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ABSTRACT

Economists promote energy taxes as cost-effective. But policymakers raise concerns about their regressivity, or disproportional burden on poorer families, preferring to set energy efficiency standards instead. I first show that in theory, regulations targeting energy efficiency are more regressive than energy taxes, not less. I then provide an example in the context of automotive fuel consumption in the United States: taxing gas would be less regressive than regulating the fuel economy of cars if the two policies are compared on a revenue-equivalent basis.

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Energy Efficiency Standards Are More Regressive Than Energy Taxes:

Theory and Evidence

For nearly 100 years, economists have been explaining that a pollution tax would reduce environmental damage in the least costly way.[1] But that advice is almost never followed. Instead, environmental regulations typically rely on technology or performance standards. In the United States, rather than a cost-effective carbon tax to reduce greenhouse gas emissions, we rely on energy efficiency standards. Rather than a gasoline tax, we set fuel economy standards for cars.

A recurring concern about pollution taxes is that they would be regressive. Lower-income households spend a relatively larger proportion of their incomes on energy and goods whose production uses energy, and as a result they would pay a disproportionate share of any tax on the carbon content of electricity or fuel.[2]

That basic argument can be seen in Figure 1, which plots annual household gasoline use by income, from the 2009 National Household Travel Survey (NHTS).[3] The poorest 5 percent of households use 247 gallons of gas per year, on average. The richest 22 percent, with incomes over ten times higher, each use about four times as much. A $0.29 per gallon gas tax—one estimate of the monetized climate damage from gasoline—would cost poor households $71 dollars per year and rich households $286. (This assumes no change in behavior in response to the tax, which is typical of these analyses but defeats its purpose.) Families with more than ten times the income would pay only four times the tax, and thus a gas tax would be regressive. So even though an energy tax would reduce energy use in the most cost-effective way, opponents raise distributional concerns.

But until now, no studies have asked the obvious follow-up question. Would an energy tax be more or less regressive than the energy efficiency standards used instead? If an energy tax would be more regressive, a case might be made to forgo the tax's cost-effectiveness in exchange for the efficiency standard's distributional benefits. But if the energy tax would be less regressive, that case collapses.

After making a few preliminary points in Section 1, I begin in Section 2 by describing the tradeoff between taxes and standards in theory, in a static, two-good model, with no uncertainty

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[1] The idea dates to Pigou (1920). There is now even a "Pigou Club" Wikipedia page listing economists and politicians who support the idea (https://en.wikipedia.org/wiki/Pigou_Club).

[2] For bipartisan examples see Bill Chameides, "Is the conservative-friendly carbon tax a regressive flat tax in disguise?" *The Huffington Post*, May 25, 2011; and "Who pays for cap and trade?" *The Wall Street Journal*, March 9, 2009. For recent examples see Mark Paul, Anders Fremsted, and James K. Boyce, "Can markets solve climate change?" *The Nation*, April 12, 2016; and Dan Wilson and Kyle England, "Initiative 732's Carbon Tax Hurts Families," *The Spokesman-Review* September 24, 2016. For a more academic example see Grainger and Kolstad (2010), which documents the regressivity of a broad-based carbon tax.

[3] The 2009 NHTS is the latest survey available. The 2016 NHTS is being collected now. For details see http://nhts.ornl.gov.

or discounting, where consumers differ only by income. Perhaps surprisingly, even this simple framework generates a stark result: an energy tax would be both more cost-effective and less regressive.

I then turn in Section 3 to an empirical application using automobiles and corporate average fuel economy (CAFE) standards, with data from the 2009 NHTS. The choice of automobiles as an example stems from the fact that cars are the one energy-using durable with readily available data on energy input, gallons of gasoline used. I show that in practice the theoretical result from Section 2 is borne out: a gasoline tax would be less regressive than a revenue-equivalent efficiency regulation. Moreover, the footprint-based CAFE standards adopted by the United States in 2011 have exacerbated the regressivity of US fuel economy standards, making them approximately as regressive as an equal-sized lump-sum tax per household.

Pieces of these results have been noted by others. Since economists first began studying energy efficiency, researchers have observed that lower-income households purchase less efficient appliances and vehicles, sacrificing higher future energy costs for lower current appliance costs. Hausman (1979) attributed that choice to liquidity constraints. Others have described behavioral explanations, such as present bias (Allcott and Mullainathan, 2010) and heterogeneity in discount rates (Newell and Siikamäki, 2015). But in the model I outline, even rational consumers differing only in their incomes choose energy-using appliances and vehicles with different levels of fixed costs and efficiency, and poorer households choose the low-fixed-cost, high-variable-cost models. As a consequence, either of the two policies under consideration—taxes or standards—make poor households worse off. But the burden of energy taxes falls relatively less on poor households than the burden of efficiency standards.

Researchers also have compared CAFE standards to gas taxes on efficiency grounds. Austin and Dinan (2005) estimate that a gas tax would cost 58 to 71 percent less than the CAFE standards, per gallon of fuel saved. More recently Jacobsen (2013) finds that the CAFE standards cost three to ten times as much as a gasoline tax, per ton of carbon dioxide avoided. So efficiency standards are, ironically, inefficient. That is easy to show in my simpler model as well.

A few researchers have analyzed CAFE standards on distributional grounds. Jacobsen (2013) shows that in the long run, welfare losses for the poorest households are twice that of the wealthiest, per dollar of income, and that therefore the CAFE standards are regressive. Davis and Knittel (2016) use nationally representative data on car registrations to show the same thing: CAFE standards disproportionately burden lower-income households.

Existing work by others has thus demonstrated three things: energy taxes like carbon and gas taxes are regressive; energy taxes are more cost-effective than energy efficiency standards; and efficiency standards are also regressive. Until now what has not been shown is whether energy efficiency standards are *less or more regressive* than an energy tax would be. If efficiency standards are less regressive, their extra costs might be worth the distributional benefits. If efficiency standards are more regressive, then energy taxes are both more efficient and more equitable. Answering that question is the goal of this paper: which policy is more regressive, energy taxes or efficiency standards?

One other current paper does pose a question similar to the one I pose here, though it's not the main focus: Davis and Knittel (2016). That paper has one major advantage over the approach I take, in that it uses comprehensive data on all vehicle registrations in the United States in 2012, including rich data about those cars' characteristics. The tradeoff is vehicles can only be matched with demographic information at the level of the US census tract in which the vehicle was registered, not at the level of the individual house. In particular, that paper cannot measure two key inputs necessary to compare the distributional effects of gas taxes and CAFE standards: how many cars each household owns, and how much gas those households use. For that reason, I rely on the NHTS. Though it is only a survey, and only covers one year, 2009, it does contain all the necessary information: household income, characteristics of the vehicles owned by the household, and gasoline consumption.

Before describing the model and empirics, I need to be clear about four points. First, I focus on the "static" incidence of taxes throughout, ignoring the demand response that is the intended result of the policies. Second, critical to any calculation of tax incidence is what happens to the tax revenue. Third, energy efficiency standards can be treated analytically as equivalent to a tax on inefficient appliances or vehicles; and fourth, to study the incidence of energy efficiency, I need to take sides in the "energy paradox" debate. Readers not concerned about those clarifications can skip to the theoretical model in Section 2, and readers who only want the main empirical results can go straight to Section 3.

1. Preliminary Points

Energy efficiency regulations come in two broad categories. Most, like appliance standards and building codes, set minimum thresholds for efficiency. Underperforming appliances cannot be sold and substandard buildings cannot be constructed. The distributional consequences of these bans on inefficient products seems self-evident. If rich people buy the banned inefficient products the ban is progressive; if poor people buy them the ban is regressive. Those distributional outcomes are simple to show empirically, and I will return to them in the empirical analysis in Section 3.

A second type of efficiency regulation raises the price of inefficient goods. One example is the CAFE standards that have regulated automobiles in the United States since 1978 and in Europe since 2009. These types of price-based standards can be compared directly to energy taxes using graphs like Figure 1. To make the comparison, I need to raise four preliminary points.

Static Incidence

First, the distributional effect that I describe here is the "static" incidence of the energy tax, a straightforward calculation based on pre-tax consumption. Figure 1 provides an example: poor households spend a larger fraction of their incomes on gasoline and therefore are assumed to bear a larger fraction of the economic burden of a tax on gasoline. To know the true economic incidence—measured by equivalent or compensating variation—we would need to know the price and income elasticities of demand for energy by each income group, and the supply elasticities of energy and energy efficient cars and appliances. If the welfare loss to each group from a tax on a particular good is proportional to the group's pre-tax consumption of that good, then this static incidence will be a good measure of the true economic incidence. Grainger and Kolstad (2010) call this a "first-order" estimate of the incidence.

Revenue Matters

Second, critical to the distributional effects of either an energy tax or an efficiency standard is whether it raises revenue and how that revenue is spent. To see why that matters, take the $0.29 gas tax as an example.[4] The key to the tax's cost-effectiveness is the $0.29 per gallon opportunity cost of driving. But that $0.29 per gallon cost could be achieved by nearly identical policies with vastly different distributional consequences, merely by changing the fiscal policy associated with the tax revenues.

On the simplest level, from examining Figure 1, a $0.29 per gallon gasoline tax would be regressive, costing poor families $71 dollars per year and rich families $286, a $215 difference. Rich families pay four times the gas tax even as they earn over ten times the income.

But suppose we divided up the the total tax revenue evenly among all households, as a lump-sum rebate. If Figure 1 represents all US households, each would receive a check for $212. The poorest group would pay $71 each in gas taxes and come out ahead by $141. The richest group would pay $286 each in gas taxes for a net loss of $74. Unlike the tax alone, this rebate policy would be progressive.

