient and inefficient cars, m is consumption of the energy service (miles), p_g is the price of energy (gas), and future savings are collapsed into present values by factor F. The parameter γ describes the weight consumers assign to discounted future energy costs. If $\gamma < 1$, some behavioral anomaly or market failure prevents drivers from purchasing cars that would save them money.

Estimating γ requires comparing cars that differ only in price and fuel efficiency, raising concern about omitted correlated car characteristics. Six recent studies have taken creative steps to address the problem.[8] Allcott and Wozny (2014) use monthly data on new vehicle registrations. They test whether fuel-efficient cars command higher prices when gas prices rise, using fixed effects to account for unobserved model characteristics. They estimate moderate undervaluation of future fuel savings ($\hat{\gamma} = 0.76$).

Sallee et al. (2016) note that used cars with more expected remaining useful years have a higher payoff to efficiency. When gas prices increase, the auction prices of fuel-efficient used cars increase, more so for cars with lower odometer readings. They estimate that prices move approximately one for one with discounted future fuel savings ($\hat{\gamma} \approx 1$). Grigolon et al. (2018) compare different variants of the same model, as in our gas-hybrid example. They exploit changes in market shares of new registrations of these variants, finding that consumers only moderately undervalue discounted fuel savings ($\hat{\gamma} = 0.91$).

Busse et al. (2013) estimate the discount rate that would justify the price premium consumers pay for efficient cars and find that it approximately matches market rates for car loans, suggesting that consumers fully value future savings. Gillingham et al. (2019) exploit the fact that in 2012 Hyundai and Kia corrected the reported fuel economy for 13 car models. Those cars' fuel economies had previously been exaggerated. They find

7. Houde and Myers (2019) study refrigerator purchases. In that setting, usage does not vary meaningfully, so annual energy costs depend on local electricity prices. The authors find one result similar to ours: a "large share of consumers that overvalue energy costs."

8. Helfland and Wolverton (2011) and Allcott and Greenstone (2012) review earlier papers.

little decline in willingness to pay for the cars, suggesting a value of $\hat{\gamma}$ in the range of 0.16–0.39. Leard et al. (2023) use transaction-level data and focus on variation in fuel economy induced by technology adoption, again finding substantial undervaluation ($\hat{\gamma} = 0.54$).

All of those papers calculate future savings based on the miles driven by the average driver. But as Bento et al. (2012) remind us, that will result in underestimates of the value of fuel economy ($\hat{\gamma}$). Grigolon et al. (2018) estimate the size of this bias by simulating the distribution of actual mileages, but their analysis remains at the level of car models, not individual consumers.

Our approach differs from prior work in that we examine the individual, realized, postpurchase mileage for each driver. We do not ask whether the price premium for a hybrid Toyota Camry is justified given the average mileage or even the average for Camry drivers. We examine the actual miles driven and gas prices paid for each driver. In the context of equation (2), our study focuses on variation in individual mileage (m_i), whereas much of the existing work focuses on variation in cost across products for the average driver ($\bar{m}$). This builds on results in Banzhaf and Kasim (2019), who find imperfect matching between drivers' mileage and the efficiency of their vehicles, and Davis (2019), who finds that electric vehicles are typically driven fewer miles than gas cars.[9] We go further by explicitly weighing individual fuel savings against the cost of more fuel-efficient cars. We ask whether each driver would have been better off paying more for a more efficient car or paying less for a less efficient car. This allows us to characterize which drivers over- or underinvest in fuel economy, by income, education, and other demographics. To help frame the empirical analysis, we start with a simple model, following Levinson (2019).

2. A THEORETICAL SKETCH

Consider a representative driver with utility over two goods: miles driven, m, and a numeraire, x. Miles driven is the product of gasoline, g, and the car's energy efficiency, μ, expressed as miles per gallon, or mpg. Utility is then

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

Driving requires two expenditures: gasoline g at price p_g and a car at price P_v. Assume the car price is annuitized, or that the car is leased and P_v is the annual rental cost. Cars with higher μ cost more. Call that premium p_μ as in equation (2). Here p_μ is the cost of one extra mile per gallon. The price of a car is $P_v + p_\mu \mu$, the base price plus an increment for fuel economy. A car owner's budget constraint is thus

9. A different source of heterogeneity comes from differences in longevity between car models. Jacobsen et al. (2020) find that this is only weakly correlated with fuel economy ratings. We hold vehicle lifetimes constant and focus on driver-specific heterogeneity in mileage instead.

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

But miles are in the utility function, not gasoline, so for a more familiar and graphable view of the trade-offs, replace g with m/μ in (4):

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

Maximizing utility in (3) with respect to the budget constraint (5), paired with a typical convexity assumption, results in two first-order conditions:

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

The first condition in (6) indicates that the marginal rate of substitution between miles and the numeraire should equal the cost of going one more mile by purchasing more gasoline. The second condition in (6) indicates that it should also equal the cost of going one more mile by purchasing a more efficient car.

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 μ. For any μ, there is a linear trade-off between miles (m) and the numeraire (x). Figure 2*A* plots that trade-off for two cars: a solid budget line for an inefficient car with mpg μ_1 and a dashed one for an efficient car with mpg μ_2. The first condition in (6) is represented in figure 2*A* by a tangency between an indifference curve (with slope U_m/U_x) and a budget line (with slope p_g/μ_1).

The second way that drivers can travel an extra mile is by purchasing a car with better fuel economy at price p_μ for a fixed amount of gasoline g. That represents a lowering of the vertical intercept in figure 2*A*, as from μ_1 to μ_2. Figure 2*B* sketches the trade-off between fuel economy and the numeraire, 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 μ until the cost of an extra unit of fuel economy p_μ equals the savings from that extra efficiency.

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

That is just another way of writing the combined first-order conditions in (6), replacing gallons g with m/μ. The optimum is depicted in figure 2*B* as μ^* for a car owner driving m_1 miles per year. A car owner driving m_2 miles will have different trade-offs, represented by the dashed line with lower possible expenditures on the numeraire x and higher optimal fuel economy.

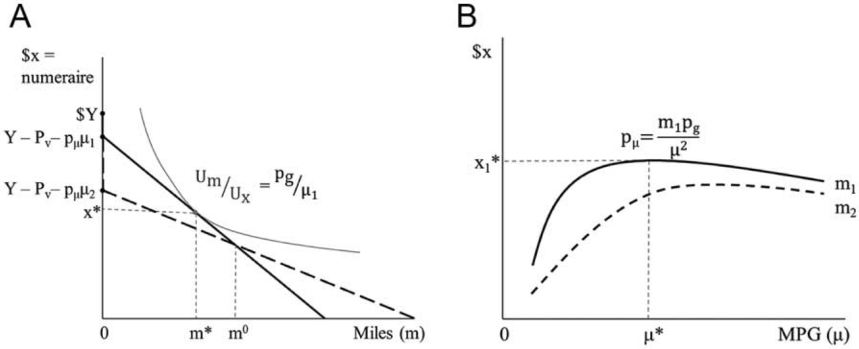

Figure 2. Two views of the budget constraint. Panel A (holding efficiency constant) illustrates the budget trade-off between miles driven (m) and other consumption (x), comparing a less efficient vehicle purchased at a lower price (*solid budget line*) and a more efficient vehicle purchased at a higher price (*dashed budget line*). Panel B (holding miles constant) illustrates the optimal choice of fuel economy (mpg) that minimizes fuel expenditure and thus maximizes consumption of the numeraire (x), holding miles driven (m) constant. Comparison between a driver with low mileage (*solid budget line*) and one with higher mileage (*dashed budget line*). Color version available as an online enhancement.

The two first-order conditions in (6), and their representations in figure 2, motivate our two empirical tests. Given two cars with efficiencies μ_1 and μ_2, like the gas and hybrid Camrys in the introduction, drivers' choices will depend on their willingness to trade off miles traveled for other goods in the numeraire. Given the indifference curve in figure 2*A*, the driver would be best served choosing the inefficient car and driving m^* miles. However, a driver with a flatter indifference curve might be better off choosing the efficient car and driving more than m^0 miles. Because we cannot observe utility, we cannot identify all drivers who would be better off in more or less efficient vehicles.

We can, however, identify cases that cannot be financially optimal, even without knowing utility. In figure 2*A* anyone driving more than m^0 miles in a vehicle with efficiency μ_1, choosing a point on the solid budget line to the right of m^0, is forgoing savings. Albert in our introduction may be in that position. He could drive the same miles at lower total cost in the efficient vehicle μ_2. Similarly, anybody driving fewer than m^0 miles in the efficient vehicle could save money in the less efficient car. That may be Betty. Our first empirical test looks for such cases in models that come in both gas and hybrid-electric versions.

