Gasoline price and new vehicle fuel efficiency: Evidence from Canadian micro-data

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Abstract

Using data on all vehicles registered in Canadian provinces from 2000-2010, we estimate the elasticity of the fuel economy of the new vehicle stock with respect to gasoline price. We demonstrate that a 10% increase in gasoline price causes a 0.8% improvement in the fuel economy of new vehicles. We show that consumers in dense urban areas respond more to changes in fuel price than other consumers and that fuel taxes cause a much larger response in vehicle fuel economy than other components of the gasoline price. This finding has important implications for the assessment of market-based policies for reducing greenhouse gas emissions.

Keywords: gasoline demand, vehicle choice, elasticity.

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1 Introduction

Gasoline consumption is a major source of emissions in Canada. In 2013, private vehicles generated 82 million tonnes of greenhouse gas in Canada, roughly 12% of the country's total emissions (Environment Canada, 2015). Combustion of gasoline also produces a range of other pollutants (e.g., nitrogen oxides, carbon monoxide and particulate matter) that adversely affect human health. Many of the costs associated with these emissions accrue to society rather than to private consumers, so reducing gasoline consumption in vehicles has become important for public policy makers.

A range of policies have been deployed to reduce vehicular greenhouse gas emissions in Canada (Antweiler and Gulati, 2013). Several provinces offered rebates for the purchase fuel efficient vehicles such as hybrid-electric or electric vehicles (Chandra et al., 2010). Ontario and the federal government used a system of taxes and rebates based on fuel economy (Rivers and Schaufele, 2014; Sallee and Slemrod, 2012). British Columbia and Quebec apply a carbon price to provide incentives to consumers to reduce consumption of fossil fuels (Rivers and Schaufele, 2015). The federal government provides a tax credit to encourage commuting by public transport rather than private vehicle (Rivers and Plumptre, 2016; Chandler, 2014) and recently adopted new vehicle greenhouse gas intensity regulations, requiring manufacturers to reach certain targets for fleet greenhouse gas emissions per kilometre.[1] Despite the breadth of policies targeting vehicle fuel efficiency, little is known about how gasoline prices influence consumer decision-making with respect to fuel economy.

Gasoline consumption from vehicles is the product of two factors. First is the fuel efficiency of the on-road vehicle stock – i.e., the number of litres required to travel a kilometre. We denote this fuel efficiency with F. Consumers consider the price of gasoline when selecting the fuel efficiency of vehicles, so F is a function of the price of gasoline, p. The second factor in gasoline consumption is vehicle utilization or number of kilometres travelled which is represented by D. Conditional on the fuel consumption rating of the vehicle, consumers choose the distance to drive.

[1] See `http://www.gazette.gc.ca/rp-pr/p2/2014/2014-10-08/html/sor-dors207-eng.php`.

This means that this second factor, the intensity of vehicle use, is a function of both the price of gasoline, p, as well as fuel efficiency, F. Taken together, these two factors determine the cost of driving. As a result, a reduced-form expression for total gasoline consumption is:[2]

$$G = F(p)D(F(p), p)$$

Taking the total derivative of this expression yields an intuitive decomposition for the elasticity of gasoline demand with respect to price (ε):

$$\varepsilon = \frac{dG}{dp}\frac{p}{G} = \eta(1+\mu)+\mu, \tag{1}$$

where $\eta \equiv \frac{\partial F}{\partial p}\frac{p}{F}$ is the elasticity of vehicle stock fuel efficiency with respect to gasoline price and $\mu \equiv \frac{\partial D}{\partial p}\frac{p}{D}$ is the elasticity of distance driven with respect to gasoline price.[3] This decomposition illustrates that the elasticity of gasoline demand with respect to price is comprised of two parts: the change in fleet fuel economy with respect to gasoline price and the change in distance travelled with respect to gasoline price. The term in brackets describes the interaction between changes in fleet fuel economy and distance travelled. This interaction is referred to as the "rebound effect", whereby increases in fleet fuel economy result in additional driving demand by reducing the private cost of driving (Borenstein, 2013; Sorrell and Dimitropoulos, 2008; Chan et al., 2014).

Several studies estimate μ. For example, Gillingham et al. (2015), Gillingham (2014), and Greene et al. (1999) estimate the elasticity of vehicle miles travelled with respect to gasoline price in the US. The consensus value is approximately -0.2. Using aggregate data, Barla et al. (2009) finds a comparable long-run estimate for Canada.

[2]This expression is derived from a simple model of a utility-maximizing consumer that consumes transport services (D) and other goods (X, the numeraire good), such that $U = U(D,X)$. The consumer maximizes utility subject to a budget constraint: $p_D D + X = M$, where the price of driving is given by $p_D = pF$. This yields $F^* = F(p) = -\frac{1}{\lambda}\frac{U_D}{p}$ and $D^* = D(F(p), p) = \frac{M-X}{pF^*}$, where λ is the marginal utility of consumption. Gasoline consumption in vehicles is proportional to greenhouse gas emissions, so this expression can serve to evaluate changes in greenhouse gas emissions as well as gasoline consumption.

[3]Note that the derivation imposes the assumption that $\frac{\partial D}{\partial F}\frac{F}{D} = \mu$, which is a common assumption in the literature on gasoline demand (but see Chan et al. (2014) who caution that it may not always be appropriate).

This paper focuses on estimating η, the elasticity of fleet fuel economy with respect to gasoline price. A handful of papers estimate this elasticity, although very few in Canada. Li et al. (2009) use detailed US vehicle registration data from 1997 to 2005 to determine how changes in gasoline prices affect the fuel economy of vehicle sales. They find that a 1% increase in gasoline prices causes an improvement in fleet fuel economy of 0.2%. Klier and Linn (2010) identify changes in US fuel economy from monthly vehicle sales. They find that a 1% change in gasoline price results in about a 0.1% improvement in fuel economy. Burke and Nishitateno (2013) use cross-sectional aggregate data from 43 countries to estimate the relationship between new vehicle fuel economy and gasoline price. They find an elasticity of about 0.2.[4] Unfortunately, many prior estimates of η impose strong assumptions to identify the effect of gasoline prices on fuel efficiency of new vehicle purchases (Klier and Linn, 2010). In cross-sectional studies, such as West (2004) and Burke and Nishitateno (2013), a maintained assumption is that there is no relationship between gasoline prices and unobserved consumer preferences. This would be violated, for example, if consumers selected into particular locations based on gasoline prices or if unobserved consumer preferences are an important determinant of gasoline taxes (Hammar et al., 2004). Other studies based on aggregate time series data, such as Barla et al. (2009) and Small and Van Dender (2007), are unable to control for time-varying unobservable shocks. Moreover, because they are based on aggregate data, estimates are less precise.

