Centre de Recherche en Économie et Statistique

CREST

Série des Documents de Travail

n° 2012-13

The Environmental Effect of Green Taxation : The Case of the French "Bonus/Malus"

X. D'HAULTFOEUILLE[1]

P. GIVORD[2] – **X. BOUTIN**[3]

July 17, 2012

1 CREST. Email : xavier.dhaultfoeuille@ensae.fr

2 CREST (INSEE). Email : pauline.givord@insee.fr

3 European Commission, Directorate General for Competition, Chief Economist Team.

The Environmental Effect of Green Taxation: The Case of the French "Bonus/Malus"*

Xavier D'Haultfœuille[†] Pauline Givord[‡] Xavier Boutin[§]

July 17, 2012

Abstract

At the beginning of 2008 was introduced in France a feebate on the purchase of new cars called the "Bonus/Malus". Since January 2008, the less polluting cars benefited from a price reduction of up to 1,000 euros, while the most polluting ones were subject to a taxation of 2,600 euros. We estimate the impact of this policy on carbon dioxide emissions in the short and long run. These emissions depend on the market shares and the average emissions per kilometer of each car, but also on their manufacturing and the number of kilometers traveled by their owners. We first develop a simple tractable model that relates car choice and mileage. We then estimate this model, using both the exhaustive dataset of car registrations and a recent transportation survey which provides information on individual journeys. We show that if the shift towards the classes benefiting from rebates is spectacular, the environmental impact of the policy is negative. The reform has notably increased sales, leading to an important increase in manufacturing and traveling emissions. We thus stress that such policies may be efficient tools for reducing CO_2 emissions (French consumers do react to the feebate in their car choice), but should be designed with care to achieve their primary goal.

JEL : C25, D12, H23, L62, Q53.

Keywords : environmental taxation, automobiles, carbon dioxide emissions, policy evaluation.

---

*We are grateful to Didier Blanchet, Aymeric De Loubens De Verdalle, Eric Dubois, Isis Durrmeyer, Philippe Février, Stéphane Gauthier, Stefan Gössling, Marc Gurgand, Johan Hombert, Cristian Huse, Vincent Marcus, Nicolas Riedinger and participants to the 11th CEPR IO, the 10th Econometric Society World Congress and 4th World Congress of Environmental and Resource Economists for their useful comments. We also thank Julien Mollet, Pierre-Louis Debar (CCFA) and Marina Robin (SOES) for providing us with the data.

[†]CREST. E-mail: xavier.dhaultfoeuille at ensae.fr.

[‡]INSEE. E-mail: pauline.givord at insee.fr.

[§]European Commission, Directorate General for Competition, Chief Economist Team.

1 Introduction

Public awareness on environmental issues has raised in the past decade and global warming is now a growing concern for developed and emerging nations. Policy initiatives are launched in many countries to reduce the human contribution to greenhouse gas emissions, especially carbon dioxide (CO_2). Cutting vehicle emissions is a crucial objective, as the transportation sector accounts for a third of the CO_2 emissions in developed countries. Several instruments have been tried to achieve this aim. While gasoline taxes and standards such as the Corporate Average Fuel Economy in the US are the most commonly used, feebates have been recently received attention. A feebate is an original policy instrument that makes individuals internalize the pollution externalities of specific goods, typically automobiles, by providing a rebate (respectively a fee) for purchasers of low-emitting (respectively high-emitting) cars.[1] Such a policy has several advantage over usual instruments that aim at reducing automobile CO_2 emissions (see Fullerton & West, 2002 for a discussion of alternative instruments). The rebate makes this policy easier to implement than gasoline taxes, which are optimal in theory but have proven to be very unpopular.[2] Besides, several empirical evidences suggest that consumers undervalue future fuel costs when they choose a new vehicles (see, e.g., Allcott & Wozny, 2011), selecting lower fuel economy automobiles than they should optimally do. Feebates may thus be a useful complement to gasoline taxes.

The effect of feebates on CO_2 emissions is ambiguous, yet. As other policies based on fuel economy performance, they do not act on the intensive margin. With higher fuel efficient vehicles, drivers are likely to travel more. This "rebound effect" mitigates the reduction of CO_2 emissions. If badly designed, feebate systems may also have the opposite effect to that intended, by increasing automobile sales and, as a result, overall CO_2 emissions. Moreover, an appropriate design may be difficult to achieve. It depends in particular on price elasticities, which may not be known accurately by policy makers (for a discussion of the optimal design of a feebate system, see for instance Greene et al., 2005, or Peters

[1] Up to now, feebates have been implemented in Austria, France and Wallonia (a Belgium region), and are debated in other European countries (see Adamou et al., 2010). Most of other European countries have implemented a taxation which is more or less related to the average CO_2 emissions of the vehicles (for more details, see for instance the ACEA site). California also proposed in 2007 a feebate system called the "Clean Car Discount" program on new cars, but the Bill failed to pass.

[2] In France, for instance, the government attempted to implement a carbon tax of 17 euros per ton of CO_2 in 2009. This tax was adopted by the Parliament but rejected by the Constitutional Court. Because of its unpopularity both in the opinion and in the governing party, the government finally decided to withdraw its proposal.

et al., 2008).

This paper estimates the impact on CO_2 emissions of the introduction in France of a feebate, the "Bonus/Malus écologique", in January 2008. We took advantage of the celerity in the introduction of the feebate to identify the shift in demand created by the induced change in the set of prices and compute the counterfactual emissions that would have prevailed in the absence of the feebate. For that purpose, we develop a simple demand model that combines car and annual mileage choices. This model accounts for consumers' heterogeneity in preferences, the differentiation of the automobile market and the existence of rebound effects, while remaining very tractable. We estimate this model on an exhaustive monthly dataset of new cars registrations. This dataset contains not only detailed information on vehicles but also on drivers. We can thus accurately take into account heterogeneity in taste due to observable characteristics of consumers. We also use a transportation survey conducted in 2007 which records in particular annual mileages on a large sample of French households. Our model and these two datasets allow us to recover both choices with and without the feebate system, and average emissions related to car use for a particular choice of car. An originality of our method is that we do not rely on list prices, but rather on a reduced form that combines the demand model and a simple price model. The reason for this is that list prices are typically modified once a year only, and are thus likely not to reflect the changes in transaction prices that occur quickly after the introduction of the feebate.

We observe that despite a substantial shift towards the classes benefiting from a rebate, the environmental short-run impact of the feebate is actually negative. This disappointing result is mainly explained by too generous rebates. As a result, the policy appears to enhance the total sales of new cars by around 13%, despite the slowing down of the economy observed at this period. This large scale effect translates into extra CO_2 emissions by an increase in mileages and the manufacturing of these new vehicles. Reactions of French consumers actually exceeded the forecasts of the French government. Planned to be neutral for the State budget, the measure turned out to cost 285 millions euros in 2008 because of its overwhelming success in favor of low CO_2-emitting cars. This suggests that automobile consumers may be very reactive to modest changes in prices. In a different setting, Busse et al. (2010) observe a similar pattern on the US market. Even though consumers reacted massively to the policy, this reaction did not translate into a large decrease in average CO_2 emissions of new cars. Buyers shift their purchase to cars benefiting from rebates but with hardly lower emissions. This strategic response was already observed by Sallee & Slemrod (2010) for automakers in Canada.

As the reform was announced only by the end of October 2007, manufacturers were unable to modify immediately their vehicles characteristics. The short-run impact is thus only a consequence of the demand reaction to the policy. One should interpret this impact with caution, however. In the short run, the demand shift due to the feebate corresponds to a very small part of the whole fleet of cars. One has to estimate the long-run impact of the policy on CO_2 emissions, once the whole fleet has been replaced. The policy can also impact the replacement rates of vehicles. Li et al. (2009) and Adda & Cooper (2000) show, in related settings, that such replacement effects may be large. To estimate the effect of the policy on replacement rates, still ignoring supply-side reactions, we consider a simple dynamic model with competitive prices in the second-market. It relates the change in replacement rates to changes in initial prices, following Engers et al. (2009). At the end, the scale effect of the policy still dominates in the long run, implying once more an increase in CO_2 emissions.

Due to data availability, our analysis is restricted to the demand reaction of the feebate. In the long run, however, automakers reactions are likely to enhance the environmental effect of the policy. Klier & Linn (2010) observe for instance medium-run firm responses to high gasoline prices (see also Knittel, 2011). To check the robustness of our results, we perform a sensitivity analysis on such reactions on our final results by simulating a 5% reduction of the fuel economy of all new vehicles. This does not modify the overall assessment of the policy. On the other hand, we show that a modest decrease of the rebates would slightly decrease overall CO_2 emissions, highlighting once more the importance of an appropriate design of feebates.

The paper is organized as follows. The next section presents the reform and the datasets at our disposal. The third part presents the parameters of interest and our identification strategy. Finally, the fourth part displays our results.

2 First insights on the policy

2.1 The feebate system

The feebate system on new cars sales was introduced by the French government for all cars registered after the 1st of January 2008. The purchasers of new cars emitting less than 130g of CO_2 per kilometer benefit from a direct price cut on their invoice. The amount of the rebate varied, depending on the class of the vehicle (see Table 1), with a maximum of 1,000 euros. It is as high as 5,000 euros for electric cars, which however represent a negligible share of the market. Conversely, purchasers of cars emitting more than 160g of CO_2 per kilometer had to pay a tax of up to 2,600 euros. The system was neutral for cars emitting between 130 and 160 g per kilometer. The chosen classification corresponds to the one defined by the European Union for the cars energy labels, except that the government split the A, C and E classes into two subclasses.

In practice, rebates apply to new cars ordered on or after 5 December 2007, while fees apply to vehicles first registered in France on or after 1 January 2008. At the same moment, the government introduced a scrapping subsidy of 300 euros (called the "super bonus") for more than 15 year-old automobiles, provided that the purchaser bought a new vehicle emitting less than 160g of CO_2. In 2008, this additional rebate concerned only 5.4% of the purchases of vehicles benefiting from a rebate (see Friez, 2009), and we ignore it hereafter. This scrapping subsidy was extended to 1,000 euros and to cars between 10 and 14 years in 2009, in order to dampen the economic consequences of the 2009 crisis on car industry. We shall not be concerned with this here as we focus on 2008 only. The feebate concerns all new cars registration, whether the purchaser is an individual purchaser or a firm. Companies have thus no incentive to have their business cars (falsely) registered as their employees individual ones. They have probably less reacted to the introduction of the feebate, as they were already subject to a specific tax in favor of high fuel economy cars.

Table 1: Amount of the feebate as a function of CO_2 emissions.

Class	CO_2 Emissions (g/km)	Rebate	Average Price (2007)	Market shares (2007)
A+	≤60	5,000	-	-
A-	61-100	1,000	12.500	0.0%
B	101-120	700	15.500	18.4%
C+	121-130	200	19.000	10.2%
C-	131-140	0	19.000	18.8%
D	141-160	0	23.000	26.6%
E+	161-165	-200	23.500	3.2%
E-	166-200	-750	29.000	15.9%
F	201-250	-1,600	40.000	5.0%
G	≥251	-2,600	60.500	1.9%

Source (for prices and market shares): dataset on the registration of new cars (CCFA).
Note: we observe no sales for class A+ in 2007. Average price corresponds to list prices.

The feebate policy was decided and then implemented with an unusual speed. It resulted from a national environmental roundtable organized in Autumn 2007 by the newly elected president, whose aim was to define the key points of government policy on ecological and sustainable development issues for the coming five years.[3] The policy measures, including the feebate system, were presented on 25 October 2007, for an almost immediate application. This roundtable and the feebate policy came as quite a surprise as they were not mentioned during the electoral campaign and the right-wing government party was considered not to be preoccupied with environmental issues.

