Car Notches*

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First Draft: November 10, 2009

This Draft: March 24, 2010

Abstract

Notches — where small changes in behavior lead to large changes in a tax or subsidy — figure prominently in many policies, but have been rarely examined by economists. In this paper, we analyze a class of notches associated with policies in the United States and Canada aimed at improving vehicle fuel economy. We provide several pieces of evidence showing that automakers respond to notches in fuel economy policy by precisely manipulating fuel economy ratings so as to just qualify for more favorable treatment. We then describe the welfare consequences of this behavior and derive a welfare summary statistic applicable to many contexts. Finally, we use a comparison of the amount of strategic manipulation that occurs surrounding tax notches to the amount surrounding presentation notches in fuel economy label rules as a way of estimating the consumer willingness to pay for fuel economy.

*The authors would like to thank for helpful comments Jeff Alson, Raj Chetty, David Good, Mark Jacobsen, Robert Mull, Tom Kenney and seminar participants at Cornell University, the Harris School at the University of Chicago, Hebrew University, the IGPA at the University of Illinois at Chicago, the National Tax Association Annual Conference on Taxation and the University of Michigan. David Cashin and Matthew Johnson provided valuable research assistance.

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1 Introduction

Notches — where small changes in behavior lead to large changes in tax liability or the amount of a subsidy — figure prominently in many policies. These notches imply large, capriciously varying, local incentives to make small changes in behavior for relatively large private, but not social, rewards. Such behavioral responses erode the intended welfare benefits of policies, whose notch features are presumably justified by the increased salience and administrative convenience of policies that appear as step functions rather than smooth, continuous schedules.

In this paper we investigate these issues by focusing on notches in policies intended to encourage the production and use of fuel-efficient vehicles, what we call *car notches*. Key aspects of U.S. and Canadian policy toward motor vehicle fuel economy feature policy notches. For example, under the U.S. Gas Guzzler Tax, a car with a 14.5 miles-per-gallon (MPG) rating is subject to a $4,500 tax, while a car with a 14.4 MPG rating (and as low as 13.5) is subject to a $5,400 tax, so that a tax increase of $900 is triggered by a decrease of just 0.1 MPG. Under the Canadian EcoAuto rebate program, cars that consume less than 5.5 liters of gasoline per 100 kilometers (L/100km) qualify for a $2,000 rebate, but a vehicle that consumers 5.6 L/100km (up to 6.0) receives just a $1,000 rebate.

Policy notches have a bad reputation among economists, for the reason mentioned already. Only Blinder and Rosen (1985) have risen to their defense, in the context of encouraging the consumption of some socially desirable good; their running example is charitable giving. Supporting their case is a simulation analysis of a model with multiple individuals, each with an identical endowment and the same constant elasticity of substitution utility function, but who have heterogeneous share parameters that are distributed uniformly. Their numerical simulations show that when general non-linear Pigouvian subsidies cannot be used, in a world of heterogeneous preferences a single-notch program can improve the ratio of induced incremental consumption to either revenue cost, welfare, or revenue cost plus welfare cost. Their intuition is that, “by targeting the subsidy to those whose tastes for the favored commodity are relatively insensitive, the notch subsidy does not "waste" money on those whose consumption is not stimulated much" (p. 742). This occurs because the notch is a non-linear subsidy that can, depending on the distribution of tastes, economize on the revenue loss from subsidizing inframarginal consumption of the desirable good.

In spite of the folk wisdom that they are sub-optimal, policy notches are ubiquitous. One example, discussed in Ramnath (2009) is the U.S. Saver's Credit, which provides a tax credit equal to a percentage of contributions to retirement to savings accounts, where the credit rate is a notch function of adjusted gross income. In the U.K. Family Credit system, one eligibility criterion is that a family with children needs to have one adult working 16 or more hours per week (Blundell 2000). Note also that notches in time (a policy change takes effect on a specific date) and space (a policy changes at the border of a county, state or country) are present in most policies. As Slemrod (2009) discusses, they may in some cases be justified by administrative simplicity or because of enhanced salience. However, policy notches also induce consumers or producers to change their behavior just enough to be situated on the beneficial side of a notch. In the case of car notches, a vehicle manufacturer may have an incentive to re-engineer its cars so as to just qualify for a more advantageous policy category, be that a lower Gas Guzzler Tax or a higher rebate. Kleven and Slemrod (2009) call such producer response *tax-driven product innovation*. They note that in Indonesia, the preferential tax treatment of motorcycles relative to autos led to the creation of a new type of motorcycle with three wheels and long benches at the back seating up to eight passengers—car-like but not so car-like as to be taxed as a car. When Chile imposed much higher taxes on cars than on panel trucks, the market there soon offered a redesigned panel truck that featured glass windows instead of panels and upholstered seats in the back.[1] In the United States, a number of vehicles which have characteristics similar to passenger cars, such as the Chevrolet HHR and the Chrysler PT Cruiser, are carefully designed to qualify as light trucks, yielding preferential treatment under fuel economy regulation.

[1] These examples are drawn from Harberger (1995).

Although presumably the fuel economy policies of the U.S. and Canada are motivated by an externality argument, so that some re-engineering is part of an anticipated and desirable response, the lumpy nature of the responses to policy notches is, *ceteris paribus*, an inefficient way to reduce the external costs of fuel consumption. In this paper we study the behavioral responses to the U.S. Gas Guzzler and Canadian feebate programs and examine the welfare consequence of these programs.[2]

We also address another notch-like aspect of fuel economy policy—publicly disclosed and highly visible fuel economy ratings that are designed to provide information to prospective vehicle purchasers. In the U.S., each vehicle must disclose in a visible way two such ratings—one for miles-per-gallon in a typical highway driving situation and one for miles-per-gallon in a typical city driving situation. These two fuel economy ratings are presented as integers. This means that, just as for the Gas Guzzler Taxes and feebate system, an underlying continuous fuel economy measure is condensed into coarser categories by policy. To the extent that consumer demand depends on the publicized ratings, and not on the underlying tests—a plausible assumption, given the difficulty of obtaining and interpreting these underlying test data—manufacturers have an incentive to re-engineer vehicles to achieve a higher integer rating.

Tax economists have recently taken interest in the study of *kinks*—points where a policy causes a discrete change in the *slope* of a tax or policy schedule, arguing that the extend of bunching can identify structural parameters of utility functions.[3] Often, empirical estimates have shown a more muted behavioral response to kinks than would be suggested by theory. The incentives surrounding notches are frequently much starker, suggesting that notches

[2]Many European countries offer subsidies for the purchase of fuel-efficient hybrid cars. These programs often feature notches that depend on the CO_2 emissions level. For example, Sweden offers rebates up to €4000 when purchasing a hybrid car with CO_2 emissions below 120 grams per kilometer. Other countries have notched subsides related to engine displacement; Malaysia has offered RM625 a year for vehicles with a displacement up to 2000 cubic centimeters (cc). As of May 2010, in Malaysia there were subsidies to fuel purchase are a notched function of engine displacement. In the U.K., the annual vehicle tax is notched. Before 2001, the notches were based on engine size; after, they were based on CO_2 emissions. This may explain why there are so many 1399cc cars.

[3]For example, see Saez (2009).

may prove more useful than kinks in uncovering behavioral parameters. A systematic study of the difference between kinks and notches may even shed light on phenomena related to some form of bounded rationality — if agents respond to notches but not kinks, a leading explanation might be salience.[4]

We begin in Section 2 by describing U.S. and Canadian fuel economy policies and the notches they create. In Section 3 we describe the sources of our data. Our empirical analysis begins in Section 4. There, we first show histograms of the distribution of fuel economy ratings for vehicles subject to the U.S. Gas Guzzler Tax. We find evidence of local fuel economy response, as evidenced by a statistically significant number of "extra" vehicles with fuel economy ratings just on the tax-preferred side of notches. Next, we show similar diagrams for fuel economy label ratings, which corroborate the results from the Gas Guzzler Tax. Finally, we perform a false experiment by looking for similar bunching in the fuel economy measure used for Corporate Average Fuel Economy (CAFE) standards, which is similar to the Gas Guzzler Tax rating but does not feature notches. We find no evidence of bunching in the CAFE data, which bolsters our main results. Taken together, this evidence strongly supports our hypothesis that automakers do respond to local notch incentives by strategically altering fuel economy ratings.

In Section 5, we show regression-based evidence that the amount of manipulation surrounding a notch is positively correlated with the payoff to being on the "right" side of the notch. This analysis forms the basis of several exercises we perform in subsequent sections. In Section 6 we turn to a welfare analysis of notches. First, we show that, under some simplifying assumptions there is a simple statistic, what we call the *average effective tax rate* around a notch, that summarizes how local manipulation distorts the intended effects of a corrective tax. Second, we demonstrate that this value, in conjunction with *ex post* aggregate data, determines a measure of the local welfare cost of using a notched policy. Third, we calculate this for the Gas Guzzler Tax data, concluding that the welfare benefits from local

[4] Chetty, Friedman, Olsen and Pistaferri (2009) develop an explanation based on optimization frictions.

manipulation are negative. Finally, we argue that in a second-best setting, where a policy maker is constrained to choose the notch value for a given set of notches, local distortions cause the average effective tax to exceed the average intended tax. This implies that, the second-best corrective tax in this context will fall below the Pigouvian tax that would be optimal in a system without notches.

In Section 7 we use our notch data to provide a novel estimate of the consumer valuation of fuel economy. In the Gas Guzzler Tax data, we observe the notch value, because it is determined by law. In contrast, the value of notches surrounding fuel economy label values depends on how much consumers value fuel economy, which is not directly observable. By comparing the amount of fuel economy shifting across the two types of notches, we can infer the consumer valuation of fuel economy. Our preliminary estimates indicate that consumer valuation is approximately in line with the true value of fuel savings, and may in fact be too high, which is in contrast to most existing estimates.

In Section 8 we return to the case of the Canadian feebate. The feebate program, which was announced in the middle of the 2007 model year, was unexpected. We take advantage of this by comparing the fuel economies of the same vehicles in model year 2007, before the policy was known, and in model year 2008, at which point automakers had the opportunity to adjust. This natural experiment provides an additional piece of evidence that automakers respond to notches. We also compare the number of vehicles that manipulated their ratings in response to the notch to the predictions of our model from the Gas Guzzler Tax. We find that there was more apparent manipulation in Canada than our model predicts, and we speculate as to why. Our current estimate may be biased by an implicit assumption regarding fixed costs, which we plan to relax by incorporating sales data into our analysis, or by our assumptions about the mechanical relationship between different fuel economy tests, which we plan to test directly in subsequent work. Section 9 concludes.

2 Policy and Presentation Notches in Fuel Economy Policies

2.1 The U.S. Gas Guzzler Tax

When the United States government introduced Corporate Average Fuel Economy (CAFE) ratings in 1978, it also created the Gas Guzzler Tax that penalizes cars with particularly low fuel economy ratings. Light trucks, a designation that includes pickup trucks, sport-utility vehicles and vans, were exempted from the program from its inception, originally with the intention of not penalizing trucks used for farming and commercial purposes. The preference for light trucks has remained, many claim, because of the entrenched interests of the domestic automakers. Also from its inception, the amount of the Gas Guzzler Tax has been a step function of vehicle fuel economy. During a phase-in period the tax schedule was changed each year between 1980 and 1985, but it has not been changed since 1991. The tax is not indexed for inflation, so all values are nominal and the real value has eroded over time. Because of the notches in the Gas Guzzler Tax, vehicles with very small differences in fuel economy are subject to discretely different taxes. Table 1 shows the amount of the tax as a function of fuel economy over time.

Because the Gas Guzzler Tax does not apply to light trucks, relatively few vehicles are subject to the tax. These vehicles tend to be higher-priced, high-performance cars with relatively low sales volumes. In 2008, 77 (out of 1,248) vehicle configurations – a unique engine (including cylinders and displacement) and transmission – were subject to the tax, which raised about $172 million in revenue.[5]

The fuel economy ratings used to determine these policy treatments are based on data from fuel economy tests specified by the Environmental Protection Agency (EPA). To estimate vehicle fuel economy, automakers "drive" a test vehicle through a specified course on a chassis dynamometer (a treadmill for cars), during which the vehicles exhaust is connected to

[5]Source: Internal Revenue Service, Statistics of Income, Historical Table 20.

Table 1: Gas Guzzler Tax Rates Over Time (Dollars Per Car)

Vehicle fuel economy (MPG)	1980	1981	1982	1983	1984	1985	1986-90	1991+
Over 22.5	0	0	0	0	0	0	0	0
22.0–22.4	0	0	0	0	0	0	500	1,000
21.5–21.9	0	0	0	0	0	0	500	1,000
21.0–21.4	0	0	0	0	0	0	650	1,300
20.5–20.9	0	0	0	0	0	500	650	1,300
20.0–20.4	0	0	0	0	0	500	850	1,700
19.5–19.9	0	0	0	0	0	600	850	1,700
19.0–19.4	0	0	0	0	450	600	1,050	2,100
18.5–18.9	0	0	0	350	450	800	1,050	2,100
18.0–18.4	0	0	200	350	600	800	1,300	2,600
17.5–17.9	0	0	200	500	600	1,000	1,300	2,600
17.0–17.4	0	0	350	500	750	1,000	1,500	3,000
16.5–16.9	0	200	350	650	750	1,200	1,500	3,000
16.0–16.4	0	200	450	650	950	1,200	1,850	3,700
15.5–15.9	0	350	450	800	950	1,500	1,850	3,700
15.0–15.4	0	350	600	800	1,150	1,500	2,250	4,500
14.5–14.9	200	450	600	1,000	1,150	1,800	2,250	4,500
14.0–14.4	200	450	750	1,000	1,450	1,800	2,700	5,400
13.5–13.9	300	550	750	1,250	1,450	2,200	2,700	5,400
13.0–13.4	300	550	950	1,250	1,750	2,200	3,200	6,400
12.5–12.9	550	650	950	1,550	1,750	2,650	3,200	6,400
Under 12.4	550	650	1,200	1,550	2,150	2,650	3,850	7,700

Source: Internal Revenue Service, Form 6197. All values are nominal.

a device that collects the gases emitted by the vehicle. Dynamometers are set to simulate an appropriate amount of resistance based on the weight of the test vehicle in a way that itself creates notches. Dynamometers are set according to discrete weight classes, so that a very small change in the actual weight of the vehicle can create a discrete change in fuel economy rating by causing the dynamometer to be set for a different weight class. The amount of fuel consumed during the trial is determined based on the quantity of several gases captured from the exhaust. Two different courses are used to estimate separate ratings for a city and highway driving test.