Recent studies including Klier and Linn (2010) and Li et al. (2009) have used detailed micro-datasets and relaxed identifying assumptions to provide credible causal estimates of the elasticity of vehicle fuel economy with respect to gasoline price. We build on these studies in two ways. First, we estimate the elasticity in a Canadian context. Consumer behavior may differ between Canada and the US. Second, we examine how different components of gasoline prices – i.e., taxes versus market fluctuations – influence consumer decisions.

We estimate η by exploiting a rich dataset covering gasoline prices, vehicle registrations, vehicle fuel economy and demographic variables in 40 Canadian cities from 2000 to 2010. We control

[4]Papers use different measures for fuel economy. Some use distance travelled per unit of fuel input, while others use the inverse. For small changes, elasticities are equivalent.

for unobserved time-varying and cross-sectional variables that may otherwise bias the coefficients and find that a 1% increase in gasoline prices leads to a 0.09 to 0.13% improvement in the fuel economy of new vehicles. We show that the response to gasoline prices is more concentrated in larger urban areas and also more concentrated in core urban areas compared with suburbs. Gasoline prices are also shown to influence the types of vehicles that are sold. Higher gasoline prices result in more compact and subcompact vehicle and fewer sport utility and mini van sales. Beyond identifying the elasticity of fuel economy with respect to price, we demonstrate another important result: consumers are much more responsive to changes in excise taxes than to equivalent changes in gasoline price due to other factors. This over-reaction to changes in taxes has been noted in several papers focused on gasoline demand (Rivers and Schaufele, 2015; Li et al., 2014; Scott, 2015), but to the best of our knowledge no study has focused on the effect of changes in excise taxes on vehicle purchase behavior. Our results suggest that consumers respond to a change in excise tax by improving fuel efficiency almost 10 times as much as to an equivalent change in gasoline price due to other factors. This has important implications for policy makers considering using excise taxes as a way to encourage more fuel efficient vehicle choices.

The rest of the paper has three sections. Section 2 explains the data and empirical strategy. Section 3 presents results while section 4 concludes.

2 Data and empirical strategy

2.1 Dataset Construction and Summary Statistics

Several data sources are assembled for the analysis. First, a database purchased from RL Polk covers the universe of passenger vehicles registered in all Canadian provinces from 2000 to 2010. Vehicles are categorized by make (e.g., Toyota), model (e.g., Camry), series (e.g., XLE), model year, engine size, number of engine cylinders, transmission type and fuel type. Registrations are recorded according to the forward sortation area (FSA) of the home address of the vehicle registrant.[5] Data consists of the number of registrations of each type of vehicle in each forward sortation area in each year. We focus on new vehicle purchases rather than the total stock of registered vehicles, so only retain new vehicles.

Although the vehicle registration data provides significant detail for each vehicle, it does not include vehicle-specific fuel economy. We use information from Natural Resources Canada (NR-Can) and the US Environmental Protection Agency (EPA) to obtain fuel economy ratings. Each agency issues this information annually and the data include the rated city and highway fuel consumption for each new vehicle according to its characteristics (make, model, model year, series, engine size, etc.). A regression-based imputation method is applied to match fuel economy ratings to vehicles in the dataset. For each data set (EPA and NR-Can), we impute vehicle fuel economy using two alternative models: (1) which predicts fuel economy based only on main vehicle effects (e.g., make, model, engine size, etc.), and (2) which predicts fuel economy based on main effects and interactions between variables (e.g., make, engine size, make $\times$ engine size, etc.). We label these models NRCan1, NRCan2, EPA1, and EPA2. Our models provides accurate predictions for vehicle fuel economy with R^2 values, depending on the specification, between 0.77 and 0.94. We describe this imputation and fit in the appendix.[6]

Gasoline prices for 50 Canadian cities are collected from MJ Ervin/Kent Marketing Services, based on a weekly survey of over 700 gasoline stations located throughout each city.[7] This group conducts a weekly survey of petroleum prices in each city and constructs a city-specific sales-weighted average annual price series.

Data on population, median income and other demographics are from a summary of the T1 tax filer data released by the Canada Revenue Agency and supplied by Statistics Canada. These data provide annual information for each FSA in Canada.

[5] A forward sortation area corresponds to the first three digits of the Canadian postal code. There are roughly 1,600 FSAs in Canada, each covering between 0 and about 70,000 households. An FSA can be thought of as a large neighborhood.

[6] It is important to emphasize that the dependent variable in this paper is the *rated* fuel economy of vehicles, based on laboratory dynamometer tests. It is well-known that vehicle fuel economy ratings deviate somewhat from actual on-road performance, and so our empirical model may not capture the effect of gasoline prices on on-road performance perfectly.

[7] Data are available at the following website: `http://charting.kentgroupltd.com/`.

We combine these data sources as follows. The vehicle data record the number of new vehicle registrations of vehicle i in FSA f in year t. We refer to this value as R_{ift}. We impute the fuel economy rating of each vehicle i in the registration dataset. We use both NRCan and EPA series to conduct the imputation and impute using two models (see Appendix for details). This yields a predicted fuel economy rating for each vehicle i: $\hat{F}_i$. We determine the average fuel efficiency of newly registered vehicles in each forward sortation area by: $\hat{F}_{ft} = \frac{\sum_i(\hat{F}_i R_{ift})}{\sum_i R_{ift}}$. This data is plotted in Figure 1 for cars, trucks and all vehicles. A clear difference between the NRCan and EPA ratings is visually apparent and is a feature of the rating methodologies. NRCan updated its rating methodology in 2015 to improve the match between rated fuel economy and on-road fuel economy, so our data uses the older methodology as this is the information that would be available to consumers at the time.[8] Despite differences in levels between the NRCan and EPA ratings, trends are similar across the two series.[9] We conduct analysis using both NRCan or EPA ratings and the different imputation models.

$\hat{F}_{ft}$ is the dependent variable. We match this with gasoline prices for each city c in year t.[10] To do this, we establish a concordance between forward sortation areas f and cities c, by taking the centroid of each city and each forward sortation area. We then determine the distance between each centroid pair. Gasoline prices from city c are assigned to FSA f: (1) if it is the closest city in the dataset, and (2) if it is no further than 30km from the centroid of the FSA. Beyond 30km, we judge that gasoline prices in city c will not be the same as in FSA f (results for alternative distance measures are presented in section 3). The complete set of matched FSA-city pairs is shown in a map in Figure 2. Next, we map gasoline prices in city c to each FSA within city c for each year t. Gasoline prices in each of the cities in the dataset are given in the top panel of Figure 3. A common trend in gasoline prices across cities (illustrated by the black line) is evident, but there is distinct variation over time and between cities. The bottom panel Figure 3 plots the residuals of a regression of city gasoline price on year and city fixed effects and shows this inter-temporal and

[8]See `http://www.nrcan.gc.ca/energy/efficiency/transportation/cars-light-trucks/buying/7491`.

