Winners and Losers: The Distributional Effects of the French Feebate on the Automobile Market *

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October 24, 2018

Abstract

I quantify the monetary and environmental gains and losses of an environmental purchase tax/subsidy (feebate) for new cars using a structural model of demand and supply that features a high level of heterogeneity in consumers' preferences. I simulate the market equilibrium without the feebate to quantify its causal effects. The regulation favors middle-income individuals but has redistributive effects when combined with a proportional to income tax. It reduces average carbon emissions at the cost of extra emissions of local air pollutants. The emissions, however, increase the least where they are the highest, implying another type of redistribution.

*I would like to thank Estelle Cantillon, Rob Clark, Allan Collard-Wexler, Pierre Dubois, Xavier D'Haultfœuille, Philippe Février, Gautam Gowrisankaran, Nina Leheyda, Laurent Linnemer, Andrea Pozzi, Mathias Reynaert, Alex Sanz Fernandez, Philipp Schmidt-Dengler, Monika Schnitzer, Andre Trindad and Frank Verboven for their helpful comments and suggestions. I would also like to thank the participants of various seminars and conferences. I acknowledge financial support from the Deutsche Forschungsgemeinschaft through SFB-TR 15 and the Agence Nationale de Recherche ANR-CAREGUL. I would like to thank Pierre-Louis Debar and Julien Mollet from the Comité des Constructeurs Français d'Automobiles for providing me with the data.

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1 Introduction

Tinbergen's rule recommends that one policy instrument should be used to achieve only one objective in the context of macroeconomic policy. Public policies, indeed, have results that extend beyond the desired outcome. Yet, the same objective can sometimes be reached with different alternative instruments, and the magnitude of the aftereffects can be used as selection criteria. It is therefore crucial to identify and evaluate the side effects of a potential regulation. This paper quantifies the direct effects and aftereffects of a specific environmental regulation on the French automobile market.

Environmental regulations on the automobile market have become very common in developed countries over the past 10 years, and countries have used various policy tools to reduce carbon emissions (CO_2) related to automobiles. Regulation instruments include standards that manufacturers must meet, purchase or annual carbon emission-based taxes, purchase subsidies and feebates (a combination of purchase taxes and subsidies). The French feebate has been in place since 2008 and affects the purchases of all new cars. The purchase of low emission vehicles is encouraged through a rebate ("bonus") that reaches €1,000, and the purchase of high emission cars is discouraged through a tax ("malus") that could be as high as €2,600 in 2008.

This paper analyzes the effects of the feebate on the French automobile market in 2008. I evaluate the causal direct effects of the feebate on consumers, car manufacturers and the CO_2 emissions of new cars. I also evaluate the collateral effects of this regulation on inequalities and local pollution. I analyze the distributional effects of the feebate and identify the winners and losers across consumers and car manufacturers. Such a rebate/tax scheme implies, by nature, that some agents are better off while others are worse off and has distributional consequences. When designing a new policy, the regulator is subject to an acceptability constraint and the progressive or regressive nature of the policy can play an important role in practice.

I also quantify the causal effect of the feebate on the emissions of local air pollutants such as carbon monoxide (CO), nitrogen oxide (NO_X), hydrocarbon (HC) and particulate matter (PM) which are not directly targeted by this regulation. These collateral effects are crucial since local air pollutant emissions have a direct impact on air quality and adverse effects on health. The World Health Organization estimates that ambient air pollution causes 4.2 million premature deaths worldwide in 2016.[1] NO_X and PM are the most hazardous air pollutants since they direct affect lungs and the respiratory system of individuals. CO and

[1] `http://www.who.int/en/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health`.

HC emissions have, on the other hand, less direct adverse effects on health. CO is estimated to be less than 40 times less harmful than NO_X for individuals while HC is a volatile organic compound and contributes to ozone pollution which is responsible, among others, of smogs and pollution peaks. I finally investigate the performance of the actual feebate scheme for redistributing across individuals and manufacturers and for limiting the emissions of local pollutants and quantify the potential gains associated with the optimal schemes.

I use a structural model for the demand and supply of new automobiles to simulate the market equilibrium without the feebate regulation. The comparison between the observed market equilibrium and the counterfactual equilibrium identifies the causal effect of the feebate regulation. I estimate the model using data on car characteristics, prices and market shares in France between 2003 and 2008. The demand model incorporates a high level of heterogeneity in terms of preferences for car attributes, and the identification of the heterogeneity parameters is ensured by leveraging granular data on car sales at the local level. More specifically, I exploit the correlation that exists between the characteristics of car purchases and consumers' demographic characteristics across municipalities. Standard models account for individual heterogeneity which is typically modeled as unobserved and these models fail to characterize the winners and the losers. On the supply side, I model the pricing strategies of car manufacturers when they are subject to the feebate regulation and estimate the marginal costs of all the cars proposed on the market. I use the demand and supply model to simulate the purchases and pricing strategies in 2008 without the feebate regulation.

Finally, I compare the aftereffects of the feebate to hypothetical feebates with identical monetary cost and effects on CO_2 emissions but are optimal with respect to its aftereffects. I quantify the performance of the feebate in terms of its collateral effects by simulating market equilibrium under alternative simple linear feebate schemes and select the schemes that are optimal for several outcomes and objective functions. I consider the consumer surplus, the national manufacturers' profits and reductions in the emissions of local pollutants as outcomes. For each of these outcomes, I consider different objective functions: a simple average, a weighted average, the individual (car manufacturer) with the minimal surplus (profits) or municipality with the maximum level of emissions and the difference between the maximum and the minimum (as a measure of inequality).

I adopt a structural approach that models consumers' and car manufacturers' behaviors to evaluate the causal effects of the feebate since direct policy evaluation methods cannot separately identify demand and supply reactions to the regulation. Furthermore, most of the outcomes of interest are not directly observable and measurable such as consumers surplus and manufacturers profits but can be expressed as functions of parameters of the structural model. Finally, it is possible to perform counterfactual simulations which are used to evaluate the performance of the feebate. In contrast, if the causal effect of the feebate was identified through a reduced-form approach, I would have to make the assumption that the relation between the outcome of interest and the feebate remains identical under alternative feebate schemes. This would be a very strong assumption because the transition from one market equilibrium to another is driven by the interaction between the responses of consumers and those of manufacturers, which has no reason to be identical under alternative policy environments. The structural model of demand is also useful to understand how the policy modified consumers' choice and convert the choice modification into monetary terms.

I find that the policy increases total welfare by 124 million euros. This global welfare effect takes into account the consumer surplus, the manufacturers' profits, the monetary cost of the policy for the government and the value of CO_2, HC, NO_X and PM emissions that have been generated or avoided. The consumer surplus increases when no tax is introduced to compensate the deficit but decreases by 36 million euros with a tax. The French manufacturers clearly benefited from the feebate policy, with an increase of 94 million euros in their profits. The average CO_2 emissions of car purchases successfully decreased by 1.56%, but overall annual emissions increased. Annual emissions increased for two reasons: first, more consumers purchased a new car, and second, more diesel cars were purchased, which are driven relatively more than gasoline cars. Lastly, the average emissions of all the local pollutants increased by a small amount, but total emissions increased significantly, and the extra emissions represent increases from 2.2% to 2.8% of annual emissions.

Yet, the feebate has heterogeneous effects across consumers and car manufacturers. On the consumers' side, the distributional impacts depend on the tax system used to finance the feebate cost and I investigate two simple mechanisms: a uniform tax and a proportional to the income tax. Under a flat tax, the feebate scheme favors individuals in the middle-income class, while if the tax is proportional to the income, then the feebate achieves some redistribution from the richest households to the poorest. The feebate performances are good for maximizing the consumer surplus, but the inequalities could be further reduced. On the car manufacturers' side, the feebate heavily stimulated French manufacturers at the expense of most of the German car manufacturers and some Asian and American car manufacturers. However, there is room to further improve the French manufacturers' profits; the current feebate achieves 75% to 90.3% of the maximum profits depending on the weights assigned to each car manufacturer.

The emissions of local pollutants increased the most in areas where they are the lowest, implying another type of redistribution from high emission municipalities to low emission ones. The assessment of the feebate performance reveals that this type of redistribution could be even more important with optimal feebates. I find further redistributive effects for NO_X and PM: the average emissions increased the most in rich and dense municipalities, while they actually decreased in the poorest areas. In contrast, the average emissions of CO and HC increased the most in low-income and rural cities. The current feebate scheme could also be improved to limit the emissions of local pollutants, but it is impossible to improve emission rates of all the pollutants simultaneously.

This paper complements two other studies on the effects of the French feebate policy. The first study by D'Haultfœuille et al. (2013) quantifies the short and long term environmental impacts of the feebate, while a second study by D'Haultfœuille et al. (2016) disentangles the sources of CO_2 emission reduction in the automobile market for the period 2003-2008. These two papers focus only on aggregate outcomes and do not consider the heterogeneity of the feebate impacts and its distributional consequences nor do they consider its collateral effects on the emissions of local air pollutants.

Other related papers evaluate the impacts of hypothetical and actual environmental policies on the automobile market using structural models. Goldberg (1998) was the first to model and analyze the effects of fuel economy standards in the U.S. Huse (2012) examines the effect of an asymmetric regulation in the Swedish car market: the "Green Car Rebate" that is awarded under different standards depending on whether the car uses fossil or renewable energy. Adamou et al. (2014) evaluate the welfare effects of a hypothetical feebate policy in the German automobile market. Durrmeyer and Samano (2017) compare the efficiency of hypothetical feebate-type policies with fuel economy standards. These studies focus on aggregate effects and do not investigate the distributional consequences of the regulations nor their aftereffects.

The externalities of a regulation on local pollution has been theoretically investigated by Ambec and Coria (2013) and empirically by Linn (2016). The latter compares hypothetical fuel taxes and vehicle taxes on the level of NO_X. He does not rely on the car level of NO_X emissions as I do here and the only heterogeneity in NO_X emissions comes from the fuel type in his model.