Our second empirical test focuses on the second condition in (6) and on figure 2*B*. For each driver, we calculate the annual gas savings from purchasing a car with one more mile per gallon: mp_g/μ^2. If that is larger than the cost of an extra mile per gallon, the driver has underinvested in fuel economy. If annual savings are smaller than the cost of an extra mile per gallon, the driver has overinvested in fuel economy.

To reiterate, these examples of forgone savings are mistakes only in the financial sense, in that the up-front cost of fuel efficiency does or does not exceed future fuel savings. In the next sections, we look for examples of each type.

3. IDENTIFYING FORGONE SAVINGS BY COMPARING GAS AND HYBRID CARS

For postpurchase data on vehicle ownership and driving, we rely on the 2009 and 2017 waves of the National Household Travel Survey. It includes household demographics, the annual mileage 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, including size, engine power, and EPA combined city-highway fuel economy.[10]

Table 1 presents summary statistics. The first two columns contain data for the vehicle models that come in both gas and hybrid versions. Hybrids get more miles per gallon and travel more miles. The mileage difference translates to a 7% increase, relative to the midpoint. That is the rightward shift in the hybrid distribution in figure 1. The fuel economy difference in the second row of table 1 translates to a 30.4% drop in the cost of driving.[11] The ratio of those two numbers, 0.23, is not an arc elasticity of driving demand because it combines both the ex post response by hybrid owners to cheaper driving and the ex ante selection of hybrids by high-mileage drivers. It overstates the true price elasticity. Two recent estimates place the price elasticity of demand for gas in the United States somewhere between 0.27 and 0.37 (Coglianese et al. 2017; Levin et al. 2017). If we randomly assigned drivers to cars, the mileage difference in table 1 between hybrid and gas models is at the low end of what we should expect to see based on responses to driving costs alone. In aggregate, selection of fuel-efficient cars by high-mileage drivers appears to play little role in the cars people drive.

To examine the choices by individual drivers, we start with the strategy that matches the introductory intuition and the first empirical test from section 2, comparing gas and hybrid versions of the same model. While some car buyers may have actively considered

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10. The two waves of the NHTS have data on 294,409 households that own 776,731 cars and light trucks (pickup trucks, SUVs/CUVs, and vans). We restrict our sample to those households for which we have information on miles driven and a complete set of covariates (income, age of household head, education, rural or urban). We limit the sample to those vehicles that we successfully matched (by make, model, and year of production) to engineering characteristics (mpg, length, width, height, weight, liters, valves, horsepower, and revolutions per minute, rpm) from WardsAuto. When a model year has multiple trims, we assign the characteristics of the cheapest. This final sample contains 155,572 household-vehicle observations. A subsample of 24,362 comprises vehicle models that come with either a gas-powered or a hybrid engine and for which both are present in the sample.

11. The cost of traveling one mile is p_g/μ. The price of gas cancels, and the percentage difference in the cost of driving a mile in cols. 1 and 2 of table 1 is $2(^1/_{\mu_e} - ^1/_n)/(^1/_{\mu_e} + ^1/_n)$.

Table 1. Summary Statistics

	Gas-Hybrid Pairs		
	Gas (1)	Hybrid (2)	All Cars (3)
Annual miles	12,350	13,251	12,428
	(74.55)	(219.0)	(29.01)
Combined city-highway mpg	27.72	37.67	25.72
	(.0233)	(.149)	(.0154)
Household income (2017 $):			
Less than $25k	.0850	.0345	.0891
$25k–$50k	.186	.102	.181
$50k–$75k	.199	.129	.187
$75k–$100k	.165	.165	.161
$100k–$150k	.217	.271	.216
More than $150k	.148	.299	.166
Age	52.73	54.58	53.22
	(.118)	(.311)	(.042)
Education:			
High school	.169	.0980	.184
Some college	.544	.485	.550
Graduate	.242	.380	.235
Rural	.213	.199	.245
Length	186.4	186.0	186.7
	(.0442)	(.138)	(.0312)
Width	71.63	71.59	72.60
	(.0136)	(.0408)	(.00868)
Height	59.80	60.55	62.54
	(.0325)	(.113)	(.0156)
Weight	3,279	3,630	3,527
	(4.068)	(11.64)	(1.686)
Liters	2.417	2.464	2.776
	(.00355)	(.0180)	(.00217)
Valves	3.949	3.914	3.793
	(.00213)	(.00837)	(.00153)
Horsepower	171.9	162.4	195.6
	(.230)	(1.025)	(.151)
Rpm	6,014	5,850	5,927
	(1.753)	(4.756)	(1.280)
Vehicle Age (years)	4.69	4.20	4.89
	(.021)	(.066)	(.008)
Observations	22,025	2,337	155,572

Sources. 2009 and 2017 National Household Travel Survey, limited to households with cars and complete demographic information. Vehicle characteristics from Wardsauto.com.

Note. There are 24,362 gas-hybrid models in cols. 1 and 2, and 155,572 observations for all cars in col. 3. The income variables in cols. 1–3 are only for the 2017 NHTS. Standard errors in parentheses. rpm = revolutions per minute.

the gas and hybrid versions, others may have looked at only hybrids. Either way, we assume that they preferred the version they chose to its alternative.

For each driver in a car available in both gas and hybrid models, we calculate the annual fuel cost difference between the two versions. That difference, in equation (1), differs for every driver depending on miles (m_i), gas prices (p_g), and the difference between the gas and hybrid fuel economies for the particular car. It is plotted in figure 1.

For each gas-hybrid pair, there is some benchmark value of annual fuel savings above which driving a hybrid would make sense for personal financial reasons. Figure 3 depicts the distributions of drivers as frequencies rather than densities, to emphasize that the hybrid market share is smaller. The benchmark cost difference is depicted as a vertical line. Drivers of gas cars spending more than the benchmark could have saved money by spending more up front on the hybrid. The share of gas drivers in that position is B/(A + B). Drivers of hybrids spending less than the benchmark could have saved money by purchasing the less expensive gas car. That share is C/(C + D).

Finding the true benchmark is difficult. It requires knowing all the parameters of equation (2), including the price premium for the hybrid, the cars' life spans, and consumers' discount rates. As our main approach, we assume that the hybrid price premium for each model pair is the difference in MSRPs. That may overstate the cost of fuel economy if consumers receive tax incentives or rebates for purchasing hybrids. We assume that each driver purchased their vehicle new at the time it was released. If a respondent to the 2017 NHTS drives a model year 2010 Toyota Camry, we assign to

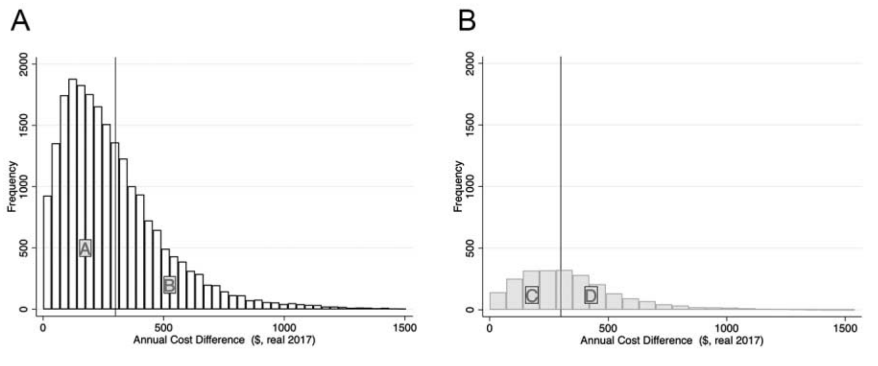

Figure 3. Benchmark annual savings, gas versus hybrid. Panel *A*, Gas-powered cars. Panel *B*, Hybrid cars. Graphs illustrate a cutoff value in counterfactual annual fuel cost savings for switching from a gas to a hybrid version of the same car model. These savings are forgone by owners of gas vehicles in panel A and realized by owners of hybrid vehicles in panel B. Hybrid owners saving less than the cutoff (*area* C) would have saved money by buying the gas version; owners of gas vehicles with savings exceeding the cutoff (*area B*) would have saved money by buying the hybrid. Data identical to that used in fig. 1. Color version available as an online enhancement.

that car its 2010 MSRP. Below, we also demonstrate that our main findings do not differ when we instead use the buyer's actual purchase prices or survey-year used car prices.

