Gasoline prices and fuel economy of new vehicles in Quebec
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Abstract
We evaluate the short run impact of gasoline prices on registration of new vehicles by fuel economy using monthly data from 2002 to 2008 in the province of Quebec. We find that a gasoline price increase stimulates registration of new vehicles with a fuel consumption rate below 8.65L/100km while it lowers those of vehicles above that limit. While the impact is modest for a large share of vehicles, we still find that large gasoline price fluctuations can lead to noticeable changes in the composition of vehicles by class. The impact on the average fuel consumption rate remains in any cases rather modest as the elasticity is low at -0.1. The corollary of these results is that a large gasoline price increase would be required to neutralize the growing popularity of light trucks. We evaluate that gasoline prices should have doubled from 2002 to 2008 to maintain the share of light truck at its 2002 level.

Keywords: Fuel economy, gasoline price
1. Introduction

In response to growing concerns over climate changes, many governments around the world have adopted policies to improve the fuel efficiency of new light duty vehicles (LDV). For example, in 2007, the U.S. corporate average fuel economy standards were strengthened for the first time since 1975. The objective is now to reach an average level of 163 grams per mile of carbon dioxide for new LDV in 2025 (or equivalently 54.5 MPG or 4.3L/100km).\(^1\) In 2010, Canada switched from voluntary to mandatory standards that are now aligned with regulations in the US. The European Union also moved from voluntary to mandatory limits in 2009 with a target of 95 gram of CO\(_2\) per km for new passenger cars in 2021 (Miller and Façanha, 2014). Beside standards, other policy instruments have been adopted to foster fuel economy such as feebate programs, gas guzzler tax or subsidies for alternative fuel vehicles. The effectiveness of these policies depends however very much on the changes in the composition of vehicle sold.

For example, despite a strengthening of the CAFE standards, little improvements in the average fuel economy were achieved in the US from 1983 to 1990 when the share of light trucks and SUV increased (Knittel, 2011). Gasoline prices are often suspected to be one of the driving determinants of new vehicle sales structure by fuel economy as car buyers would use the price of gasoline at the time of the purchase as an indicator for future gasoline costs and thus operating costs. In the US, the growing popularity of light trucks in the eighties is often related to the low gasoline prices during that period. Correspondingly, the steady increase in gasoline price from 2002 up to the financial crisis has shown to be one of the main cause for the decline of large SUV in the US (Klier and Linn, 2010). Even more recently, the sharp decline in gasoline prices at the end of 2014 has spurred fear of a renewed interest of drivers for big and fuel inefficient vehicles.\(^2\)

In this paper, we address this issue by estimating the short run impact of gasoline price on the composition and fuel economy of new LDV in the province of Quebec (Canada). The analysis is carried out using monthly data on new LDV registrations in the province from January 2002 up to September 2008. Specifically, we measure the differential impact of gasoline price on the monthly sales of vehicles by fuel economy. Since our analysis is conditioned on the characteristics of vehicles offered (including fuel economy), it specifically measures the short run reactions of new vehicle buyers and manufacturers to gasoline price fluctuations.\(^3\) In other words, we do not measure the medium and long term adjustments process such as changes in the design of vehicles or technological innovations. Assessing short run effects is important as they likely determine the magnitude of the long-term adjustments. For example, if the composition of new vehicles is unaffected by gasoline prices, it is unlikely that manufacturers will invest to

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1 See NHTSA (2012).
2 For example, D. Flavelle (2015), « Drivers trade up as gas price fall », Toronto Star, January 6, 2015 [Retrieved from: http://www.thestar.com/business/2015/01/06/drivers_trade_up_as_gas_prices_fall.html]
3 In the short run, manufacturers may, for example, adjust vehicle prices.
improve fuel economy. Also, vehicles are durable goods that last for more than fifteen years so that short run changes have in fact long lasting consequences.

While there are ample empirical studies on the impact of gasoline price on gasoline demand and on travelled distance (see Graham and Glaister, 2004, Transportation Research Board, 2009), the evidence on vehicle fuel economy is much more limited. Some studies measure the impact of gasoline price variations on the aggregate fuel economy of the fleet. For example, Small and Van Dender (2007) estimate a reduced form system of equations for vehicle stocks, distance driven and average fuel economy using a panel of US States from 1966 to 2001. They obtain short and long run elasticities of fuel intensity with respect to gasoline price of -0.04 and -0.19 respectively. Using a similar approach on a panel of Canadian provinces over the 1990-2004 period, Barla, Lamonde, Miranda-Moreno and Boucher (2009) report short and long run elasticities of -0.04 and -0.12. It should be stressed that these elasticities are related to the impact of gasoline price on the whole fleet rather than on new vehicles. For new vehicles, the seminal paper Berry, Levinsohn and Pakes (1995) estimates a structural model of the US demand and supply market over the 1971 to 1990 period. They find that market shares of fuel efficient vehicles are more responsive to gasoline price variations than inefficient ones. Consumer unobservable heterogeneity would explain this result as fuel efficient cars likely attract consumers that are more reactive to gasoline cost.

Other studies use household level data to estimate structural models of the vehicle market (Goldberg, 1998, West, 2004, Train and Winston, 2007). Bento, Goulder, Jacobsen and von Haefen (2009) estimate model where consumers decide on buying a new or used vehicle, scrap of an old vehicle and miles driven. The model is estimated using a 2001 cross-section of about 20 000 U.S. households. The results suggest a long term gasoline demand elasticity at -0.35 with most of the adjustment occurring through the distance driven. They simulate the impacts of a 25 cents per gallon increase in gasoline tax which approximatively correspond to a 17% increase in gasoline price. Their results suggest very low short and long run elasticity of the fleet fuel efficiency with respect to gasoline price (less than 0.005 and 0.1 respectively). Furthermore, they find that the 25 cents gasoline tax increase would reduce the stock of vehicle by 0.5% in the short run with a fall of 1% for new cars and 0.4% for used cars. The stock of inefficient vehicles would drop by 0.5% compared to 0.4% for efficient vehicles. Overall, the study concludes to a small compositional impact both in short and long run.