The first papers studying the distributional consequences of regulations on the automobile market were focusing on gas and carbon taxes. Bento et al. (2009) study the distributional consequences of an increase in the gas tax using a model for car purchases and car usage, while West (2004) investigates alternative regulations to gas taxes such as vehicle subsidies. There are a few papers that evaluate whether other types of environmental regulations on the automobile market are progressive or regressive. For instance, Jacobsen (2013) estimates the welfare effects of an increase in fuel economy standards by income class. My paper is close to three recent papers that focus on the distributional effects of regulations. Davis and Knittel (2018) quantifiy the distributional effects of fuel economy standards in the U.S. and find that standards are mildly progressive. Their study differs from mine since they do not rely on an equilibrium model for the car market. Instead, they calculate the implicit subsidy or tax implied by the standard for all the cars purchased and use them to measure consumers' gains or losses. The second recent study is by Holland et al. (2018), and it investigates the distributional effects of the introduction of electric vehicles and the consequences of the displacement of emissions from the road to power plants. Finally, Levinson (2018) provides theoretical and empirical evidence that fuel economy standards are more regressive than fuel taxes using household transportation survey data. This study, similar to the study by Davis and Knittel (2018), does not use a demand and supply model and assumes that agents do not reoptimize their vehicle choice under different tax schemes.

Several recent papers quantify the distributional effects of environmental regulation in other contexts: Bento et al. (2015) study the distribution of the gains and costs of the Clean Air Act Amendments using a hedonic approach on housing prices; Borenstein and Davis (2016) evaluate the effects of tax credits on clean energy in the U.S.; Reguant (2018) analyzes the distributional consequences of alternative subsidy schemes for renewable electricity generation; and Feger et al. (2017) focus on the distribution of the gains and losses associated with subsidies for solar panels in Switzerland.

This paper evaluates the performance of the current feebate by comparing its outcomes to those of optimal schemes associated to given objective functions and outcomes. This study contributes to the literature on optimal environmental regulation in line with the recent papers by Holland et al. (2016) and Allcott and Kessler (2018). The first paper computes the optimal electric vehicle purchase taxes or subsidies when they can be geographically differentiated, and the second paper derives the optimal targeting of individuals in the context of an energy conservation information program.

From a methodological point of view, this paper uses a combination of aggregate and individual data to estimate demand and supply. Unlike Berry et al. (2004) and Petrin (2002), I do not observe individual car purchases with direct links between individual choices and demographic characteristics. Instead, I exploit the correlation that exists between the average characteristics of cars purchased and the average demographic characteristics at the local municipality level. The way I exploit the local level data and the estimation method closely follow Nurski and Verboven (2016).

The remainder of the paper is as follows. The next section presents the feebate policy, describes the data and provides some descriptive evidence. In Section 3, I describe the structural model of the market equilibrium and the estimation method. Section 4 presents the estimation results, the analysis of the feebate effects and its performance. Finally, Section 5 concludes.

2 The feebate policy

2.1 Institutional details and data

The environmental feebate policy was announced at the end of November 2007 and was applied on the 1st of January, 2008. This policy was one of several measures taken by the government following the *Grenelle Environnement* roundtables that address environmental issues. The main objective of this policy was to reduce CO_2 emissions related to automobiles. The policy was announced to be permanent and was supposed to be neutral for the state budget (its actual cost was 244 million euros in 2008).

The feebate scheme includes rebates and taxes associated with 9 classes of CO_2 emissions (see Table 1 below). The amounts of the rebates and the taxes were supposed to remain constant, whereas the thresholds were to be reduced by 5 grams per kilometer (g/km hereafter) each year from 2010 on to take into account technical progress. I focus only on the feebate effects for the year 2008 because car manufacturers were not able to react to the policy by modifying their car characteristics and car assortment between November 2007 and 2008 but rather reacted to the policy by changing their car prices, which is possible to credibly model. The quantification of the welfare effects after 2008 is more challenging since it requires a model with endogenous product characteristics. In the medium run, environmental regulation is likely to foster innovation (see Klier and Linn, 2012). The issue with such models is the existence of multiple counterfactual equilibria.

As Table 1 shows, the amounts of the rebates and fees represent a non-negligible percentage of the purchase prices and reach 8.1% of the gross price for class A. They are also rather heterogeneous across classes, indicating that the feebate scheme affected the market equilibrium in a non-symmetric way.

Table 1: Feebate scheme in 2008.

Class of emissions	Emissions (in g/km)	Feebate (in €)	Percentage of 2007 prices
A	(60-100]	+1,000	8.1%
B	(100-120]	+700	4.8%
C+	(120-130]	+200	1.2%
C-	(130-140]	0	0.0%
D	(140-160]	0	0.0%
E+	(160-165]	-200	-0.98%
E-	(165-200]	-750	-3.2%
F	(200-250]	-1,600	-4.3%
G	> 250	-2,600	-5.2%

In this analysis, I combine data from three different sources. The first dataset was obtained from the French Syndicate of Car Manufacturers (CCFA) and contains data on new car characteristics and sales from 2003 to 2008 at the municipality level.[2] This database is constructed from the records of all the registrations of new cars purchased by French households. I observe the main car characteristics, including the level of CO_2 emissions (from driving cycle tests) and the catalogue price. The level of CO_2 emissions from tests are likely to underestimate true CO_2 emissions as pointed out by Reynaert and Sallee (2016). However, this is not problematic for the estimates of the changes in CO_2 emissions in percentage as long as the cheating is by a constant factor proportional to the true emissions and uniform across cars and car manufacturers; which is Reynaert and Sallee (2016)'s modeling strategy. I also observe the car's horsepower, weight, cylinder, type of fuel, and body style. I use data obtained from the French National Survey Institute to compute the average cost of driving 100 km from cars' CO_2 emissions and the average fuel prices for each year.[3]

I construct a detailed dataset that includes the demographic characteristics of all the households for the 36,569 municipalities in France; these data were obtained from several publicly available datasets provided by the French National Survey Institute.[4] I use data on the median income and the number of households for each year between 2003 and 2008 as well as data from the 2008 census on household size and socio-professional activities.[5]

[2] "Comité des Constructeurs Français d'Automobiles".

[3] The fuel cost ψ_j of car j is related to the CO_2 emissions and the fuel price $\rho_{f(j)}$, which depends on the type of fuel $f(j)$, through the formula: $\psi_j = \frac{CO_{2j}}{k_{f(j)} \times \rho_{f(j)}}$, where $k_{f(j)}$ is a constant that is equal to 22.87 for gasoline cars and 26.86 for diesel cars.

[4] See `https://www.insee.fr/fr/statistiques?categorie=1` .

[5] The information is provided at the "arrondissement" level for the three largest cities (20 for Paris, 16

I use a third dataset obtained from the French Energy Agency (ADEME), which provides information on the emission levels of local air pollutants for all the car models from 2012 to 2015. I observe the emission levels of CO, NO_X, HC and PM measured with driving cycle tests and are likely to underestimate the real-world emissions. Again, the relative changes in emissions are still relevant provided that the underestimation of the driving cycle tests is uniform across cars and proportional to emissions. The second drawback of such data is that they do not exist for car models before 2012. Therefore, I use a simple model to predict the values of the emissions of these local pollutants in 2008 based on the observable car characteristics and estimated using the 2012-2015 data.

I regress the emissions on the main car characteristics: horsepower, weight, CO_2 emissions, and body style. I allow these characteristics to have differentiated effects depending on the fuel type. I also include a fuel specific time trend, year fixed effects and a dummy if the car is subject of Euro 6 standard and the limit of the emissions of the pollutant was modified between Euro 5 and Euro 6 standards for that specific engine.[6] This is the case for NO_X but only for diesel cars and PM for both types of engines (see the limits set by Euro 4, Euro 5 and Euro 6 in Table 18 of Appendix A). I also introduce model name fixed effects and exclude car models (i.e., model names) that are in the ADEME dataset but not in the CCFA dataset. I explain below how I deal with the car models that are not present in the ADEME dataset for the prediction.

I estimate the models for CO, NO_X, PM, and HC separately. The parameter estimates are displayed in Table 19 of Appendix A. Overall, the observable car characteristics explain a significant percentage of the intra-car model variance in terms of the emissions of pollutants. The effects of car characteristics depend on the fuel type and the pollutant. Horsepower is positively correlated with the emissions of all pollutants except for PM for gasoline engines. The correlation between the emissions of local pollutants and CO_2 emissions are heterogeneous across pollutants and fuel types. While there is a positive association between CO_2 emissions and the emissions of CO and PM for gasoline cars and NO_X for diesel cars, I obtain a negative correlation for the other pollutants and engine types. The high correlation that exists between car attributes probably explains this contrast. The dummy for the Euro 6 norm consistently has a negative effect on the level of emissions. Time trends are also negative and appear rather differentiated with the type of fuel. For all pollutants, the trends are steeper for gasoline cars than they are for diesel cars. Finally, the parameters of the diesel dummies indicate that diesel cars emit on average more NO_X than gasoline but less of the other local pollutants. It may seem surprising that diesel cars emit less PM than gasoline

for Marseille and 9 for Lyon), which is a finer level than that of a municipality.

[6] Cars from 2012 to 2015 are subject to either Euro 5 or Euro 6, while in 2008, all the cars were under Euro 4. More details on Euro emission standards are provided in Appendix A.

cars; this result is actually consistent with the fact that new diesel cars are all equipped with a particulate filter and no longer emit more PM than gasoline cars. I account for this with a strategy to predict emissions under Euro 4 using the parameters of Euro 6.

I use the estimated parameters and make several assumptions to predict the emission levels of the 4 pollutants during the period 2003-2008. First, I extrapolate the fuel-specific time trends. Second, for the car models in my CCFA dataset that are not in the ADEME data, I use the average model fixed effect of the segment. Finally, I use the parameters of the dummy for Euro 6 to predict average emissions under Euro 4, which I assume the cars purchased from 2003-2008 are subject to. This calculation is a good approximation of the major part of the study period since Euro 4 was in place between 2005 and 2009. Furthermore, the crucial predictions are for 2008; the predictions for 2003-2007 are only used in the descriptive analysis. I predict the Euro 4 effects only for the pollutants for which the limits changed between Euro 4 and Euro 5. I use the negative of the coefficient of the dummy for Euro 6 multiplied by a proportionality factor that is equal to the difference in the limits between Euro 4 and Euro 5 divided by the difference of the limits between Euro 5 and Euro 6 (see Table 18 in Appendix A for the values of the predicted parameters for Euro 4). Since there is no change in the regulation of NO_X for gasoline cars between Euro 5 and Euro 6, I use the coefficient for diesel cars. For gasoline cars, there was no regulation on PM before Euro 5, so I cannot compute a proportionality factor. Instead, I multiply the negative of the parameter of Euro 6 by 2.[7]

The average emissions predicted are presented in Table 2. As expected, emissions of NO_X and PM are much higher for diesel engines than gasoline engines. In contrast, emissions of CO and HC are lower for diesel engines than gasoline engines. This result is consistent with differences in the emission technology of the different engines and observed emissions over 2012-2015. I also find that the emissions are higher in 2008 than 2012-2015 except for HC and only in the case of gasoline cars, which are 2 mg/km lower in 2008 than in 2012-2015. It is, however, not possible to make a direct comparison between 2008 and 2012-2015 for two reasons. First, emissions are averaged over different sets of cars, and there are cars in the CCFA sample that are not in the ADEME database. Second, there are several versions of the same car model in the ADEME database and the number of versions is heterogeneous across models. In the end, since the objective of the paper is to analyze the consequences of the feebate, it is crucial to correctly estimate the heterogeneity of emissions across car models and less important to make realistic predictions of the levels of emissions.