Or consider the alternative of subsidizing gas conservation at $0.29 per gallon. Give every household an imaginary allotment of, say, 991 gallons of gasoline per year, the amount used by the richest 23 percent of households in 2009. Then pay each household a $0.29 subsidy for each of those 991 gallons not consumed. Looking again at Figure 1, with no change in behavior, rich families would get nothing, while the poorest families would receive a check for $215.[5]

From a cost-effectiveness perspective, the three policies are the same. Drivers would face the same $0.29 opportunity cost per gallon, providing exactly the same cost-effective incentive to conserve.[6] But the policies have very different distributional consequences for reasons unrelated to their cost-effectiveness or environmental efficacy. While the $0.29 gas tax raises revenue, disproportionately from poor households, the $0.29 the subsidy disburses funds,

[4] The official US social cost of carbon is $36 per ton in 2015, with future damages discounted at 3 percent. Because burning one gallon of gasoline releases 17.68 pounds of carbon, the carbon tax on gasoline would be about $0.29 per gallon ($36/ton × 1/2204.6 tons/lb × 17.68 lbs/gallon). See https://www3.epa.gov/climatechange/EPAactivities/economics/scc.html for the social cost of carbon, and http://www.eia.gov/tools/faqs/faq.cfm?id=307&t=11 for carbon per gallon of gasoline. This ignores other externalities from driving: local air pollution, congestion, and accidents. The exact tax rate doesn't matter, however, as it only serves as an example here.

[5] $215= $0.29×(991-247).

[6] This ignores income effects on driving and on the decision to own a car.

disproportionately to poor households. Unless we know how the tax revenues will be spent or the subsidy funds raised, we cannot assess their distributional consequences. In my theorectical and empirical examples to follow, I take care to compare taxes and standards with equivalent financing.

Efficiency Standards Are Equivalent to Inefficiency Taxes

A related point is that energy efficiency standards are economically equivalent to a tax on inefficient appliances or vehicles. For example, an equivalent tax on air conditioners would be levied on the unit's watt-hours of electric power used to create one British thermal unit (BTU) of cooling. For vehicles, a tax would be levied on the car's gallons per mile (gpm), the inverse of the common miles per gallon (mpg) measure of efficiency.

In the case of automobiles, CAFE has the same cost-effectiveness at the margin as an outright tax on inefficient cars with high gpm or a pure subsidy to low-gpm cars (setting aside the revenue consequences, per the previous section). Appendix 1 demonstrates that result in a partial equilibrium model based on Kwoka (1983). Anderson and Sallee (2016) and Gillingham (2013) similarly model the CAFE standard as a "feebate"—a set of taxes and subsidies based on the fuel economy of the vehicle rather than on actual gas consumption.

Framing efficiency standards as taxes on inefficient appliances or vehicles makes them easier to compare to an energy tax. Both raise revenue. The energy tax targets fuel consumption directly. The inefficiency tax targets appliance or vehicle characteristics and could be paid either at the time of purchase or annually as part of registration. As with an energy tax, the distributional effects of an inefficiency tax would depend on the collection and disbursement of the revenues. And again, it will be important to compare taxes and standards with equivalent financing.

The Energy Paradox

Finally, note that by describing efficiency standards as a tax on inefficient appliances or vehicles, I am implicitly taking sides in the "energy paradox" debate. Some policy advocates support efficiency standards on the grounds that market failures or consumer errors lead to the purchase of less efficient appliances and vehicles than would be privately optimal. In that view, an efficiency standard improves private welfare, even without considering the environmental benefits. The US Department of Energy estimated that its 2011 energy efficiency standards for refrigerators would save owners $200 over the life of the appliance.[7] Similarly, the US

[7] US Department of Energy, "Department of Energy joins with manufacturers, environmentalists to announce new efficiency standards for home refrigerators," press release, August 26, 2011, www.energy.gov/articles/department-energy-joins-manufacturers-environmentalists-announce-new-efficiency-standards.

Department of Transportation (DOT) says that that its 2016 CAFE standards will save drivers over $4,000 in gasoline costs, more than offsetting the higher up-front vehicle costs.[8]

The case of the privately beneficial standard raises a natural question: if more energy efficient cars would make consumers better off, why don't consumers demand them and manufacturers sell them without being regulated? This "energy paradox" applies to cars, appliances, and home construction and forms the basis for an enormous amount of research. Greene (2010) summarized that body of work for the US Environmental Protection Agency, suggesting that for automotive fuel economy, the empirical literature is evenly divided between studies showing that consumers do undervalue fuel savings and that they do not. Allcott and Greenstone (2012) conclude from the literature that "it is difficult to substantiate claims" that consumers and firms "fail to make investments that would increase utility or profits." Recently, several papers have added to the ranks of those finding they do not (Allcott, 2013; Busse, Knittel, and Zettelmeyer, 2013).

More importantly for this paper, if the regulation makes consumers better off even ignoring the environmental benefits, then the distributional comparison with a gasoline or energy tax becomes moot. Thus, in what follows I focus on the case where both the tax and the standard reduce welfare. That is what recent empirical work seems to suggest, and the question of the gas tax's regressivity is otherwise irrelevant.

2. Energy Taxes Versus Efficiency Standards in Theory

The model I present in this section has two aims. First, it describes the framework I use to compare revenue-equivalent energy taxes and efficiency standards. And second, the model shows theoretically, with the fewest possible assumptions, the result I find empirically in Section 3: efficiency standards are more regressive than energy taxes.

Start with a representative consumer or household, with utility over two goods, x, a numeraire good with a price of 1, and s, energy services, such as cooling, heating, refrigeration, lighting, or miles driven. Denote efficiency as μ, energy services per unit of energy, which for cars would be mpg. Energy services (s) are then the product of energy consumption (e) and efficiency (μ): $s=e\mu$.

$$U(s,x) = U(e\mu, x)\ . \tag{1}$$

For air conditioners this means cooling equals kilowatt hours of electricity used times BTU per kilowatt hour. For cars, miles is gas consumption times mpg.

Households have income (Y) to spend on the numeraire and energy services. Rather than purchase energy services directly, they purchase it indirectly through the cost of energy and the

[8] US Environmental Protection Agency Office of Transportation and Air Quality, "EPA and NHTSA finalize historic national program to reduce greenhouse gases and improve fuel economy for cars and trucks," regulatory announcement, April 2010.

energy efficiency of the appliance or vehicle. More efficient appliances and cars are more expensive, and the price of that extra efficiency is p_μ.[9] The household budget is

$$Y = x + p_e e + p_\mu \mu \,. \tag{2}$$

For now assume that the cost of energy efficiency (μ) has a constant price (p_μ), but I will relax that assumption shortly.

Figure 2 depicts the setup for two appliances. A household can purchase no energy services and spend its entire income (Y) on the numeraire. Or it can purchase an inefficient appliance for $p_\mu \mu_i$. In that case, the cost of one unit of the energy service will be p_e/μ_i, the slope of the solid budget line in Figure 2. Or third, the household can purchase a more expensive and efficient appliance (μ_e). Then its budget in Figure 2 has a lower intercept ($Y - p_\mu \mu_e$) and the correspondingly shallower, dashed budget line with slope p_e/μ_e.

Figure 2 transforms an intertemporal decision (pay more up front, save fuel costs later) into a one-shot, static decision. Think of $p_e e$ as the present discounted cost of purchased energy over the life of the durable and $p_\mu \mu$ as the up-front fixed cost of its efficiency. Alternatively, think of $p_e e$ as annual costs and $p_\mu \mu$ as the annual amortized fixed cost of efficiency. Or even more simply, consider the energy-using durable to be something that is leased for one period with fixed rental cost $p_\mu \mu$ and variable costs $p_e e$.

The household chooses e and μ to maximize utility in (1) with respect to the budget constraint in (2), leading to two familiar looking first-order conditions:

$$\begin{aligned} &\text{(i)} \qquad U_s/U_x = p_e/\mu \\ &\text{(ii)} \qquad U_s/U_x = p_\mu/e \,. \end{aligned} \tag{3}$$

The first comes from maximizing with respect to e. It just says that the marginal rate of substitution between energy services and the numeraire should equal the cost of energy services from purchasing more energy, for a given quantity of efficiency (μ), which is the price of energy (p_e) divided by output per unit of energy (μ). The second condition in (3) comes from maximizing with respect to μ and indicates that same marginal rate of substitution equals the cost of energy services from purchasing more efficiency, for a given quantity of energy (e), which is the price of efficiency (p_μ) divided by energy. Basically there are two ways to purchase an extra unit of energy services (s). With given efficiency, μ, you can buy some more energy at price p_e, or with a given amount of energy, you can buy a more efficient appliance at price p_μ.

Now add public policies to the mix. First, a tax on energy, t_e raises the price of energy to $p_e(1+t_e)$. That tax in turn raises the cost per unit of energy services to $p_e(1+t_e)/\mu$, rotating the budget lines in Figure 2 down. Panel (a) of Figure 3 depicts such a tax.

[9] The US Department of Transportation estimates that fuel economy standards add nearly $1,000 to the cost of a typical vehicle.

Next consider an energy efficiency standard. To put the standard on the same revenue basis as the tax, imagine the efficiency standard as an "inefficiency tax" t_μ or tax on μ below some regulated amount, $\bar{\mu}$. The new budget line with both taxes t_e and t_μ added is

$$Y = x + (p_e + t_e)e + p_\mu \mu + t_\mu(\bar{\mu} - \mu). \tag{4}$$

Each unit of energy efficiency, μ, costs $p_\mu – t_\mu$. Note that the tax on inefficiency is effectively a subsidy for efficiency. It shifts the budget constraints down, but shifts the efficient ones down less because they have higher μ. Panel (b) of Figure 3 depicts that inefficiency tax.

To see how taxes on energy and inefficiency would be borne differentially by rich and poor households, turn back to the first-order conditions in equations (3). Cross multiplying, the two equations imply that $p_e e = p_\mu \mu$. Expenditures on energy equal expenditures on efficiency, and the ratio of e to μ is fixed at p_μ / p_e. Why? No matter the utility function in (1), energy services are a function of the product of e and μ. This is like having a subutility function over e and μ that is Cobb Douglas. However it decides between the two goods s and x, the household will divide expenditures on s evenly between its two components, e and μ.