This green taxation for the purchase of new cars by private owners has no precedent in France in magnitude and scope. Some measures already intended to increase the population's awareness of the environmental costs of motor vehicles. But for private users, they either focused on very specific segments of the market only, or were larger in scope but marginal in magnitude. Examples include an income tax reduction to the purchasers of hybrid vehicles, or a very slight taxation of the most polluting vehicles (around 100 euros for cars costing on average 35,000 euros). In contrast, the feebate introduced at the end of 2007 applied to all cars, the rebate representing up to 8.8% of the list price of the corresponding cars, while the penalty could be as large as 14.1% of this price.

The objective of the feebate system was twofold. First, it intended to shift consumers' demand towards low CO_2-emitting cars. Second, it aimed at encouraging manufacturers to develop greener vehicles. To better achieve this second purpose, it was mentioned from the beginning of the reform that the thresholds of eligibility for the rebates and imposition of the fees were to be lowered, at a pace allowing manufacturers to adapt their production (5g of CO_2/km every two years).

2.2 Descriptive evidences on the impact of the policy

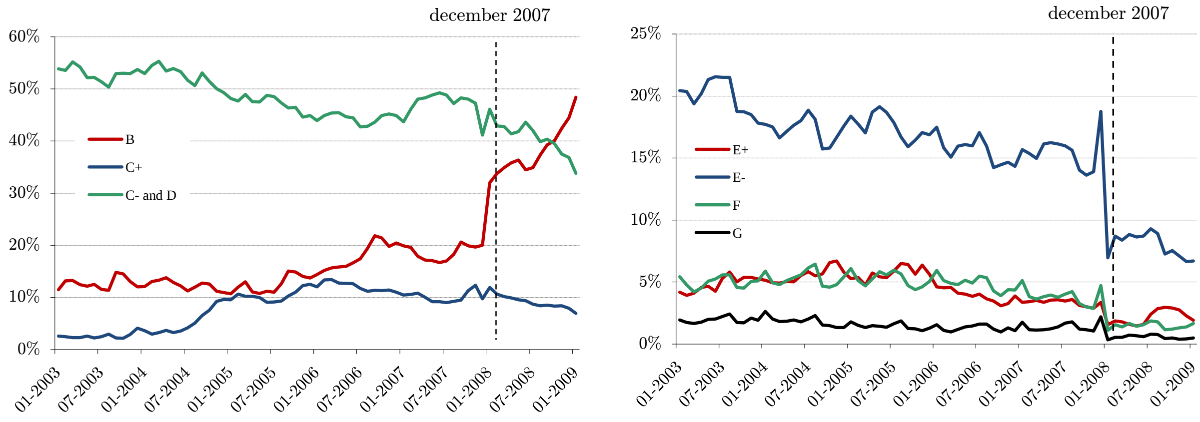
First insights on the impact of the policy show that French consumers have strongly reacted to the feebate system.[4] This reaction results in a substitution from polluting cars to less polluting ones targeted by the tax rebates, but also, more surprisingly, in a net increase in the total sales of new cars. These trends cannot be explained by seasonal effects or changes in the macroeconomic situation. By contrast, we do not observe in the very short run any clear evidence of a sharp break in CO_2 emissions of supplied cars.

[3]This roundtable was called "Grenelle de l'Environnement" as an evocation of the "Accord de Grenelle" concluded in May 1968, see http://www.legrenelle-environnement.fr/spip.php?rubrique112.

[4]To be consistent with the rest of the paper, we provide figures for personal cars only. Our data suggest that companies also react to the feebate, but to a somewhat smaller extent. Company cars were already taxed on the basis of energy classes since 2006.

First, the changes in the market shares of the classes of energy after the reform took place were impressive. While class B only represents 20% of sales at the end of 2007, its market share reaches nearly 50% at the beginning of 2009 (see Figure 1). In the same time, the market share of class E- fells from nearly 15% to 5%. These changes induce a significant impact on average emissions (see Figure 2). However, this effect is much smaller than the one observed on market shares. When one compares to the trend observed between November 2005 and November 2007, the average decrease between March 2008 and January 2009 only reaches 5%. This mainly results from threshold effects (see Figure 7 in Appendix A1). Many buyers have only marginally modified their purchasing decisions, choosing for instance a car emitting 120 g/km, thus belonging to class B, rather than one emitting 121 or 122g/km belonging to class C+.

As the implementation of the measure was almost immediate, neither consumers nor manufacturers could anticipate the reform before November 2007. On the other hand, Figure 1 shows that anticipation was spectacular on consumers' side in December 2007, especially for the most polluting cars for which the fee only applied in January 2008. Not surprisingly, this large increase for the last classes was followed by an "undershooting" in January and, to a lesser extent, in February. We do not observe any noticeable change in November even though the reform was already announced then. This is probably due to the delivery time of new cars, as well as the waiting time between the purchase and the registration of a new car.

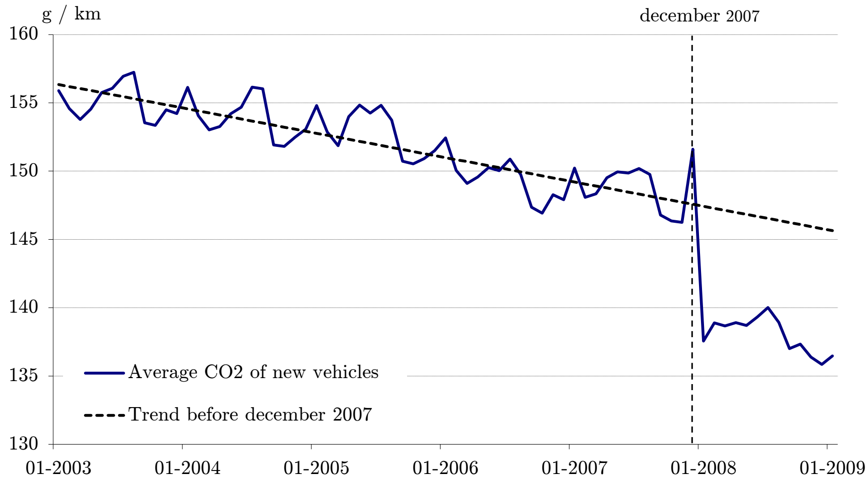


Vehicles benefiting from a rebate

Vehicles affected by a fee

Sources: dataset on the registration of new cars (CCFA).
Note: market shares of the different classes sum to one.

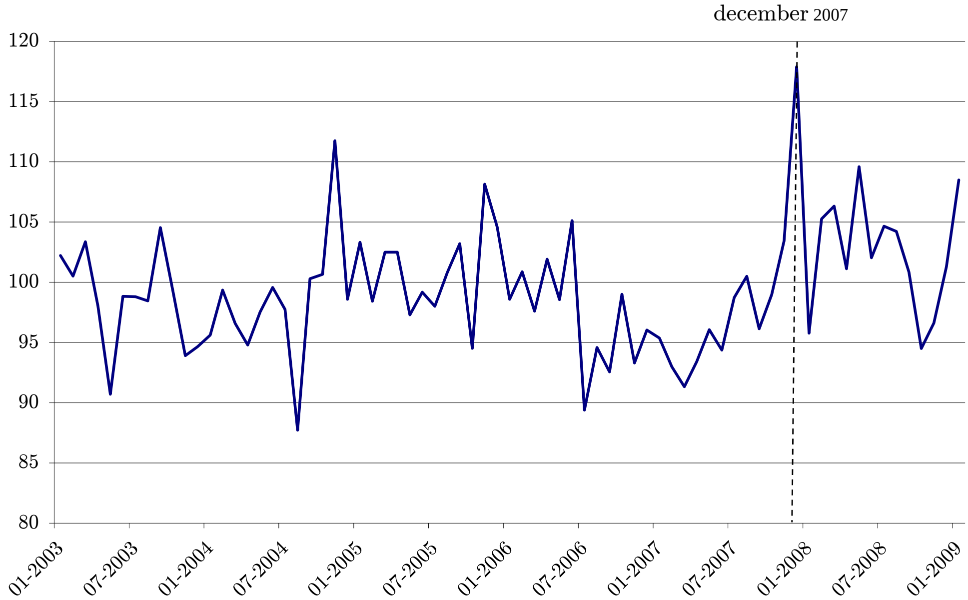
Figure 1: Evolution of the market shares of the different classes of CO_2 emissions.



Sources : dataset on the registration of new cars (CCFA).

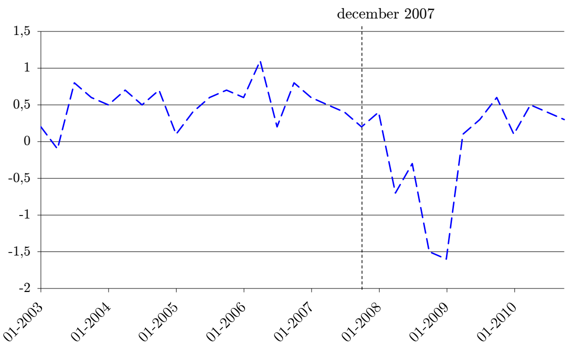
Figure 2: evolution of the average CO_2 emissions of new cars.

Market share variations are quite striking given that the feebate only represents a modest fraction of list prices, around 4.7% for class B and 2.6% for class E-. Reactions of French consumers actually exceeded the forecasts of the French government. While the measure was designed to be neutral for the State budget, it finally cost 285 millions euros in 2008. Part of this unexpected result is due to a sharp increase in the total sales of new cars. A simple comparison of the quarters just before the reform took place (from September to November 2007) and just after (from March to May 2008), shows that total sales increase by around 13.4%. This increase largely exceeds usual seasonal variations in this market and cannot be explained by such effects. When considering the quarter from March to May 2007 instead of the one from September to November 2007, we still observe in our data an increase in sales of 13.8%. When using instead of this raw data a seasonally-adjusted index of purchase of new cars by individuals consumers computed by the national statistical institute (Insee) for the same period, we still observe a sharp increase in 2008 compared to 2007, after the anticipation effect in December 2007 (see Figure 3). This increase in total sales is all the more impressive that this period corresponds to a sharp drop in economic activity and to an important increase in fuel price (see Figures 4 and 5). These two factors are expected to depress, not to boost, the total sales of new cars.



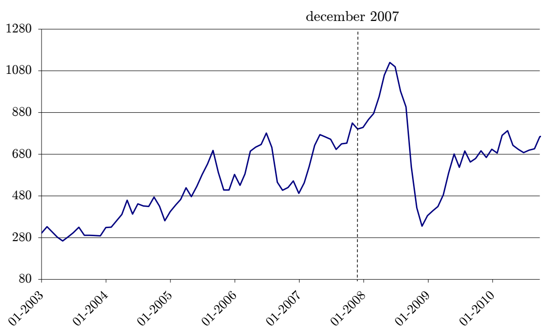
Source : INSEE

Figure 3: Seasonally-adjusted index of the sales of new cars.