Recently, several papers have reexamined the gasoline price-fuel economy relationship in the U.S. using more detailed data and reduced form models. Li, Timmins and von Haefen (2009) use registration data for 20 US metropolitan areas from 1997 to 2005. They find that an increase in gasoline price shifts the demand for new vehicles toward fuel efficient ones. Specifically, sales of new vehicles with MPG higher than 23.3 (10L/100km) would increase following a gasoline price hike while sales of vehicles with a MPG lower than that level would decline. The resulting fuel economy elasticity for new vehicles would be about 0.2 in the short run. They also find that higher gasoline price delay the scrappage of used efficient vehicle while speeding the
exit of inefficient vehicles. These latter two effects are however very small so that most of the fuel economy improvement is due to the shift toward more efficient new vehicles.

Busse, Knittel and Zettelmeyer (2013) examine the short run impact of gasoline price on new and used vehicles equilibrium prices and quantities by fuel economy categories. Using a very rich dataset of transactions from US car dealers from 1999 to 2008, they find that gasoline price has a relatively modest effect on new vehicles prices but a larger impact on the distribution of sales across fuel economy categories. In fact, a 1$ per gallon increase in the price of gasoline would reduce the unit sales of the less fuel economy quartile by more than 25% and increase the unit sales of the most fuel economy quartile by more than 10%. For used vehicles, they find that the adjustment is mostly through changes in relative prices across fuel economy quartiles. They use these results to evaluate the implicit discount rates associated with consumers’ valuation of fuel economy. They find little evidence of undervaluation of future gasoline costs as often suggested. Indeed, the implicit discount rates are comparable to car loans interest rates.

The two former studies aggregate sales observations by fuel economy categories. This may mask within category substitutions following a gasoline price increase. Moreover, they imperfectly control for unobservable vehicle and consumer characteristics that may be correlated with gasoline prices. For example, in the late 2000, there was a renewed interest for subcompact vehicles in part because of high gasoline prices but also probably because of the need for small vehicles suited for dense urban settings. Klier and Linn (2010) estimate the impact of gasoline prices directly at the model-year level using monthly US sales data. Their empirical strategy controls for unobserved vehicle and average consumers characteristics by including model-year fixed effects. The identification of their model rests on gasoline price changes within a model-year. The monthly level of sales of a specific model-year is assumed to be affected by the cost of driving per mile which in turn depends upon the ratio of gasoline price and MPG. In other words, the short run impact of gasoline price is assumed to be inversely proportional to MPG. Their results confirm a short run shift in the distribution of sales toward efficient vehicles following a gasoline price increase. The overall impact on the average fuel economy of new vehicles is however limited with an elasticity of fuel economy with respect to gasoline price around 0.12.

In this paper, we contribute to this growing literature by examining the short run impact of gasoline on the composition of new LDV in the province of Quebec (Canada). 4 The Quebec setting is interesting as the province has one of the most fuel efficient LDV fleet in North America. Gasoline prices could therefore have less impact than in the US as the margin for improvements is more limited. However, the higher fleet efficiency in the province could result from historically higher average gasoline prices, lower disposable income or greater concern for fuel efficiency. The responsiveness to gasoline prices could therefore be enhanced in these

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4 Light duty vehicles are those with a gross vehicle weight of less than 3855 kg (8500 lb.) or a curb weight of less than 2722 kg (6000lb.) (see Natural Resources Canada, 2008).
circumstances. Besides providing evidence in a new setting, our analysis also contributes in other ways. Our empirical specification explicitly control for unobservable vehicle characteristics while still allowing for gasoline price to have both positive and negative impact on sales of different models with different fuel economy. Our data also allows for a better control of the changing mix over time in the year of a model (i.e. the Model-Year). We are also able to test the impact of a feebate program that was set up by the Government in March 2007.

Our results indicate that the sales of vehicles with a fuel consumption rate below 8.65L/100km increase following an increase in gasoline price while the opposite occurs for vehicles above that limit. While, the impact can be substantial for vehicles that are far from this threshold, the effect is limited for a large share of vehicles. The compositional impact is thus rather modest but large gasoline price fluctuations may have noticeable consequences. The corollary of these findings is that a large gasoline price increase is needed to counteract the growing popularity of large vehicles. For example, we evaluate that the price of gasoline should have doubled from 2002 to 2008 for the share of light trucks to remain stable. We evaluate at -0.1 the short run elasticity of the average fuel consumption rate of new vehicles with respect to gasoline prices.5

The rest of this paper is organized as follows. In section 2, we describe our dataset. We present the Quebec context and provide preliminary evidence in section 3. The empirical model is discussed in section 4 and the results in section 5. We evaluate the robustness of our baseline specification in section 6 and conclude in section 7.