[7]See more details on the predictions and a discussion of the assumptions in Appendix A.

Table 2: Average emissions of pollutants by fuel type.

	Gasoline cars		Diesel cars	
	2012-2015	2008 (pred.)	2012-2015	2008 (pred.)
CO	275.5	411.3	140.4	224.3
NO_X	26.36	33.32	184.4	226.9
HC	42.81	40.78	19.3	22.4
PM	16.53	30.84	11.33	74.6

Note: All emissions are in mg/km except PM, which is in mg/10 km. Unweighted average emissions of the car models in ADEME and CCFA datasets.

Using the predicted levels of pollutants, I compute the correlation coefficients between the emissions of the different local pollutants and carbon emissions. The correlation matrix is displayed in Table 3. CO_2 emissions are positively correlated with those of CO (0.15). In addition, CO_2 emissions are weakly negatively correlated with HC emissions (-0.09) and negatively correlated with NO_X (-0.32) and PM (-0.23). This suggests that because the feebate is based on CO_2 emissions, it is likely to have heterogeneous effects across pollutants. The different local pollutants are highly correlated with each other. Clearly, there are two groups of pollutants: on one side, NO_X and PM with a correlation coefficient of 0.97 and on the other side, CO and HC with a correlation coefficient of 0.8. The pollutants of the two groups are, however, negatively and significantly correlated: the higher the emissions of HC and CO are, the lower the emissions of NO_X and PM.

Table 3: Correlations among the emissions of CO_2, CO, NO_X, HC and PM.

	CO_2	CO	NO_X	HC	PM
CO_2	1	0.15	-0.32	-0.09	-0.23
CO		1	-0.78	0.8	-0.77
NO_X			1	-0.69	0.97
HC				1	-0.73
PM					1

Finally, I use estimates for the social cost of carbon and air pollution cost. For carbon I use the uniform value of €40 per ton, in the ballpark of the values estimated by the U.S. Environmental Protection Agency.[8] It also corresponds to the lowest value suggested by the European Commission (see the report of the DG MOVE, 2014). For the cost of air pollution, I include only the damage cost estimates for PM, NO_X and HC, following the usage (there is

[8]See `https://19january2017snapshot.epa.gov/climatechange/social-cost-carbon_.html`.

not enough evidence of causal adverse effect of CO on health) and the estimates for France are provided in the report of the DG MOVE (2014). The values are displayed in Table 4, only the air pollution cost of PM depends on the density of the municipality. For simplicity, I consider municipalities with less than 20,000 inhabitants are rural, those with between 20,000 and 200,000 are suburban and those above 100,000 inhabitants as well as Paris area are considered urban. The annual emissions are computed assuming gasoline cars are driven 10,000 kilometers, while diesel cars are driven 17,000 kilometers.[9] These cost estimates imply an average car air pollution cost of €40.8 per year while the average annual carbon cost of a car is €95.6.

Table 4: Estimated air pollution costs.

	PM	NO_X	HC	CO_2
Rural	33,303			
Suburban	64,555	13,052	1,695	40
Urban	211,795			

Note: Costs are in €/ton. The values for local pollutants are taken from the report of the DG MOVE (2014).

2.2 Descriptive evidence

Heterogeneity of purchases I investigate the heterogeneity of car purchases across French municipalities. I correlate the average price, rebate and emissions to demographic characteristics through a regression analysis. These regressions are purely descriptive, and the estimated parameters are not interpreted as causal effects.

I regress the average car price (gross of feebate in 2008), rebate, CO_2 emissions and emissions of local pollutants on income, income squared, the percentage of households according to family size (split into three categories: single, couple, and couple with children), the percentage of households according to professional activity (split into 8 categories: entrepreneur, executive, intermediate profession, employee, manual laborer, retired and other activity), municipality size (rural, with less than 20,000 inhabitants; urban with between 20,000 and 200,000 inhabitants; and very urban with more than 200,000 inhabitants). The year dummies control for the general evolution of prices and emissions over time. The percentage of households in each category is multiplied by 10, so the parameters are interpreted as the effect of a 10% increase in the percentage of households in the category.

[9] These figures represent the average kilometers driven in France in 2007 for diesel and gasoline cars (see D'Haultfœuille et al., 2013).

The first two columns of Table 5 show that the demographic characteristics are significantly correlated with the average price and the average rebate of the cars purchased. Not surprisingly, I observe that the price is positively correlated with income and income squared. Couples and families are associated with cheaper cars than singles. The professional categories associated with the most expensive car purchases are farmers, entrepreneurs and executives. A 10% increase in the percentage of these professional categories are associated with approximately €500 more spent on a car. Individuals in dense areas tend to buy more expensive vehicles (they spend on average between €385 and €586 more than individuals in rural cities). Finally, car prices were slightly cheaper from 2005-2007 than in 2003, while the average price paid decreased considerably in 2008. This change in prices is the result of demand and supply effects. On the demand side, it is likely that consumers chose more fuel-efficient cars, which are also cheaper cars. On the supply side, car manufacturers probably decreased the gross prices of polluting cars in response to the feebate.

The heterogeneity in the average rebate across municipalities is significantly correlated with the demographic characteristics as well. The average rebate linearly decreases with income, which may be a sign that rich individuals were less responsive to the feebate. An additional 10% of couples and families is associated with an average rebate that is slightly less than €50 higher. This value is small but significant relative to the overall average rebate of €87, indicating that these categories may have excessively reacted to the feebate in 2008. Employees, entrepreneurs and executives are associated with significantly lower rebates than retired and manual laborers. Finally, dense cities are associated with lower rebates: €63 and €95 less in urban and very urban cities, respectively, than in rural municipalities.

Heterogeneity in emissions The correlation between average emissions of cars purchased and the demographic characteristics across municipalities reveals that income has a positive concave relation with CO_2 emissions. With 10% more couples or families, the average CO_2 emissions of car purchases is between 2.3 and 2.6 g/km lower. Entrepreneurs, executives and employees buy cars with significantly higher CO_2 emissions. Urban and very urban municipalities are associated with cars with between 3 and 4.2 g/km of CO_2 emissions higher than those purchased in rural areas. There is a clear negative time trend for CO_2 emissions, and they were particularly reduced in 2006 and 2008 (this is consistent with D'Haultfœuille et al., 2016, who analyze the different sources of the decrease in CO_2 emissions from 2003-2008).

The correlations between the demographic characteristics and average CO and HC are rather similar, and the patterns of correlations for NO_X and PM emissions are alike. This is not surprising given the important correlations between CO and HC on one hand and NO_X and PM on the other hand. Income is negatively correlated with CO and HC emissions, while it is positively associated with NO_X and PM emissions. The income effects are non-linear but remain positive for CO and HC and negative for NO_X and PM for the entire income range. Municipalities with large households are associated with lower CO and HC emissions than singles but higher emissions of NO_X and PM than singles. Municipalities with relatively more farmers, executives, and manual laborers are associated with lower emissions of CO and HC and higher emissions of NO_X and PM, while it is the exact opposite for municipalities with more entrepreneurs and employees. Finally, emissions of CO and HC are higher in dense cities (between 6 and 7.5 mg/km more CO emissions than in rural areas), while NO_X and PM emissions are lower in dense areas (average NO_X emissions are between 7.6 and 9.8 mg/km lower than in rural areas, while average PM emissions were between 1.8 and 2.2 mg/10 km lower).

CO emissions consistently decreased between 2003 and 2008, with important declines in 2004 (-6.9 mg/km) and 2008 (-8.5 mg/km). There is no clear trend for the evolution of HC emissions since they decreased between 2003 and 2005, increased in 2006 and 2007 and then decreased again in 2008. Average emissions of NO_X increased over the period, except in 2007. The increase is particularly important in 2008 (+7.8 mg/km compared to an annual trend of 3 mg/km between 2004 and 2006). PM emissions also increased significantly between 2007 and 2008 (+1.2 mg/10 km), while they increased at most by 0.6 mg/10 km between 2005 and 2006.

Overall, the correlations between average emissions and the demographic characteristics are heterogeneous across pollutants. Nevertheless, there are similar patterns of correlation for CO and HC emissions on one side and NO_X and PM emissions on the other side. The pattern of correlations for CO_2 emissions is similar to the ones for CO and HC. Nevertheless, all the correlations indicate that the year of the feebate introduction is peculiar, revealing that the feebate probably had an effect on emissions. These are pure correlations, and it is impossible to make any causal statement at this stage, which explains why I develop and use a full structural model to measure the causal effect of the feebate on emissions.

In addition to providing evidence on the heterogeneity of purchase patterns, the significant correlations support the identification strategy of the heterogeneity parameters, which leverages the covariance between the demographic characteristics and the car purchase characteristics across municipalities.

Table 5: Regression of the average characteristics of car purchases on the demographic characteristics of the municipality.