Source : INSEE

Figure 4: Quarterly GDP Growth



Source : INSEE

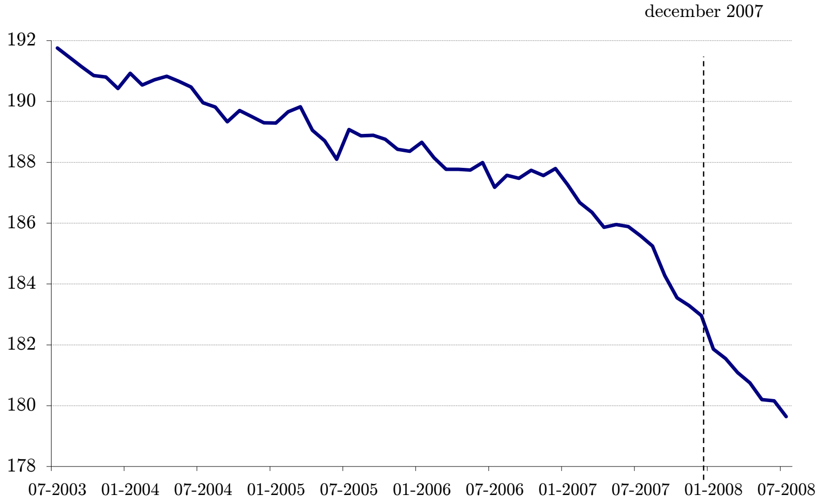
Figure 5: Gasoline Prices evolution (in real terms)

This sharp rise in sales could however be temporary and due to changes in decisions of vehicle replacement. Because of price changes, there may be a decrease in the optimal lifetime of smaller cars and an increase in the optimal lifetime of bigger ones, so that many individuals with small cars find it optimal to replace it at the beginning of the period, while a large part of individuals with bigger cars postpone their replacement. As we look at the effect in sales from March to May 2008, a large part of these adjustments should have already been done, however. This is supported by the fact that we do not observe any rise in the average level of CO_2 emissions a few months after the introduction of the feebate (see Figure 2). Moreover, aggregate data suggest that the potential decrease in automobile lifetimes does not compensate the increase in total sales. For instance, the estimated number of personal cars increases by 225,000 units from 2007 to 2008, while the share of the French households holding at least one car increase from 82.4% to 82.7%.[5]

The exact extent of the supply reaction to the feebate is difficult to assess. Data on the supply of new cars are not available. Several clues indicate that in the first months of 2008 this reaction was small, however. As the policy was announced very lately, manufacturers did not have time before January 2008 to adjust their production to the reform. Even if it is technically possible to modify horsepower (and thus CO_2 emissions) quickly, the vehicle with its new characteristics must be certified before being distributed. This process typically takes several months. More substantial technological changes are likely to take even more time. A rough quantitative analysis of the number of patents on the corresponding domains does not show any particular acceleration during this period.[6] This result is also consistent with the one of Pakes et al. (1993), who observed a two-year shift between the increase in the fuel price following the first oil crisis and the corresponding technical innovations. We also analyze the evolution of average emissions of cars that are sold each month, without weighting each product by their sales to eliminate demand effects. Figure 6 shows an acceleration of technical changes around the beginning of 2007. This may be due to the fact that European Union energy labels became compulsory in May 2006. On the other hand, we do not observe any shock in 2008. Of course, this seemingly absence of manufacturers reaction is plausible only in the short run. An explicit goal of the reform was indeed to stimulate the reduction of CO_2 in a second round, by triggering innovation by manufacturers to produce lower CO_2-emitting cars.

[5]See respectively `http://www.insee.fr/fr/themes/tableau.asp?reg_id=0&ref_id=NATTEF13629` and `http://www.insee.fr/fr/themes/tableau.asp?reg_id=0&ref_id=NATTEF05160`).

[6]According to the European Patent Offices, the patents corresponding to the domains for engine (in the innovation patent classification, F02B, F02D et F02M for fuel engine and B60L for electric ones) does not increase significantly on the considered period.



Sources: dataset on the registration of new cars (CCFA).
Note: we suppose that a model is available for sale at a given month if we observe at least one sale before or at the given month and one sale after or at the given month. To avoid boundary effects (at the beginning or at the end of the period, only vehicles with enough sales are included, and these vehicles tend to have lower CO_2 emissions), we drop the first and last six months.

Figure 6: Evolution of average CO_2 emissions of available models before and after the reform.

3 Decomposition of CO_2 emissions

Vehicles CO_2 emissions depend on the composition of the fleet, on the mileage as well as the emissions due to the production of new cars. We take into account all these elements hereafter in the estimation of short-run and long-run effects of the measure on CO_2 emissions. The first corresponds to emissions between March and May 2008. We focus on this period because, as mentioned previously, January and February are affected by the "undershooting" effects mentioned previously. The long-run effect corresponds to quarterly emissions in a long-run scenario defined below. This effect is probably the most relevant parameter, since in the short run the policy only affects new cars, which represent each month less than 1% of the whole stock of cars. In the long run, with the progressive replacement of the whole stock, the policy is expected to produce more effects. The identification of this impact relies on strong assumptions however.

Let us first define the short-run effect of the policy. Let $d \in \{0, 1\}$ denote the policy status ($d = 1$ if the feebate is introduced, $d = 0$ otherwise) and $Y(d) \in \{0, ..., J\}$ denote the new car chosen by an individual between March and May 2008 with policy status d. As it si usual in the related literature, choice 0 is the outside option, which represents either the non-replacement of an old car by a new one (or its replacement by a second-hand car), or the use of an alternative mean of transportation. For $j \in \{1, ..., J\}$, let $A_j(d)$ denote vehicle j average CO_2 emissions per kilometer. When $j = 0$, average emissions $A_0(d)$ is random and depends on the vehicle the individual already owns. Because we do not have precise information on the emissions stemming from other means of transportation (such as buses or individuals using vehicles they do not own) in the Transportation Survey, we will neglect hereafter average emissions for individuals who do not own a car.

CO_2 emissions depend on the emissions per kilometer of cars chosen by the consumers, but also on average mileage. We define $N_j(d)$ as the mileage done by an individual with vehicle j between March and May 2008.

Finally, we take into account emissions stemming from the manufacturing of new cars, and let M_j denote the emissions of producing car j (so that by definition, $M_0 = 0$). The emissions of an household with policy status d satisfy

$$\text{CO}_2(d) = \mathbb{1}\{Y(d) = 0\}A_0(d)N_0(d) + \sum_{j=1}^{J} \mathbb{1}\{Y(d) = j\}(M_j + A_j(d)N_j(d)).$$

Then the short-run average effect of the policy on total carbon dioxide emissions satisfies

$$\Delta^{SR} = nE\left[\text{CO}_2(1) - \text{CO}_2(0)\right],$$

where n is the number of potential buyers. To take into account heterogeneity among individuals in both the purchase of cars and mileage, we separate individuals according to some observable characteristics X, namely activity, type of geographical area and income (for more details on these variables, see Appendix A.2). Letting $X \in \{1, ..., K\}$, we then have $\Delta^{SR} = \sum_{x=1}^{K} \Pr(X = x)\Delta_x^{SR}$, with

$$\begin{aligned}\Delta_x^{SR} = n\Bigg[& s_{x0}(1)\overline{E}_{x0}(1) - s_{x0}(0)\overline{E}_{x0}(0) + \sum_{j=1}^{J}(s_{xj}(1) - s_{xj}(0))M_j \\ &+ \sum_{j=1}^{J}(s_{xj}(1)A_j(1)\overline{N}_{xj}(1) - s_{xj}(0)A_j(0)\overline{N}_{xj}(0))\Bigg], \qquad (3.1)\end{aligned}$$

where, for $d \in \{0, 1\}$, we let $s_{xj}(d) = P(Y(d) = j|X = x)$, $\overline{E}_{x0}(d) = E(A_0(d)N_0(d)|Y(d) = 0, X = x)$ and $\overline{N}_{xj}(d) = E(N_j(d)|Y(d) = j, X = x)$.

A decomposition of the overall impact helps to better understand the effects at stake. We denote by $\overline{A}(1)$, $\overline{N}_x(1)$ and $\overline{M}$ the average emission of the new cars with the policy, the average mileage done by individuals with characteristics x using new cars with the policy and the average production emissions of these new cars, respectively. We let $\Delta s_{xj} =$

$s_{xj}(1) - s_{xj}(0)$ denote the impact of the policy on the market share of j. From Equation (3.1), we obtain:

$$\begin{aligned}
\Delta_x^{SR} &= n\Big[\underbrace{\sum_{j=1}^{J} \Delta s_{xj}((A_j(1) - \overline{A}(1))\overline{N}_{xj}(1) + M_j - \overline{M})}_{\text{Composition effect}} \\
&\quad \underbrace{+\overline{A}(1)\sum_{j=1}^{J} \Delta s_{xj}(\overline{N}_{xj}(1) - \overline{N}_x(1))}_{\text{Rebound effect}} + \underbrace{(\overline{A}(1)\,\overline{N}_x(1) - \overline{E}_{x0}(1))\sum_{j=1}^{J} \Delta s_{xj}}_{\text{Traveling scale effect}} \\
&\quad + \underbrace{\overline{M}\sum_{j=1}^{J} \Delta s_{xj}}_{\text{Manufacturing scale effect}} \underbrace{+\, s_{x0}(0)\Delta\overline{E}_{x0} + \sum_{j=1}^{J} s_{xj}(0)\Delta(A_j\overline{N}_{xj})}_{\text{Second-order effect}}\Big]. \qquad (3.2)
\end{aligned}$$

The first component corresponds to the change in the composition of new cars in favor of less CO_2-emitting cars. If the policy is well-designed, this component should be negative (thus contributing to a decrease in the overall level of CO_2 emissions). We expect for instance the sales of the less polluting cars, i.e. those for which $A_j(1) - \overline{A}(1) < 0$, to increase, i.e. $\Delta s_{xj} > 0$. These less polluting cars are also smaller in average, so that the average emissions caused by the production of a new car should be smaller, $\Delta s_{xj}(M_j - \overline{M}) < 0$. However, three other effects may mitigate this positive composition effect. The feebate scheme is designed on (easily observed) emissions per mileage $A_j(1)$, but the result also depends on the final use of cars ($\overline{N}_{xj}(1)$). Because of the rebound effect, individuals may increase their mileage as the cost per kilometer of their car decreases. It is thus likely that $\overline{N}_{xj}(1) - \overline{N}_x(1) > 0$ for the less polluting cars. Besides, the decomposition makes it clear that the policy impact depends on a scale effect. If total sales increase because of the policy, the production of these new cars and the corresponding traveling emissions lead to a rise in CO_2 emissions. This is partly, but only partly, offset by the fact that these new cars in excess are used instead of older ones (the term $-\overline{E}_{x0}\sum_{j=1}^{J}\Delta s_{xj}$), and older cars are the higher emitting ones. Finally, the fifth component in the decomposition corresponds to what we call second-order effects. The first term in it corresponds to the change in outside emissions due to the policy. This effect is small in the short run because the composition of the whole stock of cars is hardly affected by the reform after just a few months. The second term corresponds to changes in average emissions of an individual with car j due to the policy. Such a change may be due to a supply side effect ($\Delta A_j < 0$ if manufacturers react to the policy) and a selection effect (individuals who choose vehicle j differ with and without the feebate, so that $\Delta\overline{N}_{xj}$ may change). We however expect the former to be negligible in the short run, and the latter to be small once controlled for observed heterogeneity X.

Let us now turn to long-run effects. In the main specification, we still abstract from supply side effects here. We assume that the automobiles supplied in the long run are those who were already proposed at the beginning of 2008. We also suppose that the sales of new cars and annual mileage remain constant each quarter after the beginning of 2008. Thus, we abstract from potential transitory effects in sales, supposing that sales between March and May 2008 correspond to sales a few months later. As mentioned previously, it is likely that most of transitory effects due to vehicle replacement adjustments have already taken place. With these two assumptions at hand, the only difference with the short-run scenario is that the whole fleet of cars has now been replaced.

Under these assumptions, long-run average effects for group x on quarterly emissions satisfy

$$\Delta_x^{LR} = n\sum_{j=1}^{J}(s_{xj}(1) - s_{xj}(0))M_j + (\widetilde{s}_{xj}(1)A_j(1)\overline{N}_{xj}(1) - \widetilde{s}_{xj}(0)A_j(0)\overline{N}_{xj}(0)), \qquad (3.3)$$

where $\widetilde{s}_{xj}(d)$ denotes the share of individuals of type x equipped with model j with policy status d in this long-run scenario. As previously, we neglect emissions corresponding to other means of transportation here. In a steady-state equilibrium, the share of car j in the whole fleet and its share in the flow of new cars are related by

$$\widetilde{s}_{xj}(d) = T_{xj}(d)s_{xj}(d), \qquad (3.4)$$

where $T_{xj}(d)$ is the average lifetime of vehicle j when bought by individuals of type x under policy status d.