[9]Likewise, the trends for the different imputation models are similar.

[10]We convert from nominal to real prices using the Canadian consumer price index.

inter-city variation in gasoline prices. This within-city variation is used to identify the effect of gasoline prices on vehicle fuel economy.

Table 1 presents summary statistics for the final dataset. The final dataset includes 900 FSAs across 36 cities from years 2000 to 2010. Gasoline price data are missing for about 1% of observations, and so our data is an unbalanced panel. In total, there are approximately 8,600 complete observations. The means of the four fuel efficiency rating methodologies are comparable and range from 10.1L/100km to 11.5L/100km. The average number of vehicles registered in a FSA equals 778, but ranges from one to 24,547. Mean gasoline prices are 82.6c/L of which includes 14.0c/L of tax. Finally, the average distance between city and FSA centroids is 11.8km, but ranges from 0.2 to 30km.

2.2 Econometric Model

Our aim is to quantify the influence of gasoline price on the choice of new vehicle fuel economy. Our main specification is:

$$\log \hat{F}_{ft} = \beta_0 + \beta_1 \log gasprice_{ft} + \theta X_{ft} + \delta_t + \lambda_f + \varepsilon_{ft}. \tag{2}$$

$\hat{F}_{ft}$ is the estimated fuel economy of the new vehicle fleet in FSA f in year t. It is important to note that $\hat{F}_{ft}$ is an imputed variable (as described above) and is therefore measured with error. Under the assumption that measurement error is classical, we obtain less precise, but unbiased, coefficient estimates. $gasprice_{ft}$ is the price of gasoline in cents per litre. In our preferred specification, we use the logs of these two variables, such that it is possible to interpret β_1 as the elasticity of new vehicle fuel consumption with respect to gasoline price. X represents additional covariates, while δ_t and λ_f are fixed effects for years and forward sortation areas, respectively. Including λ_f means that identification is based on within-FSA variation in gasoline price. We cluster standard errors on FSAs to accommodate arbitrary temporal correlation in the data.

3 Results

3.1 Effect of gasoline price on fuel economy of new vehicles

Table 2 presents results for our preferred model. Four specifications are displayed where we adjust the identifying variation by including and excluding fixed effects. In each case, we use the fuel economy rating imputed from the EPA rating system with the full model (including interactions, i.e., EPA2). The first column is the naive specification which pools the data (excludes all fixed effects). Identification therefore comes from variation both between regions and over time. In this specification, we obtain an elasticity of new vehicle fuel economy rating with respect to the gasoline price of -0.22, which is comparable to other estimates. Unobserved factors however vary over time as well as between regions. These confounders may bias our estimate. To address this, we include fixed effects for both time and geography in subsequent columns of the table. Column (2) includes FSA fixed effects and shows an elasticity of -0.15. An elasticity of -0.40 is presented in the third column with time fixed effects. Both time and FSA fixed effects are included in column (4), our preferred regression. Identification of the elasticity of new vehicle fuel economy with respect to gasoline price in this column comes from within-FSA variation in gasoline price. We find a statistically significant and economically meaningful elasticity of new vehicle fuel economy with respect to gasoline price equal to -0.08.

Table 3 replicates column (4) from Table 2 but uses the different measures of fuel efficiency. All models regress the log of rated fuel consumption (in litres per 100 km) on the log of gasoline price, the log of median income and fixed effects for both FSA and year. The first two columns use the fuel consumption ratings from NRCan, while the third and fourth column use the fuel economy ratings from the EPA. The first and third columns use imputed fuel economy ratings from a relatively simple model in which only the main effects of each vehicle characteristic are used to impute fuel economy ratings. The second and fourth columns use a more complex model with fully saturated interactions between main effects to increase the predictive power of the fuel economy models. In each case, the overall effect of gasoline price on new vehicle fuel economy is similar. In particular, each model implies that the elasticity of rated fuel consumption of new vehicles with respect to gasoline price is between -0.08 and -0.09. All estimates are statistically significant at the 1% level. The coefficients suggest that a 10% increase in gasoline price leads to a 0.8 to 0.9% improvement in the fuel economy rating of the new vehicle fleet.

These estimates are in the range of others in the literature but are more precise. Using aggregate Canadian data at the provincial level from 1990-2004, Barla et al. (2009) estimate that the elasticity of fleet fuel economy with respect to gasoline price is -0.12 in the long run, while, for the US, Small and Van Dender (2007) find an elasticity of -0.2. Li et al. (2009), using household level data, also obtain a value of -0.2. There are thus two conclusions. First, our estimate, using rich city-level data, produces an estimate of comparable magnitude to estimates using more aggregated information. Nonetheless we believe that our method yields more credible identification. Second, the evidence indicates that the elasticity of fleet fuel economy with respect to gasoline price is lower (in absolute value) in Canada compared to the US. Canadians appear to be less sensitive to gasoline prices than Americans when purchasing new vehicles. One potential explanation is that gasoline prices in Canada are higher, so Canadians have already made low-cost fuel economy investments.

Tables 2 and 3 show that our results are mixed with respect to the relationship between rated fuel economy and income. In our preferred specification (in column (4) of Tables 2 and 3) we find that a 1% increase in income causes a 0.01% improvement in rated fuel economy. However, this estimate does not appear to be robust to changes in the measure of fuel efficiency or identification strategy. Using aggregate data, neither Barla et al. (2009) nor Small and Van Dender (2007) found a statistically significant relationship between income and vehicle stock fuel economy.

We report a series of robustness checks in Table 9 in the Appendix. To buttress the results reported in Tables 2 and 3, in column (1) we also estimate a model in which we include FSA by year time trends. This specification controls for changes in time varying unobservables across different regions. This specification yields results that are very similar to our main specifications. In column (3) we include a host of demographic variables, including the average age, proportion of females, proportion of married individuals and proportion of individuals living in apartments for each FSA-year combination. The addition of these variables adds little explanatory power and does not affect our main estimates. Finally, in column (3), we cluster errors by city. This specification is more conservative than clustering on FSA as it allows for correlation between FSAs within a city as well as over time within a city. There is no change in statistical significance due to this different approach to clustering.

3.2 Heterogeneity in response

We next consider heterogeneity across several dimensions. Table 4 presents eight models. Each uses the same dependent variable as in Table 2 and all specifications include both FSA and year fixed effects (so, as above, identification is based on within-FSA variation in gasoline price).