	Price	Rebate	CO_2	CO	NO_X	HC	PM
Income	1.03**	−0.064**	6.53**	14.6**	−11.6**	0.743**	−2.17**
	(0.069)	(0.01)	(0.249)	(0.933)	(0.691)	(0.1)	(0.161)
$Income^2$	0.029†	−0.002	−0.456**	−1.4**	0.664**	−0.031	0.067†
	(0.015)	(0.002)	(0.054)	(0.201)	(0.149)	(0.021)	(0.035)
%Couple	−0.207**	0.047**	−2.25**	−5.69**	5.32**	−0.394**	1.13**
	(0.013)	(0.002)	(0.046)	(0.173)	(0.128)	(0.018)	(0.03)
%Family	−0.538**	0.049**	−2.58**	−3.25**	4.14**	−0.194**	0.864**
	(0.007)	(0.001)	(0.025)	(0.095)	(0.07)	(0.01)	(0.016)
%Farmer	0.469**	0.007*	−0.028	−10.9**	9.18**	−1.01**	2.24**
	(0.02)	(0.003)	(0.072)	(0.271)	(0.201)	(0.029)	(0.047)
%Entrepreneur	0.498**	−0.026**	2.54**	1.41**	−1.78**	−0.074*	−0.341**
	(0.021)	(0.003)	(0.075)	(0.282)	(0.209)	(0.03)	(0.048)
%Executive	0.556**	−0.028**	1.66**	−2.65**	0.416**	−0.335**	0.144**
	(0.012)	(0.002)	(0.042)	(0.157)	(0.116)	(0.017)	(0.027)
%Intermediate	0.1**	0.002	0.057	−3.38**	2.09**	−0.357**	0.418**
	(0.014)	(0.002)	(0.049)	(0.184)	(0.136)	(0.02)	(0.032)
%Employee	0.231**	−0.047**	2.04**	2.32**	−3.59**	0.017	−0.815**
	(0.015)	(0.002)	(0.056)	(0.208)	(0.154)	(0.022)	(0.036)
%Manual laborer	0.355**	−0.005**	0.571**	−3.29**	2.37**	−0.361**	0.602**
	(0.011)	(0.002)	(0.038)	(0.142)	(0.105)	(0.015)	(0.024)
%Other	0.801**	−0.041**	2.01**	−5.65**	2.34**	−0.735**	0.637**
	(0.015)	(0.002)	(0.054)	(0.202)	(0.15)	(0.022)	(0.035)
Urban	0.385**	−0.063**	2.99**	6.01**	−7.62**	0.344**	−1.78**
	(0.013)	(0.002)	(0.047)	(0.176)	(0.13)	(0.019)	(0.03)
Very urban	0.586**	−0.095**	4.19**	7.52**	−9.81**	0.454**	−2.18**
	(0.014)	(0.002)	(0.049)	(0.183)	(0.136)	(0.02)	(0.032)
2004	0.086**		−1.76**	−6.92**	3.36**	−0.176**	0.305**
	(0.014)		(0.051)	(0.19)	(0.141)	(0.02)	(0.033)
2005	−0.34**		−4.2**	−10.5**	6.13**	−0.54**	0.268**
	(0.014)		(0.051)	(0.191)	(0.142)	(0.02)	(0.033)
2006	−0.315**		−7.12**	−12.1**	9.96**	−0.354**	0.875**
	(0.014)		(0.052)	(0.195)	(0.145)	(0.021)	(0.034)
2007	−0.259**		−7.98**	−13.2**	8.92**	−0.279**	0.46**
	(0.015)		(0.053)	(0.199)	(0.148)	(0.021)	(0.034)
2008	−1.71**		−17**	−21.7**	16.7**	−0.521**	1.62**
	(0.015)		(0.055)	(0.206)	(0.153)	(0.022)	(0.035)
Intercept	20.2**	0.069**	154.9**	347.1**	133.9**	34.5**	54.7**
	(0.097)	(0.015)	(0.352)	(1.32)	(0.975)	(0.14)	(0.226)
R^2	0.345	0.574	0.617	0.171	0.336	0.049	0.286

Note: The average price and the rebate are in €1,000, and income is in €10,000. "%" stands for the percentage of households in each category. The household sizes and professional activities are in 10%. CO_2 emissions are in g/km; CO, NO_X and HC emissions are in mg/km; and PM emissions are in mg/10 km. The reference categories are singles, retired and rural cities. All specifications are estimated using 180,080 observations, except the regression with the rebate as a dependent variable, which uses 30,831 observations from 2008. The regressions are weighted by the number of households. Significance levels: †: 10%, ∗: 5%, ∗∗: 1%.

Price reaction To get a sense of whether and how car manufacturers have reacted to the feebate regulation instituted in 2008, I provide a simple regression of the net prices on the amount of the rebate/fee, and use the car characteristics, car models and year fixed effects as controls. This regression is not weighted by car market shares to eliminate the demand effect. The coefficient of the rebate reflects the percentage of the rebate or fee that is passed through to the final price paid by the consumers. I find that roughly 54% of the rebate or fee is passed through to the final price, which indicates a probable reaction of car manufacturers. The regression also indicates that in 2008, the average price of cars did not decrease as much as in the previous years. This mild reduction in price may be the consequence of strategic interactions between car manufacturers: the feebate modifies the entire price equilibrium, and the prices of the cars that are not directly affected change. The structural model below describes the manufacturers' optimal pricing strategies and the optimal responses to the feebate.

Table 6: Regression of the net car price on the rebate/fee and controls.

Price	Parameter	Std. error
Rebate or fee	-0.543**	0.094
Fuel cost	-205**	50.6
Horsepower	1,288**	31.7
Cylinder capacity	1,598**	174
Weight	1,331**	62.2
Coupe/convertible	2,542**	186
Station wagon	232*	102
Diesel	1,148**	237
2004	-344**	118
2005	-454**	127
2006	-570**	131
2007	-719**	131
2008	-781**	150
No. of observations	5,266	
R^2	0.978	

*Note: The regression includes car model fixed effects. The price and rebate are in €, the horsepower is the fiscal horsepower, the fuel cost is in €/100 km, the cylinder capacity is in 1,000 cm^3, and the weight is in 100 kg. Significance levels: †: 10%, *: 5%, **: 1%.*

3 Model

In this section, I present a model of demand and supply for new automobiles both with and without the feebate regulation. The model allows for heterogeneous preferences related to the demographic characteristics. The demand is represented by a random coefficients logit model that is similar to the model used in Nurski and Verboven (2016). The supply model formalizes the pricing strategies of the car manufacturers, which are multi-product firms that compete with each other as in the standard model of Berry et al. (1995).

3.1 Demand

I consider N_m potential buyers from municipality m choosing either to purchase one of the J cars offered or not to purchase a car (which is the outside option and is denoted by 0). Consumers do not have preferences for the cars themselves but for the attributes of the cars. Each consumer, denoted by i, maximizes her utility, which is a linear function of the car characteristics and the price. The index j stands for the car. I omit the year index to keep the number of indexes small.

$$U_{imj} = X_j\beta_m - \alpha_m p_j + \xi_j + \epsilon_{imj}.$$

X_j and ξ_j represent observed and unobserved car characteristics, respectively, and p_j is the price. ϵ_{imj} is an individual and car-specific preference term, which is assumed to be identically and independently distributed according to an extreme value. β_m and α_m are the parameters for preferences for car attributes and price sensitivity, respectively. These parameters are common to all individuals within a municipality. I further assume that these parameters are deterministic functions of the demographic characteristics:

$$\beta_m = \bar{\beta} + \Sigma^X D_m$$
$$\alpha_m = \bar{\alpha} + \Sigma^p D_m,$$

where D_m are the demographic characteristics of the consumers in municipality m. The mean utility of the outside option is normalized to 0 so that:

$$U_{im0} = \epsilon_{im0}.$$

The utility function can be expressed as the sum of the mean utility (δ_j), a deviation from this mean related to the demographic characteristics of municipality (μ_{mj}) and an individual error term:

$$U_{imj} = \delta_j + \mu_{mj} + \epsilon_{imj}.$$

Because of the distribution of ϵ_{imj}, the probability that consumer i from municipality m chooses car j, which is also equal to the market share of car j in the municipality, is expressed as:

$$s_{imj} = s_{mj} = \frac{\exp\left(\delta_j + \mu_{mj}\right)}{1 + \sum_{k=1}^{J} \exp\left(\delta_k + \mu_{mk}\right)}.$$

Then, the market share of car j at the national level is:

$$s_j = \sum_m \phi_m \frac{\exp\left(\delta_j + \mu_{mj}\right)}{1 + \sum_{k=1}^{J} \exp\left(\delta_k + \mu_{mk}\right)},$$

where ϕ_m is the percentage of consumers in each municipality: $\phi_m = \frac{N_m}{\sum_m N_m}$.

3.2 Supply

I assume that the car market is an oligopolistic market with F firms selling differentiated cars. Car manufacturers have market power and set their prices taking into account the demand and the prices of the competitors.[10] I assume that the car manufacturers set their prices nationally, so there is no price discrimination across municipalities. This assumption is consistent with the use of catalogue prices as optimal prices since I do not observe transaction prices.[11] The profit of manufacturer f selling the set of cars $\mathcal{F}$ is:

$$\pi_f = \sum_{j \in \mathcal{F}} \sum_m N_m s_{mj}(\mathbf{p}) \times \left(p_j - c_j\right),$$

where c_j is the marginal cost. $s_{mj}(\mathbf{p})$ is the market share of product j that depends on the prices of all the cars, which are represented by the vector $\mathbf{p}$. The optimal price p_j is derived from profit maximization such that:

$$\sum_m \phi_m \left(s_{mj}(\mathbf{p}) + \sum_{k \in \mathcal{F}} (p_k - c_k) \frac{\partial s_{mk}}{\partial p_j}(\mathbf{p}) \right) = 0, \quad \forall j \in \mathcal{F}.$$

The expression above can be written with vectors and matrices:

$$\mathbf{s}(\mathbf{p}) + \Omega(\mathbf{p})(\mathbf{p} - \mathbf{c}) = 0,$$

where $\mathbf{s}(\mathbf{p})$ is the vector of aggregate market shares, and $\Omega(\mathbf{p})$ is the matrix of semi price elasticities, which is defined as:

$$\Omega_{(k,j)}(\mathbf{p}) = \begin{cases} \sum_m \phi_m \frac{\partial s_{mj}}{\partial p_k}(\mathbf{p}), & \text{if } k \text{ and } j \in \mathcal{F} \\ 0, & \text{otherwise.} \end{cases}$$

[10] I abstract here from modeling the vertical relations between car manufacturers and dealers and assume perfect integration such that the manufacturers set the final prices paid by the consumers.

[11] I could apply the methodology developed by D'Haultfœuille et al. (2018) to allow for unobserved price discrimination across municipalities, but the computation cost would be very high given the large number of municipalities.