Using $\Delta\widetilde{s}_{xj} = \Delta T_{xj}s_{xj}(1) + T_{xj}(0)\Delta s_{xj}$, (3.3) and (3.4), we obtain as previously the decomposition

$$\begin{aligned}\Delta_x^{LR} = n\Bigg[& \underbrace{\sum_{j=1}^{J}\Delta s_{xj}\left[T_{xj}(0)(A_j(1) - \overline{A}(1))\overline{N}_{xj}(1) + M_j - \overline{M}\right]}_{\text{Composition effect}} + \underbrace{\overline{A}(1)\sum_{j=1}^{J}\Delta s_{xj}T_{xj}(0)\left[(\overline{N}_{xj}(1) - \overline{N}_x(1))\right]}_{\text{Rebound effect}} \\ & \underbrace{+\overline{A}(1)\,\overline{N}_x(1)\sum_{j=1}^{J}\Delta s_{xj}T_{xj}(0)}_{\text{Traveling scale effect}} + \underbrace{\overline{M}\sum_{j=1}^{J}\Delta s_{xj}}_{\text{Manufacturing scale effect}} \\ & \underbrace{+n\sum_{j=1}^{J}s_{xj}(1)\Delta T_{xj}A_j(1)\overline{N}_{xj}(1)}_{\text{Replacement rate effect}} + \underbrace{\sum_{j=1}^{J}s_{xj}(0)T_{xj}(0)\Delta(A_j\overline{N}_{xj})}_{\text{Second-order effect}}\Bigg]. \end{aligned} \qquad (3.5)$$

The change in emissions due to the production of new cars over a quarter is the same as in the short run, whereas the one of the composition effect is far larger, the first term in the brackets being multiplied by $T_{xj}(0)$ (around 80 quarters on average in our sample). This underlines the fact that the whole fleet is replaced in the long run. The rebound effect is also increased by the same scale factor, while the traveling scale effect is multiplied by an even larger one, as it is not mitigated anymore by the fact that in the short run, new cars substitute to older (and thus more polluting) ones. The replacement rate effect corresponds to potential changes in renewal choices. We expect that vehicles with a fee are kept on a longer period than those benefiting from a rebate, so that their share in the whole fleet is larger than their shares in total sales, partially offsetting the impact of the policy (as $\Delta s_{xj} \Delta T_{xj} < 0$). On the other hand, larger average lifetimes means that the increase in total sales due to the policy does not increase that much the share of individuals owning a car, mitigating the traveling scale effects. This replacement rate effect is thus potentially ambiguous.

4 Data

The market shares of new automobile are estimated using the exhaustive dataset on the registration of new cars from January 2003 to January 2009 provided by the Association of French Automobile Manufacturers (CCFA, *Comité des Constructeurs Français d'Automobiles*). It includes all the information that is necessary for the registration of a new car, i.e. some characteristics of the car (brand, model, CO_2 emissions, list prices, type of fuel, number of doors, type of car-body, horsepower, weight and cylinder capacity). This information allow us to define the products at a detailed level. As usually, we define a product by a set of characteristics, here the brand, the model, the type of fuel, the type of car-body (urban, station wagon, convertible, etc), the number of doors and its class of CO_2 emissions (see the Appendix for a discussion). With this definition at hand, we observe 950 different products (see Table 2) for the period between September and November 2007.

Table 2: Number of products and sales between September and November 2007

	Models	Number of sales
Overall	950	239,606
By number of doors		
3	182	42,704
5	499	168,949
Others	269	27,953
By type of car-body		
Station wagon	234	28,446
Convertible	83	6,611
Urban	626	204,538
Disabled	7	11
By type of fuel		
Gasoline	453	80,390
Diesel	497	159,216

Sources: dataset on the registration of new cars (CCFA).

The dataset on the registration of new cars includes the list prices provided by manufacturers. We do not use them hereafter, however. In the French automobile market almost all dealers negotiate prices individually with customers. List prices are thus not reliable proxies for transaction prices, as the measurement error can be correlated with individual heterogeneity. Besides, list prices are typically modified once a year only. It is thus likely that many list prices were not adjusted yet to the reform at the beginning of 2008. This is supported in our dataset, where no clear pattern in the evolution of lists price emerges (see Table 13 in Appendix A.1). We do not observe systematic differences between classes of emissions in the evolution of list prices at the period of the reform, though the feebate policy should lead to an increase in list prices (excluding the feebate) for cars benefiting from rebates and a decrease for those with fees.

The French new cars registration dataset does not only provide information on the car but also on its owner. This is a considerable advantage to take into account the heterogeneity in taste of customers for differentiated products. We observe the professional activity, age and the city in which the owner lives. Based on this information, we define 20 groups of customers according to their participation to the labor market, the type of area in which they live (urban or rural) and their income group (5 groups). This last information comes from the French income tax data, which provide the distribution of income by age class at the city level. We impute to each purchaser the median income of his age class in his city, using fiscal data.[7] Table 14 in Appendix A.2 displays the average characteristics of new car purchasers in terms of age, income, rate of activity and type of location computed from the Transportation Survey. Not surprisingly, these individuals are on average older, belong to richer households and work more often than the rest of the population, underlining the importance of accounting for consumers' heterogeneity.

Finally, mileage is measured using the Transportation Survey conducted by the French national institute of statistics (INSEE) in 2007. This survey provides detailed information about individuals traveling (in particular the annual mileage of their car) and on the characteristics of their vehicles, such as their type of fuel, weight or average CO_2 emissions. Table 3 displays the average mileage of cars depending on their characteristics and those of the owners. Results confirm the importance of taking the heterogeneity in the yearly mileage into account. Drivers who choose a heavy (and thus large) car, or those who choose a diesel one, make much more kilometers per year than the others. People with high income, people who work and those who live in rural areas also use their car more intensively.

[7]The median income is available only for cities with more than 50 households. It is decomposed by age for cities with more than 10,000 inhabitants. If the buyer live in a city with less than 10,000 inhabitants, or if his/her age is unknown, we impute the median income of the city. Sales to individuals living in less than 50 households cities (5% of the data) have been dropped.

Table 3: Average yearly mileage (in kilometers) as a function of the characteristics of the owner or of the car.

Variable	Yearly mileage (kms)
Weight (in kilograms)	
Less than 900	11,073
Between 900 and 1,100	12,156
Between 1,100 and 1,300	15,228
More than 1,300	17,747
Type of fuel	
Gasoline	10,114
Diesel	17,193
Household income	
First quintile	11,585
Second quintile	12,368
Third quintile	13,720
Fourth quintile	15,138
Fifth quintile	15,428
Type of Area	
Rural and suburban	15,108
Urban	13,024
Activity	
working	15,886
non working	10,584

Sources: Transportation survey 2007 (INSEE).

5 The identification strategy

As the decomposition (3.2) makes it clear, the identification of short-run effects requires to recover the market shares, average mileage and outside emissions that would have prevailed in the absence of the policy. For that purpose, we rely on a simple model that clarifies the link between mileage, cost of traveling and cars choice. We also impose a nested logit specification for modeling market shares. Identification is then achieved, basically, by using shifts in the market shares following the introduction of the feebate, assuming that apart from their price, the characteristics of cars were not affected by the policy in the short run. The identification of long-run effects also requires lifetimes of vehicles with and without the policy. We adjust cars lifetime using a simple model of replacement rate.

5.1 Average mileage

To model rebound effects but also the effect of the policy on market shares, we consider a model that links car choice and mileage, taking consumers' heterogeneity into account. The indirect utility of individual i with characteristics $X = x$ and income y_i, when choosing vehicle j and anticipating to travel N kilometers a year, is supposed to satisfy[8]

$$U_i(j, N) = N^{\frac{\gamma_x}{\gamma_x - 1}} \alpha_x + \left(y_i - p_j - \frac{c_j N}{r_x} \right) \beta_x + e_{ij}, \tag{5.1}$$

where p_j is the transaction price of vehicle j (including the feebate if there is one), c_j is the anticipated cost per kilometer of vehicle j, r_x denotes the discount rate and e_{ij} represents the valuation by the individual of observable and unobservable characteristics of vehicle j. The indirect utility of not buying a new car (the outside option 0) writes similarly with $p_0 = 0$. We suppose that $0 < \gamma_x < 1$ and $\alpha_x < 0$, so that utilities are increasing, concave functions of N. The dependence in x of (β_x, γ_x, r_x) reflects the heterogeneity in the way people value the corresponding characteristics of the car.

Individuals are supposed to maximize their utility both in N and j. For a given j, the optimal anticipated mileage N^*_{ij} satisfies

$$N^*_{ij} = \left(\frac{\beta_x (\gamma_x - 1) c_j}{r_x \alpha_x \gamma_x} \right)^{\gamma_x - 1}. \tag{5.2}$$

This relationship highlights rebound effects. As soon as $\gamma_x < 1$, individuals will increase their mileage following a reduction of the cost per kilometer of their car.

This equation cannot be used directly to estimate the parameters for two reasons. First, actual and anticipated mileage differ in general. We suppose hereafter that the two are related by a possibly group-specific constant and an error term. Second, we need to specify the anticipated cost per kilometer. We assume that when purchasing a vehicle consumers made very simplistic expectation on future gasoline price. This is consistent with recent empirical results. For instance, Anderson & Sallee (2011) using US data on consumer expectation on gasoline prices show that consumer beliefs are indistinguishable from a no-change forecast.

Assumption 5.1 *(Link between anticipated and actual mileage) The actual mileage for i at date t, N_{it}, satisfies*

$$\ln N_{it} = \ln N^*_{iY_{it}(d)t} + \widetilde{\delta}(X_i) + \nu_{it},$$

[8] This model is close to standard models of vehicle choice (see, e.g., Berkovec & Rust, 1985, or Goldberg, 1995), except that we also take into account mileage here.

where ν_{it} is independent of $Y_{it}(d)$ conditional on X_i, $E(\nu_{it}|X_i) = 0$ and the distribution of ν_{it} does not depend on t.

Assumption 5.2 *(Anticipated costs) We have $c_{jt} = p_{f_j t} A_j$, where $p_{f_j t}$ denotes the price of the type of fuel f_j at t.*

The important restrictions in Assumption 5.1 are that the distribution of the error term does not depend on t, and is independent of the car choice and the cost per kilometer. As a consequence, the average mileage $\overline{N}_{xjt}$ for car j is only determined by the cost per kilometer and does not depend on the policy. This means that we neglect selection effects here. For instance individual who travel more may choose a higher fuel economy vehicle. Our cross-sectional estimation can thus overestimate the rebound effect. We come back to this issue in Subsection 6.3.

Assumptions 5.1 and 5.2 lead to

$$\ln N_{t_0} = \delta(X_i) + (\gamma_x - 1) \ln c_{t_0} + \nu_{t_0}, \tag{5.3}$$

which can be estimated by OLS. The parameters will then provide us with a measure of the average mileage by type of individual x using a vehicle j at the time t_1, $\overline{N}_{xjt_1}$, since (see Appendix A.4 for the proof)

$$\overline{N}_{xjt_1} = E\left(\exp(\nu_{t_0})|X = x\right) \exp(\widetilde{\delta}_x) c_{jt_1}^{(\gamma_x - 1)}. \tag{5.4}$$

5.2 Market shares

Plugging N^*_{ij} into (5.1) and letting $\mu_x = \frac{\alpha_x}{\gamma_x - 1}\left(\frac{\beta_x(\gamma_x - 1)}{r_x \gamma_x \alpha_x}\right)^{\gamma_x}$, the utility of choosing j is equal to

$$U_i(j) \quad = \quad (y_i - p_j)\, \beta_x - c_j^{\gamma_x} \mu_x + e_{ij}. \tag{5.5}$$

Let us write $e_{ij} = \xi_{xj} + \eta_{ij}$, where ξ_{xj} denotes the average valuation of observable and unobservable characteristics of the car by group x and η_{ij} is an individual-specific tastes for j. To get realistic vehicle quantities patterns, while keeping the model simple to estimate, we rely on a nested logit assumption on the $(\eta_{ij})_{j=1...J}$. The first nest is the set of all new cars, while the second corresponds to the outside option. The underlying idea is that consumers first choose to buy a new car or not, and then, in the first case, select a model (see for instance Gowrisankaran & Rysman, 2011, for a similar sequential choice for a durable good). An advantage of this model is that it can be estimated very simply. A standard alternative is random coefficient models (see Berry et al., 1995), which is popular since it allows for heterogeneity of purchasers even when no information on these purchasers is available. Here, we already capture heterogeneity in consumers preferences since our data allow us to estimate different models for each kind of consumers. Besides, even if we consider a basic segmentation of the cars' market, we fit quite accurately the observed markets shares, as shown in Subsection 6.1.