What does that imply for the relative regressivity of energy and inefficiency taxes? Assume energy services s is a normal good. As income increases s increases, which means the product $e\mu$ increases. Since the ratio e/μ remains constant (from the first-order conditions in (3)), both e and μ increase proportionately. Richer households use more energy e and purchase more efficient appliances μ. Tax payments on energy $t_e e$ will increase with income, whereas tax payments on inefficiency $t_\mu(\bar{\mu} - \mu)$ will decrease with income. An energy tax will be less regressive than an efficiency standard.

As an aside, note that the energy tax is also more cost-effective than the inefficiency tax, meaning that it generates less energy savings for the same revenue and welfare change. Figure 4 depicts the scenario. An energy tax, with revenues refunded in lump sums to balance the budget, leads to a steepening of the slope of the budget constraint and a reduction in energy services to s^A, at point A on Figure 4. An inefficiency tax with refunded revenues leads to a shallower budget constraint and increased services s^B, at point B.

Because the budget balances at points A and B and expenditures on energy and energy efficiency will be equal under each scenario,

$$Y = x^A + 2(p_e + t_e)e^A = x^B + 2p_e e^B, \tag{5}$$

where in each case I have replaced expenditures on the sum of energy and energy efficiency with twice the expenditures on energy. Rewriting (5),

$$x^A - x^B = 2[p_e e^B - (p_e + t_e)e^A]. \tag{6}$$

We know that $x^A > x^B$ because preferences are convex. As a result, the term in square brackets on the right side of (6) is positive, or

$$p_e(e^B - e^A) > t_e e^A, \tag{7}$$

which means in turn that $e^B > e^A$ so long as t_e>0. In other words, an energy tax reduces energy demand more than a revenue-equivalent subsidy for efficient appliances. In theory, energy taxes are both more cost-effective and less regressive.

One strong assumption so far has been that the cost of energy efficiency is linear: $p_\mu \mu$. That can easily be relaxed. Suppose the fixed cost of the energy-using durable is some general function of efficiency, c(μ). Then the second first-order condition in (3) becomes

$$\text{(ii)} \qquad {U_s}/{U_x} = {c'(\mu)}/{e} \; . \tag{8}$$

Putting it together with (i) in equation (3) gives

$$p_e e = c'(\mu)\mu \; . \tag{9}$$

Differentiating with respect to income, Y,

$$p_e \frac{\partial e}{\partial Y} = \frac{\partial \mu}{\partial Y}\left[c'(\mu) + c''(\mu)\mu\right] . \tag{10}$$

If $\partial e/\partial Y$ and $\partial \mu/\partial Y$ are both positive, then richer households consume more energy (e) and more efficiency (μ). A tax on energy t_e will be less regressive than a tax on inefficient appliances or cars t_μ. Are $\partial e/\partial Y$ and $\partial \mu/\partial Y$ both positive? They will be if the term in brackets in equation (10) is positive. The first term in the brackets, $c'(\mu)$, is positive by assumption. (More efficient appliances cost more.) So a sufficient condition for the whole term in brackets to be positive is that $c''(\mu) > 0$, which just means that the cost of energy efficiency is increasing in efficiency, or convex.[10] That seems intuitive. The more energy efficient an air conditioner or vehicle, the costlier it is to make it even more efficient.

In sum, even a simple model with few assumptions predicts that an energy tax will be both more efficient and less regressive than an efficiency standard. All it requires is that energy services be normal, the cost of energy efficiency be convex (or not too concave), and the efficiency standard be framed as a revenue-equivalent tax on inefficient appliances or cars.

The benefit of this simplification is a clear demonstration of how fuel economy choices vary with income. Richer people spend more on fuel efficiency, face a lower cost of energy services, and use more energy to generate those services.

Although it is simple—simplistic even—this framework lends itself to empirical corroboration. In practice richer households should purchase more efficient air conditioners and vehicles, and use more electricity for air conditioning and gasoline for travel. In the next two sections I look for those empirical patterns in the data.

[10] Technically all we really need is for $c''(\mu)\mu/c'(\mu) > -1$—that is, the cost of efficiency can be concave but not too concave.

3. Comparing Energy Taxes and Efficiency Standards in Practice

The logic of Section 2 applies to any energy-using durable: cars, air conditioners, lightbulbs, washing machines, and even entire houses. In each case, Section 2 predicts that richer households will purchase more energy efficiency *and* more energy. Documenting the first is relatively easy, but obtaining household data on energy use is difficult for most energy-using appliances. The one exception is vehicles. The NHTS data contain information about household incomes, the characteristics of those households' vehicles, and how much gasoline they use annually. So for this empirical application I focus mainly on cars and light trucks, returning to other appliances and building codes briefly at the end.

Fuel Economy and Fuel Use in the NHTS

The 2009 National Household Travel Survey contains demographic information for about 150,000 households and their vehicles. I drop the households with more than five vehicles or missing incomes, and I drop cars or light trucks with missing characteristics, such as size. That leaves 101,232 households, which own 74,348 cars and 71,246 light trucks. Descriptive statistics about those households and their vehicles can be found in Table 1.

Gasoline taxes do exist in the United States, but they are not designed to reduce pollution and thus do not incorporate externalities such as the social cost of carbon. The federal gas tax has been \$0.184 per gallon since 1993, and state gas taxes vary from \$0.12 to \$0.52 per gallon. The tax revenues mostly fund road construction and maintenance, so they serve more as user fees than a deterrent to gasoline consumption or driving.

Fuel economy regulations in the United States take the form of CAFE standards. Each carmaker has to ensure that the sales-weighted average of the vehicles it sells in the United States exceeds a minimum threshold mpg to avoid paying fines. Carmakers can sell cars with lower fuel economy but only if they are offset by sales of more efficient cars so that the carmakers' overall averages meet the minimum. For cars, that minimum started at 18 mpg in 1978 and rose to 27.5 mpg by 1989, where it remained for the next two decades before rising again to 37.8 mpg in 2016. For light trucks like pickups and SUVs, the standards started at 17 mpg in 1979 and rose to 20 mpg by 1984. They stayed roughly constant until 2005, when they began rising to 28.8 mpg in 2016.[11]

As noted, economists have observed that the gas tax is too low and the CAFE regulations inefficient, but distributional concerns are raised about increasing the gas tax. To compare the distributional consequences of the two policies, we can think of the fuel economy standard as a tax on the gpm of the vehicles owned by each household and see how its static incidence stacks up against that of the gas tax.[12]

[11] The 2016 standards are averages, based on projected sales. See NHTSA, "NHTSA and EPA establish new national program to improve fuel economy and reduce greenhouse gas emissions for passenger cars and light trucks," http://www.nhtsa.gov/staticfiles/rulemaking/pdf/cafe/CAFE-GHG_Fact_Sheet.pdf.

[12] The model in Section 2 subsidizes mpg, or μ. Here I tax the inverse, gpm, or $1/\mu$, because the actual US CAFE regulations target gpm rather than mpg. The US CAFE standards are expressed as miles per gallon

Consider again the \$0.29 per gallon carbon tax. Multiplying the \$0.29 tax by the gallons consumed per household in each income group, from column (3) of Table 1, yields the static incidence of the tax, ranging from \$71 per year for the poorest households to \$286 for the richest. Those figure are listed in column (1) of Table 2 and plotted as the leftmost darkly shaded columns in Figure 5.

To make the comparison fair, the equivalent gpm tax has to raise the same revenue as the gas tax. That works out to \$0.39 per gpm per year, or \$39 per gallon per *hundred* miles (gphm) to make the units simpler. The resulting static incidence of that tax is listed in column (2) of Table 2, and plotted as the middle gray columns in Figure 5.[13]

Like the gas tax, a gphm tax would be regressive. The explanation can be seen in Table 1. Column (5) shows that cars owned by richer households tend to use more gas per mile driven.[14] What's more, column (2) shows that richer households own more cars, and fuel economy standards impose a cost on each car owned. The total gphm per household across all cars is listed in column (6) of Table 1. The richest households have more than ten times the income as poor households but would pay less than three times as much in a gphm tax.

Which is more regressive, the gas tax or the gphm tax? In this static framework, the answer depends on whether gasoline or gphm increases more with income. Column (3) of Table 1 shows that rich households use four times more gasoline than poor households. Column (6) shows that rich households' cars use three times the gas per mile (in total, accounting for the fact that they have more cars). So a gas tax would increase faster with income than a gphm tax and would therefore be less regressive. Because the gphm tax is equivalent at the margin to the CAFE standards, in the United States a gas tax would be less regressive than existing fuel economy standards.

Of course, the CAFE standard is not exactly the same as a gphm tax. An important caveat is that as currently configured, the CAFE standard taxes inefficient cars and subsidizes efficient ones, while a gas tax would tax all drivers. A gas tax that refunded its revenue in some way would be fiscally equivalent to CAFE and less regressive (or more progressive).

To see that, compare a gas tax and a gphm tax that both refund their revenues in a lump sum. The resulting figure would look exactly like Figure 5, but each column would be shifted down by \$215, the amount of the refund check. The poorest households would end up ahead \$141 under the gas tax, but only \$121 under the gphm tax. The richest households would end up behind \$74 under the gas tax, but only \$47 under the gphm tax. Both policies would be

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(mpg) rather than gallons per mile, so the actual standard is a harmonic average. That complicates things needlessly. Since gpm is the inverse of mpg, the Department of Transportation takes an average of the inverse of gpm, and then inverts the average (Fischer, 2009).

[13] Using the households in Table 1, I first calculate the revenue that would be raised by the \$0.29 gas tax. Then I divide that total revenue by the sum of all the gphm for all the vehicles, yielding the dollar tax per gphm that would raise the same revenue, again assuming no change in behavior. The average vehicle in the sample uses 3.98 gphm (25 mpg). A \$39 per gphm tax would cost \$155 per year for that vehicle.

[14] Column (5) of Table 1 reports the total gphm across all cars owned, which would be the tax base for a gpm tax. Columns (2) and (3) report the gpm for the average car.

progressive, but a gas tax would be more progressive than a fuel economy standard. No matter how we compare the two, the gas tax is less regressive or more progressive than the gphm tax, so long as they are compared on a revenue-equivalent basis.