To create the Gas Guzzler Tax rating, the highway and city ratings are combined into a single rating through harmonic averaging. These same tests are also used to determine the fuel economy label ratings, CAFE ratings, and to determine whether or not a vehicle meets emissions standards. Each fuel economy rating involves a slightly different transformation of the underlying test results, including differences in which vehicles are combined to calculate a single rating. This is important because it implies that each vehicle configuration may be near a notch for one rating system, but not for others.

2.2 Fuel Economy Label Ratings

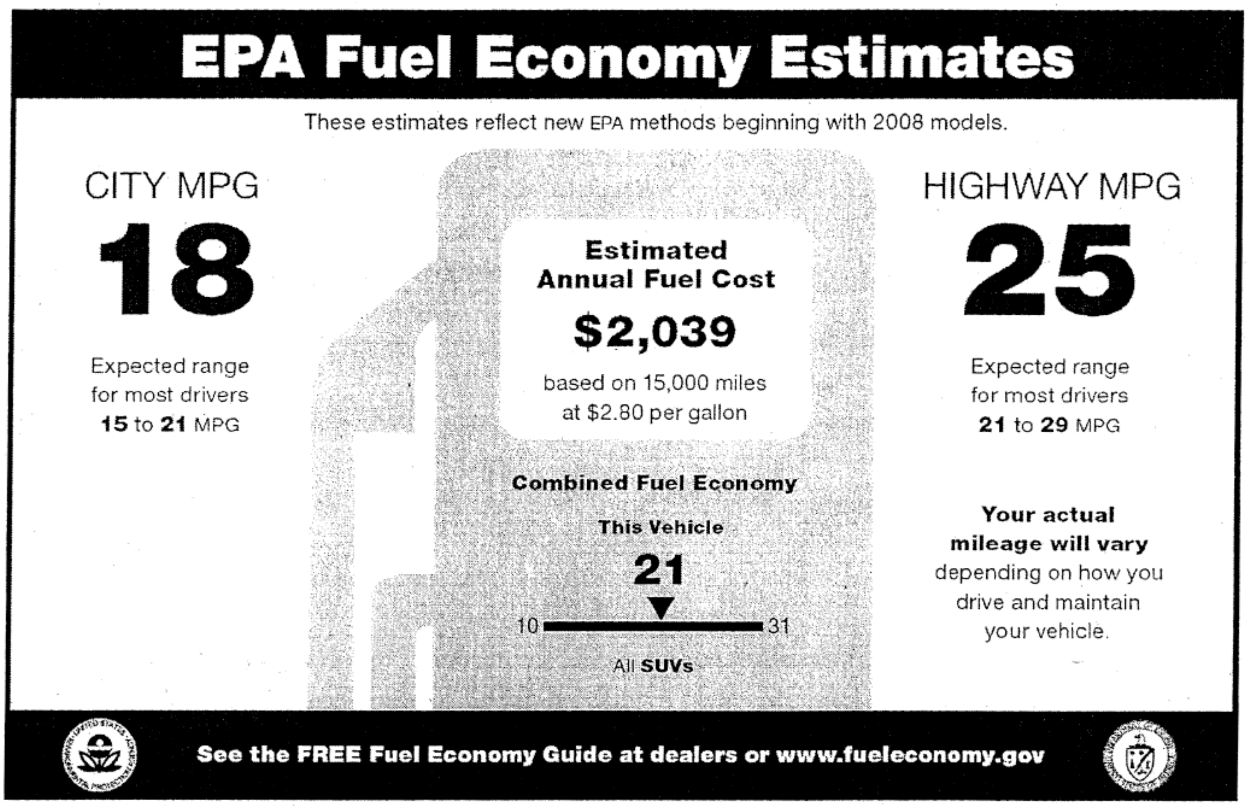
Every new vehicle sold in the United States is required to display a label that details the components of the manufacturers suggested retail price (MSRP), as well as the official EPA highway and city fuel economy ratings of the vehicle. The font size of everything on the label is mandated by law, and the separate city and highway fuel economy ratings must be set in the largest font, making these by far the most prominent numbers on the label. In much smaller print, the label also displays the combined rating, as well as a graphic that shows how this combined rating compares to other vehicles in its class, and an estimate of the annual cost of gasoline. These label ratings were introduced at the same time that the CAFE standards program began in 1978. Figure 1 is an example of the current fuel economy label in the United States.

The city and highway ratings are integers, which are determined by rounding off the underlying fuel economy estimate derived from the test procedure. This rounding creates what we call a *presentation notch* — where a marginal difference in an underlying characteristic creates a discrete change in the information transmitted in the marketplace. A vehicle with a highway fuel economy rating of 29.49 will be listed as 29 on the label, whereas a vehicle with a rating of 29.50 will be listed as 30.

If consumers value fuel economy, and if they use the official EPA ratings as a source of information, then firms may undertake costly adjustment procedures to increase the fuel economy rating as displayed on the labels, just as they would respond to tax notches.

The unrounded figures used to calculate these label ratings are public information and, indeed, we make use of these data in subsequent analysis. Thus, in principle consumers could also obtain and consider these unrounded numbers. To do so, however, they would

Figure 1: A Sample Fuel Economy Label



Source: Environmental Protection Agency.

have to download the publicly available fuel economy data files; the unrounded numbers are not included in the fuel economy guide that is available at dealerships and on the EPA's website. Even with these files in hand, a car shopper would need to know how to adjust for in-use shortfall in order to convert the unrounded numbers from the data file into an accurate fuel economy estimate. Our strong prior is that the vast majority of consumers are not aware of this underlying data and take the integers on the labels at face value, that is, without backward inducing the true unrounded fuel economy measure. (If all consumers did track down this information and perform this calculation, we would not expect automakers to respond to label notches, which is inconsistent with the evidence presented below.)

The city and highway label ratings are based on the same pair of tests — one for the highway and one for the city — as the Gas Guzzler Tax rating. Prior to 1986, the reported label rating was simply the integer nearest the value resulting from the test procedure.[6] Starting in 1986, the EPA modified the procedure to adjust for "in-use shortfall", in response to the fact that consumers consistently reported lower average actual fuel economy than the labels indicated. After attempting to measure the discrepancy, the EPA decided to adjust the test numbers by simply multiplying the test output by a scalar—0.9 for the city and 0.78 for the highway test. The product is then rounded to the nearest scalar for the label.[7] Automakers do have the right to adjust the label ratings downwards if they wish, and a very small percentage of vehicles do involve a downward adjustment, so that the test procedure indicates a higher value than appears on the label in practice. The automakers may do this to avoid consumer displeasure if actual experiences differ from their expectations.

Fuel economy labels are unique to each vehicle with a different basic engine and transmission. Thus, separate label ratings are not reported for vehicles that share a basic engine and transmission but have different vehicle weights. Testing is required, however, for each vehicle with a different weight, and the test results are combined via a sales-weighted harmonic average.[8]

2.3 The Canadian Feebate Program

In March 2007, the Canadian government introduced two new programs with many aspects that are similar to the Gas Guzzler Tax. The first was called the Green Levy (also referred to as the excise tax on fuel-inefficient vehicles), which taxed particularly inefficient vehicles. Like with the Gas Guzzler Tax, pickup trucks were exempted, but sport-utility vehicles and

[6]Note that the EPA uses ASTM International rounding, which rounds a value ending in exactly 0.50 to the nearest even integer.

[7]Starting with 2008 model years, the EPA instituted a completely new testing procedure, which is designed to improve the accuracy of label ratings. In this paper, we investigate only models that were tested during the pre-2008 regime.

[8]Note also that tests are not performed on every model separately if models share the same basic engine, transmission and weight. For example, a Mercury Mountaineer is identical to a Ford Escape in engine, transmission and weight. As a result, Ford would be required to test only one of the two models, each of which would be given the same fuel economy rating.

Table 2: Rebate and Tax Thresholds in Canadian Feebate

Fuel Economy		**Rebate**			**Tax**
L/100km	MPG Equivalent	Cars	Light Trucks	Flexible-Fuel Vehicles	Cars, Vans and SUVs
5.5 or less	42.8 or more	$2,000			
5.6 - 6.0	42 - 39.2	1,500			
6.1 - 6.5	38.6 - 36.2	1,000			
7.3 or less	32.2 or more		$2,000		
7.4 - 7.8	31.8 - 30.2		1,500		
7.9 - 8.3	29.8 - 28.3		1,000		
13.0 or less	18.1 or less			$1,000	
13.0 - 13.9	18.1 - 17.0				$1,000
14.0 - 14.9	16.8 - 15.8				2,000
15.0 - 15.9	15.7 - 14.8				3,000
16.0 and over	14.7 or less				4,000

Note: The feebate program measures fuel economy in L/100km, and the rating used is a linear combination of the city (55%) and highway ratings (45%). The rebate for flexible-fuel vehicles is determined by the fuel economy rating when E85 is used during the test. For the tax, flexible-fuel vehicles are assessed solely on their fuel economy rating using conventional gasoline. Pickup trucks and cargo vans are not subject to the tax. To facilitate comparison with the U.S. Gas Guzzler Tax, we show the miles-per-gallon equivalent. From March 2007 to December 2008, on average one U.S. dollar was worth 1.05 Canadian dollars.

vans were subject to the tax.[9] As shown in Table 2, the maximum tax was $4,000. In the 2008 model year, 156 (out of 1071) distinct vehicle configurations were taxed, representing around 2 percent of the new vehicles sold. Because many of the vehicles subject to the tax are low-volume, high-performance vehicles like Ferraris and Rolls-Royces, the taxed vehicles comprise a large number of models compared to their share of the total sales volume.

The second policy, called the EcoAuto rebate program, was introduced simultaneously. It provided rebates for vehicles with particularly good fuel economy. Unlike the Green Levy, the EcoAuto program was designed to be a temporary measure, set to expire after two years. As a result, the program was in effect from March 20, 2007 to December 31, 2008, and only model years 2006, 2007 and 2008 vehicles were eligible to receive the rebate. In the 2008 model year, only 32 vehicle configurations qualified out of 1071 vehicle configurations, representing around 8 percent of vehicles sold. Together the rebate and the tax comprise a

[9] When it was introduced, the Green Levy superseded an existing, much smaller, fee called the Heavy Vehicle Excise Tax.

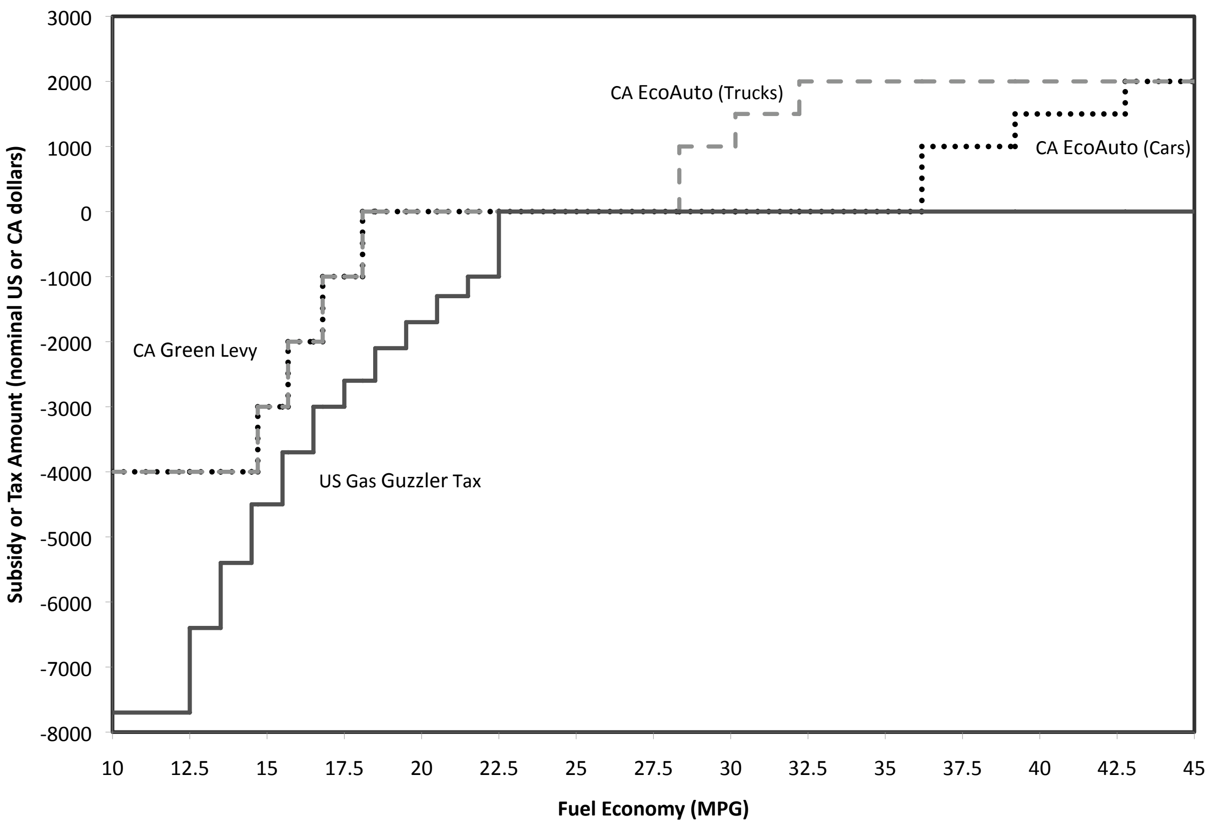
version of what is sometimes called a feebate — a set of taxes and rebates that together act to encourage the purchase of more fuel-efficient vehicles. The rebate program cost $191.2 million on the program over two years, but the magnitudes of the two programs were expected to be roughly offsetting, making the combined policy revenue-neutral.

In Canada, fuel economy ratings are measured as liters of gasoline consumed per 100 kilometers. Note that this differs from the miles-per-gallon measure both in units and in inverting the ratio of fuel to distance. The fuel economy ratings used in Canada are based on test procedures that are nearly identical to the ones used in the United States. Cars that consume less than 6.5 L/100km were eligible for a subsidy of $1,000, ranging up to a maximum of $2,000 for cars with ratings below 5.5 L/100km. Light trucks, including pickups, SUVs and vans, were subsidized if they consume less than 8.3 L/100km. A special provision was made for flexible-fuel vehicles — vehicles capable of running either on conventional gasoline or a fuel blend that is made primarily of ethanol called E85. Flexible-fuel vehicles that got 13L/100km or better when running on E85 were eligible for a $1,000 rebate. For the tax, all vehicles in the eligible vehicle classes were subject to the tax if they consume above 13L/100km. Starting at $1,000, the tax rose by $1,000 for each integer increase in L/100km, for a maximum of $4,000 for vehicles consuming more than 16L/100km. Table 2 summarizes these policies. The current values of both the Canadian policies and the Gas Guzzler Tax are also plotted in Figure 2.