Our nested logit specification leads to the simple market-level relationship between equilibrium vehicle prices, market shares, and gasoline costs at period t:

$$\ln(s_{xjt}) = \frac{1}{1-\sigma_x}\left[\ln(s_{x0t}) - \sigma_x \ln(1-s_{x0t}) - p_{jt}\beta_x - c_{jt}^{\gamma_x}\mu + \xi_{xjt}\right].$$

Estimating this equation by OLS is problematic for at least two reasons. First, it is likely that ξ_{xjt} is correlated with prices even once controlled for observable characteristics, since ξ_{xjt} includes for instance unobservable car quality. To get rid of fixed effects, we time-differentiate the log market shares of the quarters September-November 2007 and March-May 2008.[9] These two quarters correspond to periods just before and after the introduction of the policy. As mentioned already, it is unlikely that the manufacturers have adjusted their cars' supply so fast. Thus, most of the observed change can be attributed to price changes following the feebate, or specific effects of the feebate itself through consumers' valuation of CO_2 emissions for instance. Formally, we make the following assumption.

Assumption 5.3 *(No short-run effect of the feebate on cars characteristics apart from price) For all x, j, ξ_{xjt}, A_j and c_{jt} are not affected by the feebate policy.*

The second issue is that we do not observe transaction prices but list prices, which, as indicated before, do not seem very reliable. Moreover, measurement errors are likely to be nonclassical, as they may be correlated with feebates. Thus, usual instruments such as the sum of characteristics of the other products may fail in this context. To solve this issue, we posit the following flexible model on transaction prices.

Assumption 5.4 *(Dependence of transaction prices on the feebate scheme)*

$$p_j(1) = p_j(0) + f_1(Z_j) + f_2(\widetilde{Z}_j), \tag{5.6}$$

where $f_1(0) = f_2(0) = 0$.

[9]December 2007 as well as January and February 2008 are excluded from estimation to avoid to capture the anticipations or undershooting effects described in the Subsection 2.2

Z_j is the fee of vehicle j if under the feebate policy ($Z_j < 0$ if j benefits from a rebate, and $Z_j = 0$ without the feebate policy) and $\widetilde{Z}_j$ is the sum of fees of vehicles produced by the firm that produces j. Equation (5.6) captures the fact that when fixing price of j so as to maximize its profit, the firm should take into account its effect on the profit stemming from j but also from the other cars it produces.

The idea is then to replace transaction prices by their expression in (5.6). This strategy is convenient as it is both very easy to estimate and does not require any instrument, provided that the following condition holds.

Assumption 5.5 *(Exogenous residuals in market shares and no systematic trend in the short run)* $E(\varepsilon_{xj}|Z_j, \widetilde{Z}_j, c_{jt_1}, c_{jt_0}) = 0$, *where* $\varepsilon_{xj} = \xi_{xjt_1} - \xi_{xjt_0} + (p_{jt_1}(0) - p_{jt_0}(0))\beta_x$ *and* t_1 *(resp.* t_0*) refers to the quarter between March and May 2008 (resp. between September and November 2007).*

The residual ε_{xj} can be interpreted as the evolution, for a constant fuel price, of the valuation of vehicle j if the feebate had not been introduced. Assumption 5.5 states that this evolution is unrelated to its feebate and its cost per kilometer. It also rules out potential seasonal effects. We provide a robustness check of this assumption in Subsection 6.3.

Finally, we show in Appendix A.4 that under a linear specification, the change in log market shares just before and after the feebate can be approximated by

$$\ln(s_{xjt_1}/s_{xjt_0}) = \ln\left(\frac{1 - s_{x0t_0}}{1 - s_{x0t_1}}\right) x'\lambda + \sum_{l=1}^{7} \mathbb{1}\{Z_j = z_l\}\theta_l + \widetilde{Z}_j\kappa - \left(c_{jt_1}^{\gamma_x} - c_{jt_0}^{\gamma_x}\right)\widetilde{\mu}_x + \varepsilon_{xj}, \quad (5.7)$$

where $(z_l)_{l=1...7}$ denote the different nonzero possible values of the feebate. By Assumption 5.5 and because the parameter γ_x is already estimated by the mileage equation (5.3), we can identify by simple OLS these parameters. In turn, these coefficients allow us to recover the counterfactual market shares at period t_1, $s_{xjt_1}(0)$, viz. the market shares that would have prevailed without the feebate policy (see Equation (A.4) in Appendix A.4).

5.3 Outside emissions

As the decomposition (3.2) makes it clear, the short-run emissions of CO_2 depend on the emissions of the outside option, namely those of individuals who decide not to buy a new car. Total emissions corresponding to this option depend on the share of individuals who do not have a car, and on the distribution of average emissions on the stock of existing cars.

In the short run, the counterfactual outside option for the quarter March-May 2008 can be consistently estimated from measures observed at the end of 2007, apart from a rebound effect due to change in energy prices during this period. The other issue is that we do not observe the true outside emissions that prevail at the beginning of 2008. However, it is likely that in the short run, the stock of existing is only very marginally affected by the policy. This is the substance of Assumption 5.6 below. We let hereafter $F_{0t}(d)$ denote the type of fuel of the car owned by an individual when choosing the outside option ($F_{0t}(d) = 2$ for a gasoline car, 1 for a diesel one and 0 if the individual does not have a car).

Assumption 5.6 *(No short-run effect of the policy on the stock of existing cars) For all i, the distribution of $(A_{0t}(d), F_{0t}(d))$ conditional on $Y_{0t}(d) = 0$ does not depend on d and t.*

This assumption is very likely in the short run, as the policy only affects new cars. Under Assumption 5.6, we get (see Appendix A.4)

$$\overline{E}_{x0t_1}(0) = \overline{E}_{x0t_1}(1) = I_1^{\gamma_x - 1} P(F_{0t_0}(0) = 1)\overline{E}_{x0t_0,1}(0) + I_2^{\gamma_x - 1} P(F_{0t_0}(0) = 2)\overline{E}_{x0t_0,2}, \qquad (5.8)$$

where I_f is the ratio between fuel price of type $f \in \{1, 2\}$ at period t_1 and at period t_0, and $\overline{E}_{x0t_0,f}(0)$ are the average outside emissions for individuals such that $F_{0t_0}(0) = f$:

$$\overline{E}_{x0t_0,f}(0) = E(A_{0t_0}(0)N_{0t_0}|Y_{t_0}(0) = 0, X_{t_0} = x, F_{0t_0}(0) = f).$$

5.4 Long-run effects

The identification of the long-run effects of the policy requires stronger restrictions. As explained above, it depends on the long-run shares of individuals equipped with model j with policy status $d \in \{0, 1\}$, namely $\widetilde{s}_{xjt_1}(d)$. This notably depends in turn on the average lifetime of vehicle j when bought with individuals of type x.

Unfortunately, as far as we know, no French data provide recent information on cars lifetime. As a result, we have to make quite restrictive assumptions. The first is that we posit a constant average lifetime across vehicles before the introduction of the feebate, $T_{xjt_0} = \overline{T}_{t_0}$. In this case $\widetilde{s}_{xjt_0} = \overline{T}_{t_0} s_{xjt_0}$ for all $j \geq 0$, so that by summing over j, we have

$$\overline{T}_{t_0} = \frac{1 - \widetilde{s}_{0t_0}}{1 - s_{0t_0}},$$

and we can recover $\overline{T}_{t_0}$ using the Transportation Survey. Our computation gives us an average value of around 80 quarters, consistent with the official statistics (the monthly flow of new cars represents 0.5% of the stock of cars less than 15-year old, leaving us with an estimated value of 67 quarters).[10] We also assume that average lifetimes at t_1 without the policy would have remained the same as in t_0, so that $T_{xjt_1}(0) = \overline{T}_{t_0}$.

To compute lifetimes with the policy $T_{xjt_1}(1)$, we consider a model derived from Engers et al. (2009). Let us assume that at a quarter k (the purchase of the car occurring at period t), a car can either be sold on the second market at price $\widetilde{p}_{jt+k}$ or kept, generating a current net surplus of v_{jt+k}. The value W_{jt+k} of a car j of age k then satisfies the simple relation:

$$W_{jt+k} = \max\{v_{jt+k} + \rho W_{jt+k+1}, \widetilde{p}_{jt+k}\},$$

where ρ denotes the quarterly discount factor. Supposing that prices perfectly adjust at equilibrium, we get

$$\widetilde{p}_{jt+k} = \max\{\widetilde{p}_{jt+k+1}, s_j\},$$

where s_j represents the scrapping value of car j. As shown by Engers et al. (2009), the consumer keeps the car while its price remains above the scrapping value. Let us define by T_{jt} this final period. We assume that the current net surplus decreases at a constant rate r over time, so that $v_{jt+k} = v_j r^k$. We then get the following system:

$$\widetilde{p}_{jt+k} = \begin{cases} v_j r^k + \rho \widetilde{p}_{jt+k+1} & \text{if } 0 \leq k < T_{jt}, \\ s_j & \text{if } k = T_{jt}. \end{cases}$$

After a little algebra,

$$p_{jt} = v_j \frac{1 - (\rho r)^{T_{jt}}}{1 - \rho r} + r^{T_{jt}} s_j. \tag{5.9}$$

For standard values of s_j (i.e., between 0 and 200 euros), the second term in the right-hand side is negligible. Writing Equation (5.9) with and without the policy, we obtain $T_{jt_1}(1)$ as a function of $T_{jt_1}(0)$:

$$T_{jt_1}(1) = \frac{\ln\left[1 - \left(1 - (\rho r)^{T_{jt_1}(0)}\right) \frac{p_{jt_1}(1)}{p_{jt_1}(0)}\right]}{\ln(\rho r)}.$$

This equation shows that individuals choosing vehicles benefitting from a rebate (so that $p_{jt_1}(1) < p_{jt_1}(0)$) tend to replace their vehicle more often ($T_{jt_1}(1) < T_{jt_1}(0)$). Basically, this is because the value of the vehicle reaches more quickly its scrappage value, as the vehicle is initially cheaper. In the right-hand side, we approximate the car price without the policy by the observed price minus the malus, $p_{jt_1}(0) \simeq p_{jt_1}(1) - Z_j$. The importance of the

[10] Official statistics are available for cars less than 15-year old only, and are not restricted to cars owned by households, both leading probably to a negative bias of the true lifetime we aim to estimate.

adjustment also depends on the quarterly discount factor r of individuals (supposed to be independent of x here), the (quarterly) depreciation rate in the utility flow corresponding to the use of a vehicle, r, and sale prices $p_{jt_1}(d)$. In practice, we set $r = \rho = 0.987$, corresponding to an annual interest rate (resp. depreciation rate) of 5%.

6 The results

6.1 Estimation of the mileage and market share equations

This subsection presents details on the estimates of the mileage and market shares equations. We first present results from the estimation of Equation (5.3), which relates the mileage to the characteristics of households and vehicles. These estimates are used to compute average mileage (see Equation (5.4)), average outside emissions (see Equation (5.8)). It is also used to get an estimate of γ_x that is used to measure the sensitivity to market shares to the cost of travelling (see equation (5.7)). The results of Equation (5.3) are displayed in Table 4.

Table 4: Estimates of the mileage model (log) according to households characteristics and cost per kilometer.