2. The data

Our analysis uses monthly data of all new LDV registered primarily for personal usage from January 2002 to December 2008.6 The dataset combines information from the Société de l'Assurance Automobile, a governmental entity in charge of vehicle registration and insurance. Using the Vehicle Information Number (VIN), technical characteristics of the vehicles are added using data provided by ESP Data Solutions a private companies specialized in VIN decoding. Fuel consumption rates in L/100km (FCR) in city and highway conditions are those reported by ESP Data Solutions which are themselves provided by the EPA. These data are complemented by those provided by Natural Resources Canada in the Fuel Economy Guide. The fuel consumption rates are measured in laboratory by manufacturers using two standardized protocols corresponding respectively to a city and highway environment.7 These two rates are then

5 The sign of the elasticity is negative as we use the fuel consumption rate rather than MPG.
6 For a reason that will be clarified in section 4, our empirical model is estimated on the period ending in September 2008 just before the sharp drop in gasoline price following the financial meltdown.
7 These two protocols are those used in the US to assess compliance to the CAFE standards. They were developed in the late seventies and therefore do not represent very well actual driving conditions. These rates are thus adjusted upward following the procedure used by Natural Resources Canada (+22% for city FCR and +10% for highway FCR).
average using weights of 55% and 45% for road and highway respectively to produce a “combined” \( FCR \).

The Fuel Economy Guide also classifies vehicles into nine classes: six for cars and three for light trucks. For cars, the classification is based either on interior volume (subcompact, compact, mid-size and full-size cars) or carline (e.g. two-seater, station wagon). For light trucks, the classification is based on vehicle type (SUV, van and pickups). The classification for cars presents several shortcomings for our analysis of fuel economy. For example, some very popular models in Quebec such as the Mazda 3 or Honda Civic are at the limit between subcompact and compact classes and thus switch from one category to the other depending upon the model-year. Another limitation concerns the two-seater class that combines very fuel efficient vehicles like the Smart and fuel inefficient sport cars such as the Ford Thunderbird. We therefore modified the existing classification and group cars in three categories namely i) small and medium cars, ii) mid-size and full size cars and iii) sport cars.\(^8\)

The price of gasoline corresponds to the provincial average price for regular unleaded and is based on a weekly survey of gasoline price in the province by the \( \text{Régie de l’énergie} \). To obtain real prices, we use the consumer price index that excludes gasoline. All monetary values presented in the rest of this paper are expressed in 2002\$$. The other main source of data is Statistics Canada for income, population, price index etc. Finally, note that we exclude from the analysis uncommon vehicles namely Model-Year (MY) for which average monthly sales is below 10 vehicles or those with positive sales for less than three months. These criteria eliminate less than 1.6% of new registered vehicles.

3. **Context and preliminary evidences**

Before developing the empirical model, it is useful to briefly describe the Quebec context and provide preliminary evidence. Over the 2002-2008 period, the Quebec LDV fleet grew from 3.5 to 4.1 million. The number of new vehicles registered each year varied from a low of about 350 000 in 2004 to a high of 408 000 in 2008. In 2008, the average fuel consumption rate of the Quebec fleet was 11% and 9.6% lower than the average rate observed in the US and the rest of Canada respectively.\(^9\) This is due in part to the smaller share of light trucks (SUV, vans and pickups) at 31% in Quebec and 46% in the US and the ROC.\(^10\) Looking more specifically at new vehicles, the supply of models in Quebec is very comparable to those available in the US. However, the distribution of new vehicles by level of fuel efficiency appears to be quite

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\(^8\) The last category includes subcompact, compact and two seaters that have a cylinder larger than three liters.

\(^9\) For the US, the comparison is based on fuel rates reported by manufacturers (USDOT National Transport Statistics Table 4-23 and US Census, Statistical Abstract 2012 Table 1069). For the comparison with the rest of Canada, the fuel rates are measured in actual driving conditions (see Natural Resources Canada, 2008).

\(^10\) For Canada and Quebec, 2008 figure from Natural Resources Canada (2010) and Barla (2011). For the US, 2012 figures from National Archives and Records Administration (2010).
different. For MY 2008, over 72% of new vehicles registered were in the most fuel efficient quartile of the distribution of available models (i.e. FCR less than or equal to 9.3 l/100km).\textsuperscript{11} For comparison, Busse et al. (2013) report a share of less than 30% for this quartile in the US.\textsuperscript{12}

Figure 1 depicts kernel densities of the FCR for new vehicles registered in calendar year 2002 and 2008. The left panel illustrates the density of the available MY (309 MY in 2002 and 272 in 2008) while the right panel shows the density of new vehicles registered (i.e. each MY is weighted by the number of registrations). Both figures suggest fuel economy improvements. On the supply side, the mode of the distribution remains centered at about 10L/100km but the density flattens with more efficient models being offered and less gas guzzlers. On the demand side, the density of new registered vehicles clearly shifts left toward more efficient vehicles. Interestingly, the average price of gasoline was 60% higher in 2008 than in 2002.

To explore further the potential impact of gasoline prices, Figure 2 illustrates the average FCR of new vehicles sold each month and the corresponding monthly average gasoline price. We observe a general downward trend in the average FCR but also a negative correlation between the price of gasoline and average FCR. Figure 3 also suggest a positive correlation of gasoline price on the share of passenger’s car sold while the opposite occurs for the share of light trucks. Still, the share of light trucks appears to be trending up at the end of the period despite high gasoline prices. The share of light trucks was 31% in 2002 against close to 35% in 2008. Moreover, the composition of sales in the light truck segment has been progressively changing with a continuous decline of the van category (from 11% of the sales in 2002 to 5.9% in 2008) and an increasing popularity of SUV (from 12.8% to 20%) and to a lesser extends of pickups (from 6.3% to 7.9%). These observations suggest a concomitance of both short term

\textsuperscript{11} The quantile is defined on the supply of models available in 2008.
\textsuperscript{12} This figure is derived from table 7 of Busse et al. (2013, p. 238). It is based on national sales from 1999 to 2008. The quartile is redefined each year based on the available models. Comparable figures are unavailable for the rest of Canada.
fluctuations associated with gasoline price and longer term changes due to technology and preferences.\textsuperscript{13}