The introduction of the feebate program in March 2007 was said to be a surprise to automakers and consumers alike.[10] As a result, this policy represents a unique opportunity to observe how automakers respond to the introduction of a policy notch by comparing 2007 model year vehicles, which were designed and tested before the policy was revealed, and 2008 and 2009 model year vehicles, which could have been modified in response to the policy. In Section 8 we study the Canadian policy as a natural experiment and compare the results to our model estimates from the Gas Guzzler Tax.

[10] See footnote [31] for citations.

Figure 2: The Canadian Green Levy and the US Gas Guzzler Tax in 2008



Note: The figure includes nominal values, but the exchange rate was close to 1 for much of 2008.

2.4 How Is Fuel Economy Manipulated?

Our research is based on the premise that automakers perform local manipulation of fuel economy ratings in order to receive a more favorable Gas Guzzler Tax rate, an improved fuel economy label rating, or a greater subsidy in the Canadian feebate system. If an automaker wishes to boost fuel economy locally around a notch, how is this done?[11]

First, automakers may simply repeat the underlying fuel economy test. If there is sufficient variability in the test results, an automaker might retest a vehicle and hope to receive a better draw. U.S. regulation requires, however, that all valid tests must be reported, and

[11]Note that the strategies we discuss here are a subset of those available for making larger, longer-term fuel economy adjustments. These types of improvements have been explored by Klier and Linn (2008) and Knittel (2009) in the context of CAFE compliance.

the harmonic average of all valid results is used as the final value.[12]

Second, each "model type" receives a single Gas Guzzler rating and a single set of label ratings. In practice, this means that some ratings apply to two or more vehicle configurations, which are each tested separately, and then combined via sales-weighted averaging. If one configuration tested above a notch, and another tested below, the automaker could decide to produce less of one and more of the other in order to move the average rating, which determines the tax liability for all vehicles in a model type. This applies to both types of ratings.

Finally, an automaker may make modifications to the vehicle in order to improve its fuel economy. This might include light-weighting, which involves the substitution of parts in order to make the vehicle lighter, or engine recalibration, which involves reprogramming the vehicle to operate in a different gear at certain speeds, thereby creating a trade-off between fuel consumption and performance. Other possibilities include the use of low-friction lubricants, modifications to tires, small aerodynamic changes — like the addition of a spoiler, side skirts, a reshaping the air dam, or the installation of "belly pans" that smooth air flow by covering parts underneath the vehicle.[13] It is important to distinguish these methods for improving fuel economy from longer-term design methods. When designing a vehicle, the overall structure of the engine, weight, the shape of the car, the use of fuel saving technologies and the choice of transmission are all key determinants of fuel economy. These decisions are made long before vehicles are officially tested for fuel economy or sold, so that the position of a vehicle relative to a notch may be difficult to determine. In contrast, the minor adjustments we listed above could potentially be adopted late in the production cycle, in response to preliminary test results. Based on our conversations with experts from the automotive industry, we believe that the lion's share of local adjustment comes in the form

[12]We have been unable to find a published estimate of the variability of the fuel economy tests, which would inform us as to whether or not the re-test strategy is plausible. We are, however, pursuing our own original analysis of variability through an examination of the official emissions test data, which sometimes includes multiple trials for a single test vehicle.

[13]These are examples listed at Edmunds.com and in the National Academy of Sciences report on fuel economy (National Research Council 2002).

of vehicle modification.

Automakers are reluctant to share any detailed information about how local fuel economy adjustment might occur, or whether they in fact respond to notches in the incremental way that we describe. Our conversations with experts who have worked for automakers and officials at the EPA indicate that this type of manipulation does indeed take place. Anecdotal evidence from the popular press also confirms our overall story. In Canada, the media reported that automakers intentionally altered vehicle fuel economy in response to the introduction of the feebate (Keenan 2007a). In 2009, when the recent cash-for-clunkers bill was passed, Nissan stated its intention to tweak vehicle fuel economy for certain models to ensure that they met fuel economy eligibility requirements for the program (Greimel 2009). Another oft-cited example is the installation of a what is known as the Computer Assisted Gear Selection, sometimes called a "skip shift", which forces a manual transmission vehicle into a first-to-fourth gear shift at certain speeds. Popular opinion is that this feature is installed on vehicles as a way of reducing the Gas Guzzler Tax. Moreover, there is a market for tools that claim to disable this feature, enabling a savings in tax liability without the intended improvement in fuel efficiency. Against this backdrop, we now move onto empirical tests for evidence of behavioral response to these fuel economy notches.

3 Data Sources

We gathered fuel economy data from several sources. For the Gas Guzzler Tax, we obtained from the Internal Revenue Service a complete list of all vehicles that were subject to the Gas Guzzler Tax from the beginning of the program. These data include fuel economy ratings to a tenth of a mile-per-gallon, and are limited to the set of vehicles that were actually taxed. We complement this data with fuel economy ratings from the Environmental Protection Agency, which provides unrounded city and highway test results from 1978 to 1983 and from 1999 to 2009. We use these underlying test statistics to reconstruct the Gas Guzzler Tax rating for all vehicles using the formulas published in federal regulations.

These same EPA data are our source for fuel economy label ratings. We transform the unrounded city and highway test results according to the EPA's "in-use shortfall" adjustment factors in order to obtain the adjusted, unrounded fuel economy label ratings. In our analysis of CAFE ratings, we use official CAFE fuel economy ratings, which differ slightly from the EPA ratings used in the other sections, from the National Highway Transportation Safety Administration, which administers the CAFE program. Our Canadian data come from program documents available from the Canadian Government.

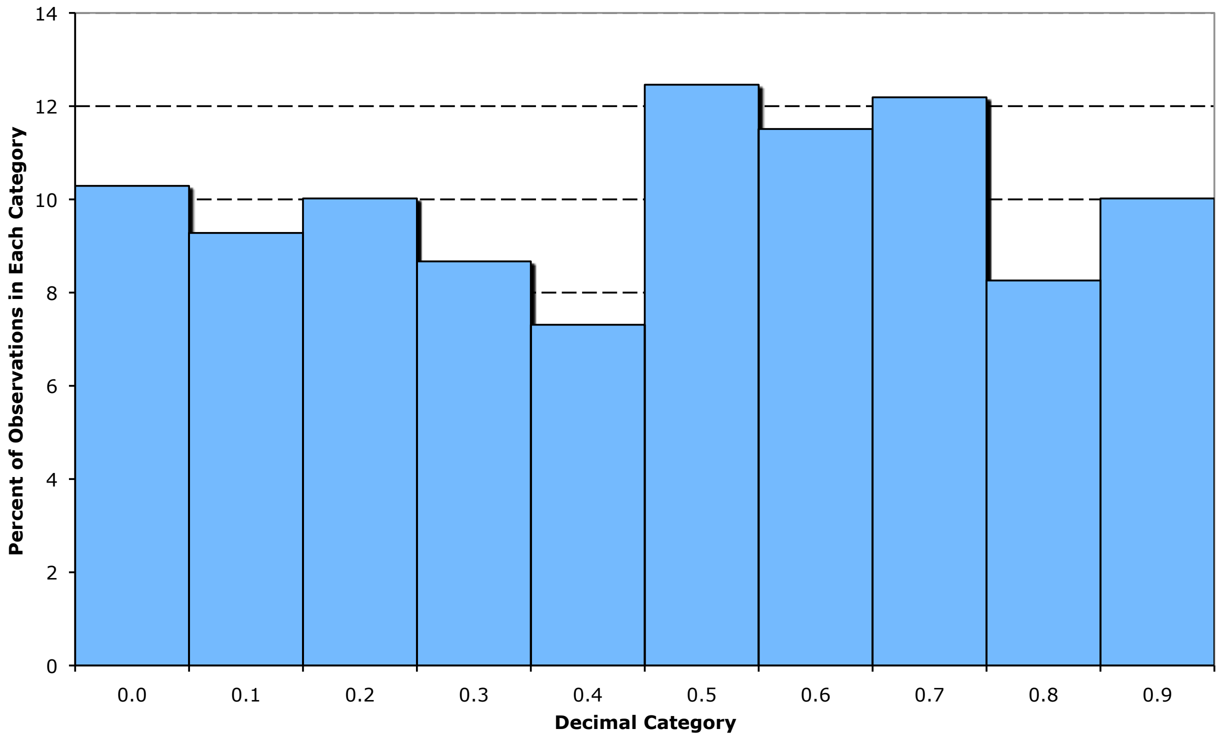
4 Evidence of the Behavioral Response to Fuel Economy Notches

4.1 The Gas Guzzler Tax

If automakers respond to notches in the Gas Guzzler Tax by modifying vehicle fuel economy, then the distribution of fuel economy ratings should feature "extra" observations just on the tax-preferred side of notches. A natural first test, then, is to examine the distribution of the rating decimal points of all taxed vehicles, relative to the tax notches.

Figure 3 below shows a histogram of the *decimal* values for all vehicles subject to the Gas Guzzler Tax from its inception in 1980 until the present. Specifically, if a vehicle had a 20.5 fuel economy rating, we put that vehicle into the .5 histogram bin. We do this for each year, so each vehicle-year is placed in the appropriate bin. As shown in Table 1 above, the value of the Gas Guzzler Tax changes at each .5 in fuel economy ratings, except for 1980, 1981, 1983 and 1985, for which years we adjust the data to match the .5 notch point in the figure. For example, a vehicle that gets a 22.4 MPG rating in 2009 is subject to a $1,000 tax, but a vehicle that gets a 22.5 MPG rating has no tax. As a result, manipulation in response to tax notches should create an unusually large number of vehicles with fuel economy rating

Figure 3: Gas Guzzler Decimal: All Vehicles, 1980 - 2007



Note: Total sample size is 1,477. Data are from the Internal Revenue Service. In 1980, 1981, 1983, and 1985, the tax liability changed at whole integers (the .0 point) of the rating rather than at half integers (the .5 point). For those years, we shift decimals by .5, so that the notch is always represented by the .5 bin in the figure. Our data come from lists of taxed vehicles, which prevents us from including vehicles whose MPG rating is just above the highest-rating tax notch, and thereby were not subject to tax at all. To make this omission symmetric, we also drop the observations with ratings just below this notch, so that no observations within .5 miles-per-gallon of this notch on either side are included. The sample also omits a few observations from 1991 to 1995 where the manufacturer was listed as an importer, because these appear to be redundant observations.

decimals at and just above .5 and an unusually small number of vehicle configurations with fuel economy rating decimals at .4 and just below. A sensible prior absent tax incentives is that the distribution of rating decimals is uniform. Thus, anything above 10 percent of the total vehicle-year configurations with a rating of .5 represents extra observations, with values below meaning the opposite.

The data support the hypothesis of behavioral response around car notches. The actual distribution of fuel economy rating decimals for taxed vehicles shows a marked departure from the uniform counterfactual distribution. There are far more observations just at, or just to the right of .5, which is the tax-preferred side. We interpret this as strong suggestive evidence of strategic response among automakers to policy notches.[14] The difference in the number of observations around the notch is highly statistically significant. Comparing either the number of vehicle configurations in the .4 bin to the .5 bin, or comparing the sum of the .3 and .4 bins to the sum of the .5 and .6 bins, yields a p-value less than .0001 that they are drawn with equal probability.[15]

We explore this further by regressing the number of vehicles at each fuel economy rating on dummy variables for each of several rating decimals. As in Figure 3, strategic fuel economy manipulation would imply "extra" observations at the .5 decimal, and other values above notches. In Table 3, this will show up as a positive coefficient on the .5 decimal (and possibly .6 or .7) dummy variable. This specification has the added benefit of allowing us to include a polynomial in the level of the fuel economy rating. This could be important because the distribution of fuel economy decimal ratings will be slightly non-uniform because the overall distribution of fuel economy is bell-shaped, and the Gas Guzzler Tax includes only vehicles in the left tail of this distribution. Because the distribution is rising in fuel economy in this area, there could be more observations above a notch than below simply for this reason.[16]

Table 3 strongly confirms the graphical evidence that there are statistically and economically significant deviations from the counterfactual unmanipulated distribution that suggests strategic behavioral responses to notches. The omitted category are vehicles in the 0, .1, .8 and .9 bins. Relative to that category, the coefficient estimate in column 1 indicates that the .5 decimal has an extra 32% more observations than would be expected by a uniform

[14] Results are qualitatively similar if we attempt to restrict the sample to unique observations by dropping all vehicles with the same manufacturer, cylinders, displacement, transmission and fuel economy rating as some other vehicle, either within or across years. This restriction is intended to drop repeated observations of the same engine, which may be installed on several different models.

[15] This significance test comes from treating the observations in the restricted distribution just around the notch as a binomial distribution, with points above the notch treated as a successful trial. We calculate the p-values reported here using the normal approximation to the binomial distribution.

[16] To include the polynomial control, we restrict our sample to 1991 to 2009, during which time the Gas Guzzler Tax notches are unchanged. Otherwise, the baseline sample in Table 3 is the same as the data in Figure 3.

