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Nicholas Rivers
University of Ottawa

Brandon Schaufele
Ivey Business School

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Abstract

New vehicle feebate programs encourage improved fleet-wide vehicle fuel efficiency; yet analyses of these policies have been limited to *ad hoc* proposals. In this paper, we exploit an extensive, multi-year dataset which includes more than 16 million observations to evaluate the welfare implications of a long-standing vehicle feebate program in the Canadian province of Ontario. We (1) show that second-best optimal feebates can be written as a function of new vehicle Pigouvian taxes; (2) find that Ontario's feebate program was welfare-enhancing relative to a no feebate scenario but that a second-best optimal benchmark would have yielded additional welfare while reducing fleet-wide emissions; and (3) that Ontarian consumers responded asymmetrically to fees versus rebates.

Keywords: Feebate; vehicle choice; environmental policy; externality; optimal tax.
JEL codes: D49, D62, H23, Q58, R48.

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†Graduate School of Public and International Affairs and Institute of the Environment, University of Ottawa, Faculty of Social Sciences, 120 University, Social Sciences Building, Ottawa, Ontario, Canada, K1N 6N5, 1-613-562-5800 ext. 4676, nrivers@uottawa.ca.

‡Business, Economics and Public Policy, Ivey Business School, University of Western Ontario, 1255 Western Road, London, Ontario, Canada, N6G 0N1, 1-519-200-6671, bschaufele@ivey.uwo.ca.

1 Introduction

Many governments are unwilling or unable to impose first-best gasoline or mileage taxes to control the external costs associated with driving.[1] This has motivated a search for alternatives to reduce vehicle-related externalities with new vehicle feebate programs receiving increased attention.[2] Feebates are comprised of "rebates" and "fees" levied on new vehicle purchases – purchases of new fuel efficient vehicles are subsidized, while fuel inefficient vehicles are taxed, with the ultimate goal of improving environmental quality. Proponents hope that this policy will appeal to governments facing spending and political constraints. This paper exploits an extensive, multi-year dataset of new vehicle registrations to examine the behavioural responses to an actual feebate program implemented in the Canadian province of Ontario. We investigate the welfare consequences of this policy vis-à-vis two scenarios and conclude that feebate programs improve upon the no policy status quo but that an improved design, even under a self-financing constraint, would have yielded greater emissions reductions and increased welfare.

Light duty vehicle fuel efficiency and emissions regulations are frequently enacted to achieve fleet-wide environmental targets. The United States has imposed corporate average fuel economy (CAFE) standards since the 1970s and Canada has used similar voluntary fuel consumption guidelines until recently when it adopted fleet-wide greenhouse gas regulations. Many jurisdictions also offer incentive programs to encourage consumers to adopt fuel efficient, electric and hybrid vehicles. Fuel economy standards, however, can be inefficient (e.g., Greene (1991), Thorpe (1997), Kleit (2004), Austin and Dinan (2005), Fischer et al. (2007)) or are potentially non-binding (Small and Van Dender, 2007), while incentive programs require significant funding to be effective (e.g., Chandra et al. (2010), Gallagher and Muehlegger (2011)). Feebate systems are often discussed in conjunction with these policies; indeed, even though we have limited empirical evidence of their effectiveness, feebates are viewed as substitutes for CAFE standards (Klier and Linn, 2012; Roth, 2012; Gillingham, 2013).[3]

Initial research into feebates found that consumers are largely unresponsive to proposed sched-

[1] Parry and Small (2005), for instance, demonstrate that for the United States the optimal gasoline in tax is more than twice its current level and that the "prospects are remote" (pg. 1287) that it will move towards its optimal level, a sentiment echoed by the lukewarm reception to other recent calls for increased gasoline taxes (e.g., Frank (2006) and Karplus et al. (2013)).

[2] US states which have considered feebates include Arizona, California, Connecticut, Maine, Maryland, Massachusetts, New York, Oregon and Wisconsin (Train et al., 1997). Starting in 2007, the Canadian federal government also imposes a "Green Levy" on fuel inefficient vehicles and an "ecoAUTO" rebate on fuel efficient vehicles (Banerjee, 2009). Among other countries, Austria has a feebate program and, in 2008, France introduced their bonus/malus policy.

[3] Feebate programs are usually connected to vehicle-related environmental issues and this is the focus of this study. Yet, these policies can be applied to a more general suite of scenarios including electricity generation (Johnson, 2006) and highway safety. For example, Anderson and Auffhammer (2014) demonstrate that crash incompatibility – accidents which involve vehicles of disproportionate weights – generates safety externalities which have costs equivalent to approximately $0.25 per litre of gasoline. Feebates could be designed to create a disincentive for heavier vehicles purchases and thus improve social welfare (e.g., Greene (2009)).

ules of taxes and subsidies. Train et al. (1997) find a very small demand response to a hypothetical feebate, yielding minor changes in consumer surplus and Greene et al. (2005) illustrate that welfare calculations from *ex ante* studies of feebate programs vitally depend on assumptions about consumer discount rates. Sallee and Slemrod (2012) examine policies aimed at encouraging the use of fuel-efficient vehicles through the lens of "notches", step-wise approximations to smooth Pigouvian subsidies. They find manufacturers strategically respond to feebates by altering their fuel economy ratings via "local" or small design modifications.[4]

d'Haultfoeuille et al. (2014) and Adamou et al. (2014) are the studies closest to the present one. d'Haultfoeuille et al. (2014) evaluate France's bonus/malus program and find that consumers had a dramatic response to French feebate policy. Counterintuitively, they demonstrate that the feebate generated a large rebound effect whereby, even though the economy was in recession, vehicles sales *increased* by 13 percent following the program's introduction, a result which led to increased vehicle emissions in the short run. French feebate rates however were set in consultation with industry and, as such, auto manufacturer's influence over the schedule is unclear. Additionally, d'Haultfoeuille et al.'s (2014) analysis of the bonus/malus program only covers a single year and does not have access to a control group unaffected by the program. Adamou et al. (2014) examine a prospective German feebate program. They determine that the German program would be welfare-decreasing and any reductions in carbon dioxide emissions would be insufficient to compensate for the distortionary effect of the program. Yet, they do establish that it is possible for well-designed feebates to be welfare-enhancing.

This study makes two advances over the existing research. First, we estimate behavioural parameters using a rich multi-year dataset that includes all vehicle registrations from each Canadian province from 2000 to 2010. We map vehicle registrations to forward sortation areas (FSA).[5] This extensive dataset contains over 16 million observations and allows us move beyond the extant literature as we (1) evaluate an actual long-running new vehicle feebate program (rather than conduct an *ex ante* study of a proposed program) and (2) are able to accurately identify the reduced form behavioural response to the Ontario feebate program without worrying about differences between list and transaction prices or unobserved heterogeneity issues that can influence structural vehicle choice models. Second, unlike other analyses of feebate policies, we derive a constrained second-best optimal feebate schedule which is a function of the externality costs of driving and explore the consumer welfare implications of this policy. This schedule is used to evaluate the efficacy of the program implemented in Ontario and provides a reasonable, but conservative, benchmark with which to evaluate other proposed and existing programs.

[4]Sallee and Slemrod (2012) suggest that automobile manufacturers may substitute vehicle parts to reduce weight, use low-friction lubricants or make small body changes (e.g., install spoilers or side skirts) in an effort to surpass some fuel efficiency threshold.

[5]FSAs are the first three digits of a Canadian postal code. There are roughly 1,600 FSAs in Canada, with an average population of slightly more than 20,000 individuals.

We highlight three main results. First, our empirical models suggest that on average a $1,000 fee (rebate) causes a 30 to 40 percent reduction (increase) in the market share of a vehicle. These estimates remain robust even after controlling for unobserved heterogeneity and vehicle-specific preferences, varying the resolution of vehicle-region-time specific fixed effects, changing the level of data aggregation and allowing for different vehicle substitution possibilities. Second, we explore unique features of feebate policies, demonstrating that fees and rebates yield asymmetric responses from consumers. This complicates conventional comparisons between gas guzzler taxes, CAFE standards and feebate schemes and has important policy design implications. Third, we find that Ontario's feebate program resulted in a only a small change in emissions, but still increased social welfare. We show that assuming no rebound or extensive margin effects an optimally-designed revenue neutral feebate would have resulted in significantly greater emission reductions and larger gains in welfare.

2 Conceptual Overview of Feebate Policies

Policy-makers interested in designing new vehicle feebate programs must be cognizant of two margins. First, consumers make purchase or participation decisions: they choose whether to purchase a new vehicle and which model to select. Second, drivers choose whether to undertake a marginal trip. Feebates have the largest impact on model selection along the former margin, yet it is the latter decision that generates most vehicle-related externalities such as congestion, accidents and greenhouse gas emissions. Because new vehicle feebates primarily influence purchase decisions, they are second-best policies. A first-best policy adjusts the price of driving the marginal kilometer, forcing drivers to internalize all costs along the kilometers driven margin. Feebates persist as a politically palatable environmental policy due to the ability to select particular program parameters: in particular, self-financing or revenue neutral feebates programs are viewed as policies which can potentially improve social welfare without the perceived political challenges associated with first-best approaches. To date however, scrutiny of feebate programs has been based primarily on *ad hoc* proposals.

Feebate programs are comprised of a schedule of fees and rebates based on rated fuel economy. Choice of feebate rates influences marginal utilities at the point when a consumer decides to purchase a new vehicle, such that there is a greater incentive to purchase a more fuel efficient vehicle. We restrict attention to revenue neutral feebates, where revenue from fees on dirty vehicles is completely exhausted in providing rebates to clean vehicles. Most discussion would be largely unchanged by opting for a different revenue target, yet revenue neutrality yields two advantages: (i) many proposed environmental policies are revenue neutral, so this represents an important real-world feature of these agendas and (ii) it yields parsimonious expressions that enable us to convey the intuition underlying the program prior to the empirical analysis.

A simple two vehicle formalization conveys the intuition underlying optimal new vehicle feebate schemes.[6] Producers supply vehicles in a competitive market with prices equal to marginal costs. Consumers' utility depends on vehicle choices and the external costs of driving with a social planner who selects the feebate parameters. The planner maximizes consumer welfare subject to a revenue constraint.[7] Appropriately designed point-of-purchase feebate rates are a function of vehicle market share, the cost of the emissions externality and vehicle fuel efficiency relative to the average fuel efficiency of the new vehicle fleet. To convey the underlying intuition and contrast feebates with Pigouvian taxes, we also show that second-best, revenue neutral feebate expressions can be written as a function of the new vehicle Pigouvian tax, but that the second-best optimal feebate is always of smaller magnitude.[8]

A representative consumer chooses the quantities of two vehicles (v) indexed by $k = \{c, d\}$: a clean vehicle, indexed with c, and a dirty vehicle, indexed with d. Although we work with a discrete choice model later in the paper, we want to convey the underlying intuition of the policy. As such, this section develops a continuous good formulation. Kilometers driven contingent on purchase are not explicitly modeled; instead, we treat the vehicle purchase and subsequent use as a bundle. Vehicle prices are therefore inclusive of the price of driving, which depends on fuel economy. Utility is given by:

$$U(v_c, v_d, x) \tag{1}$$

where x is consumption of other goods. The consumer maximizes utility subject to a wealth (M) constraint:

$$M = (p_c + F_c)v_c + (p_d + F_d)v_d + x - Z$$

where F_k is the dollar value of the fee or rebate on vehicle k (negative values are subsidies), p_k is the tax-exclusive price, x is the numeraire good, Z is the net revenue that arises from vehicle taxation ($Z = 0$ for revenue neutral feebates) and the marginal value of income is normalized to one. In this section, we also specify feebates as a rate, using the notation $f_k = F_k/p_k$. First order

[6] The appendix includes two derivations: (i) a detailed version of the two vehicle model presented in the text, and (ii) a generalized, multi-vehicle version of this simple model.

[7] Throughout, we focus on greenhouse gas emissions as the primary externality. Curtailing vehicular greenhouse gas emissions is an objective of many feebate programs (including Ontario) and this simplifies the derivation. All expressions can be generalized to include other externalities.