But that's not the end of the story because in 2011 the US DOT made an important change to the CAFE regulations with significant distributional implications: adjusting for the size, or "footprint," of vehicles.

Footprint-Based CAFE Standards

Before 2011, the fuel economy targets were simple averages. Each manufacturer could meet those targets by selling more small cars, which tend to consume less gasoline per mile, and fewer large cars, which consume more. Starting in 2011, the CAFE regulations shifted to footprint-based standards. A vehicle's footprint is the area under its four tires, measured in square feet.

The new footprint-based standards give larger cars a more lenient gphm target. A carmaker that sells only small cars in 2016, with footprints of 41 square feet or less, must meet a target of 2.43 gphm (41.09 mpg). A carmaker selling large cars with footprints over 56 square feet needs only to achieve 3.23 gphm (30.96 mpg). Cars between those two extremes face a sliding scale, with an average of 2.65 gphm (37.8 mpg) based on projected sales.[15] That formula is illustrated in Figure 6.

Ito and Sallee (2015) suggest that the switch to footprint-based CAFE standards "might be justified by distributional considerations." But as can be seen in Figure 6, that depends on the shape of the footprint formula and who buys the larger cars. The dotted line in Figure 6 plots the projected average fuel economy for cars (not light trucks) in 2016, 2.65 gphm. Under the simple CAFE rule that prevailed before 2011, carmakers could sell a mix of vehicles, illustrated by the top 50 bestselling cars on the graph. But the weighted average of sales would have to equal or fall below 2.65 gphm. As an example, General Motors could sell more Cadillacs, which cost more than $50,000, but they would have to be offset by sales of cars like Chevrolet Sonics, which cost under $20,000. Expensive Cadillacs would face an implicit tax (λR in Appendix 1), and cheaper Sonics an implicit subsidy (λ).

The solid line in Figure 6 plots the 2016 gphm target by footprint. Now large Cadillacs meet the standard, while smaller Sonics do not. GM can now sell more noncompliant Sonics, but they must be offset by sales of Cadillacs. The inexpensive Sonics now face the implicit tax, while the expensive Cadillacs receive the subsidy.

The example in Figure 6 illustrates the potential for the footprint-based standard to alter the regressivity of the CAFE rules. If poor people disproportionately purchase cars that are relatively inefficient for their size, like Sonics, the switch to footprint-based standards has exacerbated the regressivity of the fuel economy standards. To see whether the example in

[15] The average is 32.7 mpg for combined cars and light trucks (US EPA and NHTSA, 2010, Table IV.E.2-1).

Figure 6 applies in general, and whether the switch to footprint-based standards has in fact made the CAFE rules more regressive, turn back to Table 1.

Table 1 lists the average vehicle footprint by household income in column (7).[16] Richer households tend to own larger cars. Column (5) shows that those cars use more gas per mile.[17] Under the old CAFE standard, all that mattered for fuel economy was column (5). Under the new footprint-based standard, what matters is column (5) relative to column (7), which is higher for poor households than for rich households.

Another way to see that the Sonic–Cadillac example in Figure 6 represents a general result—and that the 2011 switch to footprint-based standards was therefore regressive—is in Figure 7. The typical car driven by a household in the poorest income group is both smaller and more fuel efficient than the typical car driven by richer households.

The next task is to measure how this switch affects the regressivity of the CAFE rules by translating the footprint-based rule into a tax, so it can be compared on a revenue-neutral basis to the gas tax and gphm tax in Figure 5. I start with the actual formula used by the CAFE rules for model years 2012–16.

$$\begin{array}{ll} \text{Cars:} & \text{Target gphm} = A + \textit{footprint} \times 0.05308 \\ \text{Light trucks:} & \text{Target gphm} = A + \textit{footprint} \times 0.04546 \end{array} \qquad (11)$$

For each square foot in a vehicle's footprint, required fuel consumption is allowed to increase by 0.053 gphm for cars and 0.045 for light trucks. The constant, A, decreases each year as the regulation tightens, from 0.5842 in 2012 to 0.2406 in 2016 for cars, and from 1.46 to 1.0413 for light trucks.[18]

To calculate the tax base for each vehicle, I use the difference between its fuel economy and the target for a vehicle with its footprint. I then sum that number across all vehicles in the 2009 NHTS to find the economy-wide tax base. The units of this tax base are gphm in excess of the target, where larger cars and light trucks have higher gphm targets. To ensure the gphm tax raises the same revenue as the $0.29 gas tax, I divide the gas tax revenues calculated earlier by the economy-wide footprint-based gphm tax base. That division yields a per-unit gphm tax rate that I apply to each household.

Tax revenues by income class for this footprint-based gphm tax are in column (3) of Table 2. The poorest households pay more than under either the gas tax or the straight gphm tax,

[16] The CarQuery data contain cars' wheelbase (length from front to rear tires) but not track width (distance between left and right tires). I approximate track width based on regression estimates from the top 100 bestselling cars and trucks. The estimates are track width (in millimeters) = 911.2 + 0.365 × width for cars, and 799.1 + 0.502 × width for light trucks. Footprint is track width times wheelbase.

[17] In the theoretical model in Section 2, rich households purchase more energy efficiency, but here rich households purchase less efficient cars. The difference is that in Section 2, energy-using durables differ only in their efficiency and price. In practice, cars differ along multiple dimensions correlated with both price and efficiency. Richer families purchase larger, faster-accelerating cars. I control for those other vehicle features in Section 4.

[18] US EPA and NHTSA, 2010, 25612–15.

and the richest households pay less. To show the distinction visually, Figure 5 plots those revenues as the third and lightest-shaded set of columns.

A Lorenz-Like Curve Comparing Energy Taxes and Efficiency Standards

For another visual representation of the distributional consequences, see Figure 8, where I plot lines similar to Lorenz curves but for tax revenues rather than incomes. The bottom axis plots the share of all households, from 0 to 1, and the left axis plots the share of taxes. The 45-degree line represents a per-household tax. Each household pays the same amount regardless of income, so that *x* percent of households always pay *x* percent of total taxes. The 45-degree line is the household equivalent of a head tax.

The bottom line (with open square markers), denotes the tax shares paid by each household under the $0.29 gas tax from Table 2 and Figure 5. It is bowed downward because poor households pay less in gas taxes than rich households. But it still denotes a regressive tax because a proportional income tax would be even more bowed below the 45 degree line.

The second line (with solid circles) denotes the gphm tax from column 2 of Table 2. It is closer to the 45-degree line, thus more regressive. The third line (with open diamonds), the footprint-based gphm tax, essentially mirrors the 45-degree line. The footprint-based gphm tax is as regressive as a household-level head tax.

Vehicle Age

As Jacobsen (2013) points out, CAFE standards apply to new cars, and poor households tend to buy used cars. As a result, poor households do bear some of the burden of the CAFE standards but only after those new cars trickle into the used car market—and only to a depreciated extent relative to rich households that purchase new cars. So it is worth considering the distributional consequences of a gphm tax that is disproportionately borne by owners of newer vehicles, even though a true gphm tax could be levied on all cars, new and used.

I begin by assuming that the burden of the CAFE standard declines proportionally to the price of used cars, from the National Automobile Dealers Association (NADA).[19] I regress the used car price on age and age squared and calculate weights equal to the ratio of predicted prices for cars of each vintage to the price of new cars. The weights vary from 1.0 for new vehicles down to 0.49 for 21-year-old vehicles.[20] I then scale the gphm tax so that total tax revenues equal those collected from a $0.29 gas tax, but where owners of older cars pay less than owners of newer cars, proportional to the weights from the vehicle age regression. For comparison, I also calculate a footprint-based version of that depreciation-adjusted gphm tax, again ensuring equal total revenues.

[19] www.nada.com.

[20] I also tried assuming the gpm tax declines linearly with the age of the car, from 100 percent down to zero for the oldest cars in the sample. That straight-line depreciation yields nearly identical results to the price-based depreciation.

The results are plotted in Figure 9. For reference, the gas tax from Figure 8 is plotted as the dashed line with open square markers. The depreciation-adjusted gphm tax lies almost on top of the gas tax, suggesting that even if we account for the fact that CAFE standards fall disproportionately on largely wealthier owners of new cars, the CAFE standards are just as regressive as the gas tax. Moreover, the footprint-based version (denoted by open diamonds) is more regressive than the gas tax, appearing about halfway between the gas tax and a household-level head tax represented by the 45-degree line.

On a revenue-neutral basis, a gasoline tax would be regressive, fuel economy standards more regressive, and the new footprint-based fuel economy standards that the United States switched to in 2011 the most regressive of the three. Even if we skew the fuel economy standards toward new cars, the gas tax is no more regressive than the older standards and is less regressive than footprint-based standards. Economic theory tells us that the gas tax would be the most cost-effective policy. This analysis suggests that it would also be the least regressive.

The next section ties up an important loose end from the theoretical model in Section 2: demonstrating that richer people buy more efficient vehicles, appliances, and houses.

4. Richer Households Buy More Efficient Vehicles, Appliances, and Houses

Section 2 showed that in a simple household model, an energy tax would be less regressive than a revenue-equivalent energy efficiency standard. That results follows from the model because richer households purchase more energy efficient products and use them more. Section 3 showed that in the case of cars, a gas tax would be less regressive than a flat gphm tax, which would in turn be less regressive than a footprint-based gphm tax. This final section shows that these results are more general, for vehicles, household appliances, and building construction.

Automobiles

The model in Section 2 predicted that richer households would purchase more energy efficient appliances and vehicles. But Table 1 shows that rich households drive cars that are less fuel efficient, not more. The apparent contradiction hinges on the fact that in the theoretical model in Section 2, appliances or vehicles differ only in their energy efficiency (μ). But in practice, rich households' cars are larger, heavier, accelerate faster, and differ from poor households' cars in many other ways that sacrifice fuel economy.

To control for those other vehicle characteristics correlated with income and fuel economy, I take two approaches. First, I control for all other vehicle characteristics by examining models that come in two versions: an ordinary gasoline-powered version and a hybrid battery-powered version. There are 5,211 such vehicles in the 2009 NHTS, in 8 different model pairs. They are listed in Table 3. If the hybrid and gasoline versions of the vehicles are otherwise identical, then we can compare the two without concern about other car characteristics that may affect fuel economy.