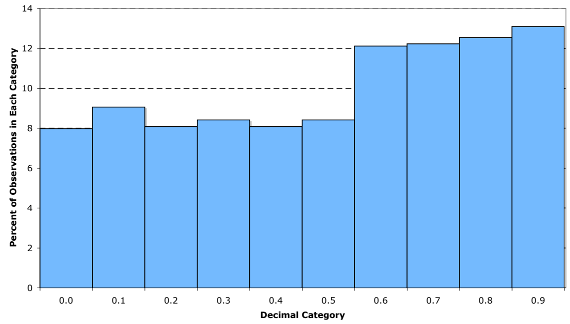
Table 3: Linear Regression of the Number of Observations at Points Around Gas Guzzler Notches on Decimal Dummy Variables

Dependent variable = number of vehicles observed at each fuel economy value	(1)	(2)	(3)	(4)	(5)	(6)
Decimal = .2	2.160**	1.326*	3.034***	2.794***	0.797	0.837*
	(0.891)	(0.734)	(0.860)	(0.737)	(0.577)	(0.478)
Decimal = .3	-2.037***	-2.816***	-0.244	-0.524	-1.095***	-1.193***
	(0.687)	(0.490)	(0.671)	(0.473)	(0.415)	(0.276)
Decimal = .4	-3.263***	-3.007***	-1.761***	-1.587***	-0.787	-0.696
	(0.736)	(0.734)	(0.524)	(0.457)	(0.556)	(0.429)
Decimal = .5	4.140***	4.128***	1.622**	1.822***	1.043*	1.088**
	(0.805)	(0.822)	(0.678)	(0.670)	(0.538)	(0.440)
Decimal = .6	1.605**	1.737***	2.724***	2.918***	1.625***	1.934***
	(0.645)	(0.497)	(0.560)	(0.425)	(0.472)	(0.331)
Decimal = .7	-0.00425	-0.326	1.391**	1.384***	-0.808*	-0.428
	(0.712)	(0.577)	(0.571)	(0.443)	(0.447)	(0.380)
Gas Guzzler Rating		-439.1***		-331.8***		-203.0***
		(74.94)		(61.24)		(43.65)
Gas Guzzler Rating^2		5.465***		4.105***		2.496***
		(0.890)		(0.724)		(0.521)
Gas Guzzler Rating^3		-0.0335***		-0.0251***		-0.0152***
		(0.00524)		(0.00424)		(0.00308)
Gas Guzzler Rating^4		0.000102***		7.56e-05***		4.57e-05***
		(1.53e-05)		(1.23e-05)		(9.02e-06)
Gas Guzzler Rating^5		-1.22e-07***		-9.01e-08***		-5.44e-08***
		(1.77e-08)		(1.42e-08)		(1.05e-08)
Constant	17.67***	13920***	12.40***	10593***	8.375***	6523***
	(0.394)	(2499)	(0.318)	(2053)	(0.288)	(1449)
Observations (Weighted)	1216	1216	909	909	588	588
R-squared	0.060	0.292	0.058	0.345	0.051	0.449
Sample	All	All	Within	Within	Between	Between
Mean Count	12.94	12.94	9.67	9.67	6.25	6.25

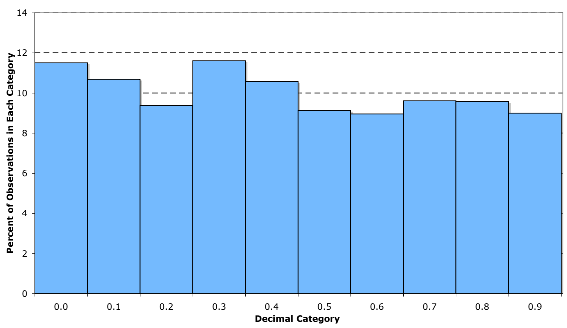
Note: Heteroskedasticity robust standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1. The unit of observation is a specific fuel economy value (e.g., 14.5 MPG), and regressions are weighted by the number of observations in each cell. The sample is restricted to vehicles subject to the Gas Guzzler Tax between 1991 to 2009, during which time the notches are unchanged and all vehicles in the sample will face a notch at the .5 decimal. The independent variables are dummy variables for several decimal values — the excluded categories are decimal values at 0, .1, .8 and .9. Vehicles at .5, .6 and .7 are on the tax-preferred side of the notch. Even-numbered columns include a polynomial in the full rating value to control for any deviation from a uniform distribution owing to the slope of the overall fuel economy distribution. Columns 3 and 4 restrict the sample to observations "unique within years" by excluding all duplicate observations where a vehicle has the same make, displacement, transmission, cylinders, and unrounded city and highway fuel economy ratings as another vehicle in the same year. Columns 5 and 6 restrict the sample to observations "unique between years" by excluding all duplicate observations matching on these characteristics across years. The mean of the dependent variable is included for reference.

Figure 4: Gas Guzzler Rating Decimals for Several Vehicle Groups: 1999 - 2009

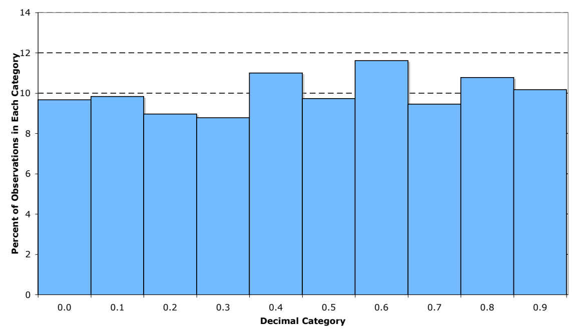
(a) Passenger Cars Subject to Tax



(b) Passenger Cars Not Subject to Tax



(c) Light Trucks with Fuel Economy in Taxed Range



Note: Total sample sizes are (a) 916, (b) 5,422 and (c) 3,236. Part (a) shows a histogram of the Gas Guzzler Tax rating for all passenger cars subject to the tax, or within .5 MPG of the upper end of the tax, from years 1999-2009. Part (b) shows the same histogram for all passenger cars with fuel economy ratings above 23 MPG, which are therefore not subject to the tax. Part (c) shows the same statistic for all light trucks in the same fuel economy range as figure (a), which are also not subject to the tax because they are trucks.

distribution (this is the coefficient, 4.140, divided by the mean, 12.94). Controlling for the polynomial to account for non-uniformity of the counterfactual distribution has a minimal effect on the estimates. In columns 3 and 4, the data are restricted to vehicles that appear to have a unique engine design and manufacturer within a sample year, in the hopes of dropping observations that may be tightly correlated. A similar restriction is placed on columns 5 and 6, but in these cases the data are restricted to have a unique engine design across years as well. The qualitative conclusions of the table are unchanged by these restrictions.

We can further test this conclusion by reproducing the Gas Guzzler Tax statistic for vehicles not subject to the tax, and see if the pattern reemerges here. To do this, we have to work with a different data source, which includes only 1999 - 2009 observations. With this alternative data source, we are able to produce a Gas Guzzler Tax rating for all vehicles, whether or not they paid the tax. Figure 4 reconstructs the same information as figure 3 using this data set in part (a). In this data source, there is also a pronounced increase in the number of vehicles above the notch, but the pattern looks somewhat different. This difference is due both to the difference in sample years and to a large number of observations that are just above the top Gas Guzzler notch at 22.5 MPG, which must be dropped from the figure **??** for reasons already discussed.[17]

In contrast, part (b) shows the distribution of fuel economy decimals for passenger cars that have ratings above the Gas Guzzler Tax minimum and therefore have no incentive to bunch at or just above .5. Likewise, part (c) shows the distribution of rating decimal for light trucks in the same fuel economy range as the passenger cars in part (a). Because light trucks are not subject to the Gas Guzzler Tax, these vehicles would have no incentive to bunch. The fact that these groups do not show bunching is further evidence that the bunching in the vehicles subject to the tax is due to an intentional response to notch incentives.

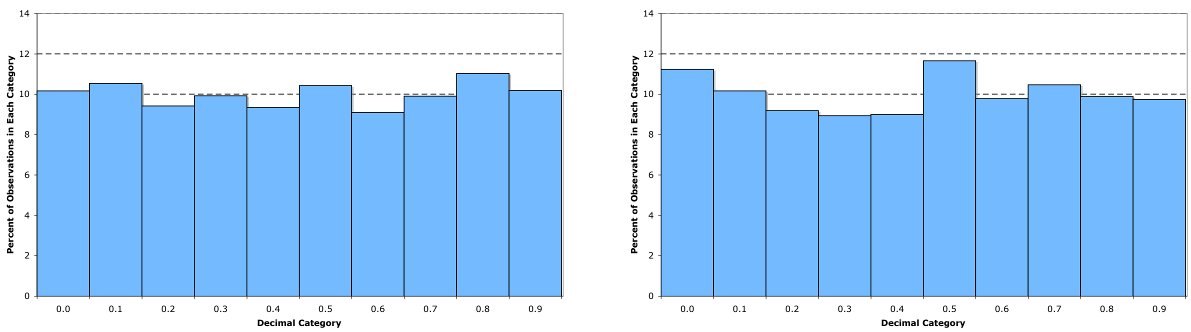
4.2 Fuel Economy Labels

Automakers face policy notches not only in the form of tax incentives, but also in the form of fuel economy labels for consumers. As noted above, automakers are required by federal law to attach a fuel economy label to all new vehicles sold in the United States. The contents of this label are strictly prescribed. In particular, the fuel economy ratings must be based on the aforementioned fuel economy test, and the values must be reported as integers that are rounded off from the test results. This results in a *presentation notch* at .5 miles-per-gallon decimals. If consumers use the rounded values as a source of information when purchasing a vehicle, and if consumers value fuel economy, then automakers may have an incentive to manipulate fuel economy ratings around these presentation notches. Note

[17]Note that if this difference is due to the overall curvature of the fuel economy distribution, this curvature is accounted for in the regression estimates of Table 3.

Figure 5: Label Rating Decimals: All Vehicles, 1999 - 2007

(a) City Label Rating Decimal **(b)** Highway Label Rating Decimal



Note: Total sample size is 5,040. Data exclude a small number of vehicles with nonstandard fuel types. Sample is restricted to observations that have a unique manufacturer, cylinders, displacement, drive type, fuel type, transmission and fuel economy rating across model years.

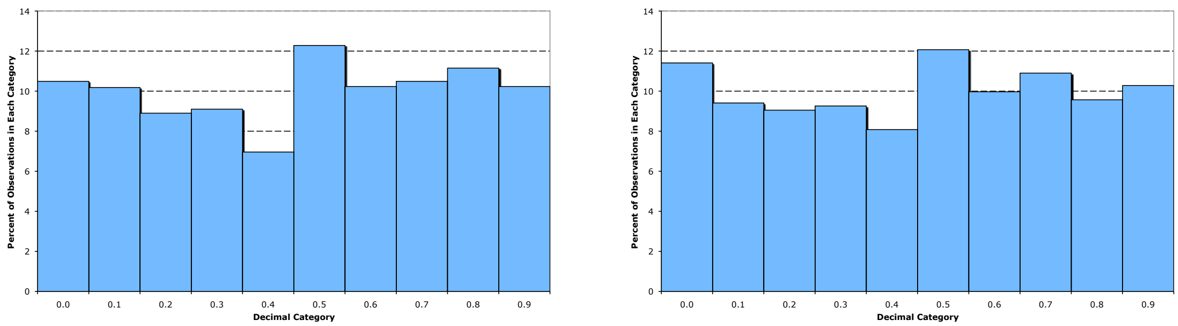
that *all* vehicles must have a label rating, whereas only high-performance passenger cars are subject to the Gas Guzzler Tax. The label ratings therefore allow us to check for notch responses throughout the entire vehicle market.

To check for this, we produce here a non-parametric test similar to the one presented above for the Gas Guzzler Tax. The EPA's publicly available data files do not include the unrounded estimates from 1984 to 1998, so we are limited to describing the data from the years before and after this data break. Figure 5 shows histograms of city and highway fuel economy label ratings decimals for all vehicles in the later data sample, between 1999 and 2007. The tabulations in these, and all subsequent figures in this section, exclude a very small number of vehicles with unusual fuel types (e.g., compressed natural gas) that are subject to a different rating procedure, very high-end brands (e.g., Lamborghini), and they drop any observation that appears to be a repeat in the sample where the manufacturer, cylinders, displacement, drive type, fuel type, transmission and fuel economy ratings are identical either within or across model years, with the intention of restricting identical engines that are included in multiple models.

Especially with respect to highway ratings, Figure 5 provides some suggestion of "extra"

Figure 6: Label Rating Decimals: Big Three, 1999 - 2007

(a) City Label Rating Decimal **(b)** Highway Label Rating Decimal



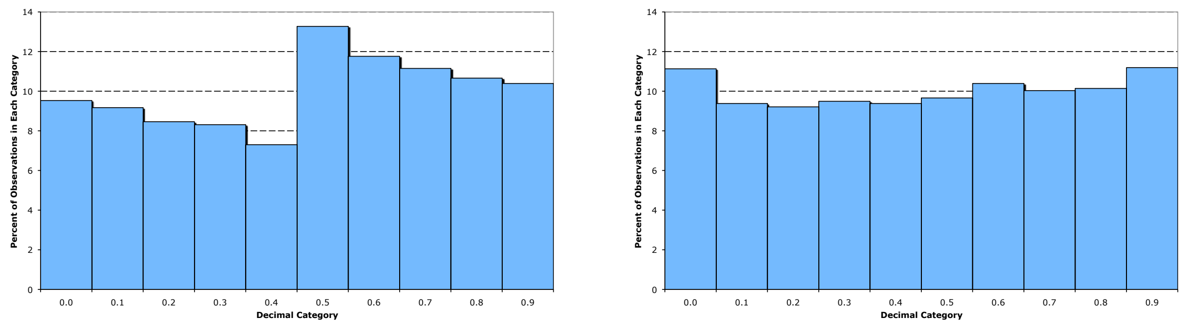
Note: Total sample size is 1,955, and it includes only vehicles produced by Chrysler, Ford and General Motors. Data exclude a small number of vehicles with nonstandard fuel types. Sample is restricted to observations that have a unique manufacturer, cylinders, displacement, drive type, fuel type, transmission and fuel economy ratings are across model years.

observations just to the right of the presentation notch: the .5 decimal is the modal decimal. In Figure 6 we restrict the sample to the major U.S. automakers — Chrysler, Ford and General Motors — and the evidence becomes much crisper, and the bunching appears in both city and highway ratings. For the domestic Big Three, the difference between the number of vehicle configurations in the .4 and .5 bin is statistically significant for both the city and the highway label ratings (p-value $<.0001$). By comparison (results not shown), there are actually *more* observations in the .4 bin than the .5 bin for the city ratings for both Asian and European automakers. For Asian automakers, the .4 and .5 bins have very similar numbers of vehicles for highway ratings, while there does seem to be a number of "extra" .5 observations for the European city ratings.