[8] Feebates can also be designed to replicate any binding CAFE standard (Klier and Linn, 2012; Gillingham, 2013); although the reverse is not necessarily true.

conditions are:[9]

$$\frac{\partial U}{\partial v_c} = p_c + F_c \qquad \frac{\partial U}{\partial v_d} = p_d + F_d \qquad \frac{\partial U}{\partial x} = 1$$

Vehicle-related external costs arise from consumers' usage decisions. Consumer welfare is utility less damages from emissions:

$$W = U(v_c, v_d, x) - \delta E \tag{2}$$

where δ is the constant marginal disutility from emissions and where emissions, E, are caused by vehicles, such that $E = v_c e_c + v_d e_d$. e_c and e_d are the per vehicle lifetime emissions from v_c and v_d, respectively.[10]

2.1 Optimal new vehicle taxes

Pigouvian taxes are more familiar than feebate policies. So, in order to compare (second-best) optimal feebates to Pigouvian taxation, it is useful to specify the optimal (second-best) new vehicle tax rates to that are applied to internalize external damages from lifetime emissions associated with vehicle purchase. Second-best optimal new vehicle tax rates for the clean and dirty vehicles are found by setting the tax rate on clean, t_c, and dirty, t_d, vehicles, respectively equal to their external damages normalized by their price:

$$t_k = \delta \frac{e_k}{p_k}. \tag{3}$$

2.2 New vehicle feebates

The government's optimal feebate problem involves choosing F_c and F_d, the dollar-valued feebates corresponding to the clean and dirty vehicle. These are found by differentiating welfare, (2), and then substituting in the first order conditions, the differentiated emissions function and the differentiated wealth constraint along with an additional revenue constraint: $F_c v_c^* + F_d v_d^* = \bar{R}$ which is evaluated at the post-feebate utility-maximizing choices of v_c and v_d. For a revenue-neutral feebate, revenue from fees and rebates is offsetting, such that $\bar{R} = 0$. After rearranging, it

[9]Section 6.2 suggests that consumers may respond differently to fees versus rebates. An informal method to incorporate this additional responsiveness to subsidies is via the inclusion of an additional parameter, $\gamma \geq 0$. We then rewrite the first-order condition on the clean vehicle, v_c, as: ${}^{\partial U}/_{\partial v_c} = p_c + \gamma F_c$.

[10]This derivation of optimal vehicle taxes and feebates focuses on consumer responses, taking vehicle characteristics as exogenous. We do this for two reasons. First, assuming minimal manufacturer response is likely an accurate reflection of the policy that we evaluate in the relatively small market of Ontario. Second, it simplifies the exposition, which emphasizes intuition, and it is straightforward to incorporate manufacturers into the model. See section 4.2 for additional justification of this assumption.

is possible to derive an expression for a second-best optimal feebate:

$$
\begin{aligned}
f_d &= w_c \delta \left(\frac{e_d}{p_d} - \frac{e_c}{p_c} \right) \\
&= t_d - \bar{t}
\end{aligned}
\tag{4}
$$

where the f_d is the optimal revenue neutral feebate rate on the dirty vehicle (recall, $F_d = f_d p_d$), w_c is the equilibrium expenditure share on the clean vehicle out of total vehicle expenditure and $\bar{t}$ is the share weighted Pigouvian tax rate of the fleet. Optimal feebates are therefore a function of the optimal new vehicle Pigouvian taxes,[11] but are everywhere smaller in magnitude. This results from the additional revenue constraint associated with feebates relative to new vehicle taxes (without the revenue constraint, optimal feebates would be equal to optimal new vehicle taxes). Whereas Pigouvian taxes reduce the size of the new vehicle fleet, feebates primary modify the composition of the fleet. By changing the mix of vehicles purchased, feebates improve the fleet-wide average fuel economy. The additional revenue constraint however reduces welfare relative to new vehicle taxation by implicitly subsidizing all new vehicle purchases relative to an optimal tax benchmark, resulting in increased sales of new vehicles relative to the Pigouvian tax equilibrium.

Beyond the mechanical correspondence between feebates and Pigouvian taxes in (4), several additional comments are warranted. There are two advantages that may lead policy-makers to support of feebate policies over Pigouvian taxation even though social welfare is lower. First, the absolute sizes of taxes, fees and subsidies are often politically important. Insofar as the welfare gains from feebates emerge from improving average fleet-wide fuel efficiency, a new mix of vehicles differentiated across fuel consumption ratings can be generated by using optimal fees that are lower than the optimal Pigouvian tax. Second, many decision-makers are tax averse. Allowing for the possibility of a revenue neutral decision smooths potential opposition. Indeed, tax aversion motivated both this study as well as several real-world proposals. Despite these potential advantages however, we emphasize that Pigouvian taxation is preferred to a feebate program from a welfare economics perspective.

3 Overview of Feebates in Practice

While feebate policies have received increasing attention in the literature (e.g., Adamou et al., 2014; Gillingham, 2013), few studies empirically evaluate extant feebate programs. Recommendations have relied on simulations of hypothetical proposals using models that are parametrized with data from markets without feebates. To the extent that actual behavior does not match modeled behavior, important questions remain unanswered. We exploit one of the handful of existing vehicle feebate programs, a longstanding policy that existed in the Canadian province of Ontario,

[11] An equivalent expression for the clean vehicle is: $f_c = t_c - \bar{t}$.

using data on the population of Canadian new vehicle registrations over the 2000-2010 period. Despite being one of only a handful of existing programs, Ontario's feebate has received scant attention.[12] Our evaluation of Ontario's feebate enables us to conclude that feebate schedules do produce economically and statistically meaningful changes in consumer vehicle purchase decisions – for example, a fee of $1000 reduces the market share of a vehicle by 30 to 40 percent – but they may also generate unexpected outcomes as consumers have differential responses to taxes and subsidies.

3.1 Ontario's Feebate Policy

Ontario's Tax and Credit for Fuel Conservation or feebate program underwent three design iterations. The initial policy, developed in 1989, was a gas guzzler-type tax on fuel inefficient cars (Government of Ontario, 1989).[13] A tax was levied on all new car purchases that had a highway fuel consumption rating exceeding 9.5L/100 km. As shown in Table 1, the initial fee was $600 for passenger cars consuming between 9.5-12.0L/100 km increasing to $3500 for cars with ratings greater than 18.0L/100 km. One year later, in 1990, tax rates were doubled and extended to cover cars with a wider range of fuel economy ratings. Fees on the most fuel inefficient vehicles now equalled $7000, while vehicles with ratings in the 8.0-8.9 and 9.0-9.4L/100 km were subject to taxes of $200 and $700, respectively.[14]

The announcement of the 1990 tax schedule proved extremely controversial (Bregha and Moffet, 1995). Concerns were raised by both the Canadian Auto Workers union and by manufacturers. Lobbying and political pressure persuaded the government to revisit the policy. The version of the program that we analyze was formulated in 1991, following consultation with stakeholders, and remained unchanged until 2010.[15] This final iteration expanded the policy to incorporate a larger number of vehicles, notably sport utility vehicles (SUVs) were included (passenger vans and pick-up trucks remained exempt). The program also started offering rebates to fuel efficient cars and lowered the threshold at which the tax applied to 6.0L/100 km. The tax rate on the bottom two brackets was also reduced relative to the 1990 levels – the fee on cars with fuel efficiency ratings of 8.0-8.9L/100 km dropped from $200 to $75, while for the 9.0-9.4L/100 km bracket it decreased from $700 to $250.[16] Table 1 displays the full schedule of taxes and rebates for each version of the

[12]Bregha and Moffet (1995) provide a qualitative discussion of the program, focusing on implementation details and political economy; however, they do not provide any quantitative analysis.

[13]Canada's fuel efficiency rating are determined by Natural Resources Canada (NRCan) in a near identical manner to the US's Enivonrmental Protection Agency (EPA) methodology.

[14]Note that the Ontario program is based on rated highway fuel consumption, rather than weighted city-highway fuel consumption. Since emissions from vehicles are optimally determined by weighted city-highway fuel consumption rather than highway consumption alone, this choice adds a distortion to the Ontario policy.

[15]Our analysis covers the period 2000-2010, a decade following the last update to the program and sufficiently distant from the program revision to allow virtually complete change of the new vehicle market. Therefore, although the policy was designed with feedback from the vehicle industry in 1990, it is reasonable to treat the policy as exogenous for the period covered by our analysis.

[16]The tax and credit applies to all vehicles which are purchased, leased or rented in the Province of Ontario.

program. On July 1, 2010, Ontario eliminated its feebate program as the province underwent large scale tax reform.

Over the life of the program, the tax on fuel inefficient vehicles generated an average of approximately \$30 million (\$2002) per year. However, tax revenue decreased throughout the period of analysis, from a high of over \$40 million to a low of less than \$20 million in 2009. In contrast, tax credits associated with the program increased over the period of analysis from \$1.9 million in 2001 to \$6.6 million in 2010. Although net revenue fell throughout the period of analysis, the combination of fees and rebates was revenue positive in every year that the program existed.

3.2 Ontario's Feebate and the Ford Mustang

Before providing detailed empirical results on the effect of the feebate, we provide some initial graphical evidence using the Ford Mustang as a case study. Mustangs were subject to a fee under Ontario's feebate program and, during our period of analysis, underwent a complete redesign. Introduced in 2004, the fifth generation Mustang had more horsepower than its predecessor. This redesign meant the car also received different treatment under Ontario's feebate program. As such, the Ford Mustang crosses two feebate brackets, provides an example of how a feebate works both in theory and practice and illustrates how we identify the effect of the vehicle feebate using our data.

Figure 1 illustrates how the Mustang was treated under the Ontario feebate program and how its tax treatment is related to its market share. The top panel shows the NRCan rated highway fuel consumption for a new automatic transmission 4.6 litre 8 cylinder Ford Mustang in each year from 2000 to 2010. This vehicle had a fuel consumption of 9.1 L/100km in 2000, a fuel consumption of less than 8.9 L/100 km from 2001 to 2003, and a fuel consumption greater than 9.0 L/100 km in each year from 2004 to 2009 before falling back below 8.9 L/100 km in 2010.[17] A threshold in Ontario's feebate scheme exists at 8.9 L/100 km, such that the Ford Mustang was taxed at \$75 in 2001 through 2003 and at \$250 between 2004 and 2009. The bottom panel of Figure 1 displays the difference of between the market shares of the vehicle in the rest of Canada and the market share of Ontario. Early in the decade, when the Mustang was taxed at \$75, the difference between market shares in Ontario and other provinces was small. However, following the redesign, a higher feebate rate applied. The Mustang's market share in Ontario fell relative to the rest of Canada (the difference between the market share in the rest of Canada and Ontario grew). Even a small change in the fee of \$175 per vehicle led Ontario consumers to substitute away from the new Mustang. In this example, the market share of the 4.6L, 8 cylinder Ford Mustang averages

Vehicles purchased outside of Ontario, but which are registered in the province, are still subject to the tax and credit (fees are paid or rebates received at the time of registration). Motorcycles and vehicles sold to non-residents are exempt.

[17] In 2010, as an example, the body of the car had minor redesigns which improved its drag coefficient and consequently its fuel efficiency.

about 0.002 in Ontario and the difference-in-difference (high vs. low feebate; Ontario vs. rest of Canada) estimate for the effect of the feebate is about 0.0004. A $100 fee changes vehicle market share by $\frac{0.0004/0.002}{(75-250)/100} = 0.13$ or 13 percent. This is notably larger than the effect we find from our econometric estimates.

We interpret this as suggestive evidence that consumers responded to the fuel economy disincentive associated with the feebate program. Still the graphical evidence is not over-whelming and many unobserved factors may motivate these trends in market shares. Whether similar substitution patterns hold for other models, across feebate rates and after controlling for confounding factors is not obvious from the figure. In the following analysis, we use a range of high dimensional fixed effects to control for a wide suite of unobserved characteristics in order to identify the true underlying behavioral response to the feebate scheme and, in section 7, determine whether the feebate program is welfare improving.

4 Data and Econometric Methodology

We present our empirical methodology in two steps. First, we review our dataset. Next, the econometric specification is briefly reviewed. Throughout, we employ a conventional differentiated products demand framework (e.g., Nevo, 2000) where markets are defined as province-years or FSA-years (see footnote 5). The appendix includes a detailed discussion of the econometric specifications and estimation procedure.

4.1 Data

Proprietary data from Desrosiers Automotive Consultants, provider of RL Polk data in Canada, is used throughout this study. The dataset covers the population of private vehicle registrations in Canada over the period 2000 to 2010. The focus of this paper is on new vehicle sales and associated policy, rather than registrations. Thus, we treat a registration of a model year t vehicle in year t as a sale.[18]

We observe all vehicle registrations by make (e.g., Toyota, Ford), model (e.g., Camry, F150), series (e.g., SE, XL) and model year, in addition to each vehicle's engine characteristics (engine size and number of cylinders). We define a "unique vehicle" as a combination of make, model, series, engine size and number of cylinders. We then merge these data on vehicle sales with information on rated city and highway vehicle fuel consumption, from Natural Resources Canada (NRCan).[19] Because the different data sources have distinct naming conventions, successfully

[18]For example, for vehicles registered in 2003, we treat model year 2003 vehicles as vehicle sales. In reality, some 2004 model year vehicles will also be sold in 2003, and we instead treat these as sales in 2004. We have also re-estimated the model such that vehicles are assigned as sales in the year in which they first appear in the data. Our results are virtually unchanged, and we include these in the appendix.