Variables	Estimate
Intercept	10.44^{***} (0.191)
Non working	-0.364^{***} (0.015)
Rural and suburban area	-0.013 (0.014)
Income in 2nd quintile	0.077^{***} (0.027)
Income in 3rd quintile	0.141^{***} (0.025)
Income in 4th quintile	0.21^{***} (0.024)
Income in 5th quintile	0.245^{***} (0.024)
Cost per kilometer ($\gamma - 1$)	-0.536^{***} (0.027)

Sources: Transportation Survey 2007 (INSEE).
Reading note: Mileages are computed on the whole 2007 year. Significance levels: *** 1%, ** 5%, * 10%.

We thus obtain $\widehat{\gamma} - 1 \simeq -0.54$. To compare this estimate with previous results, mostly based on variations in fuel price (either with macro or micro data), recall that the actual cost per kilometer satisfies $c_{Y_{it}t} = f_{Y_{it}t}A_{Y_{it}t}$, where f_{jt} is the fuel price for vehicle j at date t. A change in the fuel price induces both a modification of $c_{Y_{it}t}$ and $A_{Y_{it}t}$, because individuals may change their car according to fuel price fluctuations. Thus, by Equation (5.3), and letting ε_N (resp. ε_A) denote the price elasticity of mileage (resp. of average emissions per kilometer), we get

$$\gamma - 1 = \frac{\varepsilon_N}{1 + \varepsilon_A}.$$

We thus expect $\gamma - 1$ to be smaller in absolute value than the price elasticity of fuel consumption, which is equal to $\varepsilon_N + \varepsilon_A$. Our results are consistent with this prediction, the usual estimates of the long-run elasticities lying between -0.8 and -0.6 (see, e.g., Graham & Glaister, 2002, for a survey).[11] Interestingly, it is also very close to the estimates given by Johansson & Schipper (1997), who separately estimate ε_N and ε_A on 12 OECD countries and obtain for France $\varepsilon_N = -0.33$ and $\varepsilon_A = -0.38$, leading to $\varepsilon_N/(1 + \varepsilon_A) \simeq -0.53$.

We then estimate the reduced form of our nested logit model, using Equation (5.7). Results are displayed in Table 5. As expected, market shares of vehicles benefiting from a bonus increase at the expense of those affected by a penalty. The penalty effect is actually more pronounced for classes E+ and E- than for classes F and G, which may seem surprising. This suggests that these coefficient do not only reflect price effects, but also environmental concerns by the consumers. Classes F and G only correspond to very large cars, for which consumers were probably already aware of their environmental effect, whereas the introduction of the feebate may have acted as a negative environmental signal for cars in class E. Finally, and as expected, the estimated coefficient of the cost per kilometer is significant and negative (-3.76).

[11] These estimates are usually obtained on macro data. Noteworthy, our result is also smaller in absolute value than the price elasticity obtained on micro data by Clerc & Marcus (2009) in France, namely -0.70.

Table 5: Impact of the feebate on market shares (OLS estimates of Equation (5.7)).

Parameter	Estimate
Substituability terms (λ)	
Intercept	2.035^{***} (0.258)
Non working	-0.0001 (0.133)
Rural and suburban area	0.315^{**} (0.13)
Income in 2nd quintile	0.092 (0.215)
Income in 3rd quintile	-0.138 (0.207)
Income in 4th quintile	-0.042 (0.209)
Income in 5th quintile	0.406^{*} (0.212)
Other terms	
Cost per kilometer	-3.763^{***} (0.141)
Rebate = 1.000 €	0.3847^{*} (0.2086)
Rebate = 700 €	0.6982^{***} (0.0292)
Rebate = 200 €	0.0113 (0.0288)
Fee = 200 €	-0.257^{***} (0.0374)
Fee = 750 €	-0.2808^{***} (0.0221)
Fee = 1.600 €	-0.1484^{***} (0.0328)
Fee = 2.600 €	-0.1468^{***} (0.0491)
Sum of fees of the firm	0.003^{***} (0.0004)

Sources: dataset on the registration of new cars (CCFA).
Reading notes: significance levels: *** 1%, ** 5%, * 10%.

The model reproduces quite accurately the market shares observed in 2007 (see Table 6). We observe slight (but not significant) differences for some classes, as the model indicates that the share of classes C+ and D would also have increased, absent the reform. On the other hand, the share of the most polluting cars would have decreased. Such predictions are consistent with the sharp increase in fuel price observed at the beginning of 2008 (the gasoline price was for instance 15% higher than in September-November 2007). Overall, the average gain in terms of CO_2 emissions of new vehicles is equal to 3.9%, which perfectly matches the observed gain on our subsample. Another important indicator to look at is the prediction of the model on global sales. According to our estimates, the policy has increased sales by 13.2%. This effect is substantial, and consistent with the empirical evidence that show an increase in sales of 13.4% between September-November 2007 and March-May 2008 (see Subsection 2.2). It will prove to have large consequences on the effect of the policy on total emissions.

Table 6: Comparison between the observed market shares and those predicted by the model (%).

Class	Observed in 2007	Prediction (without bonus)
A	0.02	0.02 (0.03)
B	21.56	21.35 (4.19)
C-	11.39	11.66 (2.78)
C+ and D	48.84	50.95 (5.53)
E-	2.61	2.01 (0.63)
E+	12.87	11.92 (2.06)
F	1.98	1.56 (0.36)
G	0.72	0.53 (0.17)
Total	*100.00*	*100.00*

Sources: dataset on the registration of new cars (CCFA) and authors' computations

Reading notes: the market shares do not include the outside option and thus sum to 100%. Standard errors were computed by bootstrap (with 1,000 simulations).

6.2 Effect on CO_2 emissions and decomposition

The overall effects of the policy, both in the short and long run, are displayed in Table 7, while the decomposition of these effects are presented in Table 8. Emissions stemming from the manufacturing of new cars were computed by assuming that the production of a new car generates 5.5 tons of CO_2 per ton of new vehicle, following the carbon assessment of the French agency for environment (see ADEME, 2010).

In the short run, the composition effect of the change in the composition of the new cars' sales reaches approximately -80.4 kilotons of quarterly CO_2 emissions, well above (in absolute value) the rebound and traveling scale effects. Hence, the measure would have been positive without the manufacturing effects. However, this latter effect dominates in the short run, representing around 232.1 kilotons of quarterly CO_2 emissions. As a result, we obtain a significant increase in the short run of around 168.4 kilotons per quarter. With a cost of the ton of CO_2 fixed at 32 euros (consistent with the meta-analysis of Yohe et al., 2007), the overall environmental short-run cost of the measure would reach 5.4 million euros per quarter.

Table 7: Short and long-run effect of the feebate policy.

Parameter	Estimates		
	Kilotons	Million of euros	% of total emissions
Short-run effect Δ^{SR}	168.4^{***} (52.4)	5.4^{***} (1.7)	$1.2\%^{***}$ (0.4%)
Long-run effect Δ^{LR}	$1,029.8^{***}$ (365.7)	33^{***} (11.7)	$9.3\%^{***}$ (3.5%)

Sources: Transportation Survey 2007 (INSEE) and dataset on the registration of new cars (CCFA).

Note: we consider a price of 32 euros for a ton of CO_2. Standard errors were computed by bootstrap (with 1,000 simulations). Significance levels: *** 1%, ** 5%, * 10%.

As expected, we obtain far higher effects in the long run. When ignoring the potential impact of the feebate on cars lifetime, the impact on quarterly emissions is higher by a factor 9. While in the short run, the main component of the negative impact is the manufacturing emissions, traveling emissions predominates in the long run. Once more, this is due to the increase in overall sales. As a result, we estimate that the introduction of the feebate accounts for an increase of 13.7% in total automobile emissions.

Table 8: Decomposition of the short and long-run effects.

	Estimates (kilotons)	
Parameter	short run	long run
Composition effect	-80.4^{***} (16.1)	-895.0^{***} (184.7)
Rebound effect	6.1^{***} (1.5)	496.0^{***} (119.4)
Traveling scale effect	10.4^{***} (2.8)	$1,691.0^{***}$ (448.0)
Manufacturing scale effect	232.1^{***} (61.1)	232.1^{***} (61.1)
Replacement rate effect		-495^{***} (123.1)

Sources: Transportation Survey 2007 (INSEE) and dataset on the registration of new cars (CCFA).

Note: we consider a price of 32 euros for a ton of CO_2. Standard errors were computed by bootstrap (with 1,000 simulations). Significance levels: *** 1%, ** 5%, * 10%.

Our results also indicate that taking into account lifetime adjustments can have important effect, but not that large that they would change our assessment on the policy. With our calibration, we obtain consequent lifetime changes, the average lifetime of class B vehicles decreasing by 14% while the one of class G cars increasing by 23%. For instance, starting from a lifetime of 20 years without the reform, we obtain a lifetime of around 17 years for a class B vehicle with initial price $p_{jt_1} = 12,000$ euros, and of 30 years for a class G vehicle taxed by 2,600 euros with initial price $p_{jt_1} = 30,000$ euros. These modifications do not alter our basic conclusion, however. We still predict an increase of quarterly emissions, even if this increase is reduced by one third (1,029.8 Kilotons of CO_2). This reduction mostly stems from the fact that the average lifetime over the whole stock decreases. As a result, the policy would lead in this scenario to a 8.4% increase of the whole stock, far smaller than the 13.2% increase corresponding to the previous scenario.

Our model allows us to identify the effect of feebate schemes that differ from the one implemented in 2008. Recall however that to be as flexible as possible, we specify in the market shares' model the effect of the feebate as a sum of indicators. Thus, we cannot identify the effect of counterfactual feebate schemes with values of fees that do not exist in 2008, viz. values outside the set $\{-1,000, -700, -200, 0, 200, 750, 1,600, 2,600\}$. But we can shift these values to different classes of emissions. We compute in Table 9 below the effect of a feebate scheme where all rebates are shifted compared to the 2008 ones (700 €

instead of 1,000€ for class A-, 200€ instead of 700€ for class B and 0€ instead of 200€ for class C+). This scheme may be seen as an intermediary between those implemented in 2010 and 2011. Such a scheme would have led to a reduction in average CO_2 emissions in the long run when taking into account renewal effects. This is mainly due to the fact that total sales do not increase much in this scenario. As a result, the traveling scale effect is sharply reduced. As most of the parameter estimates, the estimate of Δ^{LR} is not significantly different from zero, however.

Table 9: Long-run effects of an alternative feebate scheme.

Parameter	Estimates (kilotons)
Composition effect	-155.0 (169.7)
Rebound effect	73.0 (112.4)
Traveling scale effect	210.5 (434.4)
Manufacturing scale effect	28.9 (59.4)
Replacement rate effect	-201.0^{*} (112.0)
Long-run effect Δ^{LR}	-43.8 (377.8)

Sources: Transportation Survey 2007 (INSEE) and dataset on the registration of new cars (CCFA).

Note: standard errors were computed by bootstrap (with 1,000 simulations). Significance levels: *** 1%, ** 5%, * 10%.

6.3 Robustness checks

Our results suggest that the feebate policy actually increases CO_2 emissions. These results are provocative, so it seems important to check their sensitivity to our underlying assumptions. First, and as stated before, we restrict the estimation periods to months around the introduction of the feebate policy in order to avoid changes in the supply induced by the policy and dramatic modifications of the macroeconomic situation. As a result, however, we may capture seasonal effects. Sales in the automobile market are cyclical, and if these cyclical effects vary with the type of cars, the dummies measuring the emission classes Z_j in Equation (A.3) will capture part of these seasonal effects. To assess the importance of these effects, we perform a falsification test using the 2006-2007 period instead of 2007-2008. More specifically, we make as if the measure had been adopted in 2007 instead of

2008, falsely attributing the corresponding feebates to cars in 2007. Without seasonal effects, the coefficients corresponding to the emissions classes should be equal to zero. Table 10 shows that their estimates are far smaller than those obtained for 2007-2008, even if several remain significant.[12] For instance the parameter corresponding to the class B is more than 7 times smaller than when comparing 2007 to 2008. Next, computing the short and long-run placebo estimates (Table 11), we obtain estimates not significantly different from zero. The point estimates are respectively -12.5 kilotons and -106.2 kilotons, namely around 10 times lower in magnitude than our estimates on 2007-2008. Hence, seasonal effects do not seem to be a major issue here.