Table 4 describes the differences between the hybrid and non-hybrid cars and the households that own them. As predicted by the theory in Section 2, the hybrids are owned by households with higher incomes. And, consistent with the model, they get better gas mileage, are driven further each year, and cost more.

Table 5 takes a different approach, using all the vehicles in the NHTS that could be matched with CarQuery data on vehicle characteristics.[21] I regress fuel economy (in gallons per *thousand* miles to make the units sensible) on vehicle characteristics and household income. Column (2) regresses fuel economy on just the log of household income, taken as the midpoint of the categorical variables in the NHTS. The coefficient on income (6.78) means that richer households' cars consume more gasoline per mile, as noted in Table 1 and in contradiction to the theoretical prediction. Column (3) of Table 5 regresses fuel economy on four vehicle characteristics: engine power, length, width, and height. Each adds statistically significantly to gallons of gas consumed per mile.

Column (4) of Table 5 includes income and vehicle characteristics together. The coefficient on the log of household income suggests that households with 10 percent higher income own cars that use 0.38 fewer gallons of gasoline per thousand miles. If the car is driven 10,000 miles in a year, that adds up to only 3.8 fewer gallons of gasoline, or about $1 in payments for a $0.29 gasoline tax.[22] Richer households drive cars that are statistically significantly more fuel efficient, but that difference is tiny.

So although the conclusion supports the results from Section 2, the difference in efficiency does not by itself explain the fact that a fuel economy standard would be so much more regressive than a gasoline tax. Rather, the difference in regressivity between taxes and standards stems from car ownership increasing less steeply with income than miles driven.

Appliances and Buildings

The model in Section 2 has the same predictions for appliances and buildings as it has for cars. Richer households will own more energy efficient appliances and homes and use more energy to run them.

Demonstrating the first part of that prediction is straightforward. Table 6 reports the average incomes of households surveyed in the 2009 Residential Energy Consumption Survey (RECS).[23] Each row lists a different household energy-efficiency characteristic, and the average incomes and numbers of houses with and without those characteristics. For example, the average incomes for households reporting that their homes had double or triple-paned windows" was 30 percent higher than the incomes for homes without that energy-saving feature. A mandate requiring all homes to have double-paned windows, or a tax on homes that do not, would be borne disproportionately by low-income households. For every one of the seven energy

[21] http://www.carqueryapi.com/

[22] A version using income categories rather than the log of income yields the same result.

[23] The RECS is collected by the US Energy Information Administration. See www.eia.gov/consumption/residential.

efficiency features listed in Table 6, households with the feature have significantly higher incomes. As predicted, income and energy efficiency are positively associated.

The second part of the theory—that richer households will use more energy in those appliances and homes—is more difficult to assess. No data tell us how many loads of laundry or dishes were washed by the Energy Star appliances, or how much light was cast by the compact fluorescent bulbs, let alone the energy services (*s* in the model) provided by the double-paned windows. So although we can tell from Table 6 that an energy efficiency mandate or tax would be regressive, directly comparing that to an energy tax is not possible without data on appliance-specific energy use.

5. Discussion

Pigou demonstrated in 1920 that a pollution tax would be the most cost-effective means of reducing pollution. That attribute—cost-effectiveness—should appeal to environmentalists worried about climate change. And it should also appeal to those concerned about the costs associated with tackling climate change. But in the nearly 100 years since Pigou, there have been almost no examples of pollution taxes.

Arguments against carbon taxes to combat climate change often invoke their distributional consequences. In the United States, we have mostly relied on energy efficiency standards rather than energy taxes, without ever making the direct distributional comparison. We know energy or pollution taxes are cost-effective and regressive, and we know energy efficiency standards are less cost-effective. But are efficiency standards also less regressive? If they are, some might view that efficiency-equity tradeoff as worthwhile.

To answer this question, I demonstrate three ideas. First, it is easy to write down a simple, static, two-good, representative household model in which an energy tax is less regressive than an energy efficiency standard. The only underlying assumptions are that energy services are normal, the efficiency standard is representable by a tax on inefficient vehicles or appliances, and the cost of efficiency is convex, or at least not too concave. As a consequence, we should not be surprised to learn that empirically, energy taxes are both more cost-effective and more progressive than efficiency standards. There is no efficiency–equity tradeoff.

Second, in the particular case of the US automobile market, a gasoline tax would be less regressive than a revenue-equivalent fuel economy standard empirically. The key is the phrase "revenue equivalent." Current CAFE standards do not raise government revenue and are not directly comparable to a gasoline tax. To evaluate the two, I compare a gasoline tax to a tax on inefficient vehicles that raises the same revenue. The gas tax is less regressive. A plausible counterargument might claim that redistribution is politically feasible through fuel economy standards, where the transfers are hidden in the prices of efficient and inefficient cars sold to rich and poor households. But that argument lies in the realm of politics, outside of economics.

The relative regressivity of US CAFE standards was exacerbated by the 2011 change to footprint-based targets. The change reduced the advantage poorer households had as a consequence of their purchasing smaller cars. So not only would a gasoline tax be less regressive than a revenue-equivalent fuel economy regulation, both would be less regressive than the footprint-based fuel economy regulations promulgated since 2011.

The third idea I demonstrate is that the simple model outlined in Section 2, in which an energy tax would be less regressive than an energy efficiency standard, is supported across a wide array of home appliances and home building construction. A regulation that targets inefficient appliances and homes will cost rich households less because they are already purchasing the efficient versions of those goods.

In sum, it is true that an energy tax would be regressive, in a static model like Figure 1, if the tax would be borne by income groups in proportion to their pre-tax consumption levels, and if we ignore what happens to the revenue. But it is also true that a revenue-equivalent energy efficiency standard would be even more regressive. So the fact that carbon taxes are regressive does not stand up as a coherent argument for supporting energy efficiency standards in their place.

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Table 1. Household and Vehicle Characteristics

Household income (2009 $)	Households	Number of vehicles	Gallons gasoline	Miles driven	Gallons per hundred miles (gphm) Average car	Total	Footprint (sq. ft.)	Car age (years)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
<$10,000	4,763	0.84	247	5,198	3.86	2.32	47.75	9.3
$10,000–$19,999	8,960	1.30	371	7,857	3.84	3.48	47.85	8.3
$20,000–$29,999	10,362	1.70	507	10,703	3.88	4.44	48.29	7.5
$30,000–$39,999	10,110	1.95	613	12,931	3.92	4.97	48.66	7.0
$40,000–$49,999	9,719	2.10	679	14,366	3.94	5.27	48.78	6.7
$50,000–$59,999	9,030	2.25	754	16,005	3.96	5.61	48.96	6.6
$60,000–$69,999	7,592	2.34	816	17,310	3.97	5.88	49.08	6.4
$70,000–$79,999	7,535	2.43	869	18,413	3.98	6.07	49.11	6.2
$80,000–$99,999	10,302	2.48	921	19,548	4.00	6.28	49.29	6.0
>=$100,000	22,859	2.58	991	20,972	4.02	6.59	49.23	5.6

Source: 2009 National Highway Transportation Survey.

Table 2. Revenue per Household from Three Revenue-Equivalent Taxes

Household income (2009 $)	Tax revenue per household		
	$0.29 gas tax	gphm tax	Footprint-based gphm tax
	(1)	(2)	(3)
<$10,000	71	91	175
$10,000–$19,999	107	137	219
$20,000–$29,999	146	174	232
$30,000–$39,999	177	195	223
$40,000–$49,999	196	207	214
$50,000–$59,999	218	220	200
$60,000–$69,999	236	231	183
$70,000–$79,999	251	238	202
$80,000–$99,999	266	247	170
>=$100,000	286	259	237

Table 3. Vehicles with Hybrid and Gasoline Versions

Make and model	Proportion hybrid in NHTS	Number
Chevrolet Blazer/Tahoe	0.462	91
Ford Escape	0.155	696
Honda Civic/Crx/Del Sol	0.167	2,058
Mercury Mariner	0.286	42
Nissan Altima	0.075	226
Saturn Vue	0.105	124
Toyota Camry	0.183	1,408
Toyota Highlander	0.276	566
Totals	**0.182**	**5,211**

Table 4. Hybrid and Gasoline Characteristics

	Non-hybrids	Hybrids
	(1)	**(2)**
Gallons per hundred miles	3.02	2.26
	(0.59)	(0.52)
MPG equivalent	33.1	44.2
Annual miles driven	12,664	14,178
	(7,462)	(7,915)
Car price	19,301	20,158
	(4,469)	(5,279)
Gasoline price	3.07	3.09
	(0.14)	(0.19)
Household income	76,098	90,746
	(35,008)	(32,987)
Number of observations	4,262	949

Note: All five differences are statistically significant at 5%.
Source: Car characteristics from CarQuery, car prices from National Automobile Dealers Association, and household characteristics from the 2009 National Highway Transporation Survey.