[19]See `http://oee.nrcan.gc.ca/transportation/tools/fuelratings/ratings-search.cfm`.

merging the datasets required significant manual processing. Further, for a small number of low-volume vehicles, rated fuel consumption data was not available from NRCan. For these vehicles, we obtained fuel economy ratings from the US Environmental Protection Agency (EPA).[20] In total, we successfully rated the fuel economy for virtually all passenger vehicles in the Polk data set, yielding a population of vehicles classified according to their fuel efficiency rating. In addition to fuel efficiency and vehicle characteristics, we also incorporate data on retail gasoline prices, demographics, provincial gross domestic product and vehicle sales retrieved from Statistics Canada.

Data are used at two levels of aggregation. First, we estimate models exploiting cross-provincial variation. Feebates are implemented at the provincial level and we are interested in the implications of the policy at the level of the intervention. Our policy evaluation thus focuses on data at this coarser level of aggregation. After matching, the complete dataset includes approximately 600 unique vehicles across 10 provinces and 11 years for a total of nearly 60,000 observations. Second, we also map registrations to forward sortation areas (FSAs).[21] There are roughly 1,600 FSAs in Canada. Moving to FSAs enables a more detailed picture of vehicle ownership trends as we are able to investigate intra-provincial variation. There are over 16 million observations in the FSA dataset. The appendix presents summary statistics for the data.

4.2 Empirical Approach and Econometric Specification

Our empirical approach is guided by the policy context as well as by the data we have available. In particular, our data cover a period in which the feebate policy is invariant: the policy was applied in 1990 and eliminated in 2010; our data covers the years 2000 to 2010. Thus, a traditional difference-in-difference approach cannot be applied. To overcome this challenge, we use two alternative approaches to identify the effect of the feebate policy on vehicle market shares.

First, we use a cross-sectional approach to identify the effect of the feebate on vehicle market shares using province-level data. This level of aggregation matches the level of the intervention. Fixed effects at a high level of resolution enable us to control for national preferences for particular vehicles over time as well as to control for preferences for particular classes of vehicles within each province. Successful parameter identification in the cross sectional approach requires the assumption that households in Ontario do not systematically value vehicles differently than households in other provinces in a way that is correlated with their treatment under the feebate policy. As we are unable to test whether these unobserved preferences differ by province or vehicle, these results are presented as a point of comparison.

Second, we identify the effect of the feebate by focusing on vehicle redesigns which lead to different tax treatment from one year to the next. By using within vehicle variation and comparing

[20]See `http://www.fueleconomy.gov/`. As EPA measures fuel economy in gallons per mile and NRCan measures fuel consumption in litres per 100km, we converted EPA ratings to fuel consumption ratings using appropriate conversion factors.

[21]FSAs are the first three digits of Canadian postal codes.

consumer responses in Ontario under different feebate rates with responses in other provinces, we obtain an estimate for the effect of the feebate on vehicle sales. Exploiting this within vehicle variation mirrors the Ford Mustang example. This approach – where we focus on vehicle redesigns – is closer to conventional difference-in-difference and relaxes the assumptions required in the cross-sectional models. This identification strategy does require an alternative assumption however: we assume that vehicle redesigns that result in different feebate treatments over time do not differentially affect the underlying desirability of the vehicle in Ontario vis-à-vis other provinces. As we control for vehicle make, model, series and engine characteristics, year-to-year physical changes in vehicles are relatively minor. For example, Sallee and Slemrod (2012) describe small changes in vehicle materials, styling and weight that can affect the fuel economy of a vehicle. In the case of the Ford Mustang, detailed descriptions of the vehicle over time suggest no substantial changes in vehicle characteristics occurring in conjunction with feebate rate changes.[22] Between 2009 and 2010, for example, the change in fuel economy is the result of a slightly modified exterior styling that reduced the drag coefficient.[23] Our identification framework requires the assumption that Ontario consumers do not systematically value these changes in vehicle styling differently compared to consumers in other provinces. We believe that this assumption is quite reasonable for a number of reasons: (i) most redesigns are minor, being confined to within vehicle variation according to our fixed effect resolution; (ii) redesigns are frequently heterogeneous, covering various vehicle aspects exclusive of engine size, and (iii) redesigns both improve and worsen vehicle fuel efficiency, depending on the specifics of the changes made. As a result, these regressions should recover the causal effect of the feebate policy on vehicle market shares.

For both identification strategies, we employ a conventional differentiated product demand model. Such models are well-known, so we only briefly present our approach. The appendix fully describes our application of this methodology. The effect of the feebate is found by estimating the following equation:

$$\log\left(\frac{s_{kpt}}{s_{0pt}}\right) = \theta_{kt} + \zeta_{kp} + \alpha F_{kpt} + \phi \log G_{kpt} + \mu_{kpt} \qquad (5)$$

where s is the market share of a unique vehicle, F is the dollar value of the feebate, G is the gasoline cost in dollars per kilometre traveled and μ is the error term. k indexes vehicles (and 0 is the outside option of not purchasing a vehicle), p indexes provinces and t indexes time.[24] The index k is at the resolution of a 'unique vehicle' as described above.

Different specifications of the model include distinct arrays of vehicle-time fixed effects, denoted

[22]Many websites provide detailed information on vehicle characteristics by model year, such as `edmunds.com`.

[23]Car and Driver Magazine compares the 2009 to 2010 model, noting: "Outside, the new model is plainly a face lift rather than an all-new design ... The new skin, in combination with fairings under the engine, reduces drag by seven percent." See `http://www.caranddriver.com/reviews/2010-ford-mustang-gt-first-drive-review`.

[24]We also estimate the model using FSA-level data, in which case we replace provinces with FSAs in index p.

by θ, and vehicle-province fixed effects, denoted by ζ. These parameters capture average preferences for a vehicle in each year and in each province, respectively. By changing the fixed effects that enter the estimating equation, we alter the source of identification. For example, in models without vehicle-province fixed effects (ζ), our identification is cross-sectional. Unbiased estimation of the α parameter requires that unobserved province-specific consumer preferences are not correlated with the feebate in Ontario. By including vehicle-province fixed effects, we control for unobserved regional preferences for particular vehicles and identification is based on redesigned vehicles whose feebate treatment changes over time as in the Ford Mustang example.

α is the coefficient of interest. If the feebate increases by one unit, α measures the responsiveness of the log of the odds ratio from choosing a particular vehicle relative to the outside option. We present our results with feebates measured in thousands of dollars where fees are positive and rebates enter as negatives. We expect and find that α is negative – an increase in the tax reduces vehicle demand, all else constant. The final parameter in (5) is ϕ, which captures the sensitivity of consumers to changes in gasoline cost. A handful of recent studies have examined the effect of gasoline prices on vehicle purchase decisions (e.g., Busse et al. (2013); Klier and Linn (2010); Li et al. (2009)).

Several of our models contain hundreds of thousands of fixed effects across several dimensions. Standard estimation techniques are not feasible with so many coefficients. Our objective is to accurately identify a single feebate parameter however. As such we invoke the Frisch-Waugh-Lovell Theorem to eliminate the fixed effects via application of a repeated demeaning process (Davidson and MacKinnon, 1993).[25] This Frisch-Waugh-Lovell procedure enables us to shrink the parameter set and use transformed data to correctly estimate effect of feebates on vehicle market shares. There are two advantages of this approach: (i) we are able to flexibly control for a broad array unobserved confounders, while (ii) dramatically relaxing computational costs involved with estimating models with millions of observations and hundreds of thousands of fixed effects. A similar approach was applied in Carneiro et al. (2012). We detail our approach in the appendix.

Throughout our analysis, we report standard errors clustered by province-class or FSA-class. Standard errors calculated from the the transformed estimating equations are correct, even with clustering, once adjusted for degrees of freedom (Guimaraes and Portugal, 2010). However, not all of the fixed effects are identified in the data. As the demeaning algorithm is automated, we do not precisely count how many parameters are removed. We therefore adopt a conservative rule of thumb and assume that all fixed effects are identified in our dataset. This implies that the reported standard errors are over-estimated and we are less likely to reject a null hypothesis of no effect for our feebate parameter.

Finally, we also estimate a variant of (5) that relaxes the independent and identically distributed

[25] As an additional note, to the best of our knowledge, we are the first to apply this estimation approach – whereby we successively demean our data eliminating hundreds of thousands of fixed effects – while also using instrumental variables. All code for all models will be freely provided on our websites.

error assumption implicit in the standard logit model. In particular, we specify a nested logit model in which we group vehicles into 15 nests reflecting the vehicle segment (c) as defined by RL Polk. This grouping allows correlation of unobserved vehicle characteristics according to vehicle segment and permits vehicles within a segment to be treated as closer substitutes for one another than vehicles in different segments. The nested logit specification is estimated as follows:

$$\log\left(\frac{s_{kpt}}{s_{0pt}}\right) = \theta_{kt} + \zeta_{kp} - \alpha F_{kpt} - \phi G_{kpt} + \sigma \log(s_{kpt/cpt}) + \mu_{kpt} \tag{6}$$

where $s_{kpt/cpt}$ is the market share of vehicle k within segment c, and σ is the inclusive value parameter, signifying the substitutability between vehicles within the same segment. This variable is clearly endogenous, so we apply the standard instrumental variable solution where our instruments are the sum of all vehicle attributes in segment c, excluding vehicle k (Berry et al., 1995).

Our empirical design highlights the consumer responses to the feebate policy and implicitly assumes that vehicle manufacturers do not strategically respond to the policy by tailoring vehicles in response to feebates. Given our focus on a single Canadian province, we believe this assumption is reasonable; it would be less reasonable for a larger jurisdictions such as countries. Some additional justification for the assumption can be obtained from the fact that vehicle models jump across feebate discontinuities in both directions (see Figure 1 above, for example, where the vehicle jumps three times across the feebate discontinuity in the 11-year period), whereas if manufacturers were responding to Ontario's policy, we might expect uni-directional jumps. To the extent that manufacturers do respond to the feebate policy in Ontario, our approach should be considered a reduced-form estimate of the feebate policy on vehicle sales (including both consumer and manufacturer response), rather than the consumer response alone.

5 Results

We demonstrate that Ontario's feebate had an economically meaningful and statistically significant effect on the mix of vehicles. A \$1,000 fee reduces vehicle market share by approximately 30 to 40 percent, a result that is robust across a wide range of specifications. Provincial-level results are presented followed by estimates from disaggregated FSA-level data. Finally, nested logit models are reviewed allowing for correlations of vehicle market shares within pre-defined classes.

Provincial-level Results

Table 2 displays province-level results. In all cases, the dependent variable is the log difference in market share of a unique vehicle type and market share of the outside option. Reported coefficients demonstrate the effect of the feebate on the market share of a vehicle. Different columns include different fixed effects, so changes the source of identification. In each case, we also control for vehicle gasoline costs per kilometre (dropping this variable does not significantly impact our estimates of the feebate coefficient, however).

In total, Table 2 contains six specifications. The parameter of interest, Feebate, indicates the percent change in vehicle-specific market share that results from a $1,000 fee (rebates are treated as negative fees). Upon initial inspection, a key observation about Table 2 is the consistency of sign, significance and magnitude of the coefficient of interest across fixed effect structures.

Moving across the six specifications, identification is conditional on capturing different unobserved sources of variation that may be correlated with the feebate. We vary the source of identification by changing the fixed effects in the model. Columns (1) through (4) use cross sectional variation to identify the effect of the feebate, while columns (5) and (6) rely on within vehicle variation.

Starting on the left-hand side, (1) includes time invariant vehicle and province-class fixed effects. With roughly 3,250 estimated parameters, this is our most parsimonious specification. The vehicle fixed effects capture long-standing preferences for specific vehicle types that are constant across the country, while the province-class fixed effects capture geographically-distinct preferences over vehicle class that could arise as a result of differences in climate, geography, urbanization, culture or other slow-moving factors. This is essentially a cross-sectional approach to identifying the effect of the feebate. The feebate parameter may be confounded if there are unobserved factors at a provincial level that are correlated with the policy or if province-specific preferences over vehicles are specific to individual vehicles, rather than just vehicle class.