In early 2007 the Canadian government announced a rebate program for efficient vehicles. From March 2007 to December 2008, new car buyers could receive from 1000$ to 2000$ in rebate when buying eligible vehicles. The rebates depend upon the fuel economy and the vehicle type. For example, cars with a FCR of 5.5 L/100 km or less receive a rebate of 2000$, between 5.6 and 6L/100km, 1500$ and between 6.1 and 6.5L/100km 1000$. Flex fuel vehicles that consume less than 13L/100 km were also eligible for a 1000$ rebate. The program only targeted MY2006 to MY2008. In parallel, a new excise tax on fuel inefficient vehicles was introduced. It varied from $1000 for vehicle with FCR between 14 and 15L/100km to $4000 for those with a $ FCR$ above 16L/100km.

![Figure 2. Average fuel consumption rate of new vehicles and average gasoline price](image)

\textsuperscript{13} Obviously the long term trends are also likely influenced by gasoline prices.
4. The Empirical Model

Following, Li et al. (2009), Klier and Linn (2010) and Busse et al. (2013), we adopt a reduced form model to examine the short run impact of gasoline price fluctuations on vehicle sales composition. We adopt this approach rather than a structural modeling for several reasons. First and for most, this approach does not require data on vehicle prices which are often unavailable (our case) or very imprecise.\textsuperscript{14} Second, it easily allows for a large number of vehicle models when structural models often require to aggregate different vehicles into a small number of categories.\textsuperscript{15} Third, the impact of a gasoline price changes on sales structure and average fuel economy can easily be simulated. The main shortcoming however is that it cannot separate out the effects due to demand or supply adjustments.

Our model aims at testing the impact of current gasoline price ($P_t^g$) on the number of model $j$ (e.g. Honda Civic) entering the fleet, as new vehicle, during a specific month ($Q_{jt}$).\textsuperscript{16} The idea is that buyer uses current gasoline price to assess the vehicle expected gasoline costs over the life of the vehicle. Moreover, in order to test for a composition effect, our specification allow for the impact of gasoline to depend upon the vehicle fuel consumption rate ($FCR$). Formally, our model has the following structure:

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure3}
\caption{Share of passenger cars and light trucks sold and average gasoline price}
\end{figure}

\textsuperscript{14} Very often only manufacturer suggested prices are available which may differ from actual transaction prices.

\textsuperscript{15} For example Bento et al. (2009) aggregate vehicles in 10 groups. Moreover, structural models à la Berry, Levinsohn and Pakes (1995) may pose serious problems of convergence as recently suggested by Knittel and Metaxoglou (2014).

\textsuperscript{16} To simplify the presentation, we referee to a ‘model’ $j$ when in fact it is technically a ‘make-model’ $j$. 
\[
\ln(Q_{jt}) = \theta_0 + (\theta_1 + \theta_2 FCR_{jt}) p_t^\theta + \theta_3 Rebate_{jt} + \theta_3 Tax_{jt} + \chi_{jt} + \varphi_{jd} + \tau_m + \tau_y + \theta_{jt} \tag{1}
\]

with

\( Q_{jt} \): the number of model \( j \) registered, as a new vehicle, during month \( t \). To be considered new, a vehicle should never have been registered before in the province. Moreover the MY should be either the current calendar year or the current calendar year plus or minus one. This account for the fact that new MYs are generally introduced at the end of the preceding year (e.g. The Honda Civic 2008 appears in September 2007). Moreover, last year MY may still be liquidated by dealers at the beginning of the following year (e.g. some Honda Civic 2006 are registered for the first time in March 2007).\(^{17}\)

\( FCR_{jt} \): the average fuel consumption rate of all the model \( j \) entering the fleet at \( t \) expressed in liter per kilometer;  
\( p_t^\theta \): the real average price of regular unleaded gasoline at time \( t \) in 2002$;  
\( Rebate_{jt} \): a binary variable equals to one if model \( j \) qualifies at time \( t \) for a rebate under the Federal Auto feebate program;  
\( Tax_{jt} \): a binary variable equals to one if model \( j \) is taxed under the Federal Auto feebate program;  
\( \chi_{jt} \): other control variables. These include a set of 6 binary variables that controls for a progressive increase in sales of new models. Specifically, \( I_{jit} \) equals 1 at time \( t \) if model \( j \) has been first introduced \( i \) months ago with \( i=1 \) to 6. We also control for the progressive reduction in sales for models that are programed to end. We thus introduced \( E_{jit} \) which is set equal to 1 at \( t \) if model \( j \) is being retired in \( i \) months with \( i=1 \) to 6. Note that these variables only applied for the introduction or retirement of a model not a new model-year.\(^{18}\) We also control for time varying economic indicators that may affect vehicles sales namely the level of income measured by \( \ln(gdp_{cap_t}) \) the log of the gross domestic product per capita and \( \ln(iperso_{t}) \) the log the average interest rate on personal loans;  
\( \varphi_{jd} \): fixed effects for MY \( jd \). As already mentioned, several generations of the same model may be sold during the same month. For example, in October 2007, 1547 new Honda Civic were registered in Quebec, 828 were MY 2007 and 719 MY 2008. We define the fixed effect \( \varphi_{jd} \) using month \( t \) dominant MY. In our example, this means that the fixed effect \( \varphi_{jd} \) corresponding