Table 5. Fuel Economy, Controlling for Car Characteristics

Dependent variable: gallons per *thousand* miles	Means	Income only	Car only	Car and Income
	(1)	(2)	(3)	(4)
ln(Income)	10.97*	6.66*		-3.869*
	(0.002)	(0.36)		(0.223)
Engine power (metric horsepower)	167.6*		0.363*	0.371*
	(0.16)		(0.004)	(0.004)
Wheelbase (length in mm)	2,766.7*		0.063*	0.062*
	(0.62)		(0.001)	(0.001)
Width (mm)	1,830*		0.054*	0.051*
	(0.32)		(0.002)	(0.002)
Height (mm)	1,590*		0.225*	0.227*
	(0.53)		(0.001)	(0.001)
Constant		325.0*	-292.6*	-247.4*
		(3.9)	(3.0)	(4.0)
Observations	130,007	130,007	130,007	130,007
R-squared		0.003	0.621	0.622

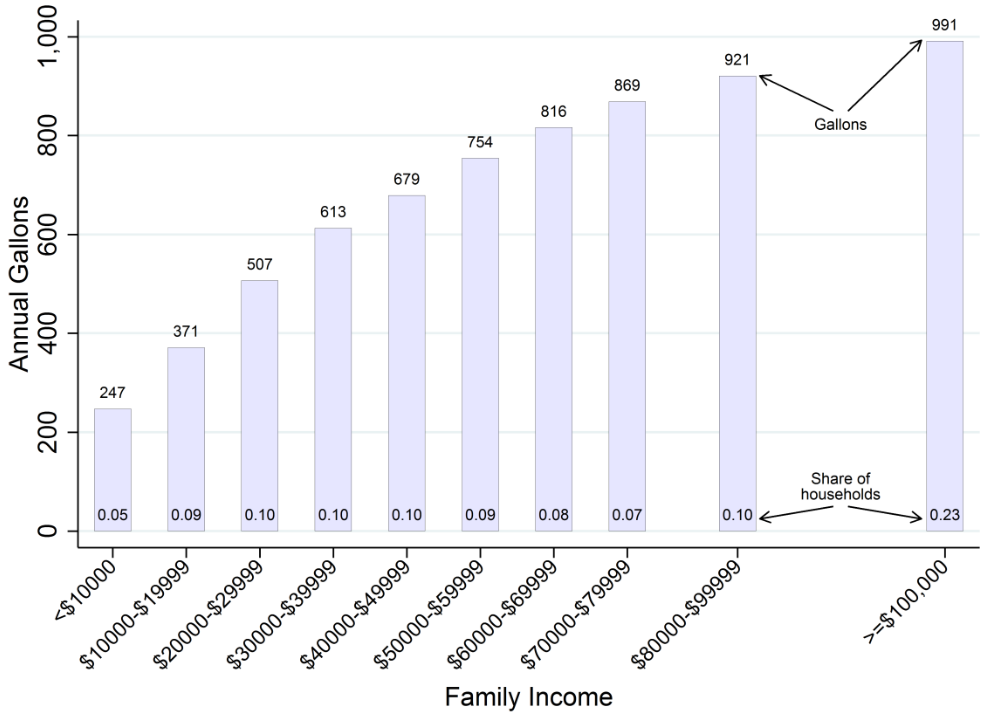
Source: Car characteristics from CarQuery and household characteristics from the 2009 National Highway Transportation Survey.
*p<0.05.

Table 6. Home Energy Efficiency and Household Income

Energy efficiency feature	**Average household income (2010 US$)**		
	No	**Yes**	**Difference**
Average (std. dev) [no. obs.]	**(1)**	**(2)**	**(3)**
Double or triple-paned windows	**$45,063**	**$61,964**	**$16,901**
	(32,859)	(37,300)	(641)
	[5,071]	[7,012]	
Compact fluorescent bulbs installed	**52,783**	**59,657**	**6,874**
	(35,185)	(36,643)	(1,287)
	[853]	[6,567]	
Energy Star clothes washer	**52,176**	**65,955**	**13,779**
	(35,093)	(36,310)	(925)
	[2,197]	[4,476]	
Frontloading washer	**55,471**	**76,189**	**20,718**
	(35,324)	(36,218)	(911)
	[8,092]	[1,941]	
Energy Star dishwasher	**57,920**	**75,121**	**17,201**
	(35,088)	(35,859)	(1,083)
	[1,642]	[3,042]	
Energy Star fridge	**46,497**	**63,198**	**16,701**
	(33,692)	(37,178)	(824)
	[2,981]	[4,645]	
Energy Star air conditioner	**40,904**	**53,332**	**12,428**
	(32,088)	(36,335)	(1,625)
	[679]	[1,176]	

Source: 2009 Residential Energy Consumption Survey.

Figure 1. Annual Household Gasoline Use by Income, 2009



Source: 2009 National Household Travel Survey.