Columns (1) and (2) subsets the sample to cover the first half of the decade (2000-05) and the last half (2006-10), respectively. The results suggest that households have become less price sensitive over time when making new vehicle purchase decisions. Small and Van Dender (2007) provide evidence that the elasticity of driving distance with respect to fuel price (μ) has declined over time in the US and Hughes et al. (2008) find a similar declining price elasticity for gasoline demand. A likely explanation for this result is that gasoline prices are higher in the second half of the decade and the marginal cost of fuel efficiency improvements for new vehicles is convex (declining marginal returns).

In columns (3) and (4), we split Canada into East (Ontario and East) and West (Manitoba and West). The results suggest a higher response to changes in gasoline prices in the Western provinces compared with the Eastern provinces.

Columns (5) and (6) look at large and small cities. We define the five largest cities (Toronto, Montreal, Vancouver, Ottawa, Calgary) as large cities, with the remainder classified as small cities. We find distinctly different coefficients in these two subsamples, with large cities being significantly more price elastic compared with small cities. In columns (7) and (8), we divide the sample into FSAs in the city core (with centroids within 5km from the city centre) and those outside the city core (suburbs). We find a larger price elasticity for more urban regions. This collection of models suggests that residents of more dense, urban areas have more ability to substitute towards more fuel efficient vehicles when gasoline prices increase. Perhaps this is because larger vehicles such as pickup trucks are a luxury for these individuals (due, for example, to parking constraints), whereas they are more of a necessity for certain residents of suburban areas and smaller cities (due, say, to employment demands).[11]

3.3 Gasoline price and vehicle type

Our main results suggest that increases in gasoline price improve fuel economy. In this section, we estimate the change in the type of vehicles sold in response to changing gasoline prices. These models reveal the mechanism that causes these fuel efficiency improvements. Based on our data, we divide vehicles into 9 standard classes (subcompact car, compact car, midsize car, fullsize car, fullsize van, minivan, pickup truck, sport utility vehicle and two seater). As there is a wide range of vehicles available within each class, there are substantial differences in fuel economy both across and within classes. Subcompact and compact vehicles have an average rated fuel economy of 8.7 and 9.0 L/100 km, respectively. In contrast, pickup trucks and fullsize vans have a rated fuel economy that is nearly twice as large, corresponding to 15.7 and 16.5 L/100 km. As a result, changes in the types of vehicles that are sold can have important impacts on overall fuel economy.

Figure 4 shows the market shares of new vehicle sales by class over time. Historically, compact cars have had the largest market share in Canada, although they have recently been eclipsed by sport utility vehicles (SUVs). SUVs have displaced sales of midsize cars and minivans, which declined over the decade. Other types of vehicles maintained a relatively constant market share. The effect of fuel prices is visible in the figure. For example, the market share of compact and subcompact cars jumped in 2009, when gasoline prices reached an apex. The shares then fell again in 2010 when fuel prices declined. Opposite trends occurred for SUVs and pickup trucks.

We formally analyze the change in new vehicle sale composition using a similar method as for

[11] Using a two sample t-test to compare coefficients across models (i.e., $\beta^A - \beta^b / \sqrt{se(\beta^A)^2 + se(\beta^B)^2}$), all heterogeneous responses are statistically distinct with the exception of columns (1) and (2).

vehicle fuel economy. Specifically, we estimate:

$$\theta_{cft} = \beta_0 + \beta_1 \log gasprice_{ft} + \theta X_{ft} + \delta_t + \lambda_f + \varepsilon_{cft}. \tag{3}$$

where θ_{cft} is the market share of vehicle class c in FSA f in year t. Once again, we include both region and year fixed effects in order to absorb region- and time-varying unobservables. We cluster standard errors at the FSA level to address potential serial correlation in vehicle sales over time. We estimate the model separately for each vehicle class c. Note that the left hand side variable is already a market share, so we do not take the log. The results for β_1 can be interpreted as the predicted change in vehicle market share, in percentage points, due to a one log point increase in gasoline prices.

Results for each class are reported in Table 5. We find pronounced effects of gasoline prices on the types of vehicles that are sold. In particular, the results suggest that sales of compact and subcompact vehicles increase when gasoline prices increase. The compact car market share is estimated to increase by 0.66 percentage points when gasoline prices increase by 10%, while subcompact cars increase by 1 percentage point. As expected, we find declines in the market share of minivans and SUVs as gasoline prices increase, by about 0.3 and 1.1 percentage points, respectively, due to a 10% increase in gasoline prices. These vehicles are relatively fuel inefficient and are relatively substitutable for by cars. We also find a decline in the market shares of pickup trucks, but it is not statistically significant.

Coefficients on income are also reported. Based on our results, higher income consumers choose fewer SUVs, and more subcompact cars, pickup trucks and midsize cars. These results are somewhat surprising, since SUVs are often marketed as a luxury vehicle choice.

3.4 Effect of excise taxes compared with tax-exclusive gasoline prices

Several recent studies examine how gasoline demand changes when the components of gasoline prices are decomposed into changes in excise taxes and variation attributable to the price of crude oil or refining and transport margins (Rivers and Schaufele, 2015; Li et al., 2014; Davis and Kilian, 2011; Scott, 2015; Tiezzi and Verde, 2014). All have reached the conclusion that in the short run, gasoline demand is more elastic with respect to changes in excise taxes than with respect to changes in other components of the gasoline price. The prevailing explanation for this phenomenon is that consumers perceive changes in excise taxes as more permanent than comparable movements in other prices and hence respond accordingly. We build on this literature to evaluate whether new vehicle fuel efficiency is also more responsive to excise taxes compared with other components of gasoline prices. Vehicles are a durable good, so expectations of future prices likely play an important role in shaping choices (this effect is likely much less important for the short-run studies on gasoline consumption).

To conduct our analysis, we incorporate data on excise taxes into the analysis. Each province sets excise taxes independently and these taxes are revised periodically. Further, several municipalities in Canada use excise taxes on gasoline sold within the city, typically to fund public transit.[12] We estimate:

$$\log \hat{F}_{ft} = \beta_0 + \beta_1 \overline{gasprice}_{ft} + \beta_2 excisetax_{ft} + \beta_3 transittax_{ft} + \theta X_f t + \delta_t + \lambda_f + \varepsilon_{ft}, \qquad (4)$$

where $\overline{gasprice}$ is the provincial excise tax-exclusive price of gasoline and *excisetax* and *transittax* are self-explanatory. Unlike the earlier regressions, this specification is a semi-log model where gasoline prices and taxes enter as levels rather than as logs (we also report results with logged variables). This approach facilitates interpretation of the coefficients, since β_1 and β_2 can be treated as the percent change in fleet fuel efficiency due to a \$1/L change in gasoline prices or taxes. If excise taxes, transit taxes and other changes in gasoline price affect consumer vehicle choice in the same manner, then we expect that $H_0 : \beta_1 = \beta_2 = \beta_3$. As a supplementary case, we also group excise taxes and municipal transit taxes together.