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\(^{17}\) Unfortunately, we cannot identify vehicles that were already registered in another province or abroad and thus are not new. This issue may be more problematic for MY registered during the following calendar year. Thus, we impose that the registration of this type of vehicle should occur during the first quarter of the following year to be considered as new. In other words, a 2006 Honda Civic registered in May 2007 is not considered new.  
\(^{18}\) For example, the first registered Mazda 3 appears in November 2003.
to the 2007 Honda Civic is set to one. Alternatively, it is possible to assign to each $\varphi_{jd}$ a value that measures the share of MY $d$ in the monthly total sales of model $j$.\textsuperscript{19} However, one issue with this approach is that $\varphi_{jd}$ may become endogenous as it is defined using $Q_{jt}$. Thus our baseline uses the dominant MY. The results obtained with the alternative specification are discussed in section 6.

\[ \tau_m: \text{year-of-the-month fixed effects (} m = 1 \text{ to } 12\text{) to control for recurrent variations in sales across the year; } \]

\[ \tau_y: \text{year specific fixed effects (with } y = 2002 \text{ to } 2008); \]

\[ \delta_{jt}: \text{a random term that has the following structure } \theta_{jt} = \delta_t + \epsilon_{jt} \text{ with } \delta_t \text{ a month-of-data specific random effects (with } t = 1 \text{ to } 81\text{) and } \epsilon_{jt} \text{ the usual error term. We assume that both terms are normally and independently distributed with mean zero and variance } \sigma_t^2 \text{ and } \sigma_{\epsilon}^2 \text{ respectively.} \]

We now explain in more details the main features of our empirical model. First, the impact of gasoline price on sales is indeed allowed to vary with FCR which makes possible to test for changes in sales patterns across models with different fuel economy.\textsuperscript{20} For example, if a gasoline price increase stimulates sales of efficient vehicles at the expense of inefficient ones, $\theta_1$ should be positive and $\theta_2$ negative.\textsuperscript{21}

Second, our model is static implying that consumers only react to current gasoline prices. This is a very common hypothesis in the literature on the demand for new vehicles and consumer valuation of energy efficiency investments. It is appropriate if gasoline prices follow a random walk. While some empirical work provides support to this hypothesis (see Davis and Hamilton, 2004, German, 2007), recent studies seem to challenge it (e.g. Baumeister, Kilian and Lee, 2015). However, even if gasoline prices do not actually follow a random walk, our specification is still adequate if consumers form their expectations about future gasoline prices using only the current price (i.e. they act as if gasoline price follows a random walk). Recently, Anderson, Kellogg and Sallee (2013) analyze this issue using the monthly Michigan Survey of Consumers. This survey asks a representative sample of 500 respondents to forecast the price of gasoline over a five year horizon. The results indicate that the average consumer forecasts no change in real gasoline prices with respect to the current level thereby justifying our specification. There is however one exception that is relevant for our analysis. Following the financial crisis, the price of gasoline sharply dropped from September 2008 to December 2008 (see Figure 2). Anderson, Kellogg and Sallee (2013) show that during that period, the average US consumers were

\textsuperscript{19} Using the same example as before we would have for October 2007 $\varphi_{Civic,2007} = \left( \frac{828}{1547} \right)$ and $\varphi_{Civic,2008} = \left( \frac{719}{1547} \right)$.

\textsuperscript{20} Li et al. (2009) use a similar functional form but to explain the quantity of vehicles by quantile of the FCR distribution.

\textsuperscript{21} Alternatively $(\theta_1 + \theta_2 FCR_{jt})P_t^\theta$ can also be expressed as $(\frac{\theta_1}{FCR_{jt}} + \theta_2) cpk_{jt}$ with $cpk_{jt} = FCR_{jt} P_t^\theta$ the fuel cost of driving a km.
expecting a 15% to 20% rebound in gasoline prices. In other words during that period, current gasoline prices were not a good measure of consumer expectations about future gasoline costs. As it is reasonable to assume that Quebec consumers are not different than US consumers, we eliminate the last three months of the year 2008 in estimating our baseline model. In section 6, we explore the robustness of our results to both the presence of past gasoline prices and the inclusion of the last three months of 2008.

Third, the fixed effects $\varphi_{jd}$ control for model $j$ characteristics as well as for the mean characteristics of consumers buying this model. As models are updated annually these fixed effects are also time dependent but with the time pattern does not fit the calendar year but rather the production cycle (thus the subscript $d$ which is different than $y$). The specification also includes calendar year specific effects to control for yearly variations in the car market. Hence, the identification of the impact of the gasoline price rests upon the monthly relative variations in quantities across models of different fuel economy. Moreover, the inclusion of month-of-the-year dummies insures that these variations are not linked to recurrent seasonal patterns.

Fourth, we also account for the potential correlation in the quantities of the same month by the inclusion of the random term $\delta_t$. This correlation could result from month-specific unobservable shocks that affect the LDV market. We treat this effect as random in order to be able to identify $\theta_1$. This supposes the absence of correlation between $\delta_t$ and the explanatory variables including $p_t^g$. While this hypothesis is debatable, it should be noted that our model includes time specific variables which should hopefully limit the risk of bias due to unobservable factors. Still, in order to assess the implications of this hypothesis, we also present the results with $\delta_t$ included as fixed effects.

Finally, it should be stressed that our analysis only measures the effect of gasoline prices on sales conditional on the existing supply of vehicles (i.e. given the $\varphi_{jd}$). In that respect, we only measure the short run effect of gasoline price. In the medium and long term, the characteristics of the new vehicles proposed by manufacturers also response to gasoline price fluctuations (Knittel, 2011).