Table 10: Estimates of the demand model on 2006-2007.

Parameter	Estimate
Rebate = 1,000 €	*not identifiable*
Rebate = 700 €	-0.091^{***} (0.027)
Rebate = 200 €	-0.155^{***} (0.025)
Fee = 200 €	0.081^{***} (0.031)
Fee = 750 €	0.074^{***} (0.019)
Fee = 1,600 €	0.047^{*} (0.024)
Fee = 2,600 €	0.123^{***} (0.041)
Sum of fees of the firm	-0.00007 (0.0003)

Sources: dataset on the registration of new cars (CCFA).
Reading notes: OLS estimates of the coefficients on Z_j and $\widetilde{Z}_j$ in Equation (5.7) on 2006-2007. Significance levels: *** 1%, ** 5%, * 10%.

Second, one can question the fact that even in this short amount of time, manufacturers do not react to incentives created by the feebate. We thus simulate a situation where the policy would lead to a 5% reduction of all average emissions. This reduction is very important, as it corresponds to the average decrease in the average CO_2 emissions of new vehicles proposed by manufacturers between January 2003 and July 2008 (see Figure 6). Considering the decompositions (3.2) and (3.5), this reduction decreases of course the composition effects, but also increases the rebound, traveling and manufacturing scale effect. At the end, and as expected, the first effect dominates the others, but our basic conclusion remains unchanged. We obtain an increase of 757 kilotons of CO_2 per quarter

[12] This may be due to long-run evolutions in preferences for low emitting cars among French consumers. See D'Haultfœuille et al. (2010) for a detailed analysis on this issue.

instead of 1,030 in the long run.

Finally, our results are based on an estimate of the price elasticity of miles traveled where households' mileage is regressed on the annual operating cost of their vehicle. This estimate may be biased, for instance because we neglect unobserved heterogeneity in the valuation of mileage (α_x is only group-specific). Households expecting to drive more would probably purchase more efficient cars. To assess how much this bias can alter our final results, we use an alternative specification that neglects this rebound effect in the demand model (5.7), in practice by setting the parameter γ to 1. Results, displayed in Table 11, show that the policy still leads to an increase of CO_2 emissions in the short and long run under this very favorable assumption.

Table 11: Robustness checks: Short and long-run effects on quarterly emissions under alternative assumptions.

Alternative Assumptions	Estimates (in kilotons) Δ^{SR}	Δ^{LR}
Baseline	168.4^{***} (52.4)	$1,029.8^{***}$ (367.3)
Placebo (2006-2007)	-12.5 (26.4)	-106.2 (271.4)
Manufacturers reaction	169.5^{***} (53.4)	757.4^{**} (382.6)
No rebound effect	160.4^{***} (51.9)	734.1^{**} (298.2)

Sources: Transportation Survey 2007 (INSEE) and dataset on the registration of new cars (CCFA).

Note: Standard errors were computed by bootstrap with 1,000 simulations. Significance levels: *** 1%, ** 5%, * 10%.

7 Conclusion

Overall, the impact of the policy is much disappointing. This does not invalidate feebate systems as efficient tools for environmental policy, yet. French consumers have strongly reacted to financial incentives created by the policy. The problem rather comes from the design of this feebate. A crucial parameter of a feebate system is indeed the "pivot point" that divides vehicles charging fees from those receiving rebates, and the rate that specifies the fee or rebate as a function of distance from the pivot point (see Greene et al., 2005). In the French case, it looks like this pivot point was too low. The rebates were also too generous. As our policy exercise shows, a shift in these rebates may easily lead to a decrease in overall CO_2 emissions. As the first-order terms in the policy effects are manufacturing or traveling scale effects, the most important point to ensure a reduction of CO_2 emissions is to calibrate it in order to decrease or keep constant total sales.

One limitation of our study, due to a lack of appropriate data, is that we do not include manufacturers reactions. Even if, as mentioned before, these reactions are unlikely to modify our conclusions, stimulating innovation in favor of less polluting cars was another objective of the measure. We leave the evaluation of these supply-side effects for future research.

A Appendix

A.1 Definition of products

The potential buyers in the automobile markets have different valuation for cars given characteristics such as brand or type of fuel. In practice, a product is defined by a set of characteristics. An important issue is then to choose which characteristics one should keep in this definition. On the one hand, if products are defined with few characteristics, very different items are mixed together, possibly leading to strong aggregation biases if the underlying model of demand is not linear, which is the case here. On the other hand, keeping too many characteristics leads to small market shares for each product, or even null markets shares as exactly similar cars are often not sold each month. The theoretical model presented before links the logarithm of the markets shares with the observed characteristics. Thus, null sales are not used, which leads to a selection bias.[13] As a compromise, we select the brand, the model, the type of fuel, the type of car-body (urban, station wagon, convertible, etc), the number of doors and its class of CO_2 emissions. Thus, we adopt a slightly more restrictive definition of a product than Berry et al. (1995). Even so, the dispersion of the remaining characteristics (such as price) within each product is not that small compared to the overall dispersion (see Table 12). A more restrictive definition of products (by including, e.g., horsepower) would reduce this dispersion but at the cost of increasing the proportion of null sales. Our definition allows us to keep this proportion of null sales relatively small on the whole population of buyers (15% of the models with positive sales between September and November 2007 have not been sold between March and May 2008).

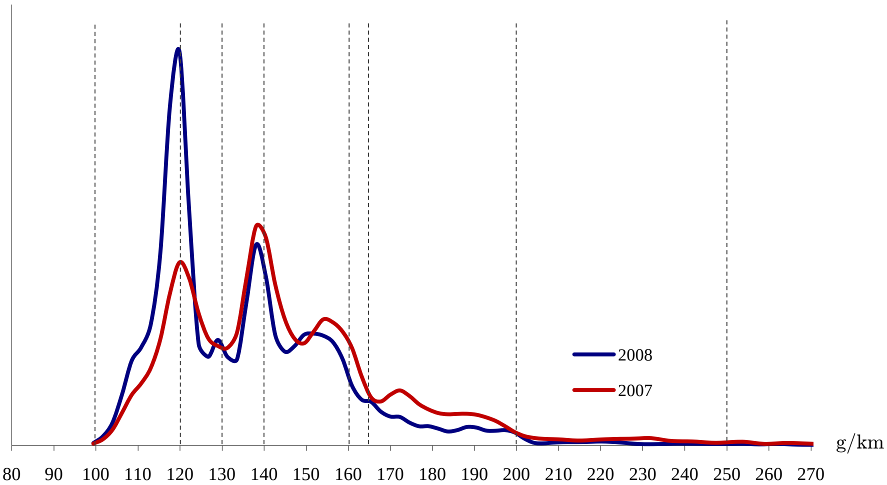
Table 12: Dispersion of prices, CO_2 emissions and fiscal power of new cars registered between September and November 2007

	Overall	Within products
Price (euros)	9,107	1,169
CO_2 (g/km)	27.8	2.4
Taxable horsepower	2.4	0.5

Sources: dataset on the registration of new cars (CCFA).

[13]The existence of null sales is a consequence of the finiteness of the French population, and does not invalidate the model. If the market share of a product is 10^{-9}, it is very unlikely that it is sold during a given quarter in France.

Figure 7 presents the density of average emissions of new cars bought just before and just after the reform. The shifts have mainly been towards the most polluting models of the lower classes. We also see that these threshold effects already existed before the introduction of the feebate. This may be due to the fact that consumers value energy classes *per se*. Since May 2006, manufacturers have to display the European Union energy labels indicating the energy class of their new cars, so that these classes were known by the consumers in 2007. It may also stem from the pre-existing taxation of company cars, already based on these classes since 2006. Car manufacturers thus already had the possibility to adapt their products to this classification.



Sources: dataset on the registration of new cars (CCFA)
Note: Dashed lines correspond to the thresholds in emision classes

Figure 7: Density of average CO_2 emissions of new cars sold in 2007 and 2008.

Table 13: Evolution of average prices (in %) before and after the reform.

Class of CO_2	2003	2004	2005	2006	2007	2008
B	0.32	-1.16	1.92	1.03	-0.22	1.60
C+	-1.36	2.01	2.79	-0.28	0.71	1.81
C- and D	0.76	0.88	1.78	1.39	-0.01	0.77
E+	0.55	0.16	0.37	0.44	0.74	0.54
E-	0.75	0.99	0.04	0.49	0.75	0.98
F	0.62	-0.14	0.48	-0.71	0.85	1.36
G	0.51	-0.82	0.69	-0.66	0.61	0.07

Sources: dataset on the registration of new cars (CCFA).
Reading notes: For year t = 2003 to 2007, changes in prices are computed between September to November of year t and March to May of year $t+1$. For year 2008, changes in prices are computed between March to May 2008 and September to November 2008. Results for class A are not reported due to the few number of sales until 2007.

A.2 Characteristics of the buyer of new cars and the overall French adult population

Table 14: Comparative statistics between characteristics of the buyer of new cars and the overall French adult population

Variable	Buyers of new cars	Overall
Activity rate (%)	60.1	58.4
Age (years)	52.3	48.7
Rural and suburban area (%)	41.7	41.1
Median income of the household (%)		
First Quintile	10.6	41.1
Second Quintile	15.7	20.1
Third Quintile	24.1	21.7
Fourth Quintile	38.0	24.5
Fifth Quintile	52.3	48.7

Sources: Transportation Survey (INSEE).

To compute market shares, we also need to define potential markets. We suppose here that they correspond, for the subpopulation with characteristics x, to the number of individuals with a driving license at quarter t. We thus assume that individuals cannot purchase more than two cars during a quarter.

A.3 Computation of the mileage N_{t_0}

Average emissions of CO_2 vary from one vehicle to another but also according to the use of the vehicle. In particular, emissions differ in urban areas and on highways. Let us denote respectively by A_j^1 and A_j^2 the corresponding average emissions for vehicle j. The total CO_2 emissions of an individual at t_0 is $N_{t_0}^1 A_{Y_{t_0}}^1 + N_{t_0}^2 A_{Y_{t_0}}^2$, where $N_{t_0}^1$ (resp $N_{t_0}^2$) corresponds to the mileage in urban area (resp. on high roads) in 2007. We only observe in the CCFA dataset the average emissions $A_j = (A_j^1 + A_j^2)/2$ corresponding to a 50% - 50% mixed use, which does not necessarily coincide with the real use of the vehicle. To obtain correct total emissions, we compute $N_{t_0}^*$, defined by

$$N_{t_0}^* \frac{A_{Y_{t_0}}^1 + A_{Y_{t_0}}^2}{2} = N_{t_0}^1 A_{Y_{t_0}}^1 + N_{t_0}^2 A_{Y_{t_0}}^2.$$

$N_{t_0}^*$ simply corresponds to a weighted average between the two mileages:

$$N_{t_0}^* = pN_{t_0}^1 + (1-p)N_{t_0}^2, \text{ where } p = \frac{2A_{Y_{t_0}}^1}{A_{Y_{t_0}}^1 + A_{Y_{t_0}}^2}.$$

Quantities A_j^1 and A_j^2 have been obtained on the ADEME website. Note that we do not observe directly $N_{t_0}^1$ and $N_{t_0}^2$ in the Transportation Survey. To compute them, we consider that 80% of "regular" travels (all travels except those made for professional purpose outside commuting, or for vacation) are made in urban areas for people living in a urban area, and on highways for people living in a rural or suburban area. We consider that other travels consist of 90 % of highways and 10 % of urban area. These assumptions allow us to compute $N_{t_0}^1$ and $N_{t_0}^2$ from the total mileage $N_{t_0}^1 + N_{t_0}^2$.