Results in (1) suggest that a $1,000 fee is associated with a reduction in the market share of a vehicle of 42 percent.[26] The level of analysis is a unique vehicle, so the market share reduction is in comparison to the counterfactual market share of this unique vehicle. The effect is precisely estimated, with a standard error equal to 11 percent.

(2) adds class-year fixed effects to (1). This regression therefore controls for time-varying vehicle class preferences at a national level. Identification remains cross-sectional, since we do not control for province-specific preferences over particular vehicles. Enlarging the set of controls has only a minor influence on the feebate coefficient: a $1,000 fee is now associated with a 37 percent decline in a vehicle's market share. Once again, the effect is precisely estimated.

Region-class-year fixed effects are added in (3).[27] We now control for heterogeneously changing preferences over time between regions. Intuitive regional groupings exist in Canada based on common geography, history and economic characteristics. Identification in (3) is again cross-sectional, since we do not include province-specific controls for preferences over particular vehicles. The

[26] The effect is linear, so a -$1,000 feebate (i.e., a $1,000 subsidy) would be associated with an increase of similar magnitude.

[27] We separate provinces into four regions (BC, prairies, Ontario, and East) and produce fixed effects from these regional groups. The prairies group includes Alberta, Saskatchewan and Manitoba, and the East group includes Quebec and the four Atlantic provinces.

feebate effect is precisely estimated and unchanged from the previous specification.

(4) includes vehicle-year as well as province-class fixed effects, respectively. Vehicle-year fixed effects remove common shocks to particular vehicles across provinces over time. For example, vehicle advertising is typically national in scope and changes in vehicle design that sway preferences over unique vehicles are likely to affect all consumers in a similar way at a given time. Since changes in vehicle design may also result in a difference in feebate treatment over time, omitting this variable could potentially bias our results. Once again, without controls for provincial preferences over particular vehicles, identification is cross-sectional. The results in (4) suggest that a $1,000 feebate is associated with a 33 percent reduction in market share.

(5) includes vehicle-province and class-year fixed effects, accounting for any province-specific but time invariant preferences over vehicles. This strategy controls for average preferences for each unique vehicle by province, identifying the effect of the feebate from within-vehicle variation in feebate treatment and market share. This mimics a difference-in-difference identification strategy. This specification also includes class-year fixed effects, which capture the shift in preferences towards larger sport utility vehicles. The results in this column suggest that a $1,000 feebate is associated with a reduction in market share of 34 percent percent for a vehicle model. The point estimates are nearly identical to previous models, but are not estimated precisely.

(6) is the most flexible specification, controlling for a full set of vehicle-year and vehicle-province factors. The vehicle-province fixed effects account for province-specific preferences over particular vehicle models that are influenced by geography, road characteristics or climate. In total, this specification controls for over 38,000 fixed effects, which provides substantial confidence that our feebate parameter is uncounfounded. Identification is based on differences in feebate treatment over time within a particular vehicle, which corresponds to the quasi-difference-in-difference identification strategy. Ultimately, the inclusion of this rich set of fixed effects does not have a large effect on our estimate: a $1,000 feebate applied on a particular vehicle approximately causes a 30 percent decline in the market share of the vehicle. While our point estimates are nearly identical to the other specifications, the coefficients are not statistically significant. In the following subsection, we increase the size of the data set by using FSA-level data and do obtain precisely estimated effects using this vehicle redesign identification strategy.

Overall, our results are robust to a wide-range of specifications. Imposing a fee of $1,000 reduces the market share of a vehicle by approximately 30 to 40 percent relative to a counterfactual where no fee is applied. These estimates are in-line with the literature on vehicle taxes and subsidies. Chandra et al. (2010) analyze hybrid vehicle rebate programs in Canada and finds a nearly identical result: a $1,000 hybrid vehicle rebate has the effect of increasing market share by around 35 percent. Diamond (2009) conducts a similar study in the US and finds that a $830 hybrid vehicle rebate results in an increase in hybrid market share of about 18 percent (for the Ford Escape model). Adamou et al. (2014) find that a €1,000 reduction in vehicle price is associated with a 20 percent increase in vehicle market share. The model of Berry et al. (1995) allows different elasticities based on observed and unobserved price elasticities of different vehicles. They find that a $1,000 increase in vehicle price is associated with a 9 to 125 percent reduction in market share, depending on the vehicle type. d'Haultfoeuille et al. (2014) find that a €1,000 rebate results in a 38 percent increase in vehicle market share.

5.1 FSA-level Results

Table 3 replicates column 6 in Table 2 with more disaggregated data at the forward sortation level rather than the province level. As a result, identification in this table is based on within vehicle variation over time, focusing on vehicles whose treatment under Ontario's feebate policy changed as a result of minor redesigns. We require two changes to the empirical strategy when using the FSA data however. First, we do not include gasoline prices as a covariate since we do not observe gasoline prices for individual FSAs. Next, the dependent variable is log market share instead of the difference in logged market shares of a vehicle and the outside option, because we do not observe population size in each year at the FSA-level.[28] The results are largely unchanged when we make similar modeling choices using provincial-level data.

The results in Table 3 generally corroborate those in in Table 2. Feebates have a statistically significant and economically meaningful effect on vehicle market shares. In (1), we include the full data set of FSA-level observations, and find that a $1,000 fee leads to a 38 percent reduction in market share. In (2) and (3), we reduce the sample by only including vehicles whose treatment under the Ontario feebate policy changes at some point during our sample. In (2), we only include the years immediately prior to and following the change in feebate treatment, while in (3) we include all data for vehicles whose feebate treatment changed at least once during our data sample. We find similar effects in both of these sub-samples, although the effect, as expected, is slightly larger when we include only the subset of vehicles whose feebate treatment changed over time.

5.2 Nested Logit Results

As a final test of the robustness of the feebate elasticity, we return to the provincial data and relax the independence of irrelevant alternatives assumption by exploiting the data's 15 pre-defined vehicle segments (minivans, two-seaters, midsize cars, etc.). Table 4 presents estimates from a nested logit specification where each vehicle class is treated as a nest. Results from this table closely match the earlier coefficients and all coefficients are statistically significant at a 1 percent level.

Over a range of specifications, the feebate parameter consistently shows that a $1,000 increase in fees leads to a reduction in vehicle market share equal to approximately 30 to 40 percent. Impor-

[28]Section 6.1 shows that the feebate has an indeterminate effect on total vehicle sales, such that this dependent variable should be an appropriate substitute to the one used in Table 2.

tantly, this result is robust to a wide assortment of fixed effects, distinct substitution structures and alternative levels of aggregation. Ontario's feebate scheme and those proposed in other jurisdictions do appear to alter the mix of the new vehicle fleet. We next examine three situations where feebate policies may generate results which are distinct from standard price or tax elasticities.

6 Extensive Margin, Fee-Rebate Asymmetries and Urban-Rural Heterogeneity

The analysis to this stage has treated feebate schedules as identical to standard gas guzzler taxes with subsidies treated as negative taxes. This section empirically investigates three situations where a feebate policy may produce behavioral responses that are distinct from a new vehicle tax policy. We first examine the effect of Ontario's feebate on the extensive, vehicles purchased margin. Unlike the expected response to new vehicle taxes, we show that feebate policies have an indeterminate effect on the total number vehicles sold. Second, we demonstrate that consumers have asymmetric responses to fees versus rebates. Finally, we illustrate heterogeneity along an urban-rural dimension.

6.1 Extensive Margin

Feebates operate by altering the mix of vehicles in the fleet. Because feebates are composed of a combination of fees and rebates, the effect on total vehicles sales is ambiguous. Still, the implications of extensive margin adjustments may be important. The analysis in section 3 is confined to a period when Ontario's feebate existed. As such, it is less amenable to evaluating whether the existence of a feebate program affected total vehicles sales. To estimate the impact of the feebate on aggregated new vehicle sales, a separate dataset spanning the introduction and removal of the feebate is required. We use two such datasets.

First, monthly data from Statistics Canada (CANSIM) on aggregate provincial passenger car sales in each month from 1980 to 2012 is used. We estimate:[29]

$$y_{it} = \alpha \tilde{F}_{it} + \beta X_{it} + \delta_i + \gamma_t + \epsilon_{it}$$

where y_{it} is log per capita passenger car sales, $\tilde{F}_{it}$ is a dummy variable capturing the presence of a feebate program, X_{it} are time-variant provincial characteristics including log real per capita income, the log unemployment rate and log real gasoline price. δ_i is a province fixed effect and γ_t

[29] Data are from Table 0079-0003. Statistics Canada divides the new vehicle market into passenger car and truck segments. The truck segment includes minivans, sport utility vehicles, pickup trucks, buses, heavy trucks and other heavy-duty road vehicles. Because the truck segment mixes passenger and freight vehicles, our regressions use data only for passenger cars. We obtain similar results in regressions using total vehicles sales or trucks as the dependent variable, further supporting the conclusion that the feebate had a minimal effect on total vehicle sales.

is a time fixed effect. γ_t is decomposed such that $\gamma_t = \gamma_y + \gamma_m$, where γ_y is a year dummy and γ_m is a month dummy. Standard errors are clustered by province.

Second, we use micro-data from Statistics Canada's Family Expenditure Survey (FAMEX), which reports household expenditures divided into pre-defined categories. The survey was conducted biennially (with some interruptions), so we use survey waves spanning the introduction of the feebate in Ontario in our data: 1986, 1988, 1992, and 1996 (there was no 1994 wave, and we omit the 1990 wave because it was conducted as the feebate program was being introduced). We create a dummy variable to reflect the presence of vehicle purchase by households ($\tilde{y}_{ijt}$), and code it as 1 if the household reported positive expenditure on passenger vehicles by household j in region i in year t and 0 otherwise.[30] Using the same notation as above, we estimate the following linear probability model:

$$\tilde{y}_{ijt} = \alpha \tilde{F}_{it} + \beta X_j + \delta_i + \gamma_t + \epsilon_{ijt}$$

where variables are described above and X_j includes age, age squared, income, income squared, spouse income, spouse income squared, a dummy variable for employment in the previous year, income from earnings, income from earnings squared, number of weeks worked full time, number of weeks worked full time by spouse, and dummy variables for educational attainment by category, gender, marital status, and household composition by category. Estimates are weighted to reflect population composition.

Results are presented in Table 5. Columns (1) and (2) are based on aggregate data from CANSIM and columns (3) and (4) use micro-data from the FAMEX. In (1), we do not include any controls and the results show that vehicle sales in Ontario dropped commensurately with the feebate; (2) however demonstrates that this decline is explained by time-varying economic variables in Ontario compared to other provinces. Column (2) suggests that the feebate had a small positive and statistically insignificant effect on vehicle sales in Ontario. Column (3) uses annual micro-data to estimate the effect of the feebate. As in (1), without controlling for other variables, the feebate is negatively correlated with vehicle sales in Ontario. Once demographic controls are included in (4), the feebate appears to have a very small positive but statistically insignificant effect on vehicle sales in Ontario.

Lack of robustness and statistical insignificance across these four specifications leads us to conclude that Ontario's feebate program had minimal implications for total vehicle sales in the province. Altering the fleet's composition – encouraging the purchase of more fuel efficient vehicles

[30]Note that the FAMEX does not distinguish between new and second-hand vehicle purchases, which creates measurement error in our variable of interest. We try to address this by coding purchase as 1 only if expenditure is above a certain threshold, which is increased over time at the rate of inflation. This should help reduce measurement error, as new vehicles are generally more costly than second-hand vehicles. We try a number of thresholds ranging from \$5,000 (in 1984 dollars) to \$20,000 and our coefficients remain similar. The results presented in Table 5 apply a \$10,000 threshold.

– appears to be the mechanism driving emissions reductions. It is important to emphasize however that our estimates of the effect of the feebate on total vehicle sales are noisy. Even in specification (4), the 95 percent confidence interval includes an effect of the policy on total vehicle sales that ranges from approximately -1.5 to +1.5 percent. We are unable to narrow the interval given the available data.

6.2 Asymmetric Responses

The feebate response parameters estimated in section 3 assume that consumers respond to fees and rebates symmetrically – a subsidy is simply a negative tax. Recent evidence suggests that the characteristics of the policy intervention may influence household decisions (e.g., Chetty et al. (2009); Gallagher and Muehlegger (2011)). In the feebate context, consumers may react differently when faced with a rebate or a fee. A plausible mechanism actually predicts asymmetric responses to taxes and subsidies: during an initial vehicle test drive, dealers are more likely to emphasize subsidies associated with a vehicle's fuel efficiency. Similarly, they may attempt to lump fees resulting from a vehicle's relative fuel inefficiency with other administrative and freight costs. As such, we may expect that consumers have differential response to fees and rebates. In contrast, asymmetric responses may reflect heterogeneity in either the density of models (hence the number of substitutes) across feebate brackets or consumer segmentation according to unobserved characteristics such as wealth. For example, consumers who purchase vehicles with very low fuel efficiencies, a segment where there are fewer substitutes, may be wealthier and less price-sensitive; hence, less price sensitivity at high feebate rates may reflect heterogeneity based on consumer characteristics rather than a fundamental difference in the response to fees versus rebates. Regardless of the source, asymmetry to fees and rebates is a feature of feebate policies that presents a notable departure from existing studies that are based on price or tax elasticities.