Results of the analysis are reported in Table 6. In column (1), we repeat the earlier analysis,

[12] The Canadian federal government also levies a gasoline excise tax, but the tax is unchanged during the period for which we have data and is not differentiated across provinces; hence, so it is not possible to econometrically identify it's effect.

but show levels of gasoline price, rather than logs, for comparability with previous tables. The coefficient is precisely estimated and suggests that a \$0.10/L increase in gasoline price reduces rated fuel consumption of the new vehicle stock by 0.9%. Columns (2) and (3) decompose the gasoline price into the base price, provincial excise tax and municipal transit tax. Column (2) suggests a significantly different response to excise taxes compared to other gasoline price movements (a Wald test rejects the hypothesis that the coefficients are equal at the $p<0.01$ level). Consumers are much more responsive to changes in excise taxes than to other changes in gasoline price. While a \$0.10/L increase in provincial gasoline excise taxes is associated with a 3.6% improvement in fleet fuel economy, the same change in other components of gasoline price is only associated with a 0.03% improvement – less than one twelfth as large. The substantial difference in these coefficients suggests that studies that apply estimates for how consumers respond to undecomposed gasoline price elasticities to changes in taxes may be too conservative. Column (2) also reports an estimate of the consumer response to changes in the municipal transit tax. The parameter is not as precisely estimated and the value is somewhat smaller. Still, the point estimate remains roughly 8 times as large as the coefficient associated with non-tax price increases. The imprecision is a result of the small number of municipalities that employ transit taxes (Vancouver, Victoria, and Montreal are the only cities in Canada with such a tax) as well as the small number of tax adjustments in the data. Moreover, it is plausible that the response to transit taxes is lower than for provincial excise taxes as it is much easier for consumers to avoid municipal transit taxes by purchasing gasoline from outside municipal boundaries (it more challenging to cross-border shop to avoid provincial excise taxes). Column (3) aggregates provincial excise and municipal transit taxes and continues to find a significant difference in the magnitude of response compared to the non-tax component of price (again, a Wald test rejects the null hypothesis of equal coefficients at $p<0.01$).

Column (4) repeats the analysis using a log-log specification for comparison with the earlier results. The results suggest an elasticity of new vehicle fuel economy with respect to the untaxed gasoline price of -0.01 and with respect to the excise and transit tax combination of -0.05.[13] We can

[13]Because most observations in our dataset do not use a transit tax, including this variable separately in a log-log specification would result in a dramatically reduced sample size. As a result, we only run this model where we combine

combine these elasticities with the mean values of these variables to compare the responsiveness of vehicle choice to prices and taxes. As shown in Table 1, the mean value of the tax-exclusive gasoline price is \$0.69/L. A 1% change in this price is associated with a 0.02% improvement in fleet fuel economy. This suggests that a one cent per litre increase in the tax-exclusive price causes a 0.03% improvement in fleet fuel economy: almost the same value as in columns (2) and (3). In contrast, the mean value of the excise and transit tax combination is \$0.14/L. Based on the coefficient in column (4), we can calculate that a one cent per litre increase in gasoline taxes causes a 0.3% improvement in fleet fuel economy (identical to the result in column (2)). Thus, the log-log specification yields virtually the same results as the semi-log specification and also suggests a much stronger consumer response to gasoline taxes than other price changes when purchasing new vehicles.

4 Conclusion

Reducing gasoline consumption from the passenger vehicle sector is an important challenge for public policy makers. One important channel to implement this reduction is by encouraging consumers to choose vehicles that are more fuel efficient. This paper provides evidence on how consumers choose vehicles in response to changes in gasoline prices. Given that a number of Canadian jurisdictions have recently implemented or are considering implementing carbon taxes or cap-and-trade systems to reduce greenhouse gas emissions, including from passenger vehicles, the evidence provided in this paper is timely.[14]

We use data on all newly registered vehicles in Canada to estimate the impact of changes in gasoline price on the fuel efficiency of the new vehicle stock. Our data is at the level of the FSA or neighbourhood and we identify the effect of interest based on within-FSA variation in gasoline

the excise and transit taxes.

[14]Starting in 2007 and 2008, Quebec and British Columbia have taxed transport (and other) fuels using a carbon tax. More recently, Quebec has used a cap and trade system to address greenhouse gases emissions. Ontario, Manitoba, and Alberta are all in the process of implementing carbon taxes and cap-and-trade schemes aimed at reducing greenhouse gases. All of these policies increase gasoline prices and should induce consumers to purchase more efficient vehicles as described in this paper.

prices over time. This allows us to control for confounding due to unobserved cross-sectional and time series shocks. Our preferred estimate suggests that consumers in Canada respond to a 10% increase in gasoline prices by selecting vehicles that are on average about 0.8% more fuel efficient. Our results are robust to alternative measures of fuel efficiency and to the inclusion of additional covariates. We show that the response of consumers to changes in gasoline price is heterogeneous along several dimensions, most importantly that more urban consumers – that is those in large cities and those closer to the city centre – respond more to changes in fuel prices than suburban consumers. Increases in gasoline price also cause Canadian consumers to significantly reduce their purchases of SUVs and increase purchases of subcompact and compact vehicles. Finally, we show that consumers respond much more to changes in the tax component of fuel prices than to the pre-tax component. Our estimates suggest that a 1c/L fuel excise tax causes consumers to improve fuel efficiency more than a 10c/L change in the pre-tax fuel price. As a result, policy makers interested in the response of consumers to changes in gasoline taxes, including those due to a carbon price as discussed above, should be cautious in using estimates of fuel economy elasticity based on changes in overall gasoline prices.