A.4 Proofs of Section 5

A.4.1 Estimation of market shares

According to the model defined in section 5, from equation 5.5 we can decompose the utility of j for individual i as

$$U_i(j) = \delta_j + \widetilde{e}_{ij}$$

with $\delta_j = (y_x - p_j)\,\beta_x - c_j^{\gamma_x}\mu_x + \xi_{xj}$ for all new car $j = 1...J$, $\delta_0 = y_x\beta_x$, $\widetilde{e}_{i0} = e_{i0} - c_0^{\gamma_x}\mu_x$ and $\widetilde{e}_{ij} = e_{ij}$ for $j = 1..J$. While we observe $c_j^{\gamma_x}$ for each new car, it is not the case for the outside option and thus $-c_0^{\gamma_x}$ is a random term integrated in the residual. The term ξ_{xj} represents the common valuation of individual of types x for unobservable characteristics of product j. Here we make the normalization $\xi_{x0} = 0$.

As stated below, we use a nested-logit distributional assumption on the residuals $(\widetilde{e}_{ij})$. We thus suppose that the residuals terms $(\widetilde{e}_{ij})$ are identically distributed and follow a Gompertz distribution. We assume two nest : one constituted by the outside option 0, and the other by all new cars. $\widetilde{e}_{i0}$ is independent of $(\widetilde{e}_{ij})_{j=1...J}$, while these latter are correlated through a common factor ζ:

$$\widetilde{e}_{ij} = \sigma_x \zeta_i + (1 - \sigma_x)\eta_{ij}.$$

The $(\eta_j)_{j=1...J}$ are independent, follow a Gompertz distribution and are independent of ζ. The distribution of ζ is implicitly defined by those of $\widetilde{e}_j$ and η_j and this independence restriction. Cardell (1997, Theorem 2.1) shows that there exists a unique distribution satisfying these conditions, for each value of $\sigma_x \in [0, 1]$.

Considering each type of consumers x as separate markets, the market shares s_{xj} of the product j satisfies (see, e.g., Berkovec & Rust, 1985) :

$$s_{xj} = \frac{\exp(\delta_j/(1-\sigma_x))}{D_{g(j)}^{\sigma_x} \sum_{g=1}^{G} D_g^{1-\sigma_x}} \tag{A.1}$$

where $g(j)$ denotes the group of product j and $D_g = \sum_{k \in g} \exp\left(\delta_k/(1-\sigma_x)\right)$ for any group g. This yields

$$\ln\left(\frac{s_{xj}}{s_{x0}}\right) = \frac{\delta_j - \delta_0}{1-\sigma_x} - \sigma_x \ln\left(\frac{D_g(j)}{D_0}\right) \tag{A.2}$$

As $\sum_{j=1}^{J} s_{xj} = 1 - s_{x0}$, we have $\ln(\frac{D_g(j)}{D_0}) = \frac{1}{1-\sigma_x}\ln(\frac{1-s_{x0}}{s_{x0}})$. Under these conditions and using the definition of the utility (5.1), we get

$$\ln(s_{xj}) = \frac{1}{1-\sigma_x}\left[\ln(s_{x0}) - \sigma_x \ln(1-s_{x0}) - p_j\beta_x - c_j^{\gamma_x}\mu + \xi_{xj} - \xi_{x0}\right] \tag{A.3}$$

As $\ln(s_{x0})$ is very small in absolute value compared to $\ln(1 - s_{x0})$ (around -0.006 on average, compared to -5.1), we neglect it in A.3.

This definition is defined at each period time. We differentiate it between t_1 (after the introduction of the feebate policy) and t_0 (prior its introduction) and use the linear price model states by (5.4). Besides, we assume for simplicity (although not needed for identification) a linear specification for $\sigma_x/(1-\sigma_x)(= x'\lambda)$, $-f_1(z)\beta_x/(1-\sigma_x)$ $(= \sum_{l=1}^{7} \mathbb{1}\{z = z_l\}\theta_l)$ and $-f_2(\tilde{z})\beta_x/(1-\sigma_x)$ $(= \tilde{z}\kappa)$. We finally obtained (5.7), where the residual ε_{xj} corresponds to $\xi_{xjt_1} - \xi_{xjt_0} + (p_{t1}(0) - p_{t0}(0))\beta_x$, with $p_{t0}(0)$ is the actual price at period t_0 and $p_{t1}(0)$ is the counterfactual one that would have prevailed absent the feebate policy.

By Assumption 5.3, the valuation ξ_{xj} and the cost per kilometer c_j are not affected by the feebate policy, we can recover the counterfactual market shares $s_{xj}(0)$ using our estimates and the observed market shares $(s_{xj}(1))_{j=0\dots J}$ (we omit t here for simplicity). We have

$$s_{xj}(d) = \frac{\exp(\widetilde{\delta}_j(d))}{\left[\sum_{k=1}^J \exp(\widetilde{\delta}_k(d))\right]^{\sigma_x} + \left[\sum_{k=1}^J \exp(\widetilde{\delta}_k(d))\right]},$$

where $\widetilde{\delta}_j = (\delta_j - \delta_0)/(1-\sigma_x)$. Moreover, $\exp(\widetilde{\delta}_j(d)) = s_{xj}(d){\frac{1-s_{x0}(d)}{s_{x0}(d)^{\sigma_x}}}^{1-\sigma_x}$ for $d = 0, 1$, and $\widetilde{\delta}_j(0) = \widetilde{\delta}_j(1) - \beta(1-\sigma_x)\left(f_1(Z_j) + f_2(\widetilde{Z}_j)\right)$. As a result, we get

$$s_{xj}(0) = \frac{s_{xj}(1)\exp(-B_j)}{\frac{s_{x0}(1)}{(1-s_{x0}(1))^{\sigma_x}}\left[\sum_{k=1}^J s_{xk}(1)\exp(-B_k)\right]^{\sigma_x} + \left[\sum_{k=1}^J s_{xk}(1)\exp(-B_k)\right]} \tag{A.4}$$

with $B_k = \sum_{l=1}^7 \mathbb{1}\{Z_k = z_l\}\theta_l - \widetilde{Z}_k\kappa$.

A.4.2 Equations (5.4) and (5.8)

Using notations of the model described in Section 5, let

$$g_x = E\left(\exp(\nu_{it})|X_i = x\right).$$

Note that by Assumption 5.1, g_x does not depend on t. Moreover, it is identified using the residuals of Equation (5.3). We then have

$$\begin{aligned}
\overline{N}_{jt_1} &= E\left[N_{it_1}|Y_{ip} = j, X_i = x\right] \\
&= \exp(\widetilde{\delta}_x)c_{jt_1}^{\gamma_x - 1}E\left(\exp(\nu_{it_1})|Y_{it_1}(1) = j, X_i = x\right) \\
&= g_x\exp(\widetilde{\delta}_x)c_{jt_1}^{\gamma_x - 1},
\end{aligned}$$

where the third equality stems from Assumption 5.1. Equation (5.4) follows.

First, by the law of iterated expectations,

$$\overline{E}_{x0t_1}(0) = P(F_{i0t_0}(0) = 1)\overline{E}_{x0t_1,1}(0) + P(F_{i0t_0}(0) = 2)\overline{E}_{x0t_1,2}(0). \tag{A.5}$$

Second, by Equation (5.3) and Assumption 5.3, we have, for $f \in \{1, 2\}$,

$$\overline{E}_{x0t_1,f}(0) = I_f^{\gamma_x - 1}\overline{E}_{x0t_0,f}(0). \tag{A.6}$$

Third, by Assumptions 5.3 and 5.6, $E_{x0t_1}(0) = E_{x0t_1}(1)$. This, together with (A.5) and (A.6), proves Equation (5.8).

References

Adamou, A., Clerides, S. & Zachariadis, T. (2010), An empirical evaluation of the effectiveness of CO_2-related vehicle taxation in europe. Mimeo.

Adda, J. & Cooper, R. (2000), 'Balladurette and juppette: A discrete analysis of scrapping subsidies', *Journal of Political Economy* **108**, 778–806.

ADEME (2010), Bilan carbone entreprises et collectivités, guide des facteurs d'émissions, Technical report.

Allcott, H. & Wozny, N. (2011), Gasoline prices, fuel economy, and the energy paradox. Working paper.

Anderson, S. T. & Sallee, J. M. (2011), 'Using loopholes to reveal the marginal cost of regulation: The case of fuel-economy standards', *American Economic Review* **101**, 1375–1409.

Berkovec, J. & Rust, J. (1985), 'A nested logit model of automobile holdings for one vehicle households', *Transportation Research Part B: Methodological* **19**, 275–285.

Berry, S., Levinsohn, J. & Pakes, A. (1995), 'Automobile prices in market equilibrium', *Econometrica* **63**, 841–890.

Busse, M. R., Simester, D. I. & Zettelmeyer, F. (2010), "'the best price you'll ever get": The 2005 employee discount pricing promotions in the u.s. automobile industry', *Marketing Science* **29**, 268–290.

Cardell, N. S. (1997), 'Variance components structures for the extreme-value and logistic distributions with application to models of heterogeneity', *Econometric Theory* **13**, 185–213.

Clerc, M. & Marcus, V. (2009), Élasticités-prix des consommations énergétiques des ménages. INSEE-D3E Working paper.

D'Haultfœuille, X., Durrmeyer, I. & Février, P. (2010), The willingness to pay for global warming reduction: Lessons from the french automobile market. CREST Working paper.

Engers, M., Hartmann, M. & Stern, S. (2009), 'Annual miles drive used car prices', *Journal of Applied Econometrics* **24**, 1–33.

Friez, A. (2009), Les immatriculations de voitures particulières neuves, un an après la mise en place du bonus-malus, Le point sur 4, Commissariat Général au Développement Durable.

Fullerton, D. & West, S. E. (2002), 'Can taxes on cars and on gasoline mimic an unavailable tax on emissions?', *Journal of Environmental Economics and Management* **43**, 135–157.

Goldberg, P. K. (1995), 'Product differentiation and oligopoly in international markets: The case of the u.s. automobile industry', *Econometrica* **63**, 891–951.

Gowrisankaran, G. & Rysman, M. (2011), Dynamics of consumer demand for new durable goods. Working paper.

Graham, D. J. & Glaister, S. (2002), 'The demand for automobile fuel: A survey of elasticities', *Journal of Transport Economics and Policy* **36**, 1–25.

Greene, D. L., Patterson, P. D., Singh, M. & Li, J. (2005), 'Feebates, rebates and gas-guzzler taxes: a study of incentives for increased fuel economy', *Energy Policy* **33**, 757–775.

Johansson, O. & Schipper, L. (1997), 'Measuring the long run fuel demand of cars: separate estimations of vehicle stock, mean fuel intensity, and mean annual driving distance', *Journal of Transport Economics and Policy* **31**, 277–292.

Klier, T. & Linn, J. (2010), 'The price of gasoline and the demand for fuel economy: Evidence from monthly new vehicles sales data', *American Economic Journal: Economic Policy* **2**, 134–153.

Knittel, C. R. (2011), 'Automobiles on steroids: product attribute trade-offs and technological progress in the automobile sector', *American Economic Review* **101**, 3368–3399.

Li, S., Timmins, C. & von Haefen, R. H. (2009), 'How do gasoline prices affect fleet fuel economy?', *American Economic Journal: Economic Policy* **1**(2), 113–37.

Pakes, A., Berry, S. & Levinsohn, J. A. (1993), 'Applications and limitations of some recent advances in empirical industrial organization: Price indexes and the analysis of environmental change', *American Economic Review* **83**, 241–46.

Peters, A., Mueller, M. G., de Haan, P. & Scholz, R. W. (2008), 'Feebates promoting energy-efficient cars: Design options to address more consumers and possible counteracting effects', *Energy Policy* **36**(4), 1355–1365.

Sallee, J. T. & Slemrod, J. (2010), Car notches: Strategic automaker responses to fuel economy policy. NBER Working Paper 16604.

Yohe, G. W., Lasco, R. D., Ahmad, Q. K., Arnell, N. W., Cohen, S. J., Hope, C., Janetos, A. C. & Perez, R. T. (2007), Perspectives on climate change and sustainability, *in* L. Parry, O. Canziani, J. Palutikof, P. van der Linden & C. Hanson, eds, 'Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change', Cambridge University Press.