3.1. Calculating Forgone Savings Using Assumptions from the CAFE Analyses

In 2012, EPA and NHTSA issued new fuel economy rules for model years 2017–25. The regulatory impact analysis (RIA) predicted that the new rules would add $1,800 to the cost of an average new vehicle and save more than $5,000 in gas costs over the life of the car (in 2007 dollars; US EPA 2010). The analyses assume model-specific life spans for cars, with an average of 14 years, discounting future fuel savings at either 3% or 7%, following standard US government guidance (US OMB 2003).

Our version of that analysis can be found in table 2. The data contain 24,362 cars that come in gas or hybrid versions. If we discount future fuel savings at 3%, then 4,120 drivers would be better off financially in hybrids.[12] But only 2,337 are actually driving hybrids, suggesting that car buyers undervalue fuel savings, on average. With the data on individual drivers, we can see not just the share of drivers but which drivers are in hybrids. Of the 4,120 drivers in column 3 of table 2 who would be better off in hybrids, only 12% (474) are actually driving hybrids. That is fraction D/(B + D) in figure 3. The other 88% forgo savings by underinvesting in fuel economy.[13]

If we discount future fuel savings at 7%, the aggregate statistics suggest that car buyers fully value savings. There are 2,430 who would save money in hybrids, and nearly precisely that many, 2,337, actually do drive hybrids. But again, those are mostly the wrong drivers. Of the 2,430 for whom a hybrid would save money, only 12% (286) drive hybrids. Increasing the discount rate reduces the number of drivers better off choosing a hybrid but does not significantly change the share who do so, 12%.

Table 2 also reports the other type of forgone savings, overinvestment in fuel efficiency. Of the 20,242 drivers predicted to be saving money in gas cars, with future savings discounted at 3%, 1,863, or 9%, forgo savings by driving hybrids. Or, of the 2,337 drivers actually in hybrids, 1,863 (80%) would save money in gas cars. That is C/(C + D) in figure 3. And again, if we discount savings at 7% the proportions are the same. More drivers would save money in the gas cars, 21,932. Of those, 2,051, or 9%, forgo savings by overinvesting in fuel efficiency.

Why do the shares of those under- or overinvesting in fuel efficiency change so little, even though the discount rate substantially cuts the value of driving a hybrid? An obvious explanation is that drivers' gas-hybrid decisions are not based on potential fuel savings.

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12. Our analysis contains vehicles with different ages. For table 2, we assume that each driver obtained a vehicle when it was new and drives it the same number of miles every year for a duration of 14 years. We later test different assumptions regarding ownership, mileage, and depreciation.

13. Figure A1 shows what fig. 1 would look like when we exclude those drivers who appear to have failed to optimize in their vehicle choice.

Table 2. Two Types of Forgone Savings: Models with Gas-Hybrid Choice

	Actual Vehicle	Optimal Vehicle (3% discount rate, 14-year life)		Optimal Vehicle (7% discount rate, 14-year life)	
	Total (1)	Gas (2)	Hybrid (3)	Gas (4)	Hybrid (5)
Total	24,362	20,242	4,120	21,932	2,430
Gas	22,025	18,379	<u>3,646</u>	19,881	<u>2,144</u>
(% of row)		(83%)	(17%)	(90%)	(10%)
(% of column)		(91%)	(88%)	(91%)	(88%)
Avg. forgone savings			$3,855		$3,353
Hybrids	2,337	<u>1,863</u>	474	<u>2,051</u>	286
(% of row)		(80%)	(20%)	(88%)	(12%)
(% of column)		(9%)	(12%)	(9%)	(12%)
Avg. forgone savings		$5,057		$5,423	

Sources. 2009 and 2017 National Household Travel Survey.

Note. Model years 2005–17. All cars with complete data on prices and incomes and that come in gas and hybrid versions. Underscores represent drivers who would be financially better off in the alternative version of the same vehicle. Forgone savings represent the cumulative discounted cost difference over the vehicle lifetime relative to the cost-minimizing choice. Row percentages show, within observed gas/hybrid choices, the shares of drivers for whom the gas/hybrid choices are cost minimizing. Column percentages show, within cost-minimizing choice groups, the shares of drivers who actually own gas/hybrid vehicles. Calculations assume a 14-year lifetime with discount rates of 3% and 7%. The 14-year lifetime roughly replicates the Corporate Average Fuel Economy (CAFE) 2017–25 regulatory impact analysis. The EPA and National Highway Traffic Safety Administration use model year–specific lifetime estimates, which average 14 years.

Look again at figure 1. Raising the discount rate from 3% to 7% will shift to the right any cutoff annual savings that would make choosing a hybrid worthwhile. That shrinks the share of drivers for whom choosing a hybrid would be optimal. But it also shrinks the number of those drivers who have chosen to drive a hybrid by almost the same amount.

More concretely, if cars were randomly assigned to drivers, regardless of gas prices or mileage, then changing the discount rate would have no effect on the shares of those apparently overinvesting in fuel efficiency. That seems to be the case. Table 2 is just one more way of demonstrating the takeaway from figure 1: many drivers could be saving money in more or less fuel-efficient cars.[14]

14. This approach relies on hypothetical comparisons of each driver's vehicle choice relative to the counterfactual of choosing the corresponding hybrid or gas alternative. Table A1 shows that both samples have similar distributions of vehicle models, with the notable exception of the Lexus NX, which only has hybrid models in our sample, and the Nissan Altima, which only has gas versions. Table A2 shows that the results of table 2 remain essentially unchanged after excluding NX and Altima owners from the sample.

Table 2 also reports the amount of money drivers could be saving. Drivers who own hybrids even though their fuel expenses do not justify the up-front cost could save, on average, over $5,000 in a gas-powered vehicle. And drivers of gas cars with high fuel expenses could save over $3,000 in a hybrid.[15]

In theory, the apparent disconnect between drivers' financial incentives and their choice of vehicle could be explained by a systematic miscalculation on our part of fuel savings or depreciation rates. In table 2 we calculate fuel savings based on each car's combined city/highway mpg (55/45). But if hybrids save more fuel when driven in cities, then urban drivers may be more inclined to purchase hybrids, making their choice look costly if evaluated at the combined city/highway mpg. To test this, we replicate table 2 but assign urban drivers the mpg for city driving only. As seen in table A3 (tables A1–A9 are available online), this makes hybrids more attractive to those drivers but does no better at explaining observed choices.[16]

Similarly, vehicles that are driven more miles could depreciate faster. To test this, we replicate table 2 but assign a fixed 170,000 miles to each vehicle, equal to 14 years multiplied by an average of around 12,000 miles in our sample. As can be seen in table A4, the disconnect between cost minimizing and observed vehicle choices remains.

Finally, it is worth reiterating that we focus on financial incentives related to fuel economy alone. Some choices that look unwise from that perspective may have good reasons. Some drivers may value other vehicle characteristics that correlate with fuel economy. For example, hybrid owners may value their lower emissions, or the need to refuel less frequently, or the insurance against uncertain fuel prices.[17] These and similar motivations are set aside by regulatory analyses which claim that drivers would save money in more efficient cars. It turns out, as we show next, that drivers' demographic characteristics are far more closely associated than fuel costs with their cars' fuel efficiency.

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15. Figure A2 shows that the individual forgone savings can be substantial for many drivers. Figure A3 shows, for the same set of drivers, the ratio of up-front cost to cumulative discounted fuel savings, equivalent to solving for γ in eq. (2). Notably, we find more frequent and stronger deviations from 1 for hybrid owners.

16. Recent work has shown variation in fuel use per mile driven based on driving speed and style (Langer and McRae 2017; Knittel and Tanaka 2021). We focus only on the number of miles driven and gas prices paid, assuming constant fuel use per mile across drivers in the same car.

17. We attempt to control, albeit imperfectly, for the value of fuel economy due to uncertain fuel prices by looking at a subset of drivers who do not consider fuel cost a major burden. The results in table A5 resemble those in table 2.

3.2. Demographic Characteristics and the Choice between Gas and Hybrid Cars

Figure 4*A* illustrates how the proportions of drivers who would save money in different versions of their same vehicles differ by household income.[18] The figure uses the cutoff corresponding to 14 years of driving discounted at 3%, as in columns 2 and 3 of table 2. The upper line depicts the share of households who have annual expenses above the cutoff but are driving gas cars, B/(B + D) in figure 3. They underinvest in efficiency. Higher-income households are less likely to fit that pattern. The lower line in figure 4*A* depicts the share of drivers with annual expenses below the cutoff but who drive hybrids, C/(A + C) in figure 3. They are likely to have overinvested in fuel efficiency. Higher-income households are more likely to have done that.