Figure 2. Energy Use versus Efficiency

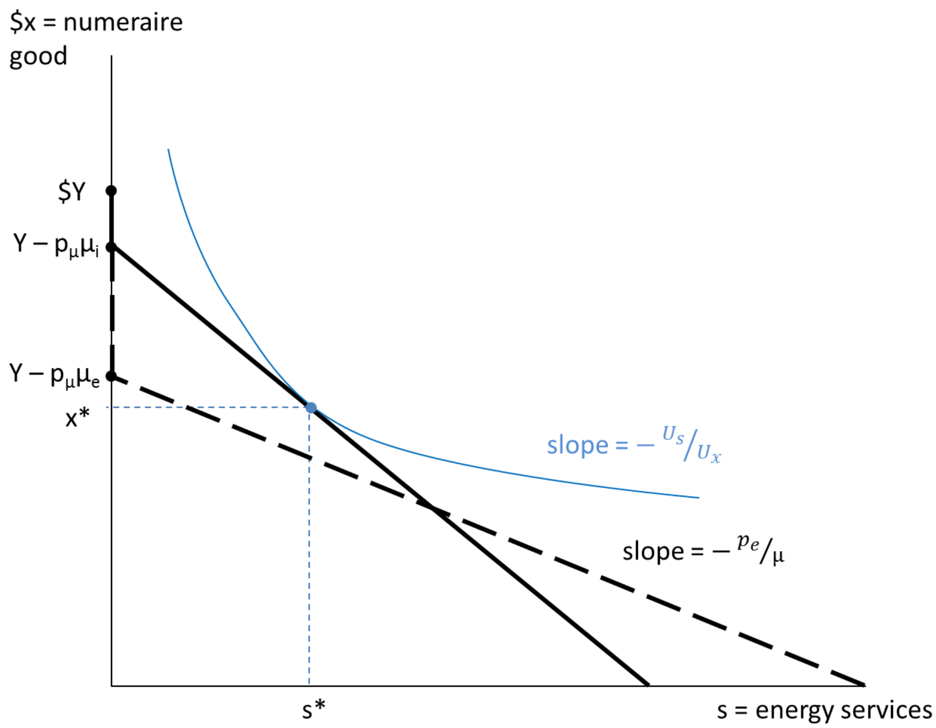


Figure 3. Energy and Inefficiency Taxes

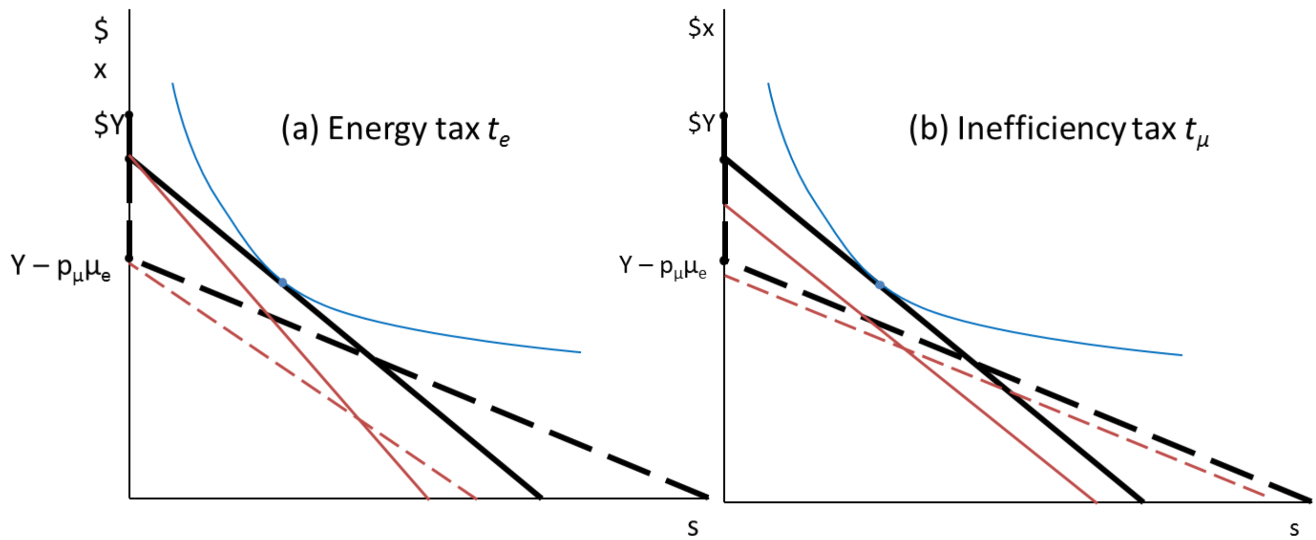


Figure 4. A Revenue-Equivalent Efficiency Subsidy Saves Less Gas

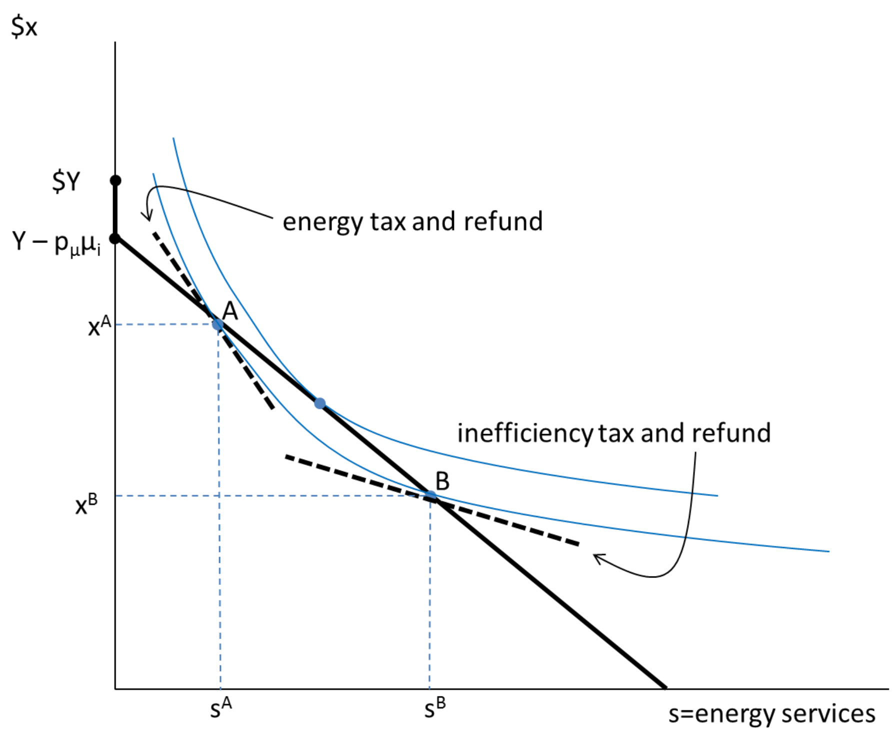


Figure 5. Revenue-Equivalent Gas Taxes and Fuel Economy Standards

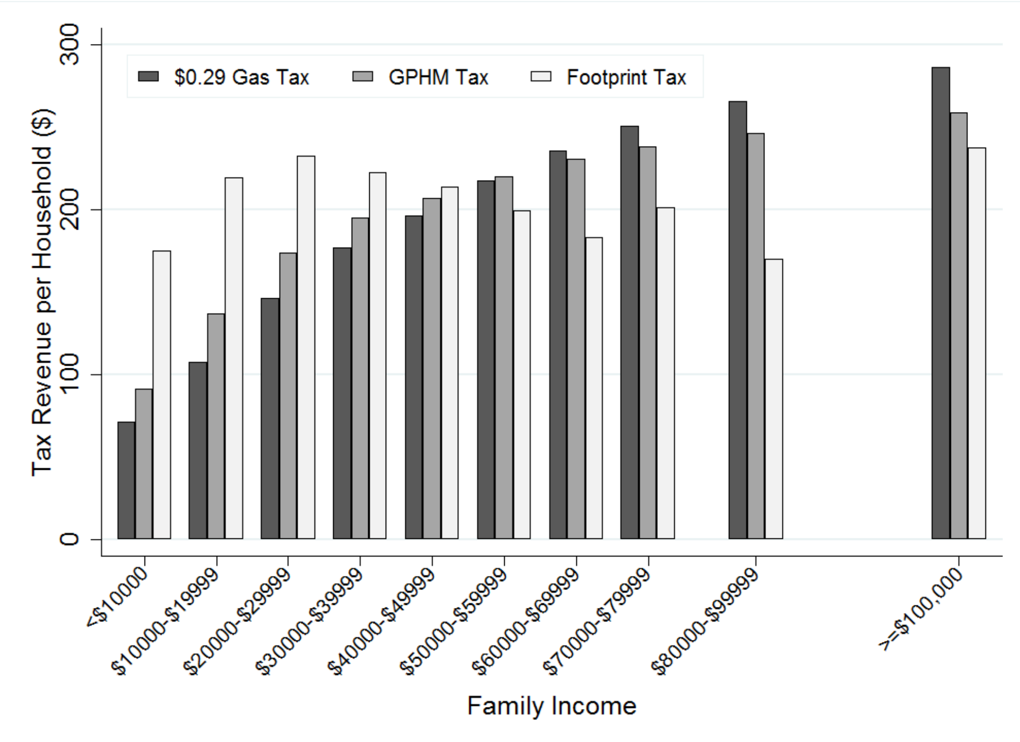


Figure 6. Footprint-Based Standard for Cars

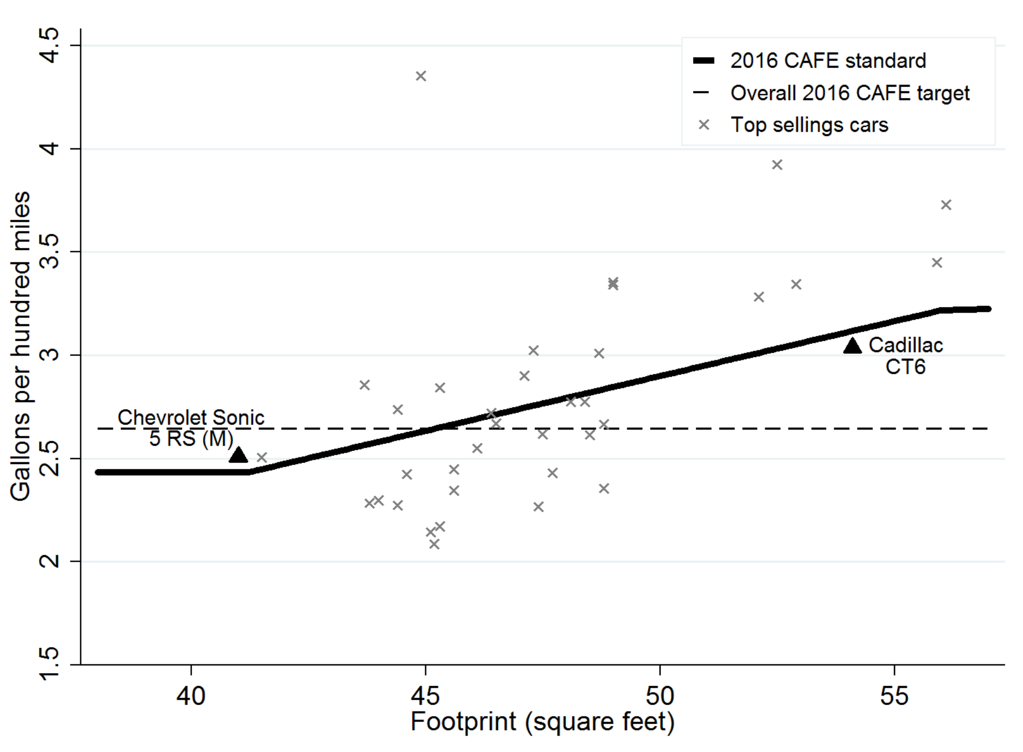


Figure 7. Fuel Economy by Car Size, By Household Income

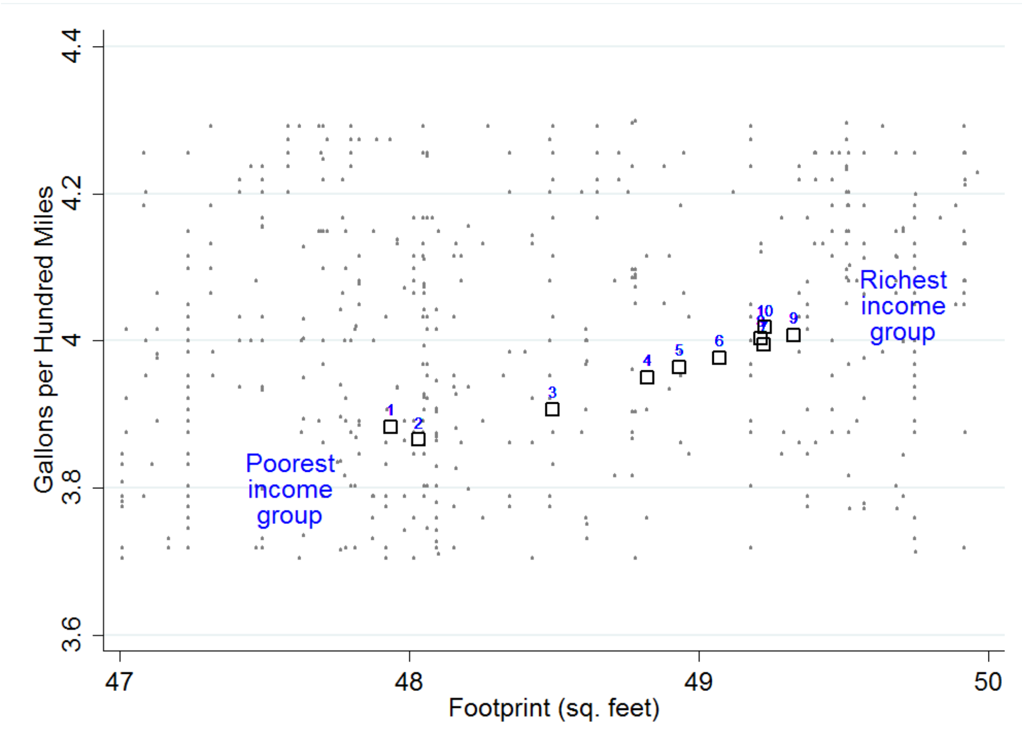


Figure 8. Tax Regressivity

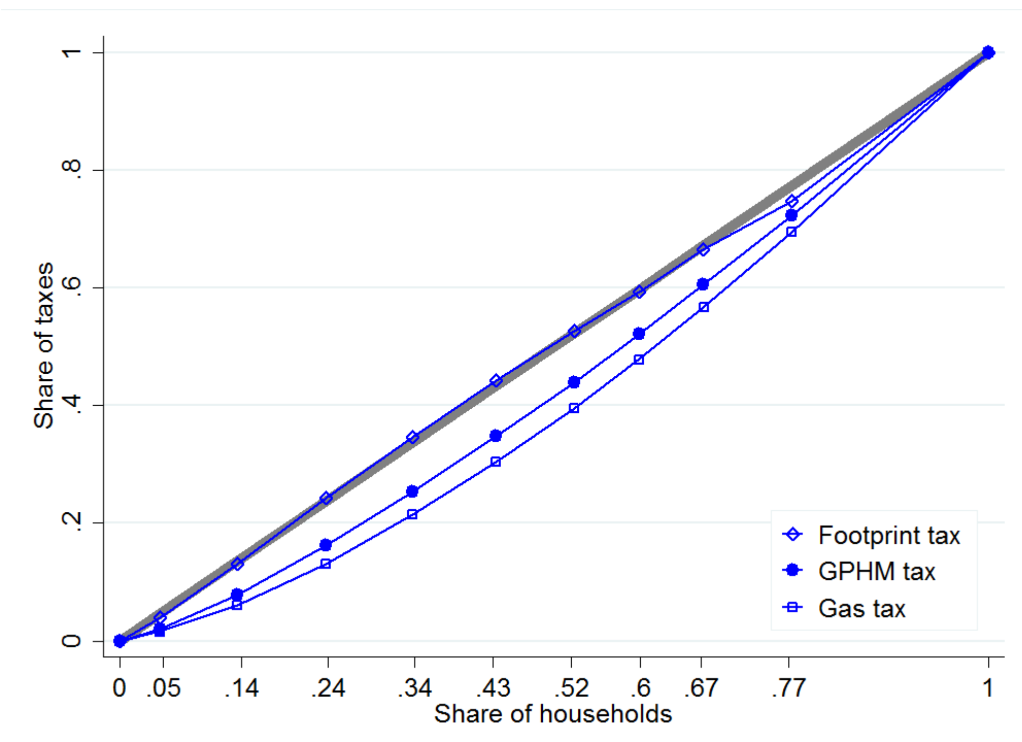
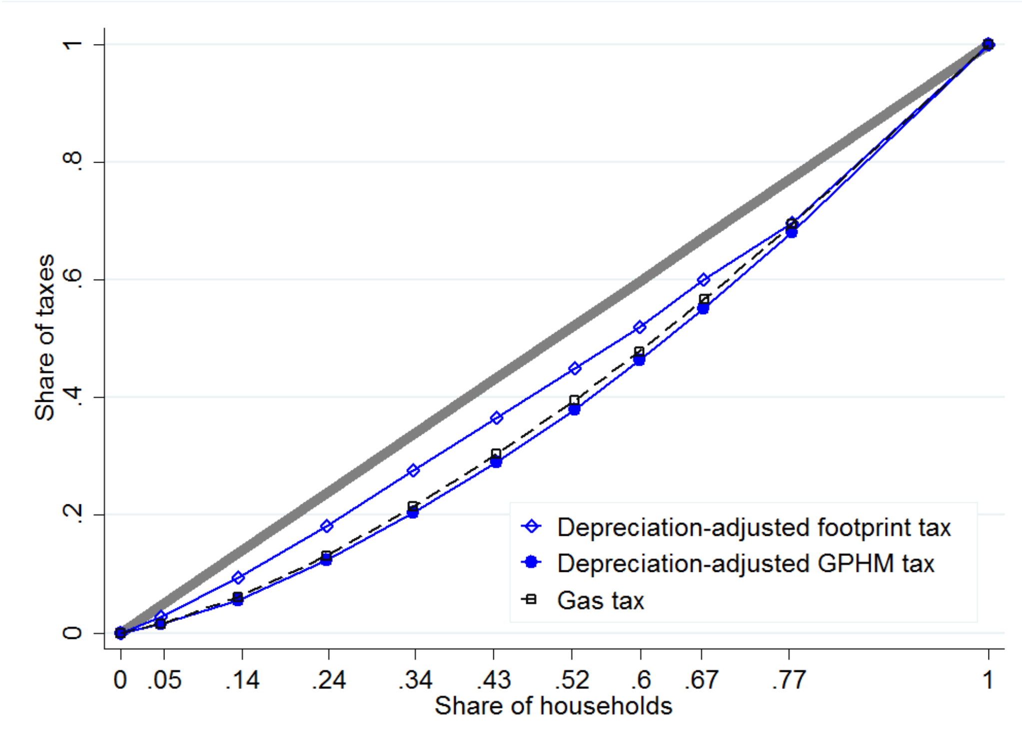


Figure 9. Depreciation-Adjusted Tax Regressivity



APPENDICES

Appendix 1. CAFE as a Combination Tax/Subsidy on Cars

Kwoka (1983) shows that a fuel economy standard has the same effect on vehicle prices as a tax on inefficient cars. I summarize and discuss that result here. Suppose there are two types of cars, efficient (subscript *e*) and inefficient (subscript *i*). Each has a different fuel economy, measured in gallons per mile (γ) and cost function to manufacture. Gallons per mile is just "inefficiency," measured as the inverse of efficiency, which in this case would be miles per gallon: $\gamma = {}^{1}/_{\mu}$.

Car type	Gallons per mile	Cost
Efficient	γ_e	$C(q_e)$
Inefficient	γ_i	$C(q_i)$

Each car manufacturers sells both types and has to meet a maximum average fuel economy in gallons per mile, $\bar{\gamma}$:

$$\frac{q_e\gamma_e + q_i\gamma_i}{q_e + q_i} \leq \bar{\gamma}\,. \tag{12}$$

This is a simple average of the gallons per mile (γ) of all vehicles sold.[24]

If the only way to meet the fuel economy standard is to change the mix of vehicles sold—more efficient cars and fewer inefficient ones—then following Kwoka, it is convenient to rewrite this regulatory standard as

$$q_e \geq Rq_i\,, \tag{13}$$

where

$$R = \frac{(\gamma_i - \bar{\gamma})}{(\bar{\gamma} - \gamma_e)}\,.$$

This just says the ratio of efficient to inefficient cars sold must be greater than *R*. As $\bar{\gamma}$ gets closer to the efficient car's fuel economy, γ_e, the standard gets harder to meet.

Now consider a firm that maximizes profits:

$$\pi = p_e q_e + p_i q_i - C(q_e) - C(q_i),$$

subject to constraint (13). The first-order conditions are

$$\begin{aligned}
&\text{(i)} && p_i = C'(q_i) + \lambda R \\
&\text{(ii)} && p_e = C'(q_e) - \lambda \\
&\text{(iii)} && q_e = Rq_i\,.
\end{aligned} \tag{14}$$

[24] See footnote 12.

Lambda (λ) is the Lagrange multiplier on the binding constraint (13) from the firm's profit maximization. The first condition (i) just says that a price-taking firm produces inefficient cars (q_0) until the market price equals the marginal cost plus an implicit tax (λR). The second (ii) says the automaker produces efficient cars (q_E) until the price equals marginal cost less an implicit subsidy (λ). And the third says the constraint binds. Regulated automakers will produce more efficient cars at higher cost and lower prices, and fewer inefficient ones at lower cost and higher prices. So a fuel economy standard amounts to an implicit tax on inefficient cars, collected by the carmakers themselves and used to subsidize efficient cars.

What happens to the total number of cars sold ($q_e + q_i$)? In its 2010 analysis of upcoming CAFE standards, DOT concluded that consumers would find the fuel efficient cars more desirable on average, causing total sales to rise. But that is not obvious *a priori*. As shown by Kleit (1988), total cars sold will increase if