The optimal prices are:

$$\mathbf{p} = \mathbf{c} - (\Omega(\mathbf{p}))^{-1}\,\mathbf{s}(\mathbf{p}).$$

3.3 Market equilibrium under the feebate regulation

The feebate regulation modifies the optimal choices of the consumers and the firms' pricing strategies. Let λ_j be the rebate or fee associated with the level of CO_2 emissions of car model j. I adopt the convention that λ_j is positive for a fee and negative for a rebate. For this analysis, $\tilde{\mathbf{p}}$ denotes the vector of the prices set by car manufacturers under the feebate regulation. Consumer i's utility is modified as follows:

$$U_{imj} \quad = \quad X_j\beta_m - \alpha_m(\tilde{p}_j + \lambda_j) + \xi_j + \epsilon_{imj}.$$

The market shares under the feebate policy are:

$$\tilde{s}_j = \sum_m \phi_m \frac{\exp\left(\tilde{\delta}_j + \tilde{\mu}_{mj}\right)}{1 + \sum_{k=1}^{J} \exp\left(\tilde{\delta}_k + \tilde{\mu}_{mk}\right)},$$

where $\tilde{\delta}_j = X_j\bar{\beta} - \bar{\alpha}(\tilde{p}_j + \lambda_j) + \xi_j$ and $\tilde{\mu}_{mj} = X_j\Sigma^X D_m + (\tilde{p}_j + \lambda_j)\Sigma^p D_m$. Car manufacturers set their prices taking into account the potential rebates and taxes consumers are subject to. The profit function of firm f is now:

$$\pi_f = \sum_m N_m \sum_{j\in\mathcal{F}} s_{mj}(\tilde{\mathbf{p}} + \boldsymbol{\lambda}) \times (\tilde{p}_j - c_j)\,,$$

The optimal prices satisfy:

$$\sum_m \phi_m \left(\tilde{s}_{mj}(\tilde{\mathbf{p}} + \boldsymbol{\lambda}) + \sum_{k\in\mathcal{F}} (\tilde{p}_k - c_k) \frac{\partial \tilde{s}_{mk}}{\partial p_j}(\tilde{\mathbf{p}} + \boldsymbol{\lambda}) \right) = 0, \quad \forall j \in \mathcal{F}.$$

Let $\tilde{p}^n_j = \tilde{p}_j + \lambda_j$ denote the price net of rebate or fee. I can rewrite the previous equation as:

$$\sum_m \phi_m \left(\tilde{s}_{mj}(\tilde{\mathbf{p}}^{\mathbf{n}}) + \sum_{k\in\mathcal{F}} (\tilde{p}^n_k - \lambda_k - c_k) \frac{\partial \tilde{s}_{mk}}{\partial p^n_j}(\tilde{\mathbf{p}}^{\mathbf{n}}) \right) = 0, \quad \forall j \in \mathcal{F}.$$

The feebate effect on the pricing strategies is identical to a marginal cost increase (for a fee) or reduction (for a rebate). Because of market power and strategic interactions, not all the fee or rebate is passed through to the consumer, but car manufacturers adapt their margins. Car manufacturers are able to extract a part of the rebate by increasing the prices of cars with rebates. In case of a fee, the car manufacturers lower their price and decrease their margins to avoid large reductions in sales.

3.4 Estimation

I estimate the parameters of utility and the firms' marginal costs using the generalized method of moments (GMM). I use the standard aggregate demand and supply moments, as in Berry et al. (1995), complemented with micro moments in the spirit of Berry et al. (2004) and Petrin (2002). The micro moments leverage the information on car sales at the municipality level and ensure the identification of the heterogeneity parameters. Specifically, I use the covariance between the characteristics of car purchases and the demographic characteristics across municipalities, as Nurski and Verboven (2016).

I do not directly use sales at the municipality level for two related reasons. First, there are many null market shares, which the logit model cannot rationalize given the assumption that the error term is extreme value distributed. Second, the sales at the local level fail to generate precise estimates of the market shares because there are only a few sales in each municipality: the maximum number of car sales is 433, and the average number of sales is 19. The estimates of the local market shares are too sensitive to the presence of outliers and are not reliable for estimating the demand model. I instead rely on annual national aggregate market shares and use the local sales in the micro moments.

Aggregate moments The aggregate moment conditions are based on the interaction of unobserved product characteristics ξ_j with the instruments Z_j. The vector $\boldsymbol{\xi}$ is unobserved, but it is such that the theoretical market shares are equal to the observed ones:

$$s_j^{obs} = s_j(\boldsymbol{\xi}, \theta)$$

θ represents the vector of the parameters $(\bar{\beta}, \bar{\alpha}, \Sigma^X, \Sigma^p)$. To invert the market share equation and recover the vector of the unobserved product characteristics $\boldsymbol{\xi}$, I use the contraction mapping suggested by Berry et al. (1995).

The price p_j is endogenous because it is likely to be correlated with the unobserved product characteristics ξ_j. The firms have market power, and their pricing decisions depend on the demand, including its unobserved component. The instruments I use are functions of other products' characteristics, such as those used in Berry et al., 1995 (more details are provided in the next section). The moment conditions are $\mathbb{E}(\xi_j z_j) = 0$, and the sample analogues are given by:

$$G^d(\theta) = \frac{1}{J} \sum_j \xi_j(\theta) z_j.$$

In addition to the moment conditions from the demand side, I construct moment conditions using the supply side, starting from the specification of the marginal cost equation:

$$\ln c_j = X_j^s \gamma + \omega_j$$
$$\ln (p_j - m_j(\theta)) = X_j^s \gamma + \omega_j,$$

where $m_j(\theta)$ is the margin of car j obtained from the price optimality condition, X_j^s are the observable cost shifters and ω_j are the unobservable cost shocks. The moment conditions are based on the independence between the cost shocks and the instruments Z^s: $\mathbb{E}(\omega_j z_j^s) = 0$. I use the sample analogue:

$$G^s(\theta, \gamma) = \frac{1}{J} \sum_j \omega_j(\theta, \gamma) z_j^s.$$

Micro moments The micro moments exploit the information on the demographic characteristics and the market shares of products at the municipality level. More specifically, the micro moments match (i) the predicted average demographic characteristics of the car purchasers and (ii) the covariances between the demographic characteristics and the products' characteristics and their empirical counterparts. The sets of micro moments are crucial for identifying the observed heterogeneity, as noted in Berry et al. (2004), Petrin (2002) and Nurski and Verboven (2016). For this analysis s_j, s_{mj}, $\bar{D}$, and $\bar{x}$ denote the observed aggregate market share, the municipality market share, the mean demographic characteristics and the mean product characteristics, respectively, while $s_j(\theta)$, $s_{mj}(\theta)$, $\bar{D}(\theta)$, and $\bar{x}(\theta)$ are the predicted values for a given parameter θ. The third set of moments is: (i)

$$G^{m,(i)}(\theta) = \frac{1}{J} \sum_j \frac{\sum_m \phi_m s_{mj} D_m}{s_j} - \frac{\sum_m \phi_m s_{mj}(\theta) D_m}{s_j(\theta)},$$

and (ii)

$$G^{m,(ii)}(\theta) = \frac{1}{J} \sum_j \frac{\sum_m \phi_m s_{mj} (x_j - \bar{x})(D_m - \bar{D})}{s_j} - \frac{\sum_m \phi_m s_{mj}(\theta) \left(x_j - \bar{x}(\theta)\right) \left(D_m - \bar{D}(\theta)\right)}{s_j(\theta)},$$

where x_j is one product characteristic, and $\bar{x}$ is its average. $\bar{D}$ is the average demographic characteristic. Since I exactly match the aggregate market shares, I have $s_j(\theta) = s_j$ and $\bar{x}(\theta) = \bar{x}$, and the moments can be written as:

$$G^{m,(i)}(\theta) = \frac{1}{J} \sum_j \frac{\sum_m \phi_m D_m \left(s_{mj} - s_{mj}(\theta)\right)}{s_j},$$

and

$$G^{m,(ii)}(\theta) = \frac{1}{J}\sum_j \frac{\sum_m \phi_m \left[s_{mj}(D_m - \bar{D}) - s_{mj}(\theta)\left(D_m - \bar{D}(\theta)\right)\right](x_j - \bar{x})}{s_j}.$$

4 Results

4.1 Estimation results

I estimate a simple logit model without heterogeneity in preferences using moments only from the demand and supply. I also estimate the model with heterogeneity relying on the three sets of moments derived in the previous section. The observed product characteristics introduced in the utility function are the price (net of feebate in 2008), the cost of driving, the horsepower, the cylinder capacity, the weight (as proxy for car size), and the type of car body (coupe, wagon or sedan). I also include year fixed effects to capture symmetric shocks on the automobile market and brand fixed effects to control for the unobserved heterogeneity of cars at the brand level. I allow for heterogeneity in terms of price sensitivity, fuel cost, weight and cylinder capacity. I assume that price sensitivity is a linear function of the income, while I allow fuel cost sensitivity to depend on the income and the size of the municipality. Municipalities are split into two categories: less than 20,000 inhabitants (rural) and more than 20,000 inhabitants (urban). I consider that the valuation for weight can be different according to municipality density. Finally, I allow the valuation of cylinder capacity to depend on household size. Household size is represented by the percentage of households in each of these two categories: singles and families (with or without children). Finally, I use a log-linear specification for the marginal cost function and consider the following variables as cost shifters: horsepower, fuel consumption (in liters for 100 kilometers), weight and cylinder capacity. I also introduce brand fixed effects in the cost function.

The estimation method relies on instruments and make the standard assumption that the products' characteristics, other than price, are exogenous, and use these product characteristics as instruments. I construct additional instruments that are functions of the characteristics of other products. The characteristics of competing products are correlated with the price through the strategic interactions across firms: if a car has close substitutes, it has lower market power and therefore a lower price. I also use functions of the characteristics of the other cars of the same brand. The argument is similar: if the brand offers many close substitutes to a car, then the manufacturer has high market power and is able to set a high price. More precisely, I use three sets of instruments: the sums of the characteristics of all the other brands' cars, the sums of the characteristics of other cars of the same brand and the sums of the characteristics of the other brands' cars in the same segment. I consider 8 segments: mini, small family, large family, executive, small minivans, large minivans, sports cars and allroad.[12] I use the same instruments to construct the demand and supply moments but do not use instruments for the micro moments.

I estimate the model using a sample of municipalities to reduce the computation cost associated with the calculation of aggregate market shares. The market share inversion uses the contraction mapping proposed by Berry et al. (1995), which involves the computation of the aggregate market shares many times, which explains why I rely on a sample. I randomly draw 3,000 municipalities (approximately 10% of all municipalities) with a weight that is proportional to the number of households. For the data to be consistent with the model, I use aggregate market shares, which are computed by summing the sales over the municipalities sampled. For more details on the representativeness of the sample, see Appendix B. Note that I rely on a sample of municipalities only for the estimation, and I use the full set of municipalities for the welfare analysis.

Prior studies note that it is necessary to aggregate different versions of products to obtain exploitable variations in market shares across products and to obtain a choice set of a reasonable size. I define a product (car model) as a brand, model name, body style (sedan, wagon or coupe), and class of CO_2 emissions. I do not use the fuel type to directly define car models, but it is highly correlated with the class of CO_2 emissions, so cars with different fuel types are generally in two different classes of CO_2 emissions and are therefore considered to be two different car models. To each car model, I assign the characteristics of the most frequently purchased version of the car model (if there are an equal number of sales, then I select the characteristics of the cheapest version). I finally obtain 5,266 different car models over the six years under study. To compute the market shares of the products and an outside option, I assume the potential market is one-fourth of the total number of households. For the estimation, I use one-fourth of the total number of households from the sample of selected municipalities.