Hybrids make up about 10% of cars among these gas-hybrid pairs, and figure 4*B* adjusts for that. The left axis reports the difference between the share of the group likely to be over- or underinvesting and the overall market share of that car.[19] The differences in figure 4*B* are based entirely on the propensity of different income groups to choose hybrid or gas cars, conditional on their annual mileage and gas prices, factoring out market shares of vehicle types. Figure 4*B* does not suggest that either poor or rich drivers make systematically better vehicle choices. Both forgo savings, but for different reasons. Poorer households are more likely to have chosen a gas car when a hybrid would save them money, and richer households are more likely to do the opposite.

In figure 5 we examine other characteristics: sex, age, education, and rural versus urban.[20] We calculate the shares of apparent over- and underinvestment for each group, normalized again by vehicle market shares. The open circles represent the shares of drivers in gas vehicles who could be saving money in a hybrid. The solid diamonds represent drivers with low expenses in hybrids who could have saved money by purchasing the gas version.

Men are less likely than women to choose a gas car when a hybrid would reduce costs. But men are more likely to be driving hybrids when a gas car would reduce costs. Drivers younger than 40 are more likely than older drivers to be in gas cars even though they would save money in hybrids. Among drivers who have not been to college, fewer drive hybrids when they would be better off in gas cars, and more drive gas cars when a hybrid would be more economical. Rural and urban drivers appear similar in their propensity to forgo savings in either way.

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18. The categories of household income in the 2009 and 2017 NHTS data are not directly comparable, so we restrict this example to the 2017 NHTS.

19. In the context of fig. 3, the top line in fig. 4*B* is $B/(B + D) - (A + B)/(A + B + C + D)$. The bottom line is $C/(A + C) - (C + D)/(A + B + C + D)$.

20. Unlike income, these other demographic variables are reported consistently across NHTS survey waves, so we include both 2009 and 2017 data in fig. 5.

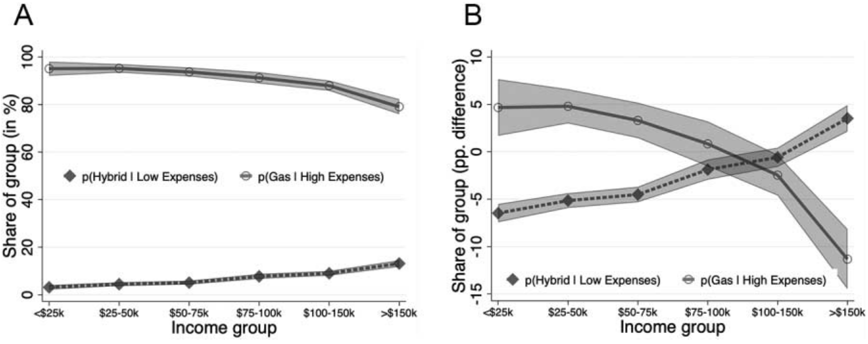

Figure 4. Forgone savings by income (gas vs. hybrid). Panel *A* shows absolute shares. Panel *B* shows shares net of overall market shares for gas cars and hybrids, respectively. Data from the 2017 National Household Travel Survey. The top line plots the share of high-expense drivers, who would be financially better off in hybrids but are driving gas cars. The bottom line plots the share of low-expense drivers in hybrids. Both assuming a 3% discount rate, 14-year vehicle life and hybrid premium based on the manufacturer's suggested retail price. Shaded areas represent 95% confidence intervals of the shares. Color version available as an online enhancement.

Figures 4 and 5 examine income, gender, age, location, and education one at a time, separately. But they covary, and so to examine how each of the characteristics is associated with fuel economy, conditional on the others, we estimate linear probability models.

3.3. Hybrid Choice and Driver Demographics

Table 3 regresses the choice of each driver on demographic characteristics, vehicle characteristics, and make and year-by-type fixed effects.[21] State fixed effects account for regional differences such as availability of hybrids or local rebates. Because income groups are not comparable between the NHTS waves, we limit the analysis to the larger 2017 survey.

The analysis in table 3 mimics figures 4 and 5 by estimating the probability of owning a hybrid for drivers with fuel savings below the cutoff that would justify doing so (cols. 1–3 where the dependent variable is 1 for hybrid and 0 for gas vehicles), as well as the probability of owning a gas car for drivers who would save money in a hybrid (cols. 4–6). In other words, table 3 estimates how the column probabilities in table 2 vary with driver demographics. Just like in figures 4 and 5, we use a 3% discount rate and 14-year vehicle lifetime to assign drivers into either group.

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21. We use NHTS type classifications, which distinguish cars (including station wagons), vans, SUVs, and pickup trucks. Interacting vehicle type indicators with vehicle years allows us to hold constant potentially important factors such as vehicle type loyalty and type-specific trends and innovation.

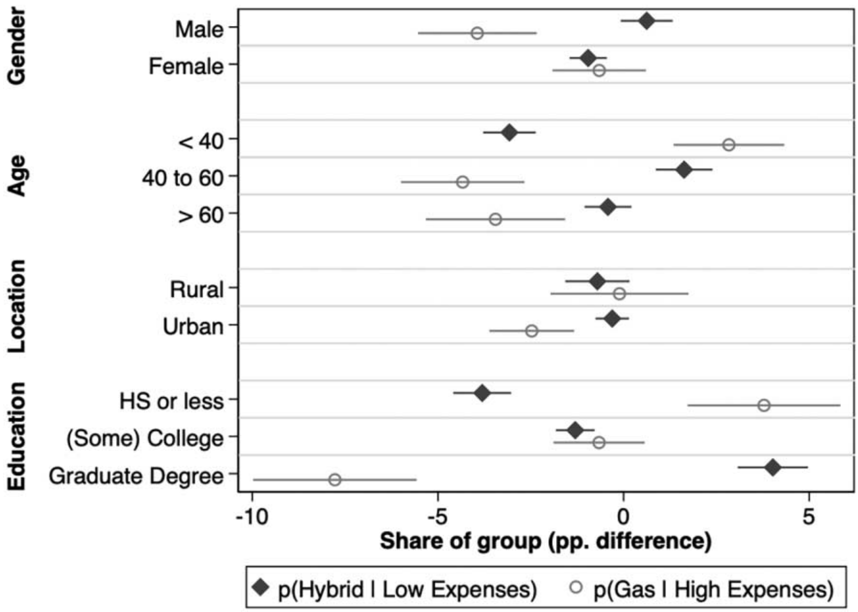

Figure 5. Forgone savings by other demographics (gas vs. hybrid). Data from 2009 and 2017 National Household Travel Survey. The open circles plot the share of each demographic with high expenses who would be financially better off in hybrids but are driving gas cars, minus the overall market share of gas cars. The solid diamonds plot the share of each group with low expenses driving hybrids, minus the market share of hybrids. Both assuming a 3% discount rate, 14-year vehicle life, and hybrid premium based on the manufacturer's suggested retail price. Lines represent 95% confidence intervals of the shares. Color version available as an online enhancement.

The results largely confirm the unconditional relationships discussed above. Looking at the results in column 1 of table 3, we see that higher-income drivers are more likely to own a hybrid even though their driving does not financially justify it. And looking at column 4, we see that higher-income drivers are less likely to own a gas-powered vehicle when they could save money in the hybrid. The same goes for drivers with a college education and older drivers—both are relatively more likely to drive hybrids when a gas car would cost less, and less likely to drive a gas car when a hybrid would cost less. The associations with gender and location are less pronounced and not statistically significant.