There are several reasons why domestic automakers may be more responsive to presentation notches. First, domestic automakers sell a much larger fraction of their vehicles to the U.S. market. Foreign producers may be reluctant to fine-tune vehicles if only a modest fraction will be shipped to the United States. Second, domestic automakers are typically on the very edge of complying with CAFE. Historically, the domestic automakers have never

Figure 7: Label Rating Decimals: All Vehicles, 1978 - 1983

(a) City Label Rating Decimal **(b)** Highway Label Rating Decimal



Note: Total sample size is 4,754. Due to incomplete matching of manufacturer information in these data, no sample restrictions can be applied.

paid fines for being out of compliance with CAFE, but they have typically had fuel economy averages that are very close to the legal minimum. In contrast, European automakers are often out of compliance and choose to simply pay fines rather than adjust their fleet, and the Asian automakers are generally well above the minimum regulatory requirement (Anderson and Sallee 2009). As a result, the domestic automakers may have developed greater expertise in finely tuning fuel economy because they used these techniques to adjust vehicles annually in response to CAFE concerns. For example, until very recently, only the domestic firms made use of a CAFE loophole for flexible-fuel vehicles (Anderson and Sallee 2009). Third, relative to American consumers of European cars, American consumers of domestic cars may be more concerned with fuel economy and, relative to the Asian automakers, domestic firms may be more concerned with boosting their fuel economy image.

The EPA does report unrounded ratings from 1978 to 1983, enabling us to perform the same analysis for those years.[18] The pattern of the decimal distribution for city ratings for these early years is the starkest of all those we have examined so far. The difference between .4 and .5 for the city ratings is statistically significant (p-value <.0001), whereas

[18] At the moment, however, our version of the data does not identify manufacturers, so we are unable to restrict the data to unique observations or cut the data by manufacturer group. Figure 7 shows results from these years for all vehicles.

the difference between .4 and .5 for the highway rating is not (p-value is .67). This suggests that, at least in the first few years of the label ratings, automakers were more concerned with city ratings than highway.

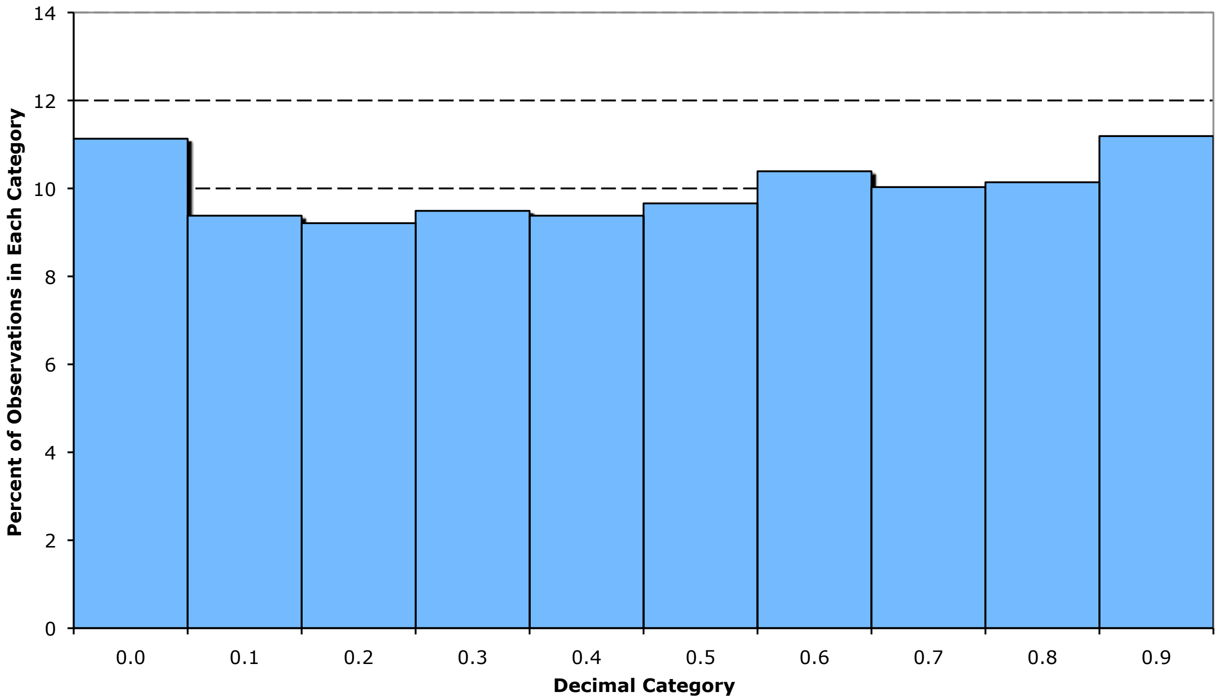
4.3 A False Experiment: CAFE

One might be concerned that the preponderance of vehicle configurations having a miles-per-gallon with a decimal at or just above .5 might be an artifact of some unknown engineering property or other unconsidered anomaly. To further check for this possibility, we construct a similar histogram for a closely related fuel economy measure, individual vehicle CAFE ratings, which do not have a notch at .5 miles-per-gallon. Each vehicle in a manufacturer's fleet is given a CAFE rating based on a weighted average of the vehicle's city and highway fuel economies. These combined ratings, which are calculated to the tenth of a MPG (e.g., 27.5 MPG), are used to calculated a sales-weighted average for all vehicles made by a given manufacturer. This sales-weighted average is then rounded to a tenth of a mile-per-gallon for use in determining compliance with CAFE. Because the individual fuel economy ratings are not rounded to integers prior to averaging, there is no discrete incentive for manufacturers to push individual vehicle CAFE ratings above any particular notch.

If a manufacturer manipulates the highway and city rating decimals in response to notches, this need not translate into a manipulation of the CAFE decimal distribution because the two numbers are combined. In addition, since 1986, the label ratings are adjusted for in-use shortfall, whereas the CAFE ratings are not. If a manufacturer manipulates the Gas Guzzler rating, however, this will translate into a manipulation of the CAFE rating, because the two numbers are identical in early years and extremely close to each other in later years. As a result, for this false experiment exercise, we omit passenger cars with combined fuel economy ratings below 23, which would be subject to the Gas Guzzler Tax.

Figure 8 is a histogram, similar to those shown above, of the fuel economy rating decimal for the combined CAFE rating, for vehicles not subject to the Gas Guzzler Tax. Compared

Figure 8: Distribution of CAFE Combined Rating: 1978 - 2005



Note: Total sample size is 18,045. Source: National Highway Transportation Safety Administration. Data exclude vehicles subject to the Gas Guzzler Tax, as well as a small number of vehicles that had a CAFE rating of 0 or above 65, which appear to be mistakes.

to the rating distributions where notches matter, the CAFE ratings are remarkably uniform. There are slightly more observations in the .5 bin than the .4 bin, but this difference is not statistically significant.[19] This is supportive of our hypothesis that the "extra" observations at or just above .5 decimals in MPG are driven by strategic responses to policy and presentation notches, and not by some unknown anomaly.

[19] A test of the difference between the .4 and .5 bins yields a one-sided p-value of .092, and a test of the difference between the .3 and .4 bins from the .5 and .6 bins yields a one-sided p-value of .400. Overall, a Chi-squared test statistic of the null hypothesis that the data are distributed multinomial with equal probability on each bin cannot be rejected (p-value is .994).

5 The Relationship Between Manipulation and Notch Value

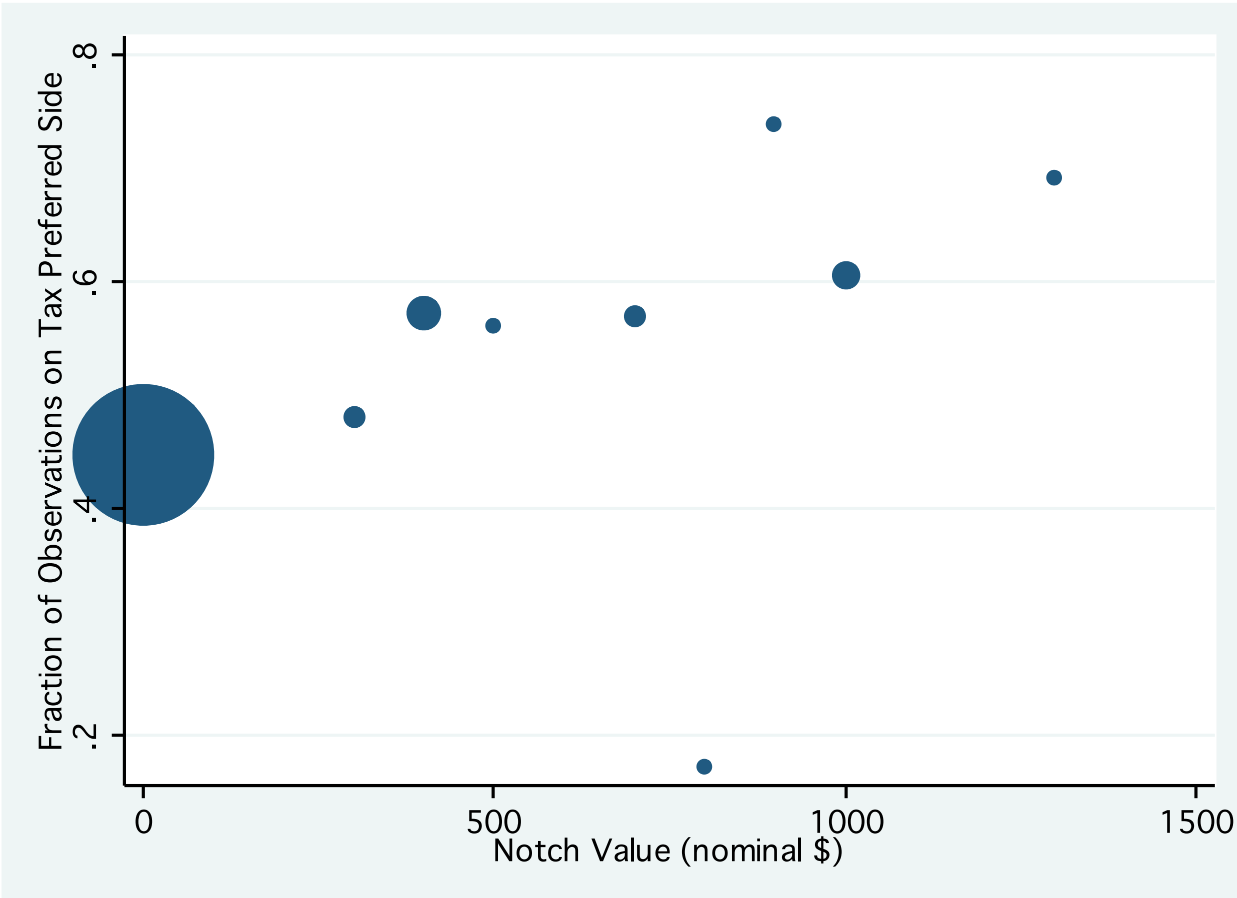
The analysis up to this point has not taken advantage of the fact that the tax liability implications of car notches vary in magnitude, both over time and within a year. Intuitively, for a given cost function of altering MPG, we expect that there should be more manipulation when the reward to jumping over a notch is greater. In this section we pursue evidence of this relationship, both as further confirmation that automakers are in fact acting strategically with respect to fuel economy notches and as a basis for subsequent calculations of the consumer valuation of fuel economy.

We begin by examining the Gas Guzzler Tax data over time. Because the tax is written in nominal dollars, the real value of the notches has fallen significantly over time, even though the nominal tax schedule has not changed since 1991—since 1980, inflation has reduced the value of the tax to 38% of its original value.[20] Consistent with this tax reduction, the divergence from a uniform distribution of the rating decimals is relatively more dramatic, although far noisier, for the 1980's. In those years, less than 4% of taxed vehicles had an MPG with a .4 decimal. The difference between the number of observations in the .3 and .4 bins versus the .5 and .6 bins was 9.2 percentage points (p-value<.0001) between 1980 and 1990, whereas the comparable number was 7.7 percentage points (p-value<.0001) from 1991 to 2009.

We can pursue this issue further by estimating reduced-form regressions that test whether or not the amount of manipulation is positively correlated with notch values in a pooled cross-section. To do this, we define a dummy variable to be equal to 1 if the Gas Guzzler Tax decimal is either .5 or .6, and restrict our sample to the set of vehicles with a guzzler rating decimal between .3 and .6. Defined this way, if there were no manipulation, we would expect the mean of this dummy variable to be about one-half. We then assign each vehicle a notch

[20] This calculation uses the CPI-U and compares the 1980 annual average to the 2008 annual average.

Figure 9: Fraction of Observations Above Notch, by Notch Value



Note: Circle areas are proportional to sample size at each value. The total sample size is 2,530. The sample is restricted to 1999 – 2008 due to incomplete information from other years for calculating the Gas Guzzler Tax statistic for vehicles not subject to the tax.

value depending on the tax saving from jumping over the closest .5 rating. For vehicles above the highest Gas Guzzler Tax notch (22.5) or below the lowest Gas Guzzler Tax notch (12.5), this value is zero. For all other vehicles, this notch ranges in value from $300 to $1300 in nominal terms.

To be able to include vehicles above the 22.5 notch, we cannot rely on the official list of Gas Guzzler Tax vehicles because vehicles with an MPG of, for example, 22.6 are not subject to the tax and are therefore not listed. To get around this limitation, we reconstruct the Gas Guzzler Tax rating using the official federal formula for all vehicles. Doing this requires the underlying fuel economy ratings coupled with vehicle characteristics so that we can distinguish passenger cars and light trucks. This limits us to analyzing data from 1999 to 2009, during which time we have complete EPA ratings data that enable this computation. In that period, the Gas Guzzler Tax nominal tax schedule did not change. Thus, the estimates should be thought of as relying primarily on cross-sectional identification, although some panel variation exists due to the erosion of the real value of the guzzler notches.

Figure 9 shows a graph of the fraction of observations that are on the tax-preferred side of each notch in the Gas Guzzler Tax, out of all observations within .2 MPG of the notches. (The figure uses nominal notch values for ease of presentation, but we use inflation adjusted values in the regressions below.) This figure clearly shows a positive relationship between the notch value and the implied amount of manipulation, though there is a significant outlier at $800.

Table 4 reports results from several alternative specifications of a linear probability model applied to passenger cars. The top row of the table shows that, across various specifications, the percentage of passenger cars located just on the tax-preferred side of a notch is indeed positively related to the tax savings from crossing a given notch. The coefficient estimates suggest that a $100 increase in the value of the notch will increase the probability that an observation close to the notch is on the tax-preferred side of the notch by about 2 percentage points. Extrapolating this estimate implies that, if vehicles were otherwise equally likely to be on either side of a .5 MPG, a notch worth $1,000 would be associated with 70% of observations on the tax-preferred side, implying that 40% of vehicles originally just on the higher-tax side would have moved just over to the lower-tax side.