Table 6 presents a model using the FSA data where each feebate rate is separately binned. (1) replicates model (1) of Table 3 and illustrates that consumers are substantially more sensitive to rebates relative to fees (recall: rebates enter as negatives).[31] A $100 rebate, for example, leads to an increase in unique vehicle share of 56 percent, whereas a $250 fee reduces a vehicle's market share by 21.5 percent. For comparison, d'Haultfoeuille et al. (2014) find that in the first year of France's bonus/malus a €700 rebate increased vehicle market shares by 69.8 percent, while a €200 fee led to 25.7 percent reduction.

Consumers' asymmetric responses to taxes and subsidies pose a challenge for policy-makers: it is more difficult to design policy that approximates an optimal benchmark when decisions may be a function of the policy's characteristics or there are distributional concerns related to unobserved consumer attributes. Estimated coefficients show a non-linear and decreasing responsiveness to

[31] Pairwise F-tests of the rebate vis-à-vis each of the fee categories confirm that the difference is statistically significant.

increasing fees. Consumers are less responsive, on the margin, to a $1600 fee than a $250 fee. Of course, the logit framework imposes specific vehicle substitution possibilities, particularly with respect to increasing prices; nonetheless, both the rebate-fee asymmetry and the decreasing responsiveness to increasing fees can pose notable challenges for program design that has yet to be addressed in the literature.

6.3 Heterogeneity

Consumers are not homogeneous and distinct groups may attempt to influence the politics of a program design process if they believe that they are disproportionately affected. While rebate-fee asymmetry poses one challenge to the design of feebate schemes, consumer heterogeneity poses another. Rural residents, for instance, may be more likely to be employed in agriculture, construction and resource industries. As such, larger, relatively fuel inefficient vehicles may be necessary for work. The burden of high fees on these vehicles would then fall on a group that has less ability to respond to the policy's incentives. Politicians may be receptive to constituents' concerns over this unequal burden.

Table 7 segments the sample into rural and urban FSAs[32] and demonstrates that rural households are actually more sensitive to feebates compared with rural residents. Table 7 estimates a model for all vehicles in (1) and cars only in (2). Two parameters are shown for each formulation. First, the feebate coefficient is statistically significant and matches the earlier results, equaling -0.35 and -0.36 in columns (1) and (2) respectively. Next, an interaction term between the feebate and a rural dummy variable is included. This parameter equals a statistically significant -0.21 in (1) and -0.20 when only cars are considered in (2). Rather than being less sensitive to the feebate schedule, rural residents are more responsive to fees and rebates. Based on these results, it is not obvious that consumer heterogeneity due to a rural-urban divide presents a major challenge for effective policy-making.

7 Counterfactual Simulations

The welfare implications of Ontario's feebate program are calculated vis-à-vis a no feebate baseline and an optimal (second-best) feebate policy. As a first step, we qualitatively compare the Ontario program to a well-designed neutral policy. Figure 2 depicts the Ontario and second-best optimal rate schedules.[33] In calculating the optimal feebate schedule, we assume a social cost of carbon of \$40/t CO_2, which is roughly the level adopted by the Canadian and US governments in conducting analysis of new regulations. Four differences between the policies are apparent. First, Ontario's fee

[32] Assignment of FSAs into "rural" and "urban" was done according to Canada Post's definition of rural and urban mail delivery routes.

[33] The second-best optimal schedule is calculated using year 2000 information.

and rebate schedule is coarse with 14 distinct levels across two classes of vehicles. This coarseness can be seen via the discrete jumps ("notches") in the Ontario schedules. An optimal schedule imposes a much finer set of rates with a unique fee or rebate for each fuel efficiency rating. In Figure 2, the optimal feebate appears continuous across fuel consumption ratings. Second, Ontario's program differentiates between cars and SUVs while omitting trucks and vans. The optimal schedule applies identically to all vehicles at a given fuel consumption rating irrespective of category. Third, Ontario's program was based on rated highway fuel economy, whereas the optimal program uses a weighted measure over all driving (city and highway). Finally, an optimal feebate program is based on the social cost of the externality (i.e., the social cost of carbon), whereas the existing program appears to use different values (i.e., the slope of the optimal and actual feebate schedules differs).

Next, the results from Column 6 in Table 2 are used to evaluate the effect of the program on vehicle sales and carbon dioxide emissions. We start by predicting vehicle sales (i) in absence of any feebate and (ii) with an optimal schedule imposed, and then compare these to the actual observations from Ontario's program. We also determine the effect of changes, as described above, to the Ontario feebate program that would mimic the second-best optimal feebate program. It is important to note that these policy attributes are not additive, and as a result our simulations do not reflect a formal decomposition but instead reflect outcomes from a series of different policy designs.

To obtain simulated vehicle purchase behavior, we simulate new market shares based on the estimated response of consumers to feebates. For each vehicle, we assume a lifespan of 15 years (Bento et al., 2013) and annual vehicle kilometers of 16,000. The product of total vehicle sales, rated fuel consumption, vehicle lifespan and annual kilometers gives predicted lifetime gasoline consumption by unique vehicle type. Gasoline consumption is multiplied by 2.4 kg CO_2/liter to obtain carbon dioxide emissions. We then sum gasoline consumption and CO_2 emissions over all vehicles to obtain the total lifetime carbon dioxide emissions for all vehicles sold in a particular cohort. In each counterfactual simulation, we use the 2010 vehicle cohort as our reference point. For the counterfactual analysis of these scenarios, we assume the feebate policy does not change total vehicle sales – i.e., we hold total sales fixed.

We also conduct an analysis of the effect of each policy on welfare. Welfare change associated with each feebate policy consists of three components: (i) the change in government revenue, (ii) the change in consumer surplus and (iii) the monetized value of changes in emissions. We assume that vehicles are supplied at their marginal cost and do not include producer surplus in our welfare calculations. Government revenue is calculated by multiplying the feebate rate for each unique vehicle by the projection of vehicle sales in the counterfactual scenario and aggregating over all unique vehicles. Changes in consumer surplus are calculated using the method of Small and Rosen (1981). Finally, the dollar value of the the change in lifetime emissions is found by multiplying the change in emissions by the social value of emission reductions. We base our analysis on $40/t

CO_2, which is approximately the consensus value of the social cost of carbon adopted by the Canadian federal government. Two assumptions underlie these calculations: we assume that there are neither rebound (Gillingham et al., 2013) nor extensive margin effects; hence, these estimates focus exclusively on fleet composition effects.

Table 8 presents results from these policy simulations. The second column estimates the lifetime emissions of the 2010 vehicle cohort under the different policy scenarios. Without a feebate policy in place, we estimate that the cohort of vehicles sold in Ontario in 2010 would have produced 20.5 Mt CO_2 during its assumed 15 year lifetime. With the actual Ontario feebate in place, we estimate that emissions are reduced to 20.2 Mt CO_2, which is roughly a 1.5 percent reduction in emissions and suggests that the existing policy had a modest overall effect on emissions. With an optimally-designed revenue neutral feebate based on a social cost of carbon of \$40/t CO_2, we estimate that a hypothetical feebate would reduce emissions to 19.2 Mt or by roughly 6.5 percent. The table also shows the changes that would need to be made to Ontario's feebate program such that it matched the optimal policy design. Using blended fuel consumption (with weights of 45:55 for highway:city driving, following the US EPA and Natural Resources Canada) as opposed to basing the feebate on highway fuel efficiency only would better represent the social cost of vehicles, and would further reduce emissions. Because the blended fuel consumption rating is typically higher than the highway fuel consumption rating, this change would also result in tightening the stringency of the policy. Indeed, the original policy adopted in Ontario has an implicit social cost of carbon of \$20.46/t, while it has an implicit social cost of carbon of \$46.86 when based on blended fuel consumption ratings.[34] Including trucks and vans in the policy would also significantly reduce emissions, as would converting the notched policy design (see Figure 2) to a design that is linear in the fuel economy rating.

The last four columns of Table 8 estimate the change in welfare associated with the each policy relative to the no-policy case. The third column reports the government revenue associated with the policy. The actual feebate implemented in Ontario was revenue positive, raising approximately \$21 million in 2010. Widening the base and increasing the stringency of the policy as described above increases revenue raised, all else equal. For the optimal revenue-neutral policy, feebate rates are set as in (4) such that no revenue is raised.

We estimate the change in consumer surplus for each policy using the method established in Small and Rosen (1981). These estimates are reported in the fourth column and suggest that the actual feebate policy applied in Ontario resulted in a loss of consumer surplus equal to \$23 million. Increasing the stringency and broadening the base of the policy, all else equal, results in a larger loss of consumer surplus. To achieve revenue neutrality, in the last line of Table 8, feebate rates are reduced, which results in a smaller loss in consumer surplus.

[34] We determined the social cost of carbon by regressing the feebate rate in dollars against the lifetime emissions from each vehicle, in tonnes. The slope of the regression line is the implicit social cost of carbon adopted by the policy.

We calculate the monetized value of emissions reductions assuming a $40/t social cost of carbon and report our estimates in the fifth column. These suggest that Ontario's feebate reduced external costs of emissions by about $10 million over the cohort's lifetime but that an optimally-designed policy would have reduced external costs by more than $50 million.

The total welfare change associated with each policy is the sum of the government revenue, the change in consumer surplus and the monetized value of the change in emissions. In sum, the simulation suggests that both the actual Ontario feebate and an optimally-designed feebate are welfare-improving, but that given our assumptions the welfare gain from the optimally-designed policy is significantly greater than the existing policy.[35] On a per-vehicle sold basis, our estimates suggest that the welfare gain of the existing policy is about $20 per vehicle sold, and for the optimal policy, the welfare gain is about $71 per vehicle sold. These values are likely sufficiently large to induce politically constrained policy-makers to seriously consider feebate programs as viable emission-reduction policies.

8 Conclusion

New vehicle feebate programs have been proposed by several jurisdictions. The properties of this class of programs are potentially appealing to politically constrained governments. Most previous literature has only evaluated proposed feebate programs from an *ex ante* perspective; few prior studies have empirically evaluated the implications of existing programs nor considered characteristics of alternative feebate designs. This paper addresses this gap by studying Ontario's long-running Tax and Credit for Fuel Conservation and by deriving expressions for second-best optimal program parameters.

Using a dataset comprised of the population of Canadian vehicle registrations over an 11 year span, we find that, compared to a no feebate option, Ontario's feebate was welfare-enhancing but less so than a second-best optimally designed revenue neutral benchmark. Our calculations suggest that Ontario's policy reduced lifetime vehicle CO_2 emissions by about 0.6 million tonnes per vehicle cohort. An optimal revenue neutral formulation, in contrast, would have reduced emissions by about 1.3 million tCO_2 relative to the no feebate scenario. We further demonstrate that, although Ontario's program did not appear to affect total vehicle sales, important practical complications may impede policy-makers' efforts to implement feebate programs based on conventional vehicle price elasticities – in particular, we highlight that consumers have asymmetric responses to fees and rebates and that rural households are more sensitive to feebate schedules than their urban counterparts. Failure to account for this heterogeneity can dramatically alter the projected welfare of selected feebate designs.

Our results suggest that new vehicle feebates may be a feasible policy option to confront the

[35] The Ontario policy breakeven social cost of carbon is $27.43/t.

external costs associated with driving. Effective policy design ensures that these policies provide the greatest benefit at the lowest social cost. Throughout we emphasize that feebates are second-best policies that may be appealing to politically constrained governments. Obviously first-best programs, policies that directly influence vehicle usage decisions, are preferred; yet, in the real world of policy-making and program design, substantial merit exists in exploring the properties and prospective outcomes of a class of *realistic* programs. Revenue neutral feebates seem to belong to this class. Insofar as they remain a viable policy option for decision-makers, it is worthwhile advocating for well-conceived programs – especially as even modest feebates affect behavior and are welfare-enhancing.