Next, we consider whether fuel savings incentives affect the probability of owning a vehicle that is not cost minimizing. We do so by adding the discounted value of future fuel savings (in $1,000s) from the hybrid relative to the gas version of the same model, given each driver's annual miles, gas prices, as well as the up-front incremental cost of

Table 3. Characteristics of Hybrid Vehicle Drivers

	P(Hybrid | Low Expenses) (3% discount)			P(Gas | High Expenses) (3% discount)		
	(1)	(2)	(3)	(4)	(5)	(6)
Cumulative fuel savings ($1,000)		.0112*	.0105*		–.0010	.00021
		(.0010)	(.0019)		(.0006)	(.0011)
Fuel savings			.000944			–.0021
× (Income >$50,000)			(.0021)			(.0016)
Up-front investment cost ($1,000)		–.0198*	–.0198*		.0162*	.0164*
		(.0012)	(.0012)		(.0038)	(.0038)
Income:						
$25k–$50k	.0171*	.0132	.0134	–.0006	.00023	.00023
	(.0075)	(.0074)	(.0074)	(.0167)	(.0167)	(.0167)
$50k–$75k	.0185*	.0133	.0108	–.0056	.0106	.0106
	(.0075)	(.0074)	(.0093)	(.0164)	(.0205)	(.0205)
$75k–$100k	.0507*	.0415*	.0389*	.00075	.0179	.0179
	(.0078)	(.0077)	(.0096)	(.0168)	(.0209)	(.0209)
$100k–$150k	.0522*	.0438*	.0412*	–.0254	–.0087	–.00871
	(.0076)	(.0075)	(.0095)	(.0162)	(.0204)	(.0204)
Over $150k	.0824*	.0750*	.0724*	–.0564*	–.0397	–.0397
	(.0082)	(.0081)	(.0100)	(.0171)	(.0212)	(.0212)
Education:						
Some college	.0101	.00814	.00818	–.0099	–.0115	–.0115
	(.0052)	(.0051)	(.0051)	(.0110)	(.0110)	(.0110)
Graduate	.0312*	.0284*	.0285*	–.0364*	–.0373*	–.0373*
	(.0060)	(.0059)	(.0059)	(.0123)	(.0123)	(.0123)
Age:						
40–60 years	.0163*	.0168*	.0168*	–.0203*	–.0191*	–.0191*
	(.0049)	(.0048)	(.0048)	(.0087)	(.0087)	(.0087)
Over 60 years	.0221*	.0282*	.0281*	–.0325*	–.0326*	–.0326*
	(.0047)	(.0047)	(.0047)	(.0094)	(.0043)	(.0094)
Male	.00431	.00305	.00305	–.00288	–.0023	–.0022
	(.0038)	(.0037)	(.0037)	(.0071)	(.0071)	(.0071)
Rural	.00542	.00311	.00309	–.0100	–.0108	–.0110
	(.0048)	(.0048)	(.0048)	(.0089)	(.0089)	(.0089)
Observations	14,183	14,183	14,183	3,397	3,397	3,397
R-squared	.327	.346	.346	.602	.604	.604

Sources. See table 1.

Note. Includes car characteristics: length, width, height, weight, liters, valves, horsepower, and rpm. Includes fixed effects by state, year-by-type, and make. Calculations for cumulative (and discounted) fuel savings assume a 14-year lifetime with discount rates of 3%. Sample using the 17,580 observations from the 2017 National Household Travel Survey wave (because of different income classification in 2009 wave). Columns 1–3 use the subsample of 14,183 drivers for whom the gas-powered version of their vehicle is cost minimizing, paired with a binary indicator of owning a hybrid vehicle as dependent variable. Columns 4–6 use the subsample of 3,397 drivers for whom the hybrid version of their vehicle is cost minimizing, paired with a binary indicator of owning a gas-powered vehicle as dependent variable.

* $p < .05$.

the hybrid car. The results, shown in column 2, suggest that an additional $1,000 in discounted fuel savings is associated with a 1.1% increase in the probability of driving a hybrid among those drivers for whom the gas vehicle is the more economical choice. By comparison, a $1,000 increase in the incremental cost is associated with a 2.0% decrease in that probability.[22] Fuel savings incentives do appear to play a role in the choice to drive a hybrid when the fuel savings do not justify it. For those drivers whose fuel cost justifies purchasing the hybrid, however, the choice seems unrelated to fuel savings, as shown in column 5.

As discussed above, drivers with higher incomes are more likely to own hybrids. This could be for many reasons, some nonfinancial. Perhaps high-income drivers have altruistic concern for the environment or want to signal that concern to neighbors (Sexton and Sexton 2014). Other reasons are financial. 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 appreciate the payoff from low future costs.

Columns 3 and 6 of table 3 test these financial explanations, that richer drivers are more likely to consider fuel savings. The specification includes an interaction between cumulative savings and an indicator for households with incomes above $50,000. Their estimated trade-off between future fuel savings and up-front investment costs is no different, as shown by the small and insignificant coefficient estimates. Higher-income drivers are more likely to own a hybrid but evidently not for reasons related to fuel savings.

The regressions in table 3 also show that some demographic traits are significantly more powerful predictors of observed vehicle choice than are fuel savings potential. Drivers with household incomes above $150,000 per year are over 5 percentage points more likely to own a hybrid despite low fuel savings than are drivers with incomes below $75,000, holding all other characteristics constant. That is equivalent to the increase in probability associated with over $5,000 dollars in cumulative fuel savings.[23] Similarly, possessing a graduate degree or being older than 60 is associated with an increase in the probability of owning a hybrid that is almost three times larger than from a $1,000 increase in fuel savings. The comparison is even starker in columns 5–6 where estimated coefficients for cumulative fuel savings are close to zero.

The results so far demonstrate that drivers' choices of fuel economy do not seem to be determined by future fuel savings. One possible explanation is that the gas-hybrid comparison is not the best way to control for other differences between less efficient

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22. Our perspective differs from much of the literature and is not designed to estimate the parameter γ. Still, if consumers fully value future energy costs—if $\gamma = 1$—the two coefficients should be equal. But our estimates suggest that γ is closer to 0.5.

23. The coefficients for incomes above $150,000 range from 0.07 to 0.08, while coefficients for incomes below $75,000 are 0.02 at most, making for a difference larger than 0.05. Meanwhile, the coefficient for each $1,000 in cumulative fuel savings is around 0.01.

and more efficient cars. Some hybrid vehicles clearly identify themselves as such, perhaps signaling the environmental concerns of their drivers. Battery life may limit their resale value. Hybrids may have less interior or cargo space. And their on-the-road performance may differ. In our second approach, based on the second condition in (6) and figure 2*B*, we expand the sample to all cars and control for other car characteristics statistically.

4. IDENTIFYING FORGONE SAVINGS USING ALL CARS

A car owner *i* who drives m_i miles each year, with gas price p_g in a car with mpg μ_i, has annual gas costs c_i equal to

$$c_i = \frac{m_i p_g}{\mu_i}. \tag{8}$$

The annual savings from buying a more efficient car, given m_i, are

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

This is the same as the right-hand side of the first-order condition in equation (7). A rational, informed car buyer will purchase fuel economy until the savings equal the cost of purchasing an additional mile per gallon, p_μ. So in equilibrium,

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

where *F* is the multiple translating annual fuel savings into a present discounted value. Any car owner for whom the right-hand side of (10) is larger than the left could have saved money in a more efficient car, with higher mpg (μ). Any owner for whom the left side is larger could have saved money in a less efficient car.

The annual savings, mp_g/μ^2, are simple to calculate, but p_μ and F are mostly unknown. What is p_μ? Before they were rolled back in 2020, the CAFE standards were projected to raise fleet-wide fuel economy from 35.5 mpg to 54.5 by 2025, at a cost of \$2,017 per car in 2017 dollars.[24] If those costs are fully passed on to consumers, that would amount to \$106 per mpg. The previous round of CAFE standards raised 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 (converted from 2007 dollars; see US EPA 2012). We use these regulatory estimates of \$106 and \$207 per mpg below.

The price that consumers actually face in order to purchase a vehicle with an incremental mpg (p_μ), given existing options for sale, may differ from these regulatory

24. Converted from 2010 dollars used in the RIA using the Consumer Price Index. See US EPA 2012.

projections. The NHTSA estimates are based on cars not yet in production, engineering estimates may understate costs, and the marginal price per mpg may not be constant. Hedonic pricing approaches surveyed by Greene et al. (2018) produce a mean value of $991 per mpg.

For comparison, the mean annual savings from one extra mile per gallon from equation (9) is $56, and the median is $42. Summed over 14 years and discounted at 3%, that is $618. Discounted at 7%, it would be $479. Both are larger than the regulatory candidates for p_μ discussed above, but lower than the hedonic average in Greene et al.

Because of uncertainty about discount rates and the value of p_μ, 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 ($106); the second uses the high discount rate (7%) paired with the high price for fuel economy ($207). We again count fuel savings over 14 years. That leads to two benchmark annual fuel savings level cutoffs, above which it would make sense for drivers to purchase one more mile per gallon: $9 and $24.[25] We classify all drivers as having purchased either too little fuel economy—because the marginal discounted savings from one more mile per gallon outweigh the cost—or too much.[26] This is shown in table 4.