5. Results

Table 1 shows the results for the specifications with $\delta_t$ as random and fixed effects. Both specifications led to very close estimates for the coefficients that are common to both specifications. Obviously, this does not guarantee that the coefficients for the time varying variables such as $p_t^g$ are not biased by time-specific unobservable factors. Still, the simulation results (discussed below) also lead to very similar conclusions. The main advantage of the random effects specification is that it allows to identify a threshold $FCR^*$ such that sales of vehicles with a $FCR$ below that limit increase with gasoline price while the opposite occurs for
values above that threshold. Based on Table 1 results, $FCR^*$ equals 8.65L/100km.\(^{22}\) The elasticity of the quantity sold with respect to the price of gasoline is given by $(\theta_1 + \theta_2 FCR_{jv}) p_t^g$. For a *Toyota Corolla* with a $FCR$ of 6.5L/100km, the elasticity is 0.37 $p_t^g$ implying that a 10% increase in gasoline price around 1$\$/L stimulate sales by close to 4%. For a *Ford Taurus* with a $FCR$ of 10.2L/100km, the price elasticity is -0.27 $p_t^g$. This suggests non-negligible sale shifting following a change in gasoline prices at least for models with $FCR$ very different than 8.65L/100km. However, note that over 60% of new vehicles registered are within a range of the threshold such as their elasticity is below 0.3 $p_t^g$ in absolute value. Thus, for a large share of vehicles, the impact of gasoline price on sales is not that high.

For comparison, recall that Li, Timmins and von Haefen (2009) find a threshold at 10L/100km for the US. Also, the estimate for the coefficient $\theta_2$ can be directly compared to the estimate obtained by Klier and Linn in the US. In the most comparable specification, they find an estimate of -25.61.\(^{23}\) These comparisons suggest a somewhat smaller impact of gasoline price on new vehicle efficiency in Quebec than in the US. This is likely due to the fact that the Quebec sales are already oriented toward more efficient vehicles than in the US.

Table 1. Estimation results for equation 1 with $\delta_t$ as random and fixed effects

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<th>$\delta_t$ Random</th>
<th>$\delta_t$ Fixed</th>
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<tbody>
<tr>
<td>$p_t^g$</td>
<td>1.48***</td>
<td>-</td>
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<td></td>
<td>(0.27)</td>
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<tr>
<td>$FCR_{jv} \times p_t^g$</td>
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<td>-17.02***</td>
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<td>(2.08)</td>
<td>(2.18)</td>
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<tr>
<td>Rebate</td>
<td>0.17**</td>
<td>0.16*</td>
</tr>
<tr>
<td></td>
<td>(0.08)</td>
<td>(0.08)</td>
</tr>
<tr>
<td>Tax</td>
<td>-0.08</td>
<td>-0.09*</td>
</tr>
<tr>
<td></td>
<td>(0.05)</td>
<td>(0.05)</td>
</tr>
<tr>
<td>$Ln(pibcap)$</td>
<td>1.16</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(2.17)</td>
<td></td>
</tr>
<tr>
<td>$Ln(iperso)$</td>
<td>0.21</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.43)</td>
<td></td>
</tr>
</tbody>
</table>

$N$ = 14734

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Coefficients for the fixed effects and those for the variables $I$ and $E$ not shown

---

\(^{22}\) This value is obtained by solving $(1.48-17.13 FCR)=0$

\(^{23}\) We adjusted their coefficient to account for the difference in units (MPG versus L/km)
To gain a better insight on the magnitude of the overall composition effect, we simulate the registration structure by vehicle category over the last 12 months of our sample period (October 2007 to September 2008) assuming that the price of gasoline had remained the same as in 2002 at $0.72. This actually corresponds to a 35% drop with respect to the average gasoline price that was actually prevailing during this period. The results are reported in Table 2. The drop in gasoline price would reduce by 11% the share of small and medium cars - the most fuel efficient vehicles. For intermediate and large cars, the reduction is somewhat smaller (-5%) while sport cars experience a 10% increase in their share. Overall the share of passenger cars would drop by 7.7% from 65.1% to 60.1%. This corresponds to an elasticity of 0.24. At the opposite side of the classification, the light truck segment sees its share increase by 16% from 34.5% to 40.1%. The SUV and VAN shares both increase by about 10% while the pickup share jumps by 35%. The average FCR of new LDV would increase by 3.6% following a 35% reduction in gasoline prices implying an elasticity of about 0.1. More than two thirds of this increase is due to changes in the sales structure across categories and less than a third to changes in sales pattern within each category. Also note that the gasoline price decline would stimulate the overall sales of new vehicles by about 2.5% suggesting an elasticity of 0.07. This is very close to Bento et al. (2009) that finds that a 17% increase in gasoline price reduces sales of new vehicles by 1% (i.e. an elasticity at 0.06).

Another worthwhile simulation exercise is to determine what should have been the price of gasoline in 2008 so as to counteract the growing trend of light trucks. In the last 12 months of our sample, the share of new registered light trucks was 34.5% compared to about 31% in 2002. Gasoline price in 2008 should have been 1.4$/L to drive the share of light trucks down to 31%. This is a 26% increase with respect to the actual average price in 2008 and a doubling with respect to 2002.

Overall, these results suggest non negligible sale shifting for vehicles that are at the extreme of the fuel economy distribution, but for the bulk of vehicles the impact is far less important. However, the large variations in gasoline prices that periodically occur can have noticeable consequences on the composition of sales across vehicle classes. Still, the resulting impact on the average fuel economy remains fairly modest. The corollary of these conclusions is that substantial gasoline prices hike would be needed to neutralize the growing appeal of larger vehicles.