The table reports a number of alternative specifications. The first column includes all passenger cars in the sample, not just those with a MPG close to where the Gas Guzzler Tax applies; in this sample, the majority of vehicles face a 0 value notch. The second column restricts the sample to those near where the Gas Guzzler Tax applies. Starting with the third column, vehicle-make fixed effects are included. The regressions shown in Columns 4 and 5 add a polynomial in the underlying Gas Guzzler Tax rating, in order to

Table 4: Linear Probability Model Estimates of the Relationship Between the Prevalence of Extra Observations on the Tax-Preferred Side of Gas Guzzler Notches on Notch Value: **Passenger Cars**

Dependent variable = 1 if gas guzzler rating decimal is .5 or .6
Sample includes all vehicles with decimals at .3, .4, .5 or .6

	(1)	(2)	(3)	(4)	(5)	(6)
Notch Value	0.0144***	0.0234***	0.0204***	0.0208***	0.0203**	0.0258***
(hundreds, 2008 $)	(0.00385)	(0.00490)	(0.00549)	(0.00696)	(0.00796)	(0.00929)
Guzzler Rating				-0.386	-0.0769	0.295
				(0.392)	(0.451)	(0.514)
Guzzler Rating^2				0.0238	0.00653	-0.0150
				(0.0225)	(0.0258)	(0.0296)
Guzzler Rating^3				-0.000682	-0.000214	0.000379
				(0.000614)	(0.000700)	(0.000813)
Guzzler Rating^4				8.99e-06	2.98e-06	-4.73e-06
				(7.93e-06)	(8.99e-06)	(1.06e-05)
Guzzler Rating^5				-4.37e-08	-1.46e-08	2.31e-08
				(3.86e-08)	(4.36e-08)	(5.17e-08)
Constant	0.441***	0.361***				
	(0.0110)	(0.0297)				
Observations	2287	505	2287	2287	1481	1172
R-squared	0.006	0.043	0.006	0.009	0.007	0.010
Make Fixed Effects	No	No	Yes	Yes	Yes	Yes
Sample	All	<24 MPG	All	All	Within	Between
Number of FE groups			47	47	46	46

Note: Standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Column 5 restricts the sample to observations "unique within years" by excluding all duplicate observations where a vehicle has the same make, displacement, transmission, cylinders, and unrounded city and highway fuel economy ratings as another vehicle in the same year. Column 6 restricts the sample to observations "unique between years" by excluding all duplicate observations matching on these characteristics across years. These regressions are limited to 1999 to 2009 due to the limited availability of data to calculate the Gas Guzzler Rating for those vehicles not subject to the tax.

allow for the possibility that there may be slightly more (or fewer) observations to the right of a notch simply because the overall fuel economy distribution is upward (or downward) sloping. Column 6 restricts the observations so that any vehicle with the same make and engine is treated as a duplicate observation within model years. Column 7 applies the same restriction across years. Glancing across the first row of Table 4 indicates that our estimate of the impact of the value of notches on the extent of bunching is fairly stable across all specifications, and is highly significant.

Table 5 repeats the same set of regressions when the observations are vehicle configura-

Table 5: Linear Probability Model Estimates of the Relationship Between the Prevalence of Extra Observations on the Tax-Preferred Side of Gas Guzzler Notches on Notch Value: **Light Trucks**

Dependent variable = 1 if gas guzzler rating decimal is .5 or .6
Sample includes all vehicles with decimals at .3, .4, .5 or .6

	(1)	(2)	(3)	(4)	(5)	(6)
Notch Value	0.00371	-0.000947	0.00499	-0.000138	-0.00203	-0.00510
(hundreds, 2008 $)	(0.00341)	(0.00453)	(0.00364)	(0.00450)	(0.00554)	(0.00618)
Guzzler Rating				-3.969	-17.50*	-15.44
				(5.408)	(9.678)	(10.63)
Guzzler Rating^2				0.381	1.515*	1.343
				(0.441)	(0.817)	(0.898)
Guzzler Rating^3				-0.0175	-0.0642*	-0.0572
				(0.0177)	(0.0340)	(0.0373)
Guzzler Rating^4				0.000386	0.00133*	0.00119
				(0.000347)	(0.000694)	(0.000762)
Guzzler Rating^5				-3.28e-06	-1.08e-05*	-9.69e-06
				(2.68e-06)	(5.58e-06)	(6.13e-06)
Constant	0.491***	0.524***				
	(0.0180)	(0.0277)				
Observations	1774	1331	1774	1774	1153	951
R-squared	0.001	0.000	0.001	0.007	0.008	0.007
Make Fixed Effects	No	No	Yes	Yes	Yes	Yes
Sample	All	<24 MPG	All	All	Within	Between
Number of FE groups			37	37	36	36

Note: Light trucks are not subject to the Gas Guzzler Tax, so these estimates serve as a false experiment. Standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Column 5 restricts the sample to observations "unique within years" by excluding all duplicate observations where a vehicle has the same make, displacement, transmission, cylinders, and unrounded city and highway fuel economy ratings as another vehicle in the same year. Column 6 restricts the sample to observations "unique between years" by excluding all duplicate observations matching on these characteristics across years. These regressions are limited to 1999 to 2009 due to the limited availability of data to calculate the Gas Guzzler Rating for those vehicles not subject to the tax.

tions of light trucks. Light trucks are not subject to the Gas Guzzler Tax, so they should not show a response to notch values. As a false experiment, we assign notch values to these observations as if they were passenger cars and run parallel specifications. Consistent with our expectations, the same specifications run on light truck data produces much smaller point estimates of the effect of notch values. A majority of these estimates are negative, and none are statistically distinguishable from zero. Thus, the false experiment lends credence to our interpretation of the passenger car regressions as providing a causal effect of the notched

Gas Guzzler Tax.

We also hypothesized that crossing some presentation notches would be more valuable than others. In particular, we expected that automakers might be more aggressive in moving over a notch that changed the fuel economy label from 19 to 20 or from 29 to 30, and possibly also from 24 to 25. We performed an exercise similar to that shown in Table 4, but we found no evidence of more manipulation around those particular label values.

6 Welfare Analysis

In this section we build a welfare framework that enables us to analyze the normative implications of strategic responses to notches. The framework presumes a stylized, simple model of the car market, both for immediate heuristic reasons and also so that this framework can be applied directly to other contexts.

On the production side, we assume car manufacturers have no market power. Firms can convert inputs into cars using a linear, CRS production technology. On the consumer side, we assume that each consumer purchases one vehicle.[21] Consumers value vehicles because of the qualities/characteristics they offer, such as performance, styling, safety, fuel economy, etc. Because of fixed per-variety costs, a finite number of varieties – assumed to be fixed – is produced, and each consumer chooses which variety of car is best, which generates a set of vehicles and a distribution of fuel economy. Each type of vehicle is optimal for one class of consumers, and given an initial equilibrium, small changes in taxes will induce small changes in vehicle fuel economy, but will not cause consumers to switch vehicles. Thus, the quantity of each vehicle sold does not respond to the fuel economy changes induced by taxes.

After these other design decisions are made, manufacturers observe how close each vehicle is to a notch, and consider whether to alter fuel economy to jump over the nearest notch.

[21] Assuming each consumer purchases two or more vehicles raises the type of issue considered in Kleven and Slemrod (2009): that one response to taxing high-performance cars will be that some people buy vehicles with higher performance within the class of low-performing cars not subject to tax, to make up for the lower performance of the taxed cars purchased. Allowing the number of cars purchased to change opens up yet another set of issues.

From a welfare point of view, it is optimal that each vehicle variety becomes more fuel-efficient as long as the private (=social) cost of so doing does not exceed the marginal social benefit of so doing, which we assume is proportional to the change in a vehicle's MPG.[22] This would happen automatically with a smooth per-MPG subsidy t that was set equal to the per-MPG externality e, so that $t = e$.

In this case the social gain SG can be approximated as follows:

$$SG = \frac{1}{2} e \Delta X. \tag{1}$$

Here the expression e denotes the difference between the marginal social cost and the marginal private cost of MPG which, in the absence of other policies, would equal the externality. The expression ΔX stands for the change in the externality-causing activity, measured in units of vehicle-MPGs.[23]

Noting that $\Delta X \approx st$, where s captures both demand and supply elasticities, then it is straightforward to show that the value of SG is maximized where $t = e$. This is the first-best outcome with a Pigouvian tax.[24]

If the tax is not set equal to the marginal externality ($t \neq e$), then social gain is as follows:

$$SG = \frac{1}{2}(2e - t)\Delta X, \tag{2}$$

which is always less than the case where $t = e$, when (2) reduces to the previous expression.

[22] This allows us to ignore the complicated externality structure of vehicle fuel economy. Fuel economy has social cost implications related to both miles driven, from congestion and accident externalities, as well as gasoline consumed, which has local air pollution, climate change and energy security externalities. Given our interest in creating a general framework for the welfare analysis of notches, we abstract from these specific concerns.

[23] Thus, for example, if manufacturers increased the MPG of one million cars by 0.1 and another 100,000 cars by 0.2, ΔX would be 120,000.

[24] We ignore the social benefit from raising revenue by invoking the argument of Bovenberg and de Mooij (1994) and Bovenberg and de Mooij (1997) that a small environmental tax generates the same labor-market distortion as the labor tax it presumably replaces, and the gross distortion to consumption patterns is small if the tax system is second-best optimal.

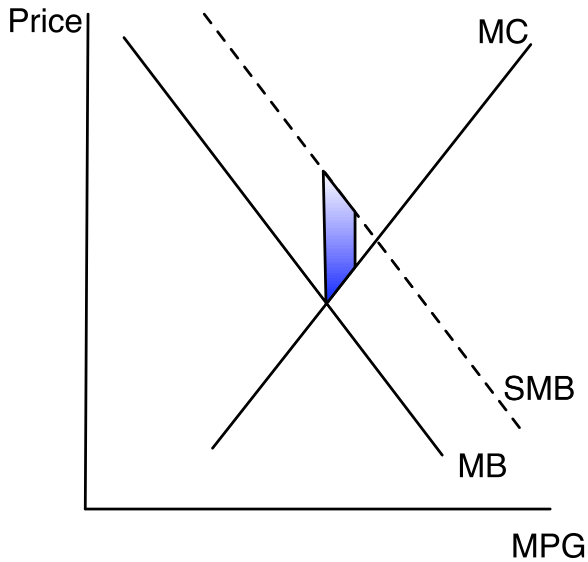
When $t \neq e$, some potential welfare gain is foregone either by failing to induce some socially valuable MPG increase (when $t < e$) or by inducing MPG increases whose marginal social cost exceeds the marginal social benefit (when $t > e$). This is illustrated in Figure 10, where the left panel shows the welfare gain from a too-small subsidy, and the right-hand diagram shows the initial gain, then subsequent loss from a too-large subsidy.

Now apply this reasoning to a notch policy. The notch design does not make a significant difference for non-marginal decisions, by consumers or manufacturers; if one is considering buying (or producing) a 12 MPG car versus a 30 MPG car, the fact that there are notches in the choice set between these two points is not important. But the notch design is important for marginal changes in the MPG of vehicles.

To see this, consider the welfare consequences of the local behavioral responses to the notches. In this case, locally the policy does not feature a uniform value of t. Instead, depending on how close to the next notch the initial MPG is, the *effective* average subsidy varies widely.

To make this concrete, consider again the design of the Gas Guzzler Tax. Over its range, the tax imposes a levy that averages about $800 per unit reduction in MPG, or about $80 for every tenth of MPG reduction. Equivalently, we can speak of an average subsidy of $800 per unit increase in MPG. If this is indeed the marginal social benefit of increasing a vehicle's MPG, an ideal Pigouvian tax would levy a tax of this magnitude that is a smooth function of MPG. Now compare that to a notched policy that cuts the tax by $800 whenever the rating decimal jumps above a notch. The effective subsidy for increasing MPG now varies considerably depending on what the MPG would be in the absence of the tax, and how large an incremental change is taken. Table 6 below quantifies the local incentives, where the rows correspond to the initial, "unmanipulated" MPG decimal points, and the columns correspond to ending MPG decimals. Each cell contains the effective per-MPG subsidy from moving from a given starting decimal to a given ending decimal, assuming the jump length is at most 0.9. The magnitude of a jump is measured by the horizontal difference to the right

Figure 10: Welfare Gains at Varied Subsidy Rates



Note: In the figure on the left, the blue shaded area represents the welfare gain from a subsidy below the Pigouvian optimum. The figure on the right shows a subsidy in excess of the Pigouvian tax, with the blue area representing a social gain and the red area a social loss.

of a diagonal entry marked with an X, including "wrap-arounds" – cases where the ending decimal is below the starting decimal but the integer (not shown) has changed.

Recall that the intended subsidy is $800 per-MPG. But Table 6 shows that the actual per-MPG subsidy varies widely depending on the starting and ending decimal. Although the effective per-MPG subsidy with the notch design averages approximately $800 across all starting decimals, it is zero for half of the possible moves of 0.9 or less, because they do not move the MPG above a notch. For the other half with an effective subsidy, the amount of the subsidy per MPG ranges from as low as $889 per-MPG, for moves of 0.9 to save $800 in tax, to as high as $8000 per-MPG when a jump of just 0.1 MPG reduces the Gas Guzzler Tax by $800.[25]

Although the subsidy is by assumption appropriate on average, the welfare effects of the notch design that imposes non-uniform effective average tax rates are notably different from

[25] Note that in no case does the Gas Guzzler Tax provide an incentive to *reduce* a vehicle's MPG, so there is no reason for "bunching from above." Compared to a smooth incentive to increase MPG, there would be more MPGs just above a notch.