I check to ensure that the micro moments are useful for identifying the heterogeneity parameters by computing the influence matrix, as suggested by Andrews et al., 2017 (see Table 21 in Appendix C). As expected, the moments that involve the covariance between the car characteristics and the consumers' characteristics have a large influence on the parameters of interactions between the cars and the consumers' characteristics.

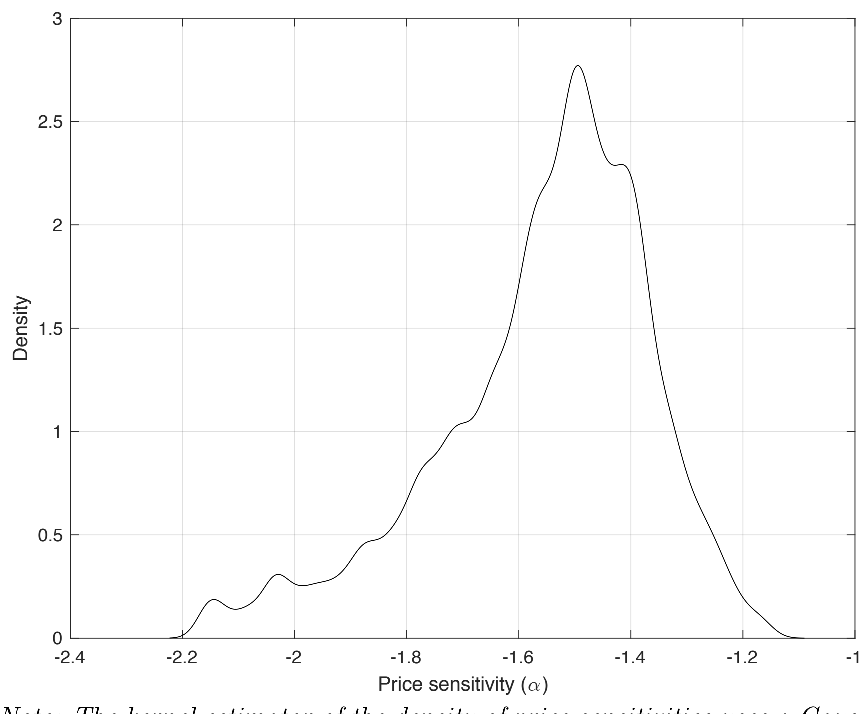
[12]Formally, I consider:

$$\sum_{k \in \mathcal{B}', \mathcal{B}' \neq \mathcal{B}} x_k, \sum_{k \in \mathcal{B}, k \neq j} x_k, \sum_{k \in \mathcal{B}, \mathcal{B}' \neq \mathcal{B}, k \in g} x_k,$$

where index g stands for the segment, and $\mathcal{B}$ and $\mathcal{B}'$ are the set of cars of brands b and b', respectively.

Table 7 displays the estimated parameters for the models both with and without heterogeneity in consumers' preferences. The price and the fuel cost have significant negative coefficients. The estimates of the model with heterogeneity are in line with those of the simple model. Since the parameters of heterogeneity are significant, I use the model with heterogeneity as the main specification. Weight and horsepower are characteristics that consumers appreciate, while they dislike cylinder capacity. On average, individuals prefer sedans or coupes to cars with a wagon body. I find, surprisingly, that price sensitivity increases with income. The distribution of price sensitivity is displayed in Figure 1. This figure shows that the price sensitivities are moderately heterogeneous and the price parameters are between -2.2 and -1.1. On the other hand, the sensitivity to fuel cost decreases with income, as expected. The sensitivity to fuel cost is also lower in urban municipalities than in rural areas. I find that consumers living in urban municipalities value the car weight less, reflecting heterogeneity in car usage across municipality densities. I also observe that couples and families value cylinder capacity more than singles. The estimated cost parameters have the expected signs, except for fuel consumption, which tends to increase the cost. However, this parameter is only significant at the 5% level. According to the estimates, it is more costly to produce cars that are heavy, have more horsepower and more cylinder capacity.

Figure 1: Distribution of price sensitivities.



Note: The kernel estimator of the density of price sensitivities uses a Gaussian kernel for 31,584 municipalities in 2008 weighted by the number of households. The top and bottom 1% are trimmed.

Table 7: Estimation results.

	Model without heterogeneity		Model with heterogeneity	
	Parameter	Std. err.	Parameter	Std. err.
Utility parameters				
Price	-1.56**	0.01	-0.423**	0.071
Horsepower	0.296**	0.021	0.294**	0.021
Fuel cost	-0.383**	0.016	-0.928**	0.023
Weight	0.326**	0.017	0.366**	0.018
Cylinder capacity	-0.088	0.125	-0.366**	0.127
Convertible	-0.089	0.093	-0.072	0.092
Wagon	-0.897**	0.066	-0.874**	0.066
Intercept	-9.27**	0.244	-9.04**	0.244
Income × fuel cost			0.283**	0.01
Income × price			-0.624**	0.037
Urban × fuel cost			0.059**	0.006
Urban × weight			-0.059**	0.004
%Couple × Cylinder cap.			0.325**	0.049
Cost parameters				
Intercept	-1.78**	0.051	-1.71**	0.063
Horsepower	0.056**	0.003	0.063**	0.003
Fuel consumption	0.036*	0.015	0.034*	0.014
Weight	0.123**	0.004	0.12**	0.005
Cylinder capacity	0.086**	0.02	0.048*	0.019

Note: Price and income are in €10,000 and deflated, horsepower is the fiscal horsepower, fuel cost is measured as €/100 km, weight is in 100 kg, cylinder capacity is in 1,000s of cm^3 and fuel consumption is in L/100 km. "Urban" is a dummy that equals one for municipalities with more than 10,000 inhabitants, and "%Couple" is the frequency of couples with or without children in the municipality. Both models are estimated using 5,266 car models × years and include brand dummies in the utility and the cost function. Significance levels: †: 10%, ∗: 5%, ∗∗: 1%.

4.2 Effects of the feebate

The effects of the feebate policy on the car market are measured by comparing the observed equilibrium in 2008 when the feebate is in place with the counterfactual market equilibrium without the feebate. Using the structural model of demand and supply and the estimated parameters of preferences and marginal costs, I first solve for equilibrium prices and market shares for the sample of 3,000 municipalities. I then compute the market share for all municipalities using the prices recovered in the first step. I prefer to solve for optimal prices using the sample of municipalities rather than using all municipalities because the observed prices in 2008 are optimal given this representative sample.[13]

Gains for consumers are measured through variations in surplus, which is the expected utility of their best choice. Since the only source of heterogeneity within each municipality is included in the individual level and product specific shock ϵ_{ik}, individual surpluses are identical in the same municipality. The average consumer surplus in municipality m is:

$$CS_m = \frac{\ln\left(1 + \sum_{k=1}^{J} \exp\left(\delta_k + \mu_{mk}\right)\right)}{\alpha_m},$$

and the variation in surplus due to the feebate is:

$$\Delta CS_m = \frac{\ln\left(1 + \sum_{k=1}^{J} \exp\left(\delta_k + \mu_{mk}\right)\right) - \ln\left(1 + \sum_{k=1}^{J} \exp\left(\tilde{\delta}_k + \tilde{\mu}_{mk}\right)\right)}{\alpha_m},$$

where $\tilde{\delta}_k$ and $\tilde{\mu}_{mk}$ represent the mean utility and the municipality-specific portion of the utility without the feebate policy, respectively, while δ_k and μ_{mk} are those with the feebate policy, respectively. I also compute consumers' surplus when a tax T_m is introduced to finance the cost of the feebate. I consider a lump-sum tax as the first mechanism to subsidize the deficit $T_m = \bar{T} =$ €32.3. I also examine a flat tax that is proportional to the income tax to offset the deficit: $T_m = \tau \frac{I_m}{10{,}000} = €20.1 \times \frac{I_m}{10{,}000}$, where I_m is the median income in the municipality. The proportional tax leads to individual taxes between €13 and €89 with a median of €31, which is slightly below the lump-sum tax. With a tax, the variation in consumer surplus is:

$$\begin{aligned}\Delta CS_m &= \frac{\ln\left(\exp(-\alpha_m T_m) + \sum_{k=1}^{J} \exp(\delta_k + \mu_{mk} - \alpha_m T_m)\right) - \ln\left(1 + \sum_{k=1}^{J} \exp\left(\tilde{\delta}_k + \tilde{\mu}_{mk}\right)\right)}{\alpha_m} \\ &= T_m + \frac{\ln\left(1 + \sum_{k=1}^{J} \exp(\delta_k + \mu_{mk})\right) - \ln\left(1 + \sum_{k=1}^{J} \exp\left(\tilde{\delta}_k + \tilde{\mu}_{mk}\right)\right)}{\alpha_m}.\end{aligned}$$

Ultimately, the type of tax used to subsidize the deficit generated by the feebate policy does not affect the total consumer surplus or the total welfare effect. This result occurs because I specify a linear utility function that rules out an income effect. However, the type of tax used has consequences on the distribution of gains and losses across municipalities.

Aggregate effects I first present the aggregate effects of the feebate policy on average and annual emissions, sales as well as the welfare effects on consumers and car manufacturers. I take into account the value of emissions in the total welfare using the pollution cost estimates

[13] I also solved for optimal prices using the whole set of municipalities and find a small average absolute price difference of €72 and an average relative price difference of only 0.34%.

presented at the end of Section 2.1. This is the first evaluation of the feebate policy that accounts for both the emissions of global and local pollutants.

As Table 8 shows, the feebate stimulated the car market with an increase in overall sales of new cars by 2%, which amounts to approximately 24,000 more cars sold than without the feebate. In this analysis I unfortunately cannot distinguish whether these new sales are due to a substitution from a purchase on the second hand market, the anticipation of the replacement of an old car or the entry of new car purchasers. In the welfare analysis, these sales are assumed to be due to the entry of new consumers because I do not have information about previous cars owned and purchases on the second hand market. In addition, I have to ignore the effect of the feebate on the second hand car market and the pace of car replacement (see Jacobsen and Van Benthem, 2015 for a study of the effects of emissions leakage in the used car market). Thus, I provide here estimates of the effect of feebate on emissions that do not take into account substitution from potentially high-emitting old cars that are acquired through the second hand market nor the indirect effect due the change in car replacement rates.