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5 Figures

Figure 1: Fuel efficiency rating of new vehicles

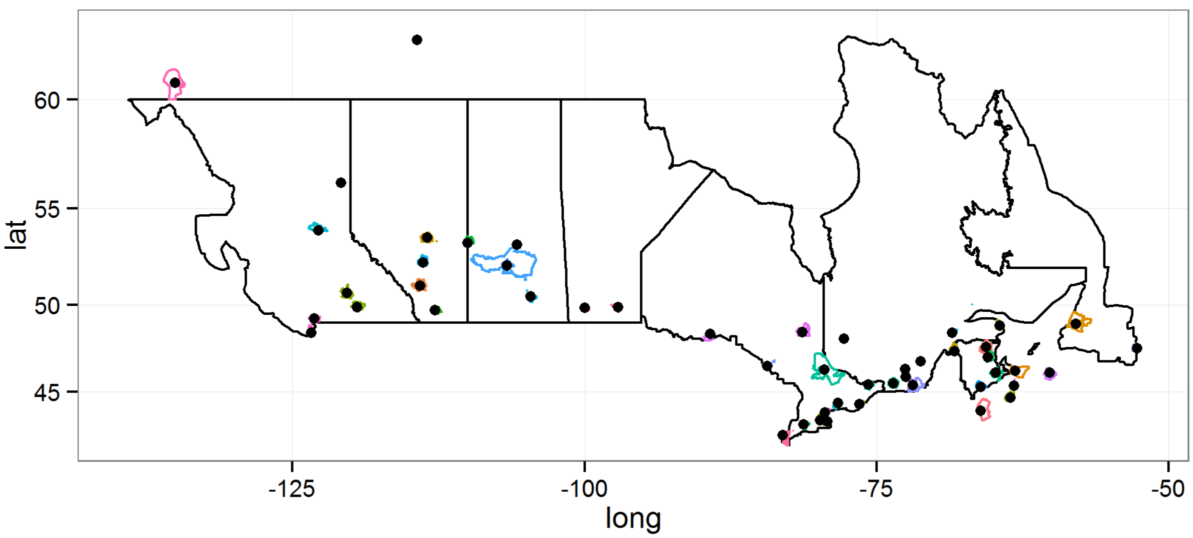

Figure 2: Cities and forward sortation areas included in the analysis. The top panel shows each of the cities that are included in the analysis. The bottom panel zooms in on the city of Toronto to illustrate how we map each forward sortation area (pink polygons) to the city of Toronto (black dot) as described in the text.

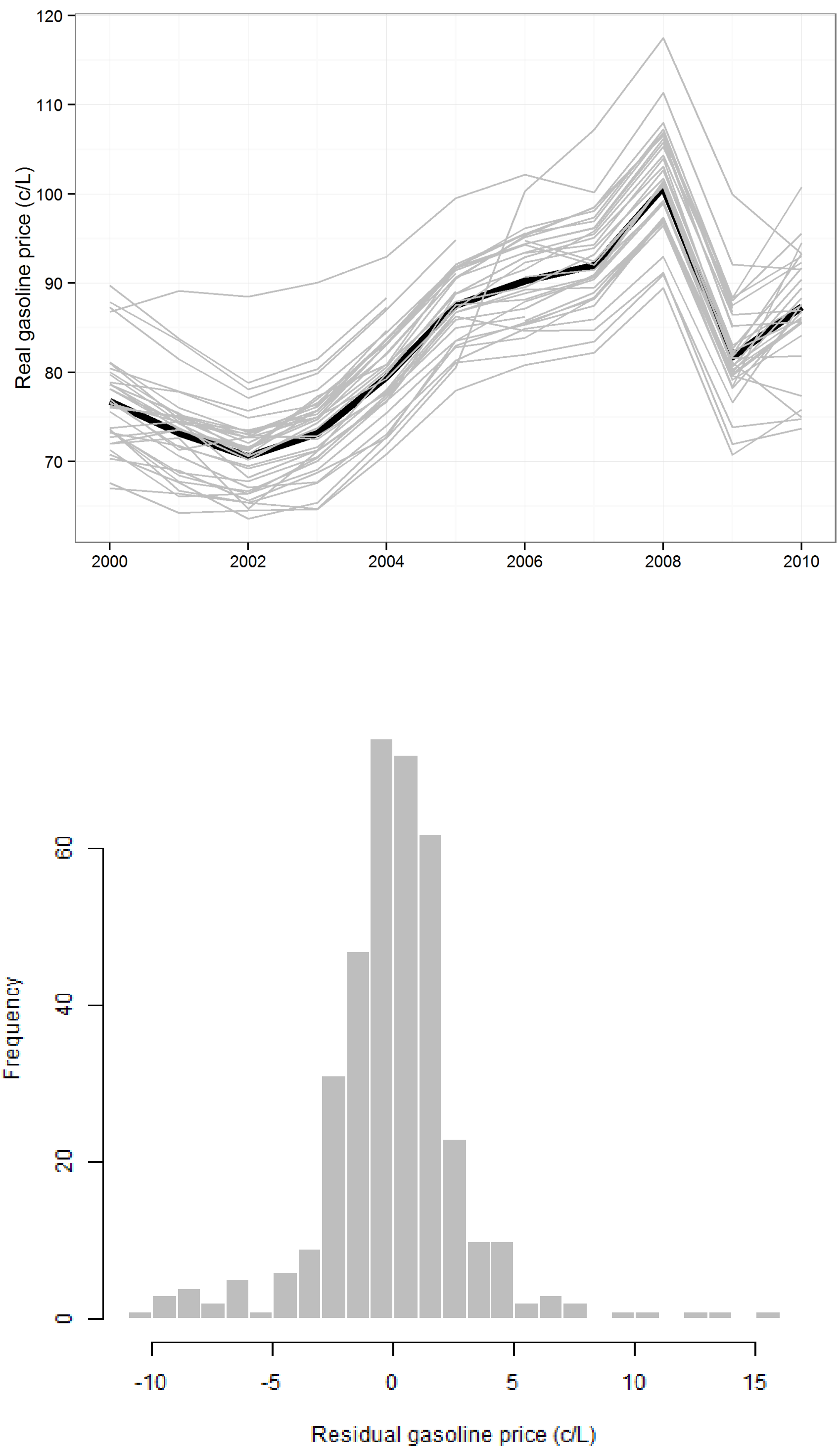

Figure 3: Gasoline prices by city. The top panel shows the recorded real gasoline price in each city (gray lines) as well as the mean gasoline price across all cities (thick black line). The bottom panel is a histogram of residual gasoline prices from a regression of gasoline price on year and city fixed effects. This is the source of variation in gasoline prices that we use to identify our coefficients in the primary specification.