$$R < \frac{\beta_i + B_i}{\beta_e + B_e}, \qquad (15)$$

where β_i is the slope of the demand curve for car type *i* ($\beta_i = \partial p_i / \partial Q_i$), B_i is the slope of the supply curve, and β_e and B_e are the slopes of the demand and supply curves for car type *e*. According to Equation (15), the sum of the slopes of the supply and demand curves for the inefficient car market ($\beta_i + B_i$) has to be sufficiently larger than the sum of the slopes of the supply and demand curves for efficient cars ($\beta_e + B_e$).[25]

This all makes intuitive sense. If inefficient cars are inelastically supplied or demanded, then the tax/subsidy combination will have to meet the regulatory standard by selling more efficient cars, increasing total car sales. If efficient cars are the ones inelastically supplied or demanded, the tax/subsidy combination will have to work by selling fewer inefficient cars, reducing total car sales.

When DOT analyzed the proposed 2012 CAFE rules change, the agency assumed no change in total cars. And when it retrospectively analyzed the results of those changes in 2016, DOT wrote "[i]t is difficult, if not impossible, to separate the effects of the standards on vehicle sales."[26] Following their lead, I assume no change in total sales.

[25] See Appendix 2 for a derivation of (15). In fact, Kleit (1988) points out that the regulation can act as a cartel, reducing sales and increasing profits on inefficient cars in a way that more than offsets profits lost selling efficient ones.
[26] US Department of Transportation, *Draft Technical Assessment Report: Midterm Evaluation of Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards for Model Years 2022-2025*, Washington, DC: US Environmental Protection Agency, 2016, 6-1, https://nepis.epa.gov/Exe/ZyPDF.cgi/P100OXEO.PDF?Dockey=P100OXEO.PDF.

Appendix 2. Effect of a Fuel Economy Standard on Total Cars Sold

Kleit (1988) showed that a fuel economy standard could increase or decrease vehicle sales, depending on the relative supply and demand elasticities for efficient and inefficient cars. Suppose each firm maximizing profits in (14) has quadratic costs for each type (*t*) of car:

$$C(q_t) = a_t q_t + 0.5 b_t q_t^2 \qquad t=\{i,e\}\ . \tag{16}$$

Then the marginal costs, including the implicit taxes and subsides from (14) are

$$C'(q_i) = a_i + b_i q_i + \lambda R$$
$$C'(q_e) = a_e + b_e q_e - \lambda\ . \tag{17}$$

And suppose there are *N* firms, each selling both types of cars, so that $Q_i = Nq_i$ and $Q_e = Nq_e$. Sum the marginal cost curves in (16) horizontally and invert to get the industry supply curves

$$C'(Q_i) = a_i + B_i Q_i + \lambda R$$
$$C'(Q_e) = a_e + B_e Q_e - \lambda\ , \tag{18}$$

where $B_t = b_t / N$ for each car type *t*.

Finally, suppose each car type has linear inverse demand

$$P_t(Q_t) = \alpha_t + \beta_t Q_t \qquad i=\{i,e\}. \tag{19}$$

Then, solving for Q_i, Q_e, and λ, Kleit shows that

$$Q_i + Q_e = \frac{(\alpha_i - a_i)}{(\beta_i - B_i)} + \frac{(\alpha_e - a_e)}{(\beta_e - B_e)} + \lambda\left[\frac{1}{\beta_e + B_e} - \frac{R}{\beta_i + B_i}\right]. \tag{20}$$

Industry output, on the left of (20), rises as a result of the implicit tax/subsidy combination, so long as the term in square brackets on the right is positive, or

$$R < \frac{\beta_i + B_i}{\beta_e + B_e}\ . \tag{21}$$

Equation (21) just says that the sum of the slopes of the supply and demand curves for the inefficient car market ($\beta_i + B_i$) has to be sufficiently larger than the sum of the slopes of the supply and demand curves for efficient cars ($\beta_e + B_e$).