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24 Recall that we eliminate the last three months of 2008 so that the last twelve months of our sample start in October 2007.
25 To calculate these figures, we evaluate the average FCR using the category shares at actual price (column 2) but with the FCR by category at P=$0.72 (column 5). This leads to 8.94L/100km. Thus, the 3.6% increase can be decomposed in 2.8% due to variations in registrations across categories and 0.8% due to changes in registrations within each category.
Table 2. Simulated shares and average FCR for the period from October 2007 to September 2008 at actual and 2002 gasoline price

<table>
<thead>
<tr>
<th>Category</th>
<th>Shares at actual prices</th>
<th>Shares at 2002 price</th>
<th>Average FCR at actual prices</th>
<th>Average FCR at 2002 price</th>
</tr>
</thead>
<tbody>
<tr>
<td>CARS</td>
<td>65.1</td>
<td>60</td>
<td>7.69</td>
<td>7.78</td>
</tr>
<tr>
<td>Small-Medium</td>
<td>40.5</td>
<td>36.1</td>
<td>7.32</td>
<td>7.38</td>
</tr>
<tr>
<td>Intermediate-large</td>
<td>24.2</td>
<td>23.1</td>
<td>8.26</td>
<td>8.34</td>
</tr>
<tr>
<td>Sport cars</td>
<td>0.8</td>
<td>0.9</td>
<td>9.82</td>
<td>9.86</td>
</tr>
<tr>
<td>LIGHT TRUCKS</td>
<td>34.5</td>
<td>40.1</td>
<td>11.09</td>
<td>11.29</td>
</tr>
<tr>
<td>SUV</td>
<td>20.1</td>
<td>22.2</td>
<td>10.39</td>
<td>10.51</td>
</tr>
<tr>
<td>Van</td>
<td>6.4</td>
<td>7.1</td>
<td>10.44</td>
<td>10.48</td>
</tr>
<tr>
<td>Pickup</td>
<td>8.0</td>
<td>10.8</td>
<td>13.39</td>
<td>13.46</td>
</tr>
<tr>
<td>All LDV</td>
<td>100</td>
<td>100</td>
<td>8.87</td>
<td>9.19</td>
</tr>
</tbody>
</table>

The simulations are done using the coefficients of the random effects model. The results obtained using fixed effects are very close and are available upon request.

Turning to the impacts of the feebate program, vehicles eligible to the rebate experience on average a 17% increase in sales. On the other hand, inefficient vehicles that are surtaxed see their sales reduced by 8 to 9%. This last effect is however only statistically significant in the fixed effects specifications. The overall impact of the feebate program on fuel economy is very small. Indeed, we compute that the average fuel economy would have been less than 1% higher in the absence of this program. Moreover, this figure is likely an upper bound since it is derived as if the rebate only generates additional sales. In reality, the rebate is likely shifting sales at the expense of competing models that, even if they do not qualify for the rebate, are still quite fuel efficient. While, it could be argued that the program created incentives for manufacturers to improve fuel economy, this effect has most likely been very limited as the rebate only lasted less than two years.

The income per capita has a positive impact on sales but the effect is not statistically significant. This is likely due to the lack of variability of this variable when year fixed effects are included. The same is true for the interest rate on personal loans which do not even have the expected sign. Finally, note that all the binary variables that controls for the introduction and disappearance of vehicle-model are statistically significant and have the right patterns (results available upon request). Sales of new models gradually take off while those of disappearing models progressively fade away.

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26 Indeed, our model does not allow us to identify the impact of the rebate on sales of competing models that are not eligible for the rebate. Some of this impact is however likely captured in the model-vintage effects. When simulating the impact of the rebate, we implicitly assume that the rebate only generates new sales which is obviously restrictive. The same is true for the tax.

27 The tax on inefficient vehicles is however still in place.
6. Robustness Checks

In order to evaluate the robustness of our results, we investigate several alternative specifications. In the baseline specification, we find a threshold $FCR^* = 8.65\text{L/100km}$ but it could be argued that this limit may have moved down over time with technological progress. To examine this possibility, we reestimate the model on a subsample starting in 2006. The results are summarized in Table 3. In fact, $FCR^*$ is somewhat larger at 8.9L/100km and the simulation indicates a somewhat larger sale shift following a gasoline price drop.

Second, buying a new vehicle is a process that takes some time so that a moving average of the price of gasoline during last three months before registering may be a better indicator for the buyer anticipations about the future of gasoline prices. With this specification, the threshold gets smaller at $FCR^* = 7.5\text{L/100km}$. The simulation results also indicate a somewhat larger impact on the average $FCR$ and the share of light trucks. We also estimate the model with lags of the gasoline price (up to six lags). None of the lags are ever jointly statistically significant. Moreover the coefficients on the current gasoline price variable do not change very much and remain in all cases highly statistically significant. We report the one lag case in Table 3. While the threshold value is somewhat smaller, the simulation results are very close.

Next, we explore the potential impact of the function form by replace $p_t^G$ and $FCR$ in equation (1) by $\ln(p_t^G)$ and $\ln(FCR)$. The results are relatively close to those obtained with our original specification. We also estimate equation (1) separately on the subsample of passenger cars and light trucks. Figure 3 illustrates the impact of $p_t^G$ on sales as a function of $FCR$ (i.e. $\theta_1 + \theta_2 FCR$). The light truck segment appears somewhat more reactive to gasoline price than the car segment but the overall pattern is similar and the simulations in Table 3 are very close.

In our baseline specification, we use the dominant vintage to define $\varphi_{jd}$. Alternatively, it is possible to assign to each $\varphi_{jd}$ a value that measures the share of MY $d$ in the monthly total sales of model $j$ (see footnote 19 for an example). The results are robust to this specification change.