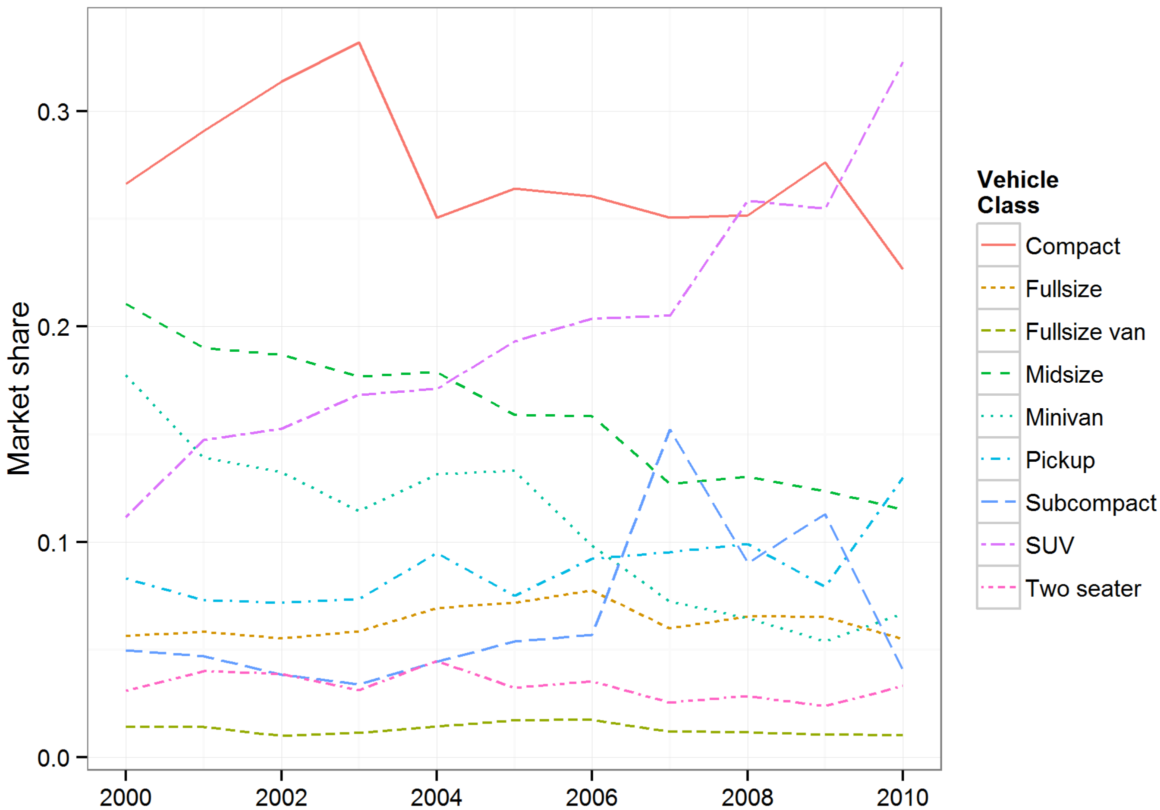

Figure 4: Vehicle market shares over time by class

6 Tables

Table 1: Summary Statistics for FSA-Years

	N	Mean	St. Dev.	Min	Max
Fuel Efficiency Ratings					
NRCan Method 1	8,665	10.2	0.9	7.8	15.0
NRCan Method 2	8,665	10.1	0.9	7.7	14.9
EPA Method 1	8,665	11.4	0.9	8.9	16.3
EPA Method 2	8,665	11.5	0.9	9.1	16.4
Vehicle and Gasoline Price Data					
Number of Vehicle Registrations	8,665	777.8	1,017.6	1	24,547
Tax-inclusive Gasoline Price	8,565	82.6	10.4	63.6	117.5
Tax-exclusive Gasoline Price	8,565	68.6	10.3	48.6	103.6
Excise Tax	8,665	13.3	2.2	7.3	17.1
Transit Tax	8,665	0.8	1.7	0.0	7.9
Distance between City and FSA centroids	8,665	11.8	7.8	0.2	30.0
Demographic Information					
Annual Income ($000)	8,665	26.2	6.7	6.0	76.9
Share Female	8,665	52.0	2.1	32.0	61.5
Share Married	8,662	39.1	8.3	12.0	68.0
Share that Reside in an Apartment	8,233	13.3	17.5	0.0	99.8
Average Age	8,665	37.9	3.6	24.0	64.0

Table 2: Effect of gasoline prices on vehicle fuel efficiency

	(1)	(2)	(3)	(4)
log(gasprice)	−0.215***	−0.154***	−0.400***	−0.082***
	(0.008)	(0.003)	(0.032)	(0.013)
log(income)	0.045***	−0.027***	0.042***	−0.002
	(0.008)	(0.006)	(0.008)	(0.009)
FSA fixed effects	No	Yes	No	Yes
Year fixed effects	No	No	Yes	Yes
Observations	8,565	8,565	8,565	8,565
R^2	0.153	0.820	0.275	0.917

***significant at the 1% level; **significant at the 5% level; *significant at the 10% level.
Dependent variable is logged fuel economy using the EPA data.
Standard errors clustered by forward sortation area.

Table 3: Effect of gasoline prices on vehicle fuel efficiency using alternative fuel economy measures

	NRCan Method 1	NRCan Method 2	EPA Method 1	EPA Method 2
	(1)	(2)	(3)	(4)
log(gasprice)	−0.080***	−0.094***	−0.076***	−0.082***
	(0.014)	(0.015)	(0.013)	(0.013)
log(income)	0.015*	0.013*	0.019**	−0.002
	(0.008)	(0.008)	(0.007)	(0.009)
FSA fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Observations	8,565	8,565	8,565	8,565
R^2	0.917	0.914	0.925	0.917

***significant at the 1% level; **significant at the 5% level; *significant at the 10% level.
Dependent variables are logged fuel economy ratings.
Standard errors clustered by forward sortation area.

Table 4: Heterogeneity in response of vehicle fuel efficiency to gasoline prices

	Year 00-05	Year 06-10	East	West	Large	Small	Core	Suburb
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
log(gasprice)	−0.092***	−0.080***	−0.026	−0.087***	−0.129***	−0.043**	−0.131***	−0.067***
	(0.023)	(0.019)	(0.021)	(0.017)	(0.021)	(0.017)	(0.031)	(0.013)
log(income)	−0.017	0.018	0.014	−0.032*	−0.005	0.017	−0.012	0.002
	(0.017)	(0.011)	(0.013)	(0.019)	(0.012)	(0.012)	(0.013)	(0.010)
FSA fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	4,895	3,670	6,065	2,500	5,012	3,553	1,906	6,659
R^2	0.917	0.940	0.902	0.906	0.908	0.919	0.917	0.918

***significant at the 1% level; **significant at the 5% level; *significant at the 10% level.
Dependent variable is logged fuel economy using EPA data.
Standard errors clustered by forward sortation area.