Table 6: Effective Average Subsidy per Mile-Per-Gallon Increment, Depending on the Starting and Ending MPG Decimal

Starting Decimal	Ending Decimal									
	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0	X	0	0	0	0	1600	1333	1143	1000	889
0.1	889	X	0	0	0	2000	1600	1333	1143	1000
0.2	1000	889	X	0	0	2667	2000	1600	1333	1143
0.3	1143	1000	889	X	0	4000	2667	2000	1600	1333
0.4	1333	1143	1000	889	X	8000	4000	2667	2000	1600
0.5	0	0	0	0	0	X	0	0	0	0
0.6	0	0	0	0	0	889	X	0	0	0
0.7	0	0	0	0	0	1000	889	X	0	0
0.8	0	0	0	0	0	1143	1000	889	X	0
0.9	0	0	0	0	0	1333	1143	1000	889	X

Note: Table shows the effective subsidy per mile-per-gallon of a vehicle that starts at the fuel economy decimal in each row value and ends up, after manipulation, in the column value. The table is based on a notch value of $800, the average value of a notch in the Gas Guzzler Tax. The table includes "wrap-around" values, but assumes that all jumps are less than one mile-per-gallon.

a smooth tax. This is because combining a set of incorrect taxes that happen to average out to the correct amount does not yield the same welfare gains as a uniformly applied correct tax. From a social point of view, it is desirable for re-engineering to occur whenever the private cost is less than $800 per-MPG, and to not occur when the cost exceeds $800 MPG. A notch system does not achieve this. For the half of cells with zeros, no re-engineering will take place even if the private cost is less than $800 per-MPG. For the half of cells with a positive number, some re-engineering will occur even when its cost exceeds $800; indeed, for jumps of just 0.1 MPG, it will take place as long as the cost is $7999 per MPG or less.

When the effective tax rate varies, we can approximate the social gain using equation 2 as follows:

$$SG = \frac{1}{2}\sum_i (2e - t_i)\Delta X_i = e\sum_i \Delta X_i - \frac{1}{2}\sum_i t_i \Delta X_i = (e - \frac{1}{2}\tau)\Delta X \tag{3}$$

where t_i refers to the ith average effective tax, ΔX_i refers to the change in vehicle miles-per-gallon of those subject to it ($\Delta X \equiv \sum \Delta X_i$), and $\tau \equiv \sum t_i \frac{\Delta X_i}{\Delta X}$ is the ΔX_i-weighted average

Table 7: Hypothetical Distribution for Welfare Calculation

Bins	Average Fuel Economy	Actual Distribution	Counterfactual Distribution
.0	0.05	0.1	0.1
.1	0.15	0.1	0.1
.2	0.25	0.1	0.1
.3	0.35	0.09	0.1
.4	0.45	0.07	0.1
.5	0.55	0.14	0.1
.6	0.65	0.1	0.1
.7	0.75	0.1	0.1
.8	0.85	0.1	0.1
.9	0.95	0.1	0.1

Note: Table shows hypothetical values only.

effective tax rate. In terms of Figure 10, this is the summation of a number of these welfare triangles. Note that there is a positive correlation between t_i and ΔX_i (the bigger the tax, the larger the response), which will tend to reduce the value of the net social gain because, for example, the vehicles most likely to have their fuel economy changed are those for which the effective local subsidy per-MPG is ten times higher than the "intended" rate of subsidy.

We can also use ex post data — that is, data on the distribution of vehicles' MPGs after manipulation — to approximate the welfare consequences of the local incentives caused by the Gas Guzzler Tax notch design. For the sake of building intuition, before we examine the actual data we first consider a simple example.

Imagine that we observed a distribution of decimals as shown in Table 7. If the cost of moving a vehicle's MPG is independent of the initial decimal, we can conclude from these data that for 30% of vehicles the cost of moving 0.1 was less than $800, and for 10% of vehicles the cost of moving 0.2 was less than $800. Suppose that, for vehicles whose MPG was strategically manipulated, the private cost of the manipulation averaged $400. Before strategic manipulation the average decimal MPG of vehicles was exactly 0.5, while after the manipulation it is 0.505. If each 0.1 MPG increase has a social gain from externality reduction of $80, the average social benefit per jumping vehicle is $100 (=(3*80+1*160)/4). The average private cost of the vehicles that increase their MPG is $400. The net social

Table 8: Actual Distribution for Welfare Calculation: Gas Guzzler Tax

Bins	Average FE	Actual Dist.	Counterfactual
.0	0.05	0.1029	0.1
.1	0.15	0.0928	0.1
.2	0.25	0.1002	0.1
.3	0.35	0.0867	0.1
.4	0.45	0.0731	0.1
.5	0.55	0.1246	0.1
.6	0.65	0.1151	0.1
.7	0.75	0.1219	0.1
.8	0.85	0.0826	0.1
.9	0.95	0.1002	0.1

Note: This sample matches the sample in figure 3. Total sample size is 1,477. Data are from the Internal Revenue Service. In 1980, 1981, 1983, and 1985, the tax liability changed at whole integers (the .0 point) of the rating rather than at half integers (the .5 point). For those years, we shift decimals by .5, so that the notch is always represented by the .5 bin in the figure. Our data come from lists of taxed vehicles, which prevents us from including vehicles whose MPG rating is just above the highest-rating tax notch, and thereby were not subject to tax at all. To make this omission symmetric, we also drop the observations with ratings just below this notch, so that no observations within .5 miles-per-gallon of this notch on either side are included. The sample also omits a few observations from 1991 to 1995 where the manufacturer was listed as an importer, because these appear to be redundant observations.

gain is -\$300 per altered car, or -\$12 per car in the range of these notch incentives. We can transform this into a social gain statistic using equation (3):

$$SG = \frac{1}{2}[(2(800) - 8000)(0.1)(0.03X) + (2(800) - 4000)(0.2)(0.01X)] \tag{4}$$

$$= \left(800 - \frac{1}{2}6400\right)(0.005X) \tag{5}$$

$$= -12X, \tag{6}$$

where τ, the weighted-average effective tax rate, is equal to \$6,400 per-MPG, and X is the total number of vehicles (not vehicle models) in the range of the notch incentives.

Now we consider the actual distribution of rating decimals for vehicles subject to the Gas Guzzler Tax. Table 8 depicts the ten possible fuel economy bins and, in the third column, shows the actual distribution of observations across bins for vehicles subject to the Gas

Guzzler Tax. Using the same methodology that we used for the hypothetical example, we can calculate the net social gain as follows:

$$SG = \left(800 - \frac{1}{2}4720\right)(.0725) = -11.31X. \tag{7}$$

The local incentives of the notch implies a social loss of \$11.31 per car in the range of the local incentives. Note that the actual ex post weighted-average subsidy (τ) of \$4,720 per-MPG is lower than the \$8,000 per-MPG that what would obtain if all the jumps were of length 0.1, but is more than the \$4,000 per-MPG if all the jumps were of length 0.2. This is a useful exercise because it can be performed on any ex post data, provided that a counterfactual is available. The researcher does not need to know the value (MPG, in our application) of each individual observation in the absence of the notch policy in order to calculate the average subsidy.[26]

To put the -12X and -11.31X figures in perspective it is useful to compare them with the expected welfare gain due to local MPG modifications from introducing an optimal (flat) Pigouvian subsidy equal to \$800 per MPG improvement. In this case, as shown in expression (1), the social gain equals $1/2e\Delta X$. To quantify this expression we need to make an assumption about how much MPG improvement would be induced by a flat Pigouvian subsidy of \$80 for every tenth of an MPG improvement. To do so we draw on the data in the example, which approximate the extent of jumping in the actual data. From the observed distribution of decimal MPG endings we infer that, in order to save \$800, 30% of vehicles would jump .1 MPG and another 10% would jump .2 MPG. Now assume that the extent of jumping is proportional to the value of jumping, so that for a tax saving of \$80 3% of vehicles would jump .1 MPG and for a tax saving of \$160 an additional 2% of vehicles would

[26] Also, because there will be a positive correlation between effective subsidy rates and manipulation, τ will exceed the average statutory t, which implies that t, the policy parameter, should be set below the Pigouvian tax that would prevail in a system without notches.

jump .2 MPG. The social gain from this behavior would equal

$$SG = \frac{1}{2}[800(0.1)(0.03X) + 800(0.2)(0.02X)] = 2.8X, \quad (8)$$

or just \$2.80 per car. To be convinced that only a small gain would be achieved with the optimal Pigouvian tax, keep in mind that with our assumptions only 5% of cars jump an average of 0.14 MPG, and that a 0.14 increase in MPG has a gross social gain of \$112 and a net-of-private cost gain of half of that; 5% of the net social gain of \$56 yields \$2.80. In contrast, in the example the notch induces 20% of those within two decimals of a notch to jump, or 4% of the total cars. But those that jump have a private cost that far exceeds the social gain of the MPG increase, turning a \$2.80 per car potential social gain from the un-notched subsidy design into a \$12 per car social loss. Thus, not only is the net social gain from the notched system negative, the social loss is over four times higher in absolute value than the social benefit of an optimally designed, i.e. flat, Pigouvian subsidy. The calculations using the actual data would be more complex, but would yield a qualitatively similar conclusion.

7 Inferring the Consumer Valuation of Fuel Economy from Bunching Around Fuel Economy Labels

An important policy question in energy and transportation economics is whether or not consumers properly value fuel efficiency in vehicles and other durables. If consumers do not properly value fuel economy, then standard results about the superiority of energy taxes to regulatory standards may be overturned.[27] This may have important implications for

[27] Researchers have traditionally concluded that fuel economy regulation is inferior to a fuel tax because fuel economy regulation lowers the cost of driving a mile (by raising fuel economy but holding fuel prices constant). If consumers do not properly value fuel economy, however, then they may not respond in an optimal way to changes in fuel prices. If consumer bias is sufficiently large, regulation could be preferred to fuel taxation (Fischer, Harrington and Parry 2007).

energy and climate change policy, as consumer undervaluation may be a justification for using CAFE or feebates in addition to a fuel or carbon tax (or cap-and-trade system).

There are several reasons to suspect that consumers might undervalue fuel economy. First, experimental evidence suggests that consumers do not understand the nonlinearity in fuel savings from changes in MPG and systematically make mistakes about the relative value of different fuel economy improvements (Larrick and Soll 2008). Second, survey evidence indicates that consumers are unable to articulate the key building blocks for a fuel economy valuation calculation, including mileage, fuel economy ratings and a discount rate (Turrentine and Kurani 2007). Third, the literature on energy-intensive durables has often found evidence of a very large implicit discount rate, which may be a symptom of consumer myopia (Hausman 1979; Dubin and McFadden 1984).[28] Finally, in the vehicle market, a number of studies have sought to test whether or not relative prices of efficient and inefficient vehicles adjust when gasoline prices change as much as standard models suggest. Much of this literature has found that consumers significantly undervalue fuel economy (Kahn 1986; Kilian and Sims 2006; Alcott and Wozny 2009), but some recent work has suggested that consumer valuation may be close to full (Sawhill 2008; Busse, Knittel and Zettelmeyer 2009; Sallee, West and Fan 2009). As a result, this important question remains unsettled.

We are able to link our analysis of the behavioral response to Gas Guzzler Tax notches to our analysis of the response to label notches to generate an estimate of the consumer valuation of fuel economy. In the case of the Gas Guzzler Tax, we know the dollar value of crossing a notch, because it is set by policy. In contrast, the value of fuel economy to consumers is unknown, so we cannot directly assign a value to fuel economy label notches. But, by comparing the amount of shifting across the two sets of notches, we can *infer* the consumer valuation of an increase in fuel economy.[29] To see this suppose, for example, that

[28] In contrast, Dreyfus and Viscusi (1995) conclude that discount rates are in line with market interest rates.

[29] Note that, even if consumers are aware of strategic manipulation by automakers, under an assumption of a uniform distribution of un-manipulated fuel economy and constant manipulation costs, the increase in *expected* fuel economy implied by an increase in the label rating is one MPG.

all Gas Guzzler Tax notches were worth \$800, and we observed the same amount of bunching around Gas Guzzler Tax notches as we observed around fuel economy label notches. If the cost of manipulation were the same in both cases, then this would imply that a fuel economy notch was also worth \$800. If we observed less bunching around the label notches, we would conclude that label notches are worth less than \$800, and so on.

Note that the value to the manufacturer and to consumers of crossing a tax notch depends on the ultimate incidence of the tax change. This does not invalidate our analysis, however, as long as the incidence of a tax reduction is the same as the incidence of an incremental attribute improvement. That is, if automakers capture the same proportion of an increased consumer willingness to pay from an exogenous tax change as they capture of an exogenous increase in fuel economy, then the notch comparison will yield the valuation of fuel economy. We proceed under this assumption.

7.1 Fuel Economy Rating Details

In order to infer consumer valuation of fuel economy from the relative amount of bunching around notches, we need to account for the fact that, although the two fuel economy measures are determined by the same underlying tests, they are transformed in different ways. In particular, the underlying test statistics for highway H and city C are turned into label ratings (denoted with an L subscript) via a linear adjustment:

$$H_L = .78H$$
$$C_L = .9C,$$

and then rounded to integers, as described earlier as the "in-use shortfall" adjustment. In contrast, the Gas Guzzler Tax rating GG is a harmonic average of the original test scores:

$$GG = \left(\frac{.45}{H} + \frac{.55}{C}\right)^{-1},$$

which is then rounded to the nearest tenth of a MPG.

Thus, a marginal increase in H increases the highway label rating by .78, but it improves the Gas Guzzler Tax rating by $.45/H^2 \cdot (.45/H + .55/C)^{-2}$. For example, consider an engineering change that increased the highway test by .1 for a vehicle with an initial highway rating of 20 and a city rating of 15. The (unrounded) highway label would rise by .078, but the (unrounded) Gas Guzzler Tax rating would increase by only .032, in part, the latter increase is lower because it reflects both highway and city fuel economy.

Thus, if manipulation takes the form of costly adjustments to H and C, the underlying test scores, then a movement of .1 MPG in the Gas Guzzler Tax rating may cost more (or less) than a .1 MPG change in a label rating, depending on how adjustments to H and C are related. We proceed under the assumption that a re-engingeering alteration that affects the two test scores by a proportional amount — that is, if the automaker increases H by amount d, the city rating C is increased by γd, where γ is some scalar.[30]

To compare the amount of manipulation surrounding each type of notch, we must determine the average change in the underlying test values of MPG required to jump across each notch type. We call these minimal manipulation values d_k^* where k indexes city, highway and Gas Guzzler Tax. Assuming that that pre-manipulation distribution of fuel economy decimals is uniform, we can calculate that the average d required for moving .1 or .2 MPG is .167 and .192, for city and highway, respectively. Because the distance required to move the Gas Guzzler Tax rating .1 or .2 MPG depends on the starting value, we turn to the data to calculate the average critical value for the Gas Guzzler Tax. We solve for these critical values for each observation in the data, which accounts for the distribution of starting values for the Gas Guzzler Tax. To calculate this number for the Gas Guzzler Tax, we must choose a value of γ; for our initial estimates, we set $\gamma = 1$. We report these critical values in Table 9. It shows that the average test improvement required to move .1 or .2 MPG will be lowest for the Gas Guzzler Tax. This implies that, if we see the same amount of bunching in the

[30]Our conversations with engineers suggest that some, but not all, re-engineering can "target" highway or city fuel economy, but that this flexibility is limited.