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9 Figures

Figure 1: Fuel Consumption Rating (top panel) and Difference Between Rest-of-Canada and Ontarian Market Shares (bottom panel) of 4.6 litre, 8 Cylinder Ford Mustang

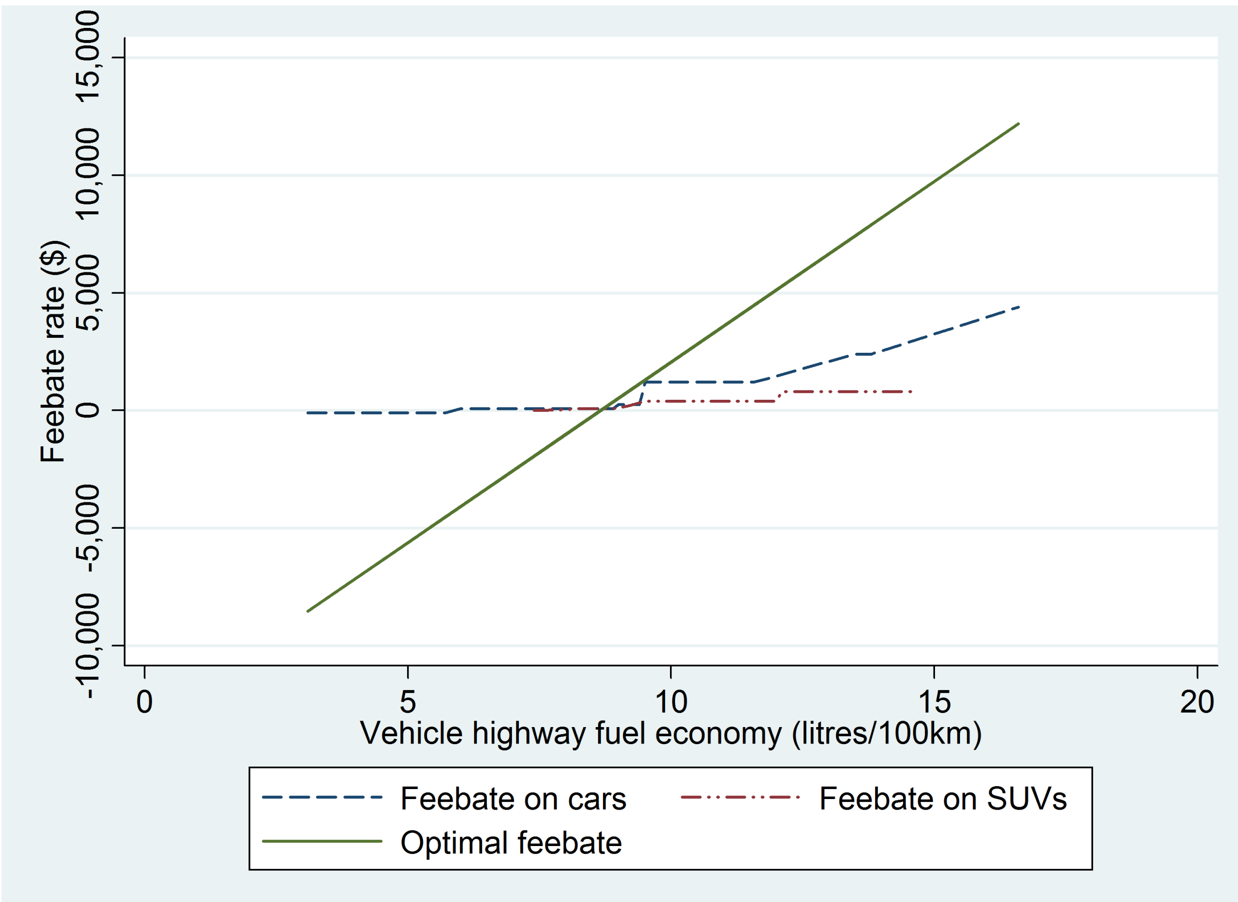


Figure 2: Comparison of the Ontario's Feebates Schedules to the Optimal Schedule. The optimal feebate schedule assumes a $40/t CO_2 social cost of carbon. The optimal feebate schedule is approximated by assuming a constant relationship between highway and overall fuel economy.

10 Tables

Table 1: Schedule of New Vehicle Fees and Rebates for the Ontario Feebate Program

Highway fuel efficiency rating (L/100km)	1989 Cars	1990 Cars	1991-2010 Cars	1991-2010 SUVs
less than 6.0	-	-	-100	-
6.0-7.9	-	-	75	-
8.0-8.9	-	200	75	75
9.0-9.4	-	700	250	200
9.5-12.0	600	1200	1200	400
12.1-15.0	1200	2400	2400	800
15.1-18.0	2200	4400	4400	1600
over 18.0	3500	7000	7000	3200

All fees and subsidies are in nominal Canadian dollars. Sources: Government of Ontario (1989), Government of Ontario (1991) and Government of Ontario (2010).

Table 2: Effect of Feebates on Vehicle Market Shares Using Provincial-level Data

	(1)	(2)	(3)	(4)	(5)	(6)
Feebate ($1,000)	-0.42**	-0.37**	-0.37**	-0.33**	-0.34	-0.30
	(0.11)	(0.08)	(0.08)	(0.09)	(0.32)	(0.29)
Vehicle fixed effects	✓	✓	✓			
Province-class fixed effects	✓	✓		✓		
Class-year fixed effects		✓			✓	
Region-class-year fixed effects			✓			
Vehicle-province fixed effects					✓	✓
Vehicle-year fixed effects				✓		✓
Observations	59,579	59,579	59,579	59,579	59,579	59,579

** - significant at 1%. Values in parentheses are standard errors clustered by province-class.

Coefficients in the table reflect the change in unique vehicle market shares resulting from a $1,000 fee. Gasoline costs are included in all models. Estimates are robust across specifications indicating minor influence of unobservables (Oster, 2013). A vehicle is defined as a unique combination of make-model-series-engine size-number of cylinders.

Table 3: Effect of Feebates on Vehicle Market Shares Using FSA-level Data

	(1)	(2)	(3)
Feebate ($1000)	-0.38**	-0.50**	-0.43**
	(0.02)	(0.02)	(0.02)
Vehicle-FSA fixed effects	✓	✓	✓
Vehicle-year fixed effects	✓	✓	✓
Observations	16,801,960	1,295,975	2,269,547

** - significant at 1%. Values in parentheses are standard errors clustered by FSA-class.

Coefficients in the table reflect the change in unique vehicle market shares at the FSA-level resulting from a $1,000 fee. Column (1) uses the full set of FSA-level observations. Columns (2) and (3) restrict the sample to just vehicles whose treatment under the feebate program changed over time. Column (2) includes only observations from the year prior to and immediately following the vehicle redesign that caused the vehicle to be treated differently by the Ontario feebate policy. Column (3) includes all annual observations for vehicles whose feebate treatment changed at least once during the period covered by the data.

Table 4: Nested Logit Estimates of the Effect of Feebates on Vehicle Market Share

	(1)
Feebate ($1000)	-0.30**
	(0.04)
Share-in-class	0.17**
	(0.05)
Vehicle-year fixed effects	✓
Vehicle-province fixed effects	✓
Observations	59,579

** - significant at 1%. Values in parentheses are standard errors clustered by province-class.

Coefficients in the table reflect the nested logit effect of a $1,000 fee on vehicle share accommodating within segment correlation of errors. There are 15 classes in the data, segmented according to conventional automobile categorization. All specifications control for gasoline cost. The share-in-class variable is instrumented using the engine size, number of cylinders and fuel economy of all other vehicles in the segment.

Table 5: Effect of Feebates on Total Passenger Vehicle Sales

	(1)	(2)	(3)	(4)
	CANSIM		*FAMEX*	
Feebate program	-0.07	0.02	-0.008	0.006
	(0.04)	(0.04)	(0.006)	(0.005)
Controls		✓		✓
Province fixed effects	✓	✓	✓	✓
Month fixed effects	✓	✓		
Year fixed effects	✓	✓	✓	✓
Observations	3,600	3,600	35,057	35,057

* - significant at 5%. Values in parentheses are standard errors.

Data in this table come from two sources. Data for columns (1) and (2) are from Statistics Canada (CANSIM), span 1980-2012 and reflect aggregate monthly passenger vehicle sales by province. The dependent variable in each column is logged per capita vehicle sales. Data for columns (3) and (4) are micro-data from 1984, 1986, 1992, and 1996 from Statistics Canada's Family Expenditure Survey. The dependent variable takes on a value of 1 if the household purchased a vehicle and 0 otherwise. Estimates of (3) and (4) include weights to reflect census household composition. *Feebate program* takes a value of one for the province of Ontario for the years 1989 through 2010. Controls for the CANSIM data include GDP per capita, the unemployment rate and gas prices (all logged). Controls for the FAMEX data include age, age squared, income, income squared, spouse income, spouse income squared, a dummy variable for employment in the previous year, income from earnings, income from earnings squared, number of weeks worked full time, number of weeks worked full time by spouse, and dummy variables for educational attainment by category, gender, marital status, and household composition by category.

Table 6: Asymmetric Consumer Responses to Fees versus Rebates

	(1)
Feebate ($1000) × I[$100 rebate]	-5.63**
	(0.42)
Feebate ($1000) × I[$75 fee]	-0.81**
	(0.34)
Feebate ($1000) × I[$250 fee]	-0.86**
	(0.14)
Feebate ($1000) × I[$400 fee]	-0.10
	(0.13)
Feebate ($1000) × I[$800 fee]	-0.13
	(0.08)
Feebate ($1000) × I[$1200 fee]	-0.62**
	(0.03)
Feebate ($1000) × I[$1600 fee]	-0.42**
	(0.09)
Feebate ($1000) × I[≥ $2400 fee]	-0.23**
	(0.02)
Vehicle-year	✓
Vehicle-FSA	✓
Observations	16,801,960

** - significant at 1%. Values in parentheses are standard errors clustered by FSA-class.

Coefficients in the table reflect the change in unique vehicle market share resulting from the indicated fee. Pairwise F-tests of the null hypothesis of equal coefficient sizes demonstrates that rebates yield a statistically significantly different consumer response than fees.

Table 7: Heterogeneity of Feebate Responsiveness in Urban versus Rural Markets

	(1) *All vehicles*	(2) *Cars only*
Feebate ($1000)	-0.35**	-0.36**
	(0.02)	(0.02)
Feebate*Rural FSA	-0.21**	-0.20**
	(0.05)	(0.05)
Make-model-year	✓	✓
Make-model-FSA	✓	✓
Observations	16,801,960	8,846,661

** - significant at 1%. Values in parentheses are standard errors clustered by FSA-class.

Coefficients in the table reflect the change in unique vehicle market share resulting from a $1000 fee. Feebate*Rural FSA is the interaction term of Feebate and Rural FSA, a dummy variable that takes a value of 1 if Canada Post classifies the FSA as a rural route, which illustrates that rural residents are more sensitive to the feebate schedule than their urban counterparts. All vehicles are included in (1). (2) restricts the sample to passenger cars only.

Table 8: Counterfactual Simulations of Vehicle Feebate Scenarios

		Sources of welfare change			
	Lifetime Emissions ($Mt\ CO_2$)	Government Revenue ($M)	Consumer Surplus ($M)	Emissions Value ($M)	Total Welfare Change ($M)
No Feebate	20.5				
Ontario Feebate Program	20.2	20.4	-23.3	10.3	7.4
w/ blended fuel efficiency	20.0	92.2	-107.5	18.9	3.6
w/ social cost of carbon	20.5	81.9	-93.8	16.7	4.9
w/ including trucks/vans	19.6	106.6	-122.6	34.7	18.6
w/ remove notches + rev-neutral					
= Optimal revenue neutral feebate	19.2	-	-24.3	51.2	26.9

All calculations are based on 2010 data and reflect the welfare gains per vehicle cohort. Emissions calculations assume that each vehicle is driven 16,000km/yr and has a 15 year lifespan. Welfare gains are based on per vehicle emissions and are calculated relative to the no feebate scenario. Values are based on a social cost of carbon of $40/t CO_2.

New Vehicle Feebates
Appendix

Nicholas Rivers* Brandon Schaufele†

August 14, 2015

This Appendix contains three sections. Section 1 presents two derivations of the second-best optimal feebate. Section 2 presents some additional details on the econometric specification used in the text. Section 3 contains the summary statistics and additional econometric results.