Table 5: Effect on vehicle classes due to gasoline prices

	Compact	Midsize	Fullsize	Subcompact	Twoseater	Full van	Minivan	SUV	Pickup
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
log(gasprice)	0.066***	−0.000	−0.001	0.100***	−0.010*	0.014*	−0.027**	−0.106***	−0.019
	(0.017)	(0.015)	(0.008)	(0.013)	(0.006)	(0.008)	(0.012)	(0.018)	(0.022)
log(income)	−0.019	0.040***	0.004	0.013*	0.002	0.009	−0.009	−0.053***	0.021**
	(0.012)	(0.010)	(0.008)	(0.007)	(0.003)	(0.007)	(0.009)	(0.011)	(0.009)
FSA fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	8,558	8,552	8,326	8,422	8,372	7,020	8,532	8,549	8,522
R^2	0.814	0.738	0.909	0.807	0.505	0.542	0.781	0.853	0.902

***significant at the 1% level; **significant at the 5% level; *significant at the 10% level.
Dependent variable is the market share of a vehicle class.
Standard errors clustered by forward sortation area.

Table 6: Effect of excise taxes and tax-exclusive gasoline prices on vehicle fuel efficiency

	(1)	(2)	(3)	(4)
I((gasnoexcisetax + excisetax + transittax)/100)	-0.089^{***}			
	(0.015)			
I(gasnoexcisetax/100)		-0.027^{*}	-0.027^{*}	
		(0.015)	(0.015)	
I(excisetax/100)		-0.362^{***}		
		(0.054)		
I(transittax/100)		-0.209^{*}		
		(0.120)		
I((excisetax + transittax)/100)			-0.331^{***}	
			(0.038)	
log(gasnoexcisetax)				−0.011
				(0.011)
log(excisetax + transittax)				-0.051^{***}
				(0.006)
log(income)	−0.001	0.007	0.006	0.004
	(0.009)	(0.009)	(0.009)	(0.009)
FSA fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Observations	8,565	8,565	8,565	8,565
R^2	0.917	0.918	0.918	0.918

***significant at the 1% level; **significant at the 5% level; *significant at the 10% level.
Dependent variable is logged fuel economy using EPA data.
Standard errors clustered by forward sortation area.

A Imputation of vehicle fuel consumption

We impute vehicle rated fuel consumption in litres of gasoline per 100 km of vehicle travel based on data from Natural Resources Canada and the US Environmental Protection Agency. In each case, we observe a large number of vehicle characteristics in both the vehicle registration data as well as the fuel economy data. We use the fuel economy data to develop a relationship between rated fuel economy and vehicle characteristics. We then use this relationship to impute vehicle fuel economy in the vehicle registration data.

Fuel economy data from Natural Resources Canada covers vehicles from model years 2000 to 2012. For each vehicle, we observe the make, model year, engine size, number of engine cylinders, vehicle class, highway fuel economy, and city fuel economy. We construct the combined fuel economy assuming a 55:45 city:highway driving share, in common with both NRCan and EPA assumptions. We estimate the following two models:

$$F_{it}^{\text{NRCan1}} = \gamma_0 + \gamma_1 \text{make}_i + \gamma_2 \text{year}_t + \gamma_3 \text{year}_t^2 + \gamma_4 \text{enginesize}_i + \gamma_5 \text{enginesize}_i^2 + \gamma_6 \text{cylinders}_i + \gamma_7 \text{vehicleclass}_i + \varepsilon_{it}$$

$$\begin{aligned} F_{it}^{\text{NRCan2}} = {} & \gamma_0 + \gamma_1 \text{make}_i + \gamma_2 \text{year}_t + \gamma_3 \text{year}_t^2 + \gamma_4 \text{enginesize}_i + \gamma_5 \text{enginesize}_i^2 + \gamma_6 \text{cylinders}_i + \gamma_7 \text{vehicleclass}_i \\ & + \gamma_8 (\text{make} \times \text{cylinders}) + \gamma_9 (\text{make} \times \text{year}) + \gamma_{10} (\text{make} \times \text{vehicleclass}) + \gamma_{11} (\text{make} \times \text{vehicleclass}) \\ & + \gamma_{12} (\text{cylinders} \times \text{enginesize}) + \gamma_{13} (\text{cylinders} \times \text{vehicleclass}) + \gamma_{14} (\text{vehicleclass} \times \text{year}) + \varepsilon_{it} \end{aligned}$$

We treat year and engine size, and fuel economy as interval variables, and summarise these in Table 8. We treat the remaining variables as categorical. There are 46 vehicle makes, 8 different engine configurations (number of cylinders), and 11 unique vehicle classes in the data. The model specification is therefore very rich. In total, the first model includes 65 independent variables (inclusive of dummy variables), and the second model - which allows interactions between variables - includes 901 independent variables. As a result of the large number of coefficients, it is not practical to show coefficient estimates for these models. We instead summarize model fit. The first model has an R^2 of 0.77, while the second model has an R^2 of 0.82.

Table 7: Summary statistics for Natural Resources Canada fuel economy ratings

Statistic	N	Mean	St. Dev.	Min	Max
CityFE	12,167	13.212	3.466	3.500	30.600
HwyFE	12,167	9.076	2.350	3.200	20.800
year	12,427	2,006.552	3.592	2,000	2,012
engsize	12,178	3.492	1.290	0.800	8.400
lp100km	12,167	11.351	2.930	3.585	25.845

Fuel economy data from the US Environmental Protection Agency covers vehicles from model years 1984 to 2016. For each vehicle, we observe the same variables as in the NRCan data, but additionally observe whether the vehicle is front wheel drive, rear wheel drive, four wheel drive, or all-wheel drive, whether it has a hybrid drive train, and whether is able to use flex fuels. Fuel economy ratings in the US EPA are in miles per gallon. We convert to litres per 100 km, and then construct the combined fuel economy rating as above. We estimate the same two models as above, but also include the additional variables and their interactions with other variables. The simple EPA model includes 85 variables, while the model with interactions includes 1291 independent variables. We obtain an R^2 of 0.88 for the simple model, and 0.94 for the model with interactions.

Table 8: Summary statistics for Natural Resources Canada fuel economy ratings

Statistic	N	Mean	St. Dev.	Min	Max
year	13,846	2,006.286	3.637	2,000	2,012
engsize	13,846	3.468	1.268	1.000	8.400
lp100km	13,846	12.636	2.770	4.375	27.302

B Additional results

Table 9: Additional robustness checks

	(1)	(2)	(3)
log(gasprice)	-0.080^{***}	-0.077^{***}	-0.082^{***}
	(0.014)	(0.013)	(0.029)
log(income)	-0.006	-0.008	-0.002
	(0.009)	(0.008)	(0.010)
FSA fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
Clustering	FSA	FSA	City
Additional covariates	City time trends	Demographics	-
Observations	8,565	8,155	8,565
R^2	0.921	0.920	0.917

Notes: ***Significant at the 1 percent level.
**Significant at the 5 percent level.
*Significant at the 10 percent level.
Standard errors clustered by forward sortation area unless specified.