Starting with the low option, table 4 suggests that 143,536 (92%) of the 155,572 drivers in our sample bought cars with too little fuel economy. Far fewer, 12,036 drivers (8%) overinvested. That supports the argument in the benefit-cost analyses done for the US fuel economy rules. The bottom row of table 4 shows the magnitudes of the average missed savings. The 143,536 drivers who underinvested incur $6,105 more in total vehicle lifetime costs, relative to cars with the optimal level of fuel economy. The 12,036 who overinvested forgo only $403 on average.

When we discount fuel savings by 7% and impose the higher fuel economy price of $207 per mpg, table 4 suggests that 73% underinvest and 27% overinvest. In other words, the $24 cutoff is closer to the $42 median savings from an additional unit of mpg. And the magnitudes are also closer.

These results support the claim that mandating higher levels of fuel economy saves drivers money, at least on average and when using the EPA numbers for the cost of fuel economy ($106 and $207 per mpg). However, if we use the average of the hedonic estimates of the price of an incremental mile per gallon, $991 per mpg, those savings vanish for most drivers. We show in table A6 that such a high cost would mean that 80%–90% of drivers would save money in less efficient cars.

25. For the first cutoff, $9 = $106/11.3. For the second, $24 = $207/8.75. The denominators, 11.3 and 8.75, are the present values of $1 discounted at 3 and 7%, respectively, for 14 years.

26. We recognize that car buyers cannot choose from a continuous set of possible fuel economies. But that is typical of all empirical analysis of bundled characteristics, such as compensating wage differentials and hedonic house price regressions.

Table 4. Two Types of Forgone Savings: All Models

		Fuel Economy Level (3% discount rate, 14-year life, \$106 per mpg)		Fuel Economy Level (7% discount rate, 14-year life, \$207 per mpg)	
	Total (1)	Too Much (2)	Too Little (3)	Too Much (4)	Too Little (5)
NHTS 2009	45,291	2,581	42,710	9,449	35,842
		(6%)	(94%)	(21%)	(79%)
NHTS 2017	110,281	9,455	100,826	31,959	78,322
		(9%)	(91%)	(29%)	(71%)
Total NHTS	155,572	12,036	143,536	41,408	114,164
		(8%)	(92%)	(27%)	(73%)
Avg. forgone savings (14 years)		\$403	\$6,105	\$743	\$3,002

Sources. See table 1.

Note. Calculations assume a 14-year lifetime with discount rates of 3% and 7%. The cumulative (and discounted) monetary value of one more unit of mpg (according to eq. [10]) is compared with the marginal cost of mpg (\$106 and \$207). Forgone savings are the cumulative discounted cost difference over the 14-year vehicle lifetime relative to the cost-minimizing choice. The 14-year lifetime roughly replicates the Corporate Average Fuel Economy (CAFE) 2017–25 regulatory impact analysis. The EPA and National Highway Traffic Safety Administration use model-year-specific lifetime estimates, which average 14 years. NHTS = National Household Travel Survey.

The share of drivers found to be underinvesting in fuel economy depends critically on assumptions about p_μ and discount rates. But no matter the assumptions, we always find a significant share of drivers who could be saving money in less expensive, less efficient cars. They would presumably be made worse off by tightened fuel economy standards. Our driver-level data enable us to ask which drivers have chosen efficient vehicles.

4.1. Demographic Characteristics and Fuel Efficiency

Start with income. Figure 6*A* plots the share deemed to have underinvested in fuel efficiency as a function of household income. Interestingly, this works in the opposite direction as our gas-hybrid comparison. Here the probability that a household underinvests in fuel efficiency increases with income.

Most of the distinction in figure 6*A* results from richer households driving more miles. As there is little association between fuel savings potential and fuel economy choices, groups that drive more are more likely to appear to underinvest. To factor out group mileage differences, we construct a counterfactual version of figure 6*A* where we assign to all drivers the median mpg in the 2017 NHTS data. This identifies the shares of drivers forgoing savings based only on group differences in mileages and gas prices. We then subtract these counterfactual shares from the actual ones depicted

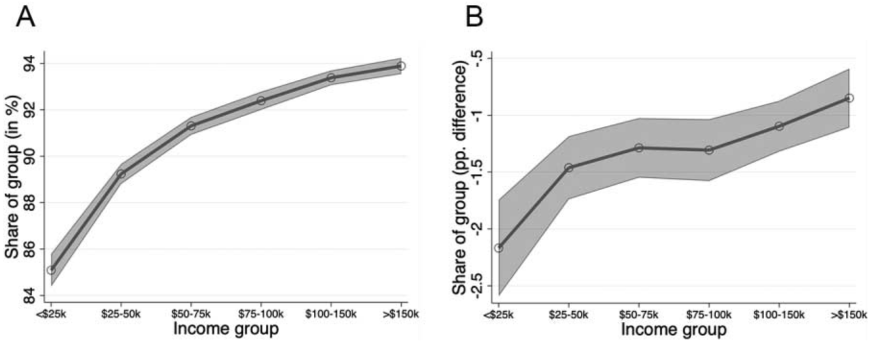

Figure 6. Forgone savings by income (all cars). Panel *A* shows absolute shares. Panel *B* shows absolute shares minus what that share would be if all drivers had the median fuel economy. Data from 2017 National Household Travel Survey. Each point represents the share of each income group that could be financially better off by driving a car with one more mile per gallon of fuel economy. Assumes a 3% discount rate and a price of efficiency (p_μ) of $106. Counterfactual shares depend only on mileage and gas prices, so panel B is adjusted for those income-group differences. Shaded areas represent 95% confidence intervals of the shares. Color version available as an online enhancement.

in figure 6*A*. The remaining differences, plotted in figure 6*B*, depend entirely on differences in fuel economy choices between groups, having controlled for differences in mileage and gas prices.

Figure 6*B* shows that the share of drivers who could benefit financially from an extra mile per gallon, given their driving expenses, is larger for drivers with higher incomes. Richer drivers are distinctly more likely to choose cars that could be more cost-effective, even after factoring out their propensity to drive more miles. Presumably those households focus on other costly car features.

Figure 7 describes the same exercise for other driver characteristics. We first calculate the share of households in each demographic likely to be driving cars with too little efficiency and then the counterfactual shares for each group if all cars had the median fuel economy. Then we report the difference. Given their annual mileage and gas prices, men are more likely than women to underinvest in fuel economy. Again, this differs from our gas-hybrid comparison, which found that low-expense men were more likely to be driving hybrids. More similar to the gas-hybrid analysis, people older than 60, with graduate degrees, and living in urban areas are less likely to be driving cars with too little fuel efficiency.

Some of the associations between car choice and demographic characteristics of drivers differ between the two approaches. This could easily be related to the different samples. In both analyses, however, both types of forgone savings—apparent over- and underinvestment in fuel economy—are common among all demographic groups, and the relationship between fuel savings and fuel economy is weak.

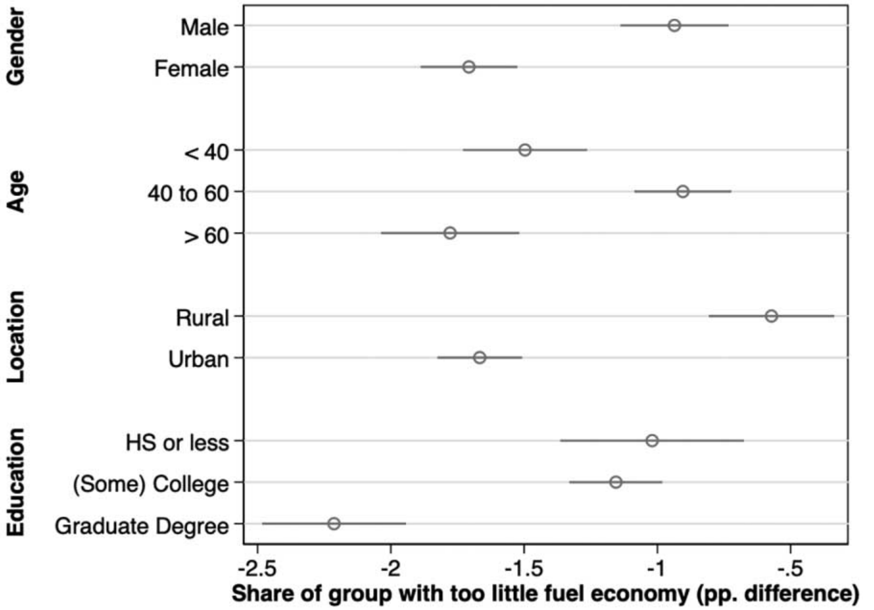

Figure 7. Forgone savings by other demographics (all cars). Data from 2009 and 2017 National Household Travel Survey (NHTS). Actual share of each demographic group deemed to be driving cars with too little fuel economy minus that same share calculated under the counterfactual assumption that each driver's car had the median mpg for each wave of the NHTS. Assumes a 3% discount rate and a price of efficiency (p_μ) of $106. Lines represent 95% confidence intervals of the shares. Color version available as an online enhancement.