1 Feebate Expressions

Two derivations of a second-best optimal feebate schedule are presented. We start with a model where consumers choose between two vehicles, one which is clean (relatively fuel efficient) and the other which is dirty (relatively fuel inefficient). This is the model discussed in section 2 of the main text. Next, this model is generalized to include K vehicles. In each approach, consumers select vehicles to maximize utility taking emissions as given, consumer welfare is defined as utility net of emission damages and the government selects tax and rebate policies with the objective of maximizing welfare. Throughout, vehicle supply (vehicle characteristics, prices) is treated as exogenous (see the main text for discussion of this assumption).

1.1 Two Vehicle Model

1.1.1 Firms

Two vehicles – indexed by $k = \{d, c\}$ where d refers a "dirty", or relatively fuel inefficient vehicle, and c is a "clean", or fuel efficient vehicle – are supplied in a competitive market where price equals marginal cost, $p_k = mc_k$. The marginal rate of transformation between the clean and dirty vehicle

*Graduate School of Public and International Affairs and Institute of the Environment, University of Ottawa, Faculty of Social Sciences, 120 University, Social Sciences Building, Ottawa, Ontario, Canada, K1N 6N5, 1-613-562-5800 ext. 4676, nrivers@uottawa.ca.

†Business, Economics and Public Policy, Ivey Business School, University of Western Ontario, 1255 Western Road, London, Ontario, Canada, N6G 0N1, 1-519-200-6671, bschaufele@ivey.uwo.ca.

is:

$$MRT = \frac{dv_c}{dv_d} = -\frac{mc_d}{mc_c} = -\frac{p_d}{p_c}. \tag{1}$$

1.1.2 Consumer

A representative consumer chooses the quantities of clean, v_c, and dirty, v_d, vehicles. Consumer utility is given by:

$$U(v_c, v_d, x)$$

where x is consumption of other goods. The consumer maximizes utility subject to a wealth, M, constraint:

$$M = (p_c + F_c)v_c + (p_d + F_d)v_d + x$$

where F_k is the fee on vehicle k (a negative value denotes a rebate), p_k is the tax-exclusive price and x is the numeraire good. In a no feebate status quo, all feebates equal zero: $F_k = 0$. Consumers do not consider emissions when making vehicle choices, so, after normalizing the marginal utility of wealth to one, the first order conditions are:

$$\frac{\partial U}{\partial v_c} = p_c + F_c \qquad \frac{\partial U}{\partial v_d} = p_d + F_d \qquad \frac{\partial U}{\partial x} = 1. \tag{2}$$

The government is exclusively interested in consumer welfare, which is utility less damages from emissions:

$$W = U(v_c, v_d, x) - \delta E \tag{3}$$

where δ is the constant marginal disutility from emissions and where emissions, E, are caused by vehicles, such that $E = v_c e_c + v_d e_d$. e_c and e_d are the per vehicle lifetime emissions from v_c and v_d, respectively.

1.1.3 Government

The government uses the feebate schedule to maximize social welfare, subject to an equilibrium revenue constraint, $\bar{R}$:

$$F_c v_c^* + F_d v_d^* = \bar{R}.$$

The government's optimal feebate problem can be set up by differentiating welfare:

$$dW = \frac{\partial U}{\partial v_c} dv_c + \frac{\partial U}{\partial v_d} dv_d + \frac{\partial U}{\partial x} dx - \delta dE$$

Substituting in first order conditions and the differentiated emissions function ($dE = e_c dv_c + e_d dv_d$) gives:

$$dW = (p_c + F_c)dv_c + (p_d + F_d)dv_d + dx - \delta(e_c dv_c + e_d dv_d)$$

Differentiating the wealth constraint ($dM = 0 = v_c dF_c + (p_c + F_c)dv_c + v_d dF_d + (p_d + F_d)dv_d + dx$), substituting and rearranging gives:

$$dW = -v_c dF_c - v_d dF_d - \delta(e_c dv_c + e_d dv_d)$$

Casting the optimal feebate problem in terms of the dirty vehicles yields:

$$\frac{dW}{dF_d} = -v_c \frac{dF_c}{dF_d} - v_d - \delta(e_c \frac{dv_c}{dF_d} + e_d \frac{dv_d}{dF_d})$$

Substituting in the differentiated revenue constraint gives:

$$\frac{dW}{dF_d} = F_c \frac{dv_c}{dF_d} + F_d \frac{dv_d}{dF_d} - \delta(e_c \frac{dv_c}{dF_d} + e_d \frac{dv_d}{dF_d})$$

Setting $dW = 0$ and solving for the optimal dirty vehicle fee gives:

$$F_d = \delta e_d + (\delta e_c - F_c)\frac{dv_c}{dv_d}. \tag{4}$$

where F_c is negative reflecting a rebate and $\frac{dv_c}{dv_d}$, the marginal rate of transformation of dirty for clean vehicles, is negative as clean and dirty vehicles are substitutes.

At this stage it is possible to compare the optimal feebate to the the optimal Pigouvian tax. The optimal indirect Pigouvian dollar valued tax, T_k, which is rebated through lump-sum transfers to the consumer, simply sets the tax to the marginal (social) damage of emissions:

$$T_d = \delta e_d \qquad\qquad T_c = \delta e_c \tag{5}$$

We will also use the optimal Pigouvian tax rate:

$$t_d = \delta \frac{e_d}{p_d} \qquad\qquad t_c = \delta \frac{e_c}{p_c} \tag{6}$$

which is the dollar-valued Pigouvian tax normalized by vehicle price.

It is apparent that the optimal feebate, (4), embeds the Pigouvian tax, (5), but is a downward translation of this schedule. We can further refine (4) by substituting in the government budget constraint. For simplicity, consider a revenue neutral feebate such that $\bar{R} = 0$:

$$F_d = \delta(e_d + e_c \frac{dv_c}{dv_d}) + F_d \frac{v_d}{v_c} \frac{dv_c}{dv_d}.$$

Next substitute in the firms' first-order condition, $MRT = \frac{dv_c}{dv_d} = -\frac{p_d}{p_c}$:

$$f_d = \frac{F_d}{p_d} \quad = w_c\big(t_d - t_c\big) \tag{7}$$

where w_k is the expenditure share of vehicle k. (7) (as well as (8)) is the expression in the main text.

The model is general, so symmetric expressions can be derived. The clean vehicle's rebate is:[1]

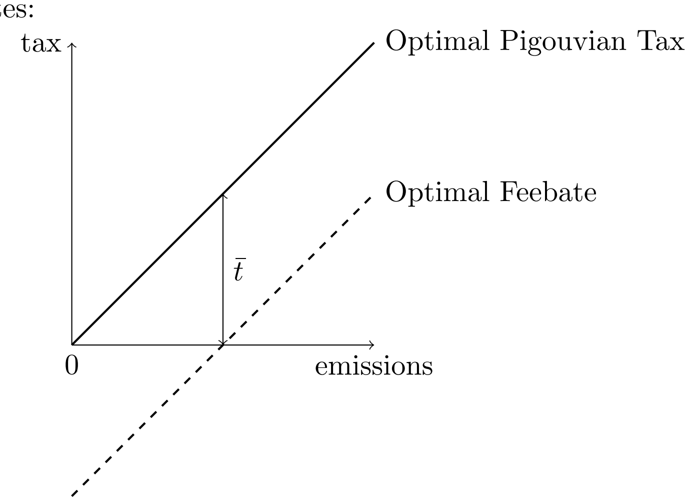
$$f_c = w_d\big(t_c - t_d\big)$$

Another expression for the optimal feebate is obtained by rearranging (7):

$$\begin{aligned} f_d &= \delta \left(\frac{e_d}{p_d} - \frac{\bar{e}}{\bar{p}} \right) \\ &= t_d - \bar{t} \end{aligned} \tag{8}$$

where $\bar{e}$, $\bar{p}$, and $\bar{t}$ are the share-weighted emissions, price, and tax from the new vehicle fleet.

Figure 1.1.3 illustrates the relationship between second-best optimal Pigouvian taxes and feebate rates:



[1] Of course only one fee/rebate is independent; the other is determined from the revenue constraint.

1.2 A K Vehicle Model

In a complete model, consumers choose between $k = 1 \dots K$ vehicles. Consumer utility is given by $U = U(v_k, x)$, and the wealth constraint is $M = \sum_K (F_k + p_k) v_k + x$. Differentiating consumer welfare as above gives:

$$dW = \sum_k \frac{\partial U}{\partial v_k} dv_k + \frac{\partial U}{\partial x} dx - \delta dE$$

Substituting first order conditions and the differentiated wealth constraint gives (again assuming the marginal value of wealth is unity):

$$dW = -\sum_k v_k \frac{dF_k}{p_k} - \delta \sum_k e_k dv_k$$

Dividing through by dF_j gives K optimal feebate conditions:

$$\frac{dW}{dF_j} = -\sum_{k \neq j} v_k \frac{dF_k}{dF_j} - v_j - \delta \sum_k e_k \frac{dv_k}{dF_j}$$

Differentiating the revenue constraint gives $v_j = -\sum_{k \neq j} v_k \frac{dF_k}{dF_j} - \sum_k F_k \frac{dv_k}{dF_j}$. Substituting this into the expression above and solving for F_j at the welfare maximum gives:

$$F_j = \sum_{k \neq j} (\delta e_k - F_k) \frac{dv_k}{dv_j} + \delta e_j$$

which is comparable to (4), the expression derived for the two-vehicle case. Solving for f_k is analogous to (7) and yields:

$$\begin{aligned} f_k &= \delta \left(\frac{e_k}{p_k} - \frac{\bar{e}}{\bar{p}} \right) \\ &= t_k - \bar{t} \end{aligned} \tag{9}$$

where $\bar{e}$, $\bar{p}$, and $\bar{t}$ are the market share weighted average emissions, prices, and taxes for all vehicles and t_k is the Pigouvian tax rate on vehicle k.

2 Econometric Specification

As mentioned in the main text, we use the conventional differentiated goods logit specification to estimate our feebate parameters. Define the utility that consumer i in province p at time t derives from the purchase of vehicle type k as:

$$U_{ikpt} = \alpha_i(y_{ipt} - q_{kpt}) + \mathbf{X}_{kpt}\beta_i + \zeta_{kpt} + \epsilon_{ikpt} \tag{10}$$

where y is income, q is vehicle price, $\mathbf{X}$ is a vector of observed vehicle characteristics, ζ captures unobserved vehicle characteristics and ϵ is a mean-zero error term that captures the consumer's idiosyncratic preferences over each vehicle type. The parameters α_i and β_i capture individual-level preferences over vehicle price and other characteristics.[2] We decompose utility into a systematic and random component: $U_{ikpt} = V_{ikpt} + \epsilon_{ikpt}$.

Assuming that in the absence of feebates vehicle prices are identical across provinces, we account for the effect of feebates by treating provincial vehicle prices as equal to the Canada-wide vehicle price net of feebates:

$$q_{kpt} = q_{kt} + F_{kpt}$$

where as above F_{kpt} is the dollar value of the feebate applied on vehicle k, with negative values for subsidies (rebates) and positive values for fees (taxes).

Recent evidence using transaction-level data in the US suggests that dealers adjust incentives in response to market conditions [5]. If this occurs in Canadian markets, we expect that a portion of the feebate would be absorbed by vehicle manufacturers or retailers such that the effect of the feebate on vehicle transaction prices would be muted compared to the specification above. To the extent that this occurs, our econometric model should be interpreted as a reduced-form model that captures the equilibrium impact of the policy on vehicle demand, not as a structural specification. Our objective is to evaluate the efficacy of actual feebate policies, thus reduced-form equilibrium impacts are the desired elasticities as they are more interesting and useful for policy analysis.

We treat observable vehicle characteristics $\mathbf{X}_{kpt}$ as consisting of two parts. The first component $\mathbf{X}_k$ is invariant across provinces and time and reflects characteristics such as engine size, vehicle design and safety ratings. Constant for particular vehicles, vehicle-specific fixed effects net out these characteristics in our analysis of the feebate policy. The second component we refer to as G_{kt}, with $G_{kpt} = p^G_{pt}\psi_k$ being the gasoline cost per kilometer for vehicle k. This is calculated as the price of gasoline multiplied by the vehicle specific fuel consumption rating (measured in liters

[2] This specification imposes a constant marginal utility of income, α_i. This is potentially problematic as vehicles represent a large purchase, and marginal utility may not be constant over the range of vehicle prices. Unfortunately, our data do not include vehicle price, we are unable to adopt a specification where the marginal utility of income is decreasing [1].

of gasoline per 100 km of driving).