We also estimate the model with the data corresponding to the last three months of 2008 and thus the sharp decline in gasoline price following the financial crisis. The results in Table 3 shows that the estimated threshold $FCR^*$ is quite larger at 10.38L/100km which lead to the questionable implication that a decline in gasoline prices lowers overall sales of vehicles. For example, a decrease in gasoline price from 1.11$ to 0.72$ would result in a reduction of about 9% in total vehicle sales. This result is likely due to the unstable economic environment that prevailed at the end of 2008 with low gasoline prices and depressed vehicles sales.28

28 In December 2008, sales were 35% lower than in December 2007 while gasoline price was 30% lower.
Table 3. Alternative specifications results for the impact of gasoline price

<table>
<thead>
<tr>
<th>Alternative specifications</th>
<th>$\theta_1$</th>
<th>$\theta_2$</th>
<th>FCR*</th>
<th>Simulation with $P_t^g$=0.72$ from Oct. 2007 to Sept. 2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Baseline</td>
<td>1.48</td>
<td>-17.12</td>
<td>8.65</td>
<td>Av. FCR</td>
</tr>
<tr>
<td>(2) 2005-2008</td>
<td>2.19</td>
<td>-24.7</td>
<td>8.85</td>
<td>Share of light trucks</td>
</tr>
<tr>
<td>(3) Moving average</td>
<td>1.92</td>
<td>-25.47</td>
<td>7.52</td>
<td></td>
</tr>
<tr>
<td>(4) Current price</td>
<td>1.41</td>
<td>-15.24</td>
<td>6.89</td>
<td></td>
</tr>
<tr>
<td>One lag price</td>
<td>-0.2</td>
<td>-2.32</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(5) Log-Log</td>
<td>4.04</td>
<td>-1.85</td>
<td>8.87</td>
<td></td>
</tr>
<tr>
<td>(6) Passenger cars</td>
<td>1.13</td>
<td>-13.42</td>
<td>8.43</td>
<td></td>
</tr>
<tr>
<td>Light trucks</td>
<td>2.23</td>
<td>-23.23</td>
<td>9.62</td>
<td></td>
</tr>
<tr>
<td>All LDV</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(7) Vintage</td>
<td>-1.56</td>
<td>-17.84</td>
<td>8.76</td>
<td></td>
</tr>
<tr>
<td>(8) Financial crisis</td>
<td>1.88</td>
<td>-18.14</td>
<td>10.38</td>
<td></td>
</tr>
</tbody>
</table>
| All the reported $\theta_1$ and $\theta_2$ are statistically significant at 1% except for the coefficients on the one lag price in alternative (4) which are not statistically significant.

Figure 3. Impact of $P_t^g$ on sales as a function of FCR with the base results and those on the subsamples of passenger cars and light trucks

As a last robustness check, we directly estimate the impact of gasoline price on the average fuel economy of new vehicles sold each month. This alternative model has the following structure:

$$\ln(FCR_t) = \mu_0 + \mu_1 \ln P_t^g + \mu_2 \ln(GDPcap_t) + \mu_3 \ln(iperso_t) + \mu_4 Feebate_t + \tau_m + \tau_y + \theta_t$$
In this setting, the variable Feebate is a binary variable which is set to one after March 2007 when the feebate program was in effect. The results of this model are reported in Table 4. The elasticity of the FCR with respect to gasoline price is estimated at 0.07 which is slightly lower but still very comparable to our baseline finding. The simulated 2007-2008 average FCR with a gasoline price of 72 cents is 9.16L/100km which is very close to our baseline.

All these alternative specifications confirm that gasoline prices have an impact on the composition of new vehicles by fuel economy but with relatively modest consequences on the average fuel economy. This conclusion is very much in line with recent US research. Furthermore, the composition effect in Quebec appears somewhat smaller than in the US. This is likely due to the fact that Quebec fleet is already more efficient.

Table 4. Estimation results of equation (2)

<table>
<thead>
<tr>
<th></th>
<th>Ln(FCR)</th>
<th>Ln(pt̄g)</th>
<th>Ln(pibcap)</th>
<th>Ln(iperso)</th>
<th>Feebate</th>
<th>Year 2002</th>
<th>Year 2003</th>
<th>Year 2004</th>
<th>Year 2005</th>
<th>Year 2006</th>
<th>Year 2007</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>-0.07***</td>
<td>0.20</td>
<td>-0.07</td>
<td>0.00</td>
<td>Ref</td>
<td>-0.005*</td>
<td>-0.015***</td>
<td>-0.012</td>
<td>-0.016</td>
<td>-0.014</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.01)</td>
<td>(0.20)</td>
<td>(0.04)</td>
<td>(0.01)</td>
<td></td>
<td>(0.003)</td>
<td>(0.005)</td>
<td>(0.01)</td>
<td>(0.01)</td>
<td>(0.01)</td>
</tr>
</tbody>
</table>
In this paper, we have evaluated the short term impact of gasoline price on the composition and average fuel economy of new vehicles registered in the province of Quebec. We find a statistically significant compositional effect: sales of efficient vehicles increase with gasoline prices while the opposite occurs for the inefficient ones. While the impact is modest for the majority of vehicles, a large gasoline price fluctuation can still lead to noticeable changes in the structure of sales by vehicle classes. The impact on the average fuel economy of new vehicles remains in any case rather modest. These results also imply that gasoline price would have to considerably increase to counteract the growing popularity of light trucks. In fact, we evaluate that gasoline price should have doubled for the share of light trucks in Quebec to remain stable from 2002 to 2008. It is important to remind that we are only measuring short run effects which are essentially driven by the demand side. The medium and long run response of both consumers and manufacturers remains to be better understood.

References