Using the estimates for marginal costs, I am able to compute the manufacturers' margins for each car and the additional profits or losses generated by the feebate. The feebate increased the overall industry profits by 2.1%, but French manufacturers' profits increased by almost twice as much (3.9%). The total consumer surplus also increased because of the feebate, with a monetary gain of 187 million euros (which corresponds to an increase in total consumer surplus of 2.2%). However, the increase in consumer surplus is lower than the cost of the feebate which reached 223 million euros. Therefore, there is a negative variation in total consumer surplus when the deficit is offset by a tax on individuals (-35.5 million euros).

The main objective of the feebate, the reduction of CO_2 emissions, was achieved since the feebate was responsible for a decrease of 2.2 g/km in the average CO_2 emissions of new cars. This reduction corresponds to a reduction of 1.56% in average emissions. This figure might appear small, but it is 40% higher than the annual trend for average CO_2 emissions observed over the period 2003-2007 (-1.57 g/km per year).[14] On the other hand, the average emissions of all local pollutants have increased because of the feebate, indicating a trade-off between global and local pollution. The effects are rather small: the feebate had virtually no impact on the average emissions of CO, while it marginally increased NO_X, HC and PM emissions. Of all the emissions, HC emissions increased the most because of the feebate.

The variation of local emissions become significant once converted to annual emissions: annual emissions increase between 2.2% and 2.8%. Even if the effect of the feebate on emissions of local pollutant is clear, it is not obvious how the raise in emissions translates into

[14] This trend is estimated by regressing CO_2 emissions on a trend using car sales over the period 2003-2007.

air quality since air pollution depends a lot on external factors and there might be interactions between pollutants and pollution sources. Moreover, even if average CO_2 emissions decreased we obtain 20,000 extra tons of CO_2 emissions each year. This is because more cars are sold and the feebate increased the share of diesel vehicles which are assumed to be driven 7,000 km more than gasoline cars each year. Indeed, the feebate is responsible for an increase of 0.44 points in the share of diesel cars. I nevertheless attempt to put a monetary value on the extra emissions generated by the feebate to take them into account in the measure of the welfare. The extra tons of CO_2 emissions are low and cost only 0.6 million euros while the increase in local pollution is estimated to cost 1.3 million euros

Because the gains for car manufacturers (162 million euros) are greater than the sum of consumer surplus losses and the additional CO_2, HC, NO_X and PM emissions (2 million euros), the overall effect of the feebate is positive and reached 124 million euros.

Identifying winners and losers I first analyze the heterogeneity of the effects of the feebate across consumers and investigate the link between consumer surplus variations and the median income of the municipality. Table 9 displays the average surplus variations by income decile both in level and in percentage of the average surplus without the feebate. Assuming that there is no deficit compensation with a consumer tax, all individuals gain from the feebate, but the monetary gains are heterogeneous. The benefits increase monotonically with the income decile and increase from €19.1 for the first decile to €35.5 for the highest income decile. However, in relative terms, these gains increase until the ninth decile and then decrease for the highest decile. Still, in relative terms, individuals below the fourth income decile gain less than average, while individuals in the higher deciles gain more than average.

When the deficit is subsidized by a lump-sum tax, the analysis is pretty similar since the variation in the average individual surplus is simply shifted by the amount of the tax (€32.3). Under this scenario, all the income categories experience welfare losses except the two highest income deciles. The maximal average loss is €13 for the lowest income decile. On average, consumers lose €5.2 which represents only 0.5% of their average surplus.

Table 8: Aggregate welfare effect of the feebate policy.

	3,000 municipalities			All municipalities		
	Feebate	No Feebate	Variation (in %)	Feebate	No Feebate	Variation (in %)
Total sales	120.9	118.5	2.07	1,249	1,225	1.99
Share of diesel	0.68	0.68	0.72	0.71	0.7	0.62
Profits French	240.3	231.2	3.98	2,488	2,395	3.91
Profits all	748.9	732.6	2.22	7,756	7,594	2.13
Consumer surplus	825.1	806.7	2.28	8,654	8,467	2.21
Average emissions						
CO_2	138.1	140.2	-1.56	138.3	140.5	-1.56
CO	307.8	307.8	0	303	302.9	0.03
NO_X	163.1	162.6	0.35	167.4	166.9	0.27
HC	32.39	32.27	0.36	31.93	31.79	0.42
PM	59.12	59.01	0.19	60.2	60.11	0.15
Annual emissions						
CO_2	246.5	244.7	0.71	2578	2563	0.6
CO	514.1	502.3	2.36	5299	5181	2.29
NO_X	324.8	317	2.48	3453	3375	2.31
HC	54.59	53.06	2.89	563.1	547.5	2.84
PM	11.41	11.14	2.43	120.7	118	2.29
Cost of emissions						
Cost of CO_2	9.86	9.79	0.01	103.1	102.5	0.01
Cost of PM	1.58	1.54	0.03	12.33	12.03	0.02
Cost of NO_X	4.24	4.14	0.02	45.07	44.05	0.02
Cost of HC	0.09	0.09	0.03	0.95	0.93	0.03
Cost of the policy (-)		21.86			222.6	
Δ Consumer surplus		18.43			187	
Δ Profits		16.29			161.9	
Δ Cost CO_2 (-)		0.07			0.62	
Δ Cost local pollution (-)		0.14			1.34	
ΔWelfare		12.64			124.4	

Note: "CS" stands for consumer surplus. The shares of diesel are in %. Total sales are in thousands. Profits, consumer surplus, monetary cost, cost of emissions and welfare are in million euros. Average emissions of CO_2 are in g/km, average emissions of CO, NO and HC are in mg/km and average emissions of PM are in mg/10 km. Annual emissions of CO_2 are in thousand of tons while other annual emissions are in tons. The costs of emissions are computed using the values displayed in Table 4.

When the deficit is offset by a tax that is proportional to the income, the pattern is different since higher incomes are associated not only with larger gains but also higher taxes. In absolute terms, the effects on the surplus are rather homogeneous between the first and the eighth deciles (between €-4.45 and €-3.78), while the ninth and tenth income deciles decrease by €5.4 and €13.4, respectively. On average. the highest income class pays a tax of €50, which is more than two times the average tax for the first income decile (€23). In relative terms, the heterogeneity is less pronounced since the average loss for the highest income decile actually represents only a small percentage of the average surplus of the individuals in this decile.

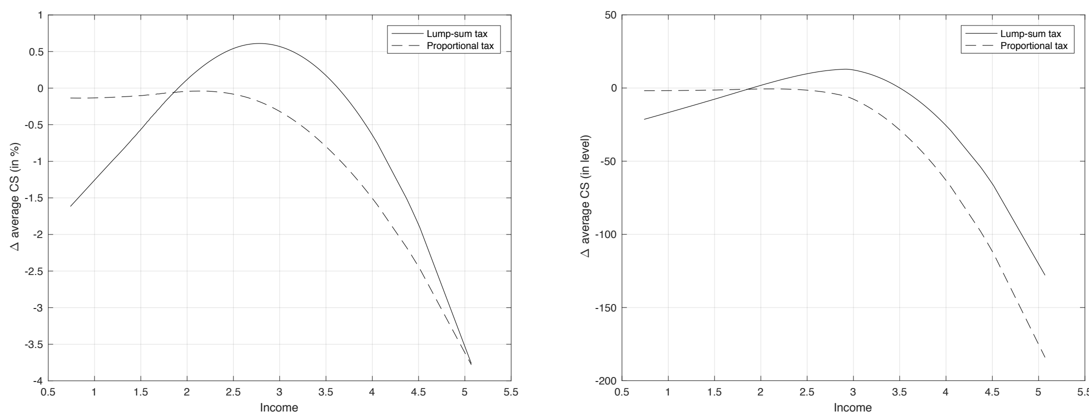
Table 9: Average consumer surplus variation by income decile.

Income decile		No tax		Lump-sum tax		Proportional tax	
		level	%	level	%	level	%
$\leq$ d1	14,629	19.1	1.8	-13.3	-1.31	-4.01	-0.41
d1-d2	15,666	22.8	2.04	-9.64	-0.92	-3.78	-0.39
d2-d3	16,356	24.2	2.13	-8.33	-0.79	-3.82	-0.38
d3-d4	17,059	25.3	2.21	-7.2	-0.69	-3.97	-0.4
d4-d5	17,661	25.9	2.29	-6.57	-0.64	-4.41	-0.44
d5-d6	18,412	27.1	2.35	-5.38	-0.52	-4.45	-0.44
d6-d7	19,475	28.9	2.38	-3.62	-0.36	-4.16	-0.4
d7-d8	20,954	30.8	2.45	-1.63	-0.18	-4.41	-0.4
d8-d9	23,589	33.2	2.54	0.74	0.02	-5.4	-0.46
d9-d10	50,696	35.5	2.28	3.03	0.24	-13.4	-0.72
Average		27.3	2.25	-5.19	-0.51	-5.19	-0.44

Note: The second column provides the value of the highest decile. "Level" represents variations in the level (euros), while "%" represents variations in relative terms, using the value of the consumer surplus without a feebate as a reference.

Figure 2 graphically shows the gains and losses as a function of income using local polynomial regressions. Under the lump-sum tax scenario, the curve is bell-shaped, while under a proportional tax, the consumer surplus variation is flat until €25,000 and then decreases rapidly. The losses are particularly high at the very top of the income distribution under both tax systems. I find that the highest income is associated with a reduction in the average surplus by -2.3%, which is much larger than the average loss of -0.72% for the highest income decile. The few very rich individuals lose the most due to the feebate regulation under the two tax schemes. I find a similar pattern for the distribution of the gains and losses in absolute terms. Under the lump-sum tax scenario, the bell shape is less pronounced, while under a proportional tax, the surplus decreases slightly less sharply.

Figure 2: Average consumer surplus variation and income.



(a) Surplus variation by percentage. *(b) Surplus variation by level.*

Note: Income is in €10,000. Local polynomial regressions with 2^{nd} order polynomials.

Next, I investigate the heterogeneity of the monetary effects of the feebate across different municipality sizes. The monetary gains in absolute terms are the largest for rural municipalities (less than 20,000 inhabitants) and the Paris area. However, the reverse occurs when considering the monetary gains in relative terms: the largest relative gains are for large municipalities. This result occurs because the average surplus is larger for small municipalities where the utility of holding a car is higher. When a tax that is proportional to income is imposed, there is a clear redistribution from the largest municipalities to the smallest ones. The surplus losses in cities of more than 200,000 inhabitants are between €-11 and €-7, which represent variations of -0.74% and -0.68% respectively.