4.2. Regression-Based Approach to Demographic Analysis: All Vehicles

Table 5 examines how all five demographic characteristics together are associated with fuel economy choices. We start by calculating the cost-minimizing fuel economy (μ^*) for each driver, given annual mileage and gas prices.[27] We then take the same backward-looking perspective as in figures 6 and 7, asking how driver characteristics are associated with the probability that a driver's observed vehicle choice appears to involve too little fuel economy. We estimate linear probability models where the dependent variable is a binary indicator equal to 1 when $\mu_i < \mu_i^*$. This is regressed on demographic characteristics, vehicle characteristics, and make, year-by-type, and state fixed effects.

The first column of table 5 largely confirms the differences from the unconditional analyses in figures 6 and 7, even after controlling for other characteristics. Drivers with

27. The optimal fuel economy, μ^*, solves eq. (10), $p_\mu = (Fmp_g)/(\mu^2)$, where F is 11.3, corresponding to cumulative savings over 14 years, discounted at 3% and the price of fuel economy is $106 per additional mile per gallon. The rearranged solution gives $\mu^* = \sqrt{(mp_g/p_\mu)F}$.

Table 5. Determinants of Having Underinvested in Fuel Economy

Dependent Variable =1 if $\mu_i < \mu_i^*$	(1)	(2)	(3)
Miles per year (m_i/1,000)		.0060*	.0077*
		(.0001)	(.0001)
Miles × (Income > $50k)			−.0024*
			(.0002)
Income:			
$25k–$50k	.0306*	.0284*	.0273*
	(.0034)	(.0033)	(.0033)
$50k–$75k	.0399*	.0369*	.0628*
	(.0034)	(.0033)	(.0037)
$75k–$100k	.0424*	.0374*	.0638*
	(.0036)	(.0034)	(.0038)
$100k–$150k	.0442*	.0379*	.0646*
	(.0034)	(.0033)	(.0038)
Over $150k	.0408*	.0355*	.0623*
	(.0037)	(.0036)	(.0040)
Education: some college	.0163*	.0119*	.0116*
	(.0023)	(.0022)	(.0022)
Graduate	.0198*	.0135*	.0131*
	(.0027)	(.0026)	(.0026)
Age:			
40–60 years	−.0146*	−.0101*	−.0094*
	(.0022)	(.0021)	(.0021)
Over 60 years	−.0757*	−.0524*	−.0515*
	(.0021)	(.0021)	(.0021)
Male	.0102*	.0058*	.0058*
	(.0017)	(.0017)	(.0017)
Rural	.0229*	.0147*	.0148*
	(.0020)	(.0020)	(.0020)
Observations	110,231	110,231	110,231
R-squared	.059	.117	.119

Sources. See table 1.

Note. Other car covariates: length, width, height, weight, liters, valves, horsepower. Miles per year: annual miles divided by 1,000 (m_i/1,000). Dependent variable is a binary indicator equal to 1 when observed mpg (μ_i) is smaller than the cost-minimizing mpg (μ_i^*), assuming 14-year vehicle lifetimes and 3% discounting. Using the 2017 National Household Travel Survey wave (because of different income classification in 2009 wave).

* $p < .05$.

low incomes are the least likely to have underinvested in fuel economy. Younger drivers, especially those under 40, as well as male drivers and those living in rural areas are more likely to have underinvested in fuel economy. All of these are in line with figure 7. The only difference appears for education. While figure 7 suggested that graduates are less likely to have underinvested in fuel economy, table 5 shows that this association flips after we control for income, age, gender, and location.

We should note that the differences shown in table 5 may be in part due to differences in miles driven between demographic groups. In figures 6 and 7, we adjusted group averages using a hypothetical counterfactual where all drivers were assigned the median fuel economy level. In table 5 we can control more directly for individual fuel savings incentives based on miles driven. We do so in column 2 of table 5, which regresses each driver's indicator of having underinvested on annual miles driven.[28] Controlling for individual fuel savings incentives in this way somewhat attenuates the demographic coefficients, but all differences remain qualitatively the same.

This analysis yet again confirms that drivers do not fully internalize fuel savings, as shown by the positive and statistically significant coefficient estimate on miles driven, which we interpret as follows: an additional 1,000 miles driven per year is associated with a 0.6 percentage point increase in the probability of having underinvested in fuel economy. Drivers with a larger financial benefit from investing in fuel economy are more likely to underinvest. If drivers were fully internalizing fuel savings incentives, we would expect a coefficient of zero.

Column 3 of table 5 includes an interaction between miles driven and an indicator for incomes above $50,000. The small and negative coefficient suggests that fuel economy choices of high-income drivers are somewhat more responsive to fuel savings incentives, although the combined coefficient remains significantly positive. Most importantly, the demographic differences remain: higher-income drivers are more likely to have underinvested in fuel economy even after controlling for their fuel savings incentives.

The disconnect between fuel savings incentives and observed fuel economy choices suggested by the positive and significant coefficient on miles driven in table 5 is robust to different measures for mileage and gas prices. So far we have used the best estimate of annual miles as judged by NHTS survey staff, a combination of self-reported miles and odometer readings paired with vehicle age. In table A7, we show that the results remain unchanged using self-reported miles only (col. 2), odometer reading divided by vehicle age (col. 3), or miles driven by the owner in any vehicle (col. 4). While we mainly rely on regional gas price averages, table A7 shows that results are unchanged with the gas price reported during each driver's most recent trip.[29]

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28. Equation (10) suggests that fuel choice should be a function of the product of the gas price and individual mileage. When we control for that, the results in table 5 are largely unchanged, but the regression coefficient becomes more difficult to interpret.

29. Figure A4 shows no association between μ and μ^* on average across 20 brackets of annual fuel costs.

5. POSSIBLE EXPLANATIONS FOR LACK OF ATTENTION TO ENERGY EFFICIENCY

We find forgone savings of both types: many households do not drive much but own fuel-efficient cars and vice versa. What explains this seeming absence of attention to fuel economy? We have seen in tables 3 and 5 that the responsiveness to savings does not vary meaningfully by income, ruling out personal finances as an important explanation for the lack of cost minimization. We now investigate two alternative explanations: mistaken expectations and bias in vehicle prices.

5.1. Possible Differences between Realized Ex Post Mileage and Ex Ante Expectations

In sections 3 and 4, we calculate fuel expenses from actual miles driven in the NHTS survey. That may differ from how much owners expected to drive when they bought their cars. To examine that, we repeat the analyses using car buyers' expected annual mileage at the time of purchase, from the MaritzCX monthly surveys of vehicle buyers conducted between 2010 and 2017.[30] These data also report the actual transacted sales price rather than the MSRP, eliminating concerns of bias if hybrid cars sell at different discounts.

As a first step, we replicated figure 1 using annual cost differences between hybrid and equivalent gas cars, based on expected miles at the time of purchase. The two distributions are indistinguishable, as shown in figure A5 (figs. A1–A5 are available online). Hybrid and gas purchasers expect to drive similar amounts, supporting the finding that hybrids are not chosen for their expected fuel savings and that postpurchase differences in driving are due to rebound, not selection.

Second, panel A of table 6 reproduces table 2 but with time-of-purchase expected miles. The results are qualitatively similar, though a larger share of cars are hybrids. Of 61,873 purchasers of cars that came in gas and hybrid versions, 24,472 would be better off choosing a hybrid, given their expected mileage, the sales price premium over the gas version, a 14-year life expectancy, and a 3% discount rate. Nearly as many do, 21,133. But as in table 2, it is mostly the wrong buyers. Of the 24,472 who would better off purchasing a hybrid, only 9,274 do (38%). And as in table 2, switching to a 7% discount rate drops the estimated number who would be better off choosing a hybrid, but it barely nudges the fraction of those who actually do (to 39%).

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30. See Leard et al. (2019, 2020) and Leard et al. (2023). Table A8 contains summary statistics for the MaritzCX data. The surveys average a 9% response rate and represent approximately 1% of US car purchases. The MaritzCX sample differs a little from the NHTS sample. MaritzCX respondents are wealthier, more educated, more urban, and own larger, more powerful, and slightly less fuel-efficient cars. The vehicles in the time-of-purchase data are also newer, purchased between 2009 and 2017 rather than cars driven in 2009 and 2017. MaritzCX was acquired by another market research company, InMoment, in 2020.