Table 9: Average Test MPG Change Required to Move .2 MPG, for Different Ratings

	Average Critical Distance ($\bar{d}^*$)	Percent Above Notch All Makes	Percent Above Notch Big Three
Gas Guzzler Tax	.143	.600	N/A
City Label	.167	.545	.560
Highway Label	.192	.503	.585

Note: See text for details of calculation.

Gas Guzzler Tax for a given notch value as we see in the label notches, that the value of the label notch is greater than the value of the Gas Guzzler Tax change.

Table 9 also presents, in the second and third columns, the observed amount of manipulation observed within .2 MPG of the notches for each notch type. Because there is more manipulation around the Gas Guzzler Tax, it suggests that the fuel economy notches are less valuable than the Gas Guzzler Tax. This difference is mitigated, however, by noting that Gas Guzzler manipulation, on average in the sample, requires a smaller critical d to achieve a notch improvement. There is, however, a significant difference between the second and third columns, as was clear from the analysis above showing that only domestic automakers appeared to respond to label notches. The Gas Guzzler Tax sample consists overwhelmingly of foreign vehicles, raising the concern that the samples are different in important ways. We return to this issue below.

By taking advantage of the variation in the value of the Gas Guzzler Tax notch, we can do more than compare the amount of label bunching to the amount of Gas Guzzler Tax bunching. To see this, note that the bunching measure shown in Table 9 is the same variable that we used as the dependent variable in Gas Guzzler notch value regressions reported in Table 4. We use that regression, along with the observed amount of bunching, to estimate the notch value of fuel economy in two steps. First, using the first column of the regression table, we solve for the notch value, measured in dollars, that would give rise to the amount of manipulation that we observe in the sample. This is the imputed value in columns 1 and 3 in Table 10.

Table 10: Estimates of the Consumer Valuation of a 1 MPG Increase in Fuel Economy Label Ratings

Sample	All Vehicles Imputed Value	All Vehicles Adjusted	Big Three Vehicles Imputed Value	Big Three Vehicles Adjusted
City Label	$603	$704	$947	$1106
Highway Label	$780	$1047	$845	$1135

Note: See text for details of calculation.

Next, this imputed value is adjusted for the relative distance required for jumping across the different notches, using the average values above. Specifically, we multiply the imputed value for highway label ratings by the ratio of the average critical values in the first column of Table 9. This adjusts for the relative magnitude of the adjustments required to move each different rating. On average, to move the same amount of MPG to reach a label notch, the underlying test MPG would have to be altered more; this implies that, *ceteris paribus*, the value of reaching a notch is higher.

The results shown in Table 10 indicate a substantial valuation of fuel economy of between $603 and $911 per MPG, and between $815 and $1,271 per MPG for vehicles sold by the Big Three manufacturers. For reference, if a vehicle was driven 12,500 miles per year for thirteen years (the national averages), and the price of gasoline stayed at $2.50 per gallon in real dollars, at a 5% discount rate, improving a vehicle's fuel economy from 20 to 21 MPG would save $734 dollars in present-value fuel costs. Because of the non-linear relationship between a unit change in MPG and the expected fuel cost, a vehicle moving from 15 to 16 MPG would save $1,285, while moving from 30 to 31 MPG saves only $331.

Although these calculations of the present value of fuel cost savings are in line with inferred values from Table 10, it is important to recognize that an improvement in either the highway or the city rating by itself should not signal this full improvement to consumers. If consumers assume that they will drive about half of their miles in each regime, they should cut the above returns in two. This means that, unless fuel economy is very low, or expected real gasoline prices are very high, our estimates seem to imply a valuation of fuel economy in excess of the predictions of a standard model.

It is important also to account for the fact that, under our assumption of the co-movement of H and C, a re-engineering aimed at getting a vehicle over, for example, a city notch has some probability of moving the vehicle over the highway notch as well. Under the assumption that H and C are independently uniformly distributed prior to manipulation, movement aimed at getting a city vehicle over the notch from .1 or .2 MPG away will, on average, increase the highway rating for 17.3% of vehicles. The corresponding number for highway ratings is 13%. Even accounting for this, however, it appears that our calculation suggests a very high valuation of fuel economy.

There are two noteworthy ways our calculation could go astray. First, if fixed costs represent a significant component of the cost of re-engineering, it may be the case that low-volume vehicles are less likely to be manipulated, as the re-engineering cost relative to the potential tax savings is relatively high. This is important because vehicles subject to the Gas Guzzler Tax tend to be low-volume. To test this issue, we are planning to merge sales volumes with the fuel economy data in order to empirically test for the relationship between quantities and the degree of manipulation. Second, if domestic automakers are more responsive to notches, then it may be inappropriate to compare Gas Guzzler Tax bunching, which includes predominantly foreign passenger cars, to label bunching without accounting for manufacturer composition. We plan to address this issue by looking at the limited Gas Guzzler Tax ratings of domestic vehicles separately and attempting a matching procedure to identify vehicles in the label rating data that better approximate the Gas Guzzler Tax sample.

8 The Canadian Feebate: A Natural Experiment and Model Check

The feebate program in Canada provides an opportunity to study local fuel economy response in a natural experiment framework where automakers did not anticipate a change in policy. The program appears to have been a surprise to automakers and, even if they had anticipated some policy, it is unlikely that they knew the policy details sufficiently well to alter fuel economy strategically for the 2007 model year.[31] The Canadian feebate program was announced in March 2007, at which point all model year 2007 vehicles had been designed, had been given official fuel economy ratings, and were in the middle of their production cycle. As a result, it seems safe to assume that the fuel economy ratings of 2007 models did not respond to the feebate notches.

Between March 2007 and the fall of 2007, when most vehicles begin production and receive fuel economy ratings, automakers had an opportunity to re-engineer their 2008 model year vehicles in response to the new policy. Thus, a comparison of how an otherwise identical vehicle changed ratings between 2007 and 2008 represents an opportunity to observe the response to a surprise change in notches.

One way to examine is to observe the fuel economy changes for vehicles near a rebate or tax threshold. We first examine the response to rebate notches. Table 11 shows the change in the fuel economy rating for all vehicles that either received a rebate in 2007 or 2008, or were within .2L/100km of receiving a rebate in 2007.[32] This group is separated into three categories: vehicles that needed to improve by .2L/100km or less in order to receive a more

[31] In 2005, a similar program was discussed but not enacted. Leading up to the 2007 budget announcement, there was anticipation that some subsidy for energy efficient products, perhaps including cars, would be part of the budget (National Post 2007). There is no indication, however, that automakers were expecting the program that emerged, and the industry immediately claimed that it was "blindsided" by the policy (Keenan 2007b).

[32] L/100km and MPG are related as follows: MPG = 235.2/(L/100km), or equivalently, L/100km=235.2/MPG. (The relationship is inverse because MPG is a measure of fuel economy while L/100km is a measure of fuel usage.) Note that although Canadian fuel economy labels report both L/100km and MPG, the MPG measure uses imperial gallons, which are equal to 1.2 U.S. liquid gallons.

favorable tax treatment; rebated vehicles that were more than .2L/100km away from a more favorable notch; and vehicles that were already in the best possible category, and therefore could not benefit from improved fuel economy.[33]

These results are strongly suggestive of notch-motivated changes in fuel economy. Of the 8 vehicles that were within .2L/100km of a rebate improvement, 6 vehicles moved to an improved tax treatment in 2008. Among the already rebated vehicles that were not very close to a notch, only 3 out of 14 experienced any change in fuel economy. While 9 vehicles experience a rebate increase, no vehicle in the sample saw a rebate decrease.[34]

The Canadian natural experiment also provides us with an informal out-of-sample test of the predictions using the Gas Guzzler Tax data of the effect of the notch value on the amount of bunching. Regressions in Table 4 relating the Gas Guzzler Tax notch size to the amount of manipulation provide a prediction about what fraction of Canadian vehicles would respond to the introduction of a notch. The Canadian notches are either \$500 or \$1,000. In 2007, the exchange rate was close to 1 to 1, so we simply treat a Canadian dollar as equal to an American dollar. The Gas Guzzler Tax regression predicts that approximately 3% of vehicles within .2 MPG of a \$500 notch and 17% of vehicles within .2 MPG of a \$1,000 notch would "jump." The small sample of Canadian vehicles shows considerably more sensitivity — 6 out of 8 vehicles within .2 L/100km of a notch moved. This is a greater proportion than would be predicted at any observed level of the Gas Guzzler Tax, and these vehicles moved a greater distance in terms of MPG, because, at the low levels of L/100km that the eligible vehicles had, a savings of .2 L/100km is equivalent to .3 or .4 MPG.

[33] Because the two measures are inversely related, a .2 L/100km change in fuel economy corresponds to a different MPG change, depending on the starting point. The range is significant. Starting at 5.7 L/100km, a reduction to 5.5 L/100km corresponds to a 1.5 MPG increase, whereas a change from 16.2 L/100km to 16.0 L/100km corresponds to just a .18 MPG increase. A simple average of the corresponding MPG improvement from a .2 L/100km change at all of the relevant thresholds is .7 MPG.

[34] A vehicle's fuel economy rating may change between model years for reasons other than tax/rebate policy, such as technological advances or change in the design of vehicles in response to changes in consumer demand or the market positioning of a given model. As such, it is possible that the improvements observed in the taxed and rebated vehicles could be motivated by something other than policy. To check the importance of such factors, we are creating a bridged data set that will allow us to estimate the fuel economy changes between 2007 and 2008 of vehicles that were subject to neither fees nor rebates, in order to understand better how variable is fuel economy.

Table 11: Response to Canadian Rebate Notches Between 2007 and 2008

All vehicles within .2 L/100km of a better rebate notch in 2007

	Fuel Economy			Rebate		
	2007	2008	Notch	2007	2008	
Ford Escape Hybrid 4WD	7.4	7.0	7.3	$1,500	$2,000	*
Honda Fit	6.6	6.5	6.5	$0	$1,000	*
Jeep Compass 4WD	8.4	8.3	8.3	$0	$1,000	*
Jeep Patriot 4WD	8.4	8.3	8.3	$0	$1,000	*
Lexus RX400H	7.9	8.1	7.8	$1,000	$1,000	
Saturn Vue Hybrid	7.9	7.3	7.8	$1,000	$2,000	*
Toyota Camry Hybrid	5.7	5.7	5.5	$1,500	$1,500	
Toyota Highlander Hybrid 4WD	7.9	7.7	7.8	$1,000	$1,500	*

Rebated vehicles that were further from a better rebate notch in 2007

	Fuel Economy			Rebate		
	2007	2008	Notch	2007	2008	
Chevrolet HHR	9.0	8.2	8.3	$0	$1,000	*
Chevrolet HHR Panel	8.8	8.2	8.3	$0	$1,000	*
Honda Civic	6.9	6.5	6.5	$0	$1,000	*
Jeep Compass 2WD (2L, CVT)	8.2	8.2	7.8	$1,000	$1,000	
Jeep Compass 2WD (2.4L, Manual)	8.2	8.1	7.8	$1,000	$1,000	
Jeep Patriot 2WD (2L, CVT)	8.2	8.2	7.8	$1,000	$1,000	
Jeep Patriot 2WD (2.4L, Manual)	8.2	8.1	7.8	$1,000	$1,000	
Mini Cooper	6.5	6.3	6.0	$1,000	$1,000	
Nissan Altima Hybrid	5.8	5.8	5.5	$1,500	$1,500	
Toyota Corolla	6.3	6.3	6.0	$1,000	$1,000	
Toyota Yaris (Automatic)	6.4	6.4	6.0	$1,000	$1,000	
Toyota Yaris (Manual)	6.3	6.3	6.0	$1,000	$1,000	

Rebated vehicles that were more fuel efficient than the best notch, and thus could not improve

	Fuel Economy			Rebate	
	2007	2008	Notch	2007	2008
Chevrolet Impala FFV	12.3	12.3	13.0	$1,000	$1,000
Chyrsler Sebring FFV	13.0	13.0	13.0	$1,000	$1,000
Ford Escape Hybrid 2WD	6.6	6.2	7.3	$2,000	$2,000
Honda Civic Hybrid	4.5	4.5	5.5	$2,000	$2,000
Toyota Prius	4.1	4.1	5.5	$2,000	$2,000

Note: * Indicates that a vehicle moved over a notch from 2007 to 2008. The table is restricted to cases where a matching vehicle exists for 2007 and 2008. The table includes all vehicles within .2 of the rebate notch, regardless of rebate status. No vehicle qualified for a lower rebate in 2008 as compared to 2007. Many other vehicles were not eligible for a rebate at any point, and were not close to the first notch. There are no vehicles within .2 of the first ($1,000) notch that did not jump. This table also omits several vehicles that were eligible for a rebate in 2007 or 2008, but were not sold in the other year. Fuel economy values are from the official Canadian government website.

Perhaps the most important caveat to this exercise is that we have implicitly assumed that there is no fixed cost involved in the manipulation. Vehicles subject to the Gas Guzzler Tax tend to be low volume, so we might expect to see less shifting among those vehicles than in the rebated sample from Canada. Unfortunately, sales data are reported at a very different level of aggregation than fuel economy data, requiring significant imputation for this merging process.

9 Conclusion

Key aspects of American and Canadian vehicle fuel economy policy are designed with notches, so that there is no incentive to incrementally improve fuel economy for many vehicles, but for other vehicles there is a large and varying incentive for incremental improvement. These notch policies may be justified by administrative or salience considerations, but they do so at a cost of distorting incentives to reduce aggregate fuel consumption, as the analysis presented here illustrates.

In this paper we show that the notch policies have real consequences, as there are significantly more vehicles produced (and purchased) just on the policy-beneficial side of the notches than otherwise would be expected. We observe this behavior not only in response to explicit notches in tax and subsidy policies, but also in response to implicit "presentation notches," where government policy dictates what (coarse) information a firm must provide to consumers. We develop a simple framework within which the negative welfare effects of local manipulation can be calculated, a framework which may prove useful in a variety of contexts as it can be utilized with only *ex post* data. We also show how our estimates can be used to deduce a unique estimate of the value of fuel economy, which remains a key parameter for environmental and energy policy.

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