We now write utility as:

$$U_{ikpt} = \alpha_i y_{ipt} - \alpha_i(q_{kt} + F_{kpt}) + \mathbf{X}_k\beta_i + \phi_i G_{kpt} + \zeta_{kpt} + \epsilon_{ijpt} \tag{11}$$

We next introduce an outside good, indexed by the subscript '0', which involves the option of not purchasing a vehicle. This captures the extensive margin implications of the feebate policy. Setting the reference utility for this option to $U_{i0pt} = \alpha_i y_{ipt}$, we assume that consumers purchase one unit of the good (vehicle or outside) that provides the highest utility. Implicitly, this defines values of observed and unobserved vehicle characteristics and preferences that are consistent with the choice of a particular vehicle. The probability that a consumer i will choose any given vehicle k is:

$$P_{ikpt} = \Pr(U_{ikpt} > U_{ijpt}) \quad \forall j \neq k$$
$$P_{ikpt} = \Pr(V_{ikpt} - V_{ijpt} > \epsilon_{ijpt} - \epsilon_{ikpt}) \quad \forall j \neq k$$

To allow a closed-form solution, we eliminate systematic consumer preference heterogeneity, such that $\alpha_i = \alpha$, $\beta_i = \beta$ and $\phi_i = \phi$. The market share of each of the k choices can then be calculated by integration:

$$s_{kpt} = \int_\epsilon I(V_{ikpt} - V_{ijpt} > \epsilon_{ijpt} - \epsilon_{ikpt} \quad \forall j \neq k) f(\epsilon) d\epsilon$$

where $I(\cdot)$ is an indicator that equals one if the condition in parentheses is satisfied and zero otherwise. Assuming that ϵ is independent and identically distributed (iid) Type-I extreme value allows evaluation of the integral and yields the familiar logit model:

$$s_{kpt} = \frac{e^{V_{ikpt}}}{\sum_j e^{V_{ijpt}}}$$

Dividing through by s_{0pt} and taking logs gives the log-odds ratio of purchasing each vehicle as follows:

$$\log\left(\frac{s_{kpt}}{s_{0pt}}\right) = -\alpha q_{kt} - \alpha F_{kpt} + \beta X_k - \phi G_{kpt} + \zeta_{kpt} \tag{12}$$

The coefficients of (12) can be estimated using least squares. Unfortunately directly estimating this equation, as is, is problematic: unobserved vehicle characteristics are likely correlated with prices, generating biased estimates. As the goal of this study is to estimate the reduced-form impact of the vehicle feebate policy, we are able to circumvent this problem by introducing vehicle-province fixed effects, ζ_{kp}. These fixed effects absorb all vehicle characteristics that are invariant across provinces, including vehicle prices exclusive of the feebate rates. We further decompose the error term into a component that is equal for all provinces and potentially correlated with price, ν_{kp}, and a mean-zero component that varies across markets, μ_{jpt}. The vehicle-province fixed effects absorb the error component ν_{kp}, such that the basic estimating equation is:

$$\log\left(\frac{s_{kpt}}{s_{0pt}}\right) = \zeta_{kp} - \alpha f_{kpt} - \phi G_{kpt} + \mu_{kpt}$$

This is equation (5) presented in section 4.2 of the main text.

Nested Logit Specification

We also estimate a variant of this equation that relaxes the iid error assumption implicit in the standard logit model. In particular, we estimate a nested logit model in which we group vehicles into 15 nests reflecting the vehicle segment (c). This grouping allows correlation of the unobserved vehicle characteristics according to vehicle segment and permits vehicles within a segment to be treated as closer substitutes for one another than vehicles in different segments. The nested logit specification is estimated as follows:

$$\log\left(\frac{s_{kpt}}{s_{0pt}}\right) = \zeta_{kp} - \alpha F_{kpt} - \phi G_{kpt} + \sigma \log(s_{kpt/cpt}) + \mu_{kpt} \tag{13}$$

where $s_{kpt/cpt}$ is the market share of vehicle k within segment c, and σ is the inclusive value parameter, and reflects the substitutability between vehicles within the same segment. This variable is clearly endogenous, so we apply the standard instrumental variable solution. As is typical, our instruments are the sum of all vehicle attributes in segment c, excluding vehicle k [1].

Estimation Procedure

Several of our models contain hundreds of thousands of fixed effects across several dimensions. Standard estimation techniques are not feasible with so many coefficients. Our objective is to accurately identify a single feebate parameter however. As such we invoke the Frisch-Waugh-Lovell Theorem to remove the fixed effects via application of a repeated demeaning process [3]. This Frisch-Waugh-Lovell procedure enables us to shrink the parameter set and use transformed data to correctly estimate effect of feebates on vehicle market shares. There are two advantages of this approach: (i) we are able to flexibly control for a broad array unobserved confounders, while (ii) dramatically relaxing computational costs involved with estimating models with millions of observations and hundreds of thousands of fixed effects. A similar approach was applied in [2].

A specific example clarifies this procedure. Column 1 of Table 3 presents results using 16,801,960 observations at the FSA-level. This specification includes two sets of fixed effects. First is a vehicle-by-year fixed effect defined at the resolution of make-model-series-engine size-number of cylinders. These coefficients capture a range of vehicle-specific attributes that are common across markets. With 11 years of data and approximately 600 unique vehicles, 6600 coefficients would need to be estimated, a number which is reasonable for on most personal computers. Next, vehicle-by-FSA effects are added. Unobserved commute times in suburban Toronto, for instance, are presumably longer than those in St. John's, Newfoundland. Thus, residents of Toronto may have different unobserved preferences for fuel economy when compared to Newfoundlanders. This suite of parameters captures these FSA-specific preferences. In this model however, up to 1600*600 or 960,000 additional parameters would need to be estimated. Inverting a 950,000 by 950,00 matrix requires approximately 1Tb of memory, well beyond what is available on most computers. The Frisch-Waugh-Lovell procedure overcomes these computational obstacles.

Step one of the Frisch-Waugh-Lovell procedure calculates the mean for all 6600 vehicle-years. Each of these $k * t$ group means are then subtracted from all remaining variables in the second step. This demeaning procedure is successively repeated for each of the fixed effects (e.g., vehicle-by-FSA). Once all group means have been removed through demeaning, a regression of the transformed dependent variable on the transformed independent variables yields identical estimates of the remaining parameters as a regression that includes the full suite of fixed effects. In our example, we estimate:

$$\log \widetilde{\widetilde{\left(\frac{s_{kft}}{s_{0ft}}\right)}} = \alpha \tilde{\tilde{F}}_{kft} + \nu_{kft} \tag{14}$$

using least squares where the $\sim$ over a variable represents the transformed data[3] and ν_{kft} is the error term.

Throughout our analysis, we report standard errors clustered by province-years or FSA-years. Standard errors calculated from the the transformed estimating equations, e.g., (14), are correct, even with clustering, once adjusted for degrees of freedom [4]. However, not all of the fixed effects are identified in the data. As the demeaning algorithm is automated, we do not precisely count how many parameters are removed. We therefore adopt a conservative rule of thumb and assume that all fixed effects are identified in our dataset. This implies that the reported standard errors are over-estimated and we are less likely to reject a null hypothesis of no effect for our feebate parameter.

[3] This study is interested in the feebate parameter, α, however it is possible to recover the fixed effects.

3 Summary Statistics and Additional Results

3.1 Summary Statistics

Table 1 presents summary statistics for the province-level data. Engine displacement is in cubic centimetres; sales are per region-year; fuel economy ratings are in litres/100 km; light duty trucks comprise the remainder of the vehicle market not captured by cars and suvs; feebates are in nominal dollars for all vehicles sold in Ontario (including trucks); and, gasoline cost is calculated annually.

Table 1: Summary Statistics for Provincial-level Data

	Mean	**Std. Dev.**	**Min.**	**Max.**
Number of cylinders	5.9	1.55	2	12
Sales (unique vehicle)	182.50	652.88	1	23348
Highway fuel economy	8.70	2.04	3.1	16.6
City fuel economy	12.73	2.99	3.7	27.7
Car share	0.53	0.50	0	1
SUV share	0.25	0.43	0	1
Feebate	178.13	351.70	-100	4400
Gasoline cost	916.19	239.65	237.90	2014.79
Observations	59,579			

Figure 1 illustrates the distribution of all vehicles (cars, SUVs, trucks and vans) by rated fuel economy.

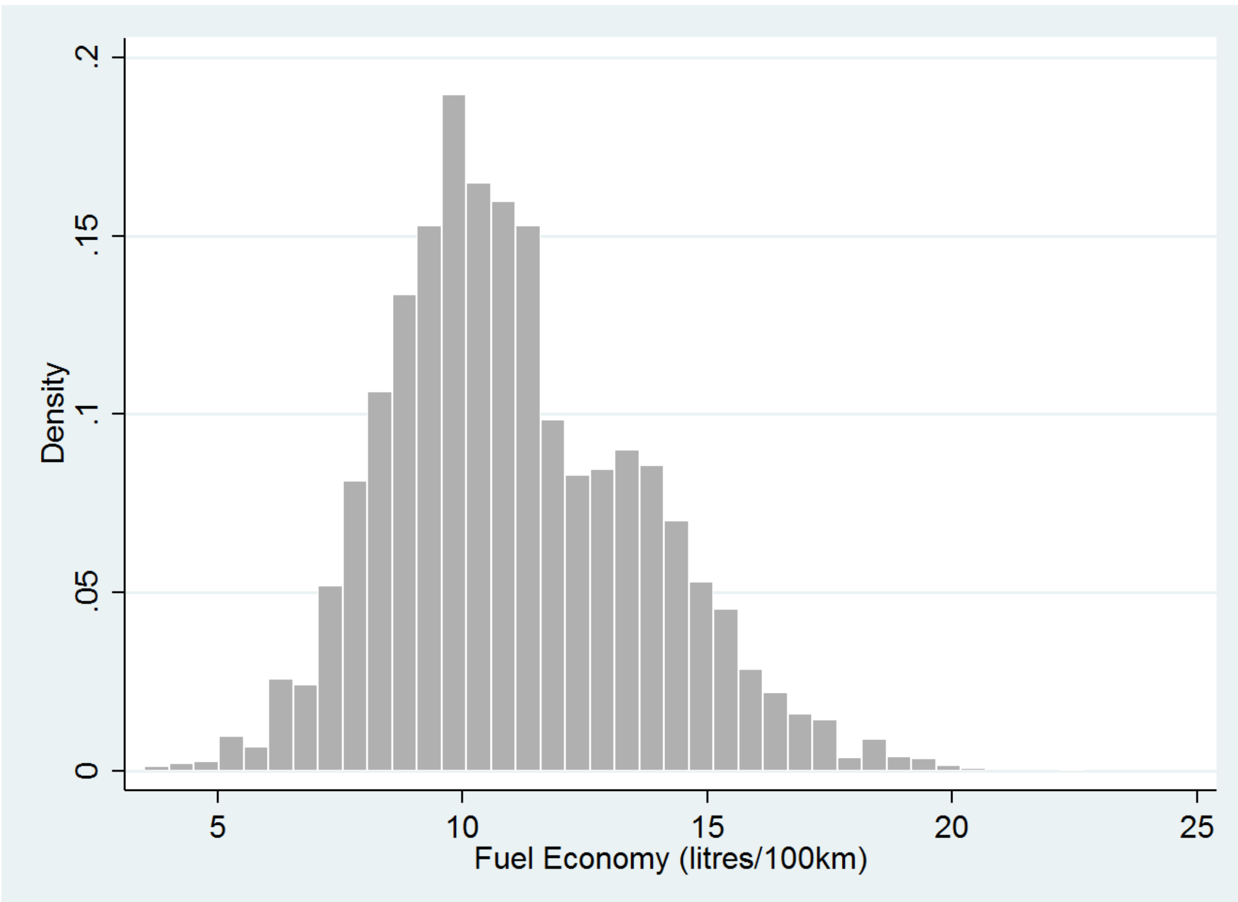


Figure 1: Distribution of Fuel Economy for All Vehicles and Years

3.2 Additional Results

Table 2 replicates Table 2 from the main text when we apply a different assignment rule for vehicle registrations and sales. Here, we treat a vehicle as a sale the first time it appears in the data, rather than when the vehicle model year is equal to the registration year. Results are nearly identical to those in the main text.

Feebate ($1,000)	-0.40	-0.35	-0.35	-0.36	-0.32	-0.30
	(0.11)**	(0.08)**	(0.08)**	(0.29)	(0.09)**	(0.29)
Vehicle fixed effects	✓	✓	✓			
Province-class fixed effects	✓	✓			✓	
Class-year fixed effects		✓		✓		
Region-class-year fixed effects			✓			
Vehicle-province fixed effects				✓		✓
Vehicle-year fixed effects					✓	✓

Table 2: Estimation results with data at provincial level of disaggregation. Standard errors clustered at province-class level.

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