Table 6. Time-of-Purchase and Used-Car Price Analysis: Models with Gas-Hybrid Choice

	Actual Vehicle	Optimal Vehicle (3% discount rate, 14-year life)		Optimal Vehicle (7% discount rate, 14-year life)	
	Total (1)	Gas (2)	Hybrid (3)	Gas (4)	Hybrid (5)
	A. Time-of-Purchase Analysis (MaritzCX)				
Total	61,873	37,401	24,472	44,121	17,752
Gas	40,740	25,542	<u>15,198</u>	29,962	<u>10,778</u>
(% of row)		(63%)	(37%)	(74%)	(26%)
(% of column)		(68%)	(62%)	(68%)	(61%)
Hybrids	21,133	<u>11,859</u>	9,274	<u>14,159</u>	6,974
(% of row)		(56%)	(44%)	(67%)	(33%)
(% of column)		(32%)	(38%)	(32%)	(39%)
	B. Used Price Analysis (NHTS + TrueCar.com)				
Total	3,254	921	2,333	1,162	2,092
Gas	2,999	874	<u>2,125</u>	1,098	<u>1,901</u>
(% of row)		(29%)	(71%)	(37%)	(63%)
(% of column)		(95%)	(91%)	(94%)	(91%)
Hybrids	255	<u>47</u>	208	<u>64</u>	191
(% of row)		(18%)	(82%)	(25%)	(75%)
(% of column)		(5%)	(9%)	(6%)	(9%)

Sources. Panel A: MaritzCX survey years 2010–17, vehicle characteristics from Wardsauto.com. Panel B: National Household Travel Survey (NHTS) 2017 survey, limited sample with available used-car prices from TrueCar.com.

Note. All cars with complete data on prices and incomes and that come in gas and hybrid versions. Underscores represent drivers who would be financially better off in the alternative version of the same vehicle. Calculations assume a 14-year lifetime with discount rates of 3% and 7%. The 14-year lifetime roughly replicates the Corporate Average Fuel Economy (CAFE) 2017–25 regulatory impact analysis. The EPA and National Highway Traffic Safety Administration use model-year-specific lifetime estimates, which average 14 years.

5.2. Possible Difference in Depreciation Rates and Used Car Prices

The main analyses explore whether, retrospectively, given their actual mileage, drivers would have been better off had they purchased more or less efficient cars. Above, we ask whether, prospectively, given their expected future mileage, car buyers would be better off by purchasing more or less efficient cars. There is a third way to frame the question. Every driver who drives a lot in an inefficient vehicle, like Albert in our introduction, could trade in his car for a more efficient one. And every Betty could downgrade. More generally, not all cars are purchased new and not all cars are held by the same owner for their entire life spans. Any systematic difference in depreciation rates and used-car prices between cars with different fuel economy levels could be responsible for at least some of the absence of sorting based on fuel savings potential that we find.

To frame the question as a choice to keep or trade in one's current car, and to account for possible differences in depreciation rates, we rely on used-car prices for about 1 million vehicles listed in September 2017 on the website TrueCar.com.[31] We match those prices to each make, model, and year in the 2017 NHTS. Only a subset of the relevant cars had a matching listing on TrueCar.com, and the drivers selling their cars on that website are likely not representative of all drivers. But even with that limited sample, we again see similar patterns.

Panel B of table 6 replicates table 2 based on used-car prices and suggests two insights. First, more drivers would be better off in hybrids, presumably because the used hybrid price premium is smaller than the new one. Second, optimal and observed choices are again only weakly related. In other words, differences in depreciation and resale value cannot explain the observed lack of sorting into what looks like the cost-minimizing vehicle choice based on individual drivers' circumstances.

We recognize that surveyed drivers may not have been the original purchaser. An alternative approach focuses on vehicles alone, rather than their drivers, and assigns to each vehicle the average annual miles it was driven based on its odometer reading and age. Table A9 replicates table 2 using this approach and tells the same story: many gas-powered cars are driven enough to render their hybrid alternative less costly. And many hybrid vehicles were driven too little to justify their up-front costs.

6. CONCLUSION

Do car buyers undervalue future fuel savings? Or do they appropriately balance the up-front cost of fuel economy with the future savings? Previous work finds mixed evidence but suggests that vehicle prices and market shares respond to the cost savings from fuel economy, at least partially and on average. We ask a related but somewhat different question: do individual drivers respond to their personal savings potential from fuel economy based on their own driving and the fuel prices they face? We find little evidence that they do.

Of more than 150,000 car owners in 2009 and 2017, we find that a large portion appear to be missing out on savings. Some own inefficient cars but drive them a lot. Others pay more for fuel-efficient cars that they drive very little. This disconnect holds whether we look at ex post realized mileage or expected mileage at the time of purchase. It holds whether we use MSRPs, actual purchase prices, or used-car prices in 2017. And it holds whether we use the price premium for hybrid versions of models that also

31. The used-car listings data from TrueCar.com are available under "CCO: Public Domain" license from the following website: www.kaggle.com/jpayne/852k-used-car-listings.

come in a gas version or examine all car models using variants of the price premium for fuel economy used by US regulators.

Our findings contain a puzzle: how can the market as a whole seemingly internalize the value of fuel economy while individual consumers mostly ignore it? One explanation might be that consumers act as if they expect to drive the average number of miles and ignore their own deviation from that average. Another explanation is that heterogeneous preferences for other vehicle characteristics drive the disconnect between fuel savings and vehicle choices. Either way, the financial benefits of fuel economy play a less important role in vehicle choice than previously claimed.

That result has been suggested by others. Allcott (2011, 99) uses a survey of 2,100 car owners to show that "American consumers devote very little cognitive attention to fuel costs when they purchase autos." And Sallee (2014) argues that ignoring fuel economy is often rational, given the complexity of the calculation and the small financial gains involved.

The observed lack of sorting into fuel economy levels based on individual monetary incentives suggests a significant, previously overlooked source of market inefficiency. Policy discussions revolve around improving fleet-wide fuel economy levels, as with the CAFE standards. But we find that many drivers already own cars for which the up-front premium for fuel economy exceeds their personal savings. A fleet-wide policy may make those drivers worse off, at least financially.

More targeted policies might achieve the same fuel-conservation objectives and make more drivers better off. Consider two stylized alternatives: (1) increase every car's fuel economy by one mile per gallon or (2) keep the same fleet-wide level of fuel economy (mpg) but reallocate it among drivers so that drivers with fuel savings potential above the median receive one mile per gallon of additional fuel economy and drivers below the median receive one mile per gallon less. In the 2017 NHTS sample, a fleet-wide increase in fuel economy of one mile per gallon would save the average driver about $50 per year. Redistributing fuel economy among drivers would save an average of $30.[32] Better sorting at constant technologies achieves 60% of the savings from a fleet-wide fuel economy improvement.

Although financial incentives linked to fuel costs seem to play a minor role in vehicle choices, we identify differences across demographic groups. Why this is important depends on how we interpret the apparently costly car choices. If the choices reflect underlying unobserved preferences, then perhaps richer people have a higher willingness to pay for hybrids for some reason unrelated to fuel savings. Or perhaps poorer drivers have higher discount rates. A policy that subsidizes hybrids would be an inframarginal

32. Average savings under the fleet-wide improvement are calculated as the mean cumulative savings from one extra mile per gallon, i.e., $(m_i p_g / \mu_i^2)F$ from eq. (10). For the redistribution scenario (2), we first multiply these savings by −1 for drivers below the median before taking the same mean again.

transfer to the rich. A policy that penalizes gas-powered cars would impose a regressive burden on poorer drivers.

On the other hand, if the observed pattern is the result of some market failure—say, the liquidity constraints faced by poorer households—then the policy implication is different. A subsidy for efficient cars could enable poorer households to afford them and save future fuel expenses. Our analysis suggests that drivers' failure to consider fuel costs is due neither to financial constraints nor to erroneous expectations about future driving.

Keep in mind, however, that our analysis considers only the private financial costs and savings for drivers. While those individual considerations weigh substantially in the benefit-cost analyses used to justify fuel economy standards, a complete assessment of their merits would depend on all of their social benefits, including reduced pollution externalities from fuel use.

In the end, we find exactly the kind of inattention to private fuel savings that might justify paternalistic regulations, in that higher-priced more efficient cars would save money for the average driver. But we also find many drivers who would lose money. Instead of systematically undervaluing fuel economy, drivers appear to simply ignore it.

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