Next, I correlate the monetary effects of the feebate with other demographic characteristics through descriptive regressions. I first regress the consumer surplus variation on the proportion of households in each household size category and each socio-professional category. I then use all the demographic characteristics together. The results of the 3 specifications are displayed in Table 11. The correlation between the welfare gains and household size in Specification (1) suggest that couples and families are associated with larger monetary gains than singles, in absolute terms. However, in relative terms, singles gain the most. This result occurs because singles obtain a lower surplus when buying a car; therefore, the monetary gains appear greater in relative terms.

Table 10: Average variation in consumer surplus variation by population density.

Number of	No tax		Lump-sum tax		Proportional tax	
inhabitants	level	%	level	%	level	%
< 2,000	30	2.06	-2.51	-0.2	-1.15	-0.08
2,000-4,999	30.2	2.11	-2.31	-0.19	-1.25	-0.09
5,000-9,999	29.9	2.12	-2.53	-0.21	-1.34	-0.1
10,000-19,999	29.1	2.1	-3.35	-0.26	-1.58	-0.11
20,000-49,999	23.7	2.35	-8.83	-0.92	-6.65	-0.67
50,000-99,999	23.2	2.34	-9.3	-0.98	-6.56	-0.67
100,000-199,999	23.9	2.4	-8.57	-0.91	-6.86	-0.7
200,000-1,999,999	24.8	2.41	-7.65	-0.8	-7	-0.68
Paris area	28.6	2.31	-3.89	-0.38	-10.9	-0.74

Note: "Level" represents variations in absolute terms (€), while "%" represents variations in relative terms, with the value of the consumer surplus without the feebate as a reference.

Specification (2) correlates the monetary benefits with the socio-professional category. When analyzing the gains in absolute terms, the categories associated with the largest gains are intermediate professionals, executives and entrepreneurs. Individuals in the low socio-professional category such as farmers, manual laborers and employees are, in contrast, associated with lower absolute gains. When examining the gains in relative terms, the comparison across categories is slightly different for executives and employees: executives' gains are comparable to those of retired individuals, and employees benefit more from the feebate than retired individuals. The intermediate professions and executives benefit the most, while farmers and manual laborers have the smallest gains.

Finally, when using all the demographics together and adding the income, the income squared and the population density, I find that household size and the socio-professional category have a smaller and different influence on the benefit, which is a consequence of the correlation between these demographic variables. Families with children and executives are associated with higher monetary gains than the reference categories. As previously emphasized, income has a non-monotonic correlation with the monetary benefits of consumers. Farmers, entrepreneurs, employees and manual laborers have slightly smaller gains than retired individuals. I find significantly lower benefits in urban cities relative to rural municipalities (€5 less). In relative terms, however, the monetary gains appear to be largest for individuals living in dense cities (0.24% more than those in rural municipalities). The relative gains are, in contrast, the lowest for large households, manual laborers and farmers.

Table 11: Correlation between the average consumer surplus variation and the demographic characteristics across municipalities.

	(1)		(2)		(3)	
	level	%	level	%	level	%
Intercept	10.4** (1.53)	2.74 ** (0.086)	−26.7** (2.69)	1.77 ** (0.247)	−28.3** (3.41)	−1.3** (0.052)
%Couple	3.72 ** (0.277)	−0.085** (0.016)			0.157 (0.098)	−0.066** (0.001)
%Family	1.58 ** (0.209)	−0.064** (0.012)			1.14 ** (0.131)	−0.062** (0.002)
%Farmer			5.16 ** (0.298)	−0.131** (0.026)	−0.588** (0.205)	−0.012** (0.003)
%Entrepreneur			7.34 ** (0.363)	−0.122** (0.026)	−0.591* (0.25)	−0.005 (0.003)
%Executive			7.89 ** (0.408)	0.016 (0.03)	1.1 ** (0.318)	−0.006 (0.004)
%Intermediate			8.75 ** (0.543)	0.324** (0.049)	−1.2** (0.413)	0.001 (0.005)
%Employee			1.26 ** (0.403)	0.07 * (0.035)	−0.694** (0.262)	−0.003 (0.003)
%Manual laborer			4.81 ** (0.278)	−0.101** (0.025)	−0.551* (0.222)	−0.012** (0.003)
%Other activity			5.6 ** (0.284)	0.046† (0.026)	−0.139 (0.186)	−0.008** (0.002)
Income					48.7** (4.26)	3.64 ** (0.054)
Income^2					−9.2** (1.1)	−0.793** (0.014)
Urban					−5.14** (0.06)	0.239** (0.001)
Very urban					−5.3** (0.072)	0.238** (0.001)

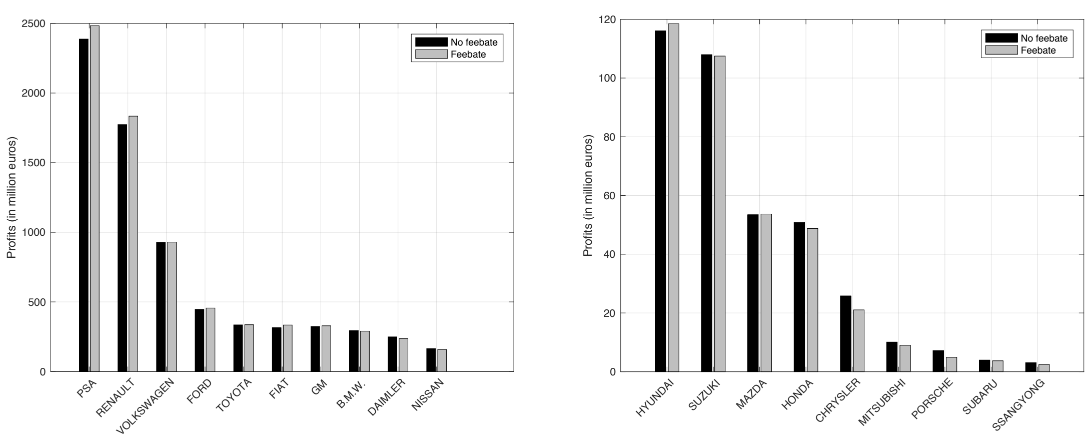
Note: The dependent variables are the average consumer surplus variation in both absolute terms and relative terms. Income is divided by €10,000. "%" stands for the percentage of households in each category. Household sizes and professional activities are in 10%. The reference category for household size is single, the reference category for the professional category is retired, and the reference category for the size of the municipality is rural (less than 20,000 inhabitants). The weighted regressions use the number of households as the weight for 31,584 municipalities in 2008.

Finally, I quantify the gains and losses for the different car manufacturers. Figure 3 displays the profits both with and without feebate (see Table 12 below for the detailed figures). Even if, overall, the feebate increased industry profits by 2.1%, the gains are heterogeneous across manufacturers, and some were worse off because of the feebate regulation. The two French manufacturers gain the most: the PSA Group's profits increase by 96 million euros, while the gains for the Renault Group amounted to 60 million euros. The third largest winner of the feebate policy is the Italian manufacturer Fiat with a net gain of 19 million euros.

Fiat's profits increased the most in relative terms (6.2%). The increase in profits in relative terms is smaller for PSA (4%) and Renault (3.4%). Daimler suffered the most in absolute terms (-12.9 million euros), which corresponds to a reduction in its profits of 5.2%. Porsche is the manufacturer with the largest profit reduction in relative terms (-32%). Mitsubishi, Chrysler, Ssangyong and Lada were very significantly harmed by the feebate, with profit reductions of 10.9%, 18.5%, 20.3% and 30%, respectively.

Overall, there are clear winners and losers across car manufacturers: the French manufacturers and the Fiat Group are the big winners, while the big losers are the German manufacturers, except Volkswagen, which was barely affected (+0.30%). Among the Asian manufacturers there is more heterogeneity: most of them lose (Nissan, Suzuki, Honda, Mitsubishi, Subaru, Ssangyong and Daihatsu), but some improved their situation (Toyota, Hyundai and Mazda). Among the American car manufacturers, Ford and GM were better off, while Chrysler was harmed.

Figure 3: Profits with and without the feebate.



(a) Top 10 car manufacturers.

(b) 11^{th}-19^{th} car manufacturers.

Note: The profits of the two smallest manufacturers are not plotted (Daihatsu and Lada).

Table 12: Profit variations by car manufacturer.

Group		ΔΠ	Δ%Π	Group		ΔΠ	Δ%Π
1	PSA	95.9	4.02	11	HYUNDAI	2.39	2.06
2	RENAULT	60.4	3.41	12	SUZUKI	-0.487	-0.451
3	VOLKSWAGEN	2.82	0.305	13	MAZDA	0.209	0.39
4	FORD	9.12	2.04	14	HONDA	-2.04	-4.02
5	TOYOTA	1.22	0.365	15	CHRYSLER	-4.76	-18.5
6	FIAT	19.5	6.19	16	MITSUBISHI	-1.1	-10.9
7	GM	5.02	1.55	17	PORSCHE	-2.31	-32.1
8	B.M.W.	-3.8	-1.29	18	SUBARU	-0.242	-6.11
9	DAIMLER	-12.9	-5.17	19	SSANGYONG	-0.625	-20.4
10	NISSAN	-6.31	-3.83	20	DAIHATSU	-0.0014	-0.499
				21	LADA	-0.0387	-30

Note: "ΔΠ" represents profit variations in million euros, and "Δ%Π" represents profit variations in percentages of the profits without the feebate.

Heterogeneity in the emissions of local pollutants I analyze the heterogeneity of the feebate's aftereffects on the emissions of local pollutants. Note that I do not analyze the distributional impacts on CO_2 emissions since these emissions do not directly affect the air quality of individuals but have a global impact on the environment. Figure 4 displays the distributions of the variations in average emissions for the 4 different air pollutants. These are the distributions over individuals since each municipality is weighted by the number of households. Even though the feebate caused an increase in the emissions of all pollutants at the aggregate level, average emissions actually decreased in some municipalities. Figure 6 in Appendix C displays the distribution of the variation of emissions in absolute terms and provides similar insights.

While the overall increase in the average emissions of CO is marginal (+0.031%), the distribution is quite dispersed and varies from -0.32% to 0.17%. Average emissions decreased in 5.4% of the municipalities, which represent 15.9% of the households, indicating that the decline occurred in very populated cities. The largest drop of CO emissions occurred in the sixth "arrondissement" of Paris, which is a rich and populated area.

Average emissions of HC decreased in only 74 of the 31,584 municipalities (0.23%), which represents 2.5% of the population. A large portion of the distribution is concentrated around relative large increases (between 0.3% and 0.7%). Similar to the average emissions of CO, the emissions of HC increased the most in the sixth arrondissement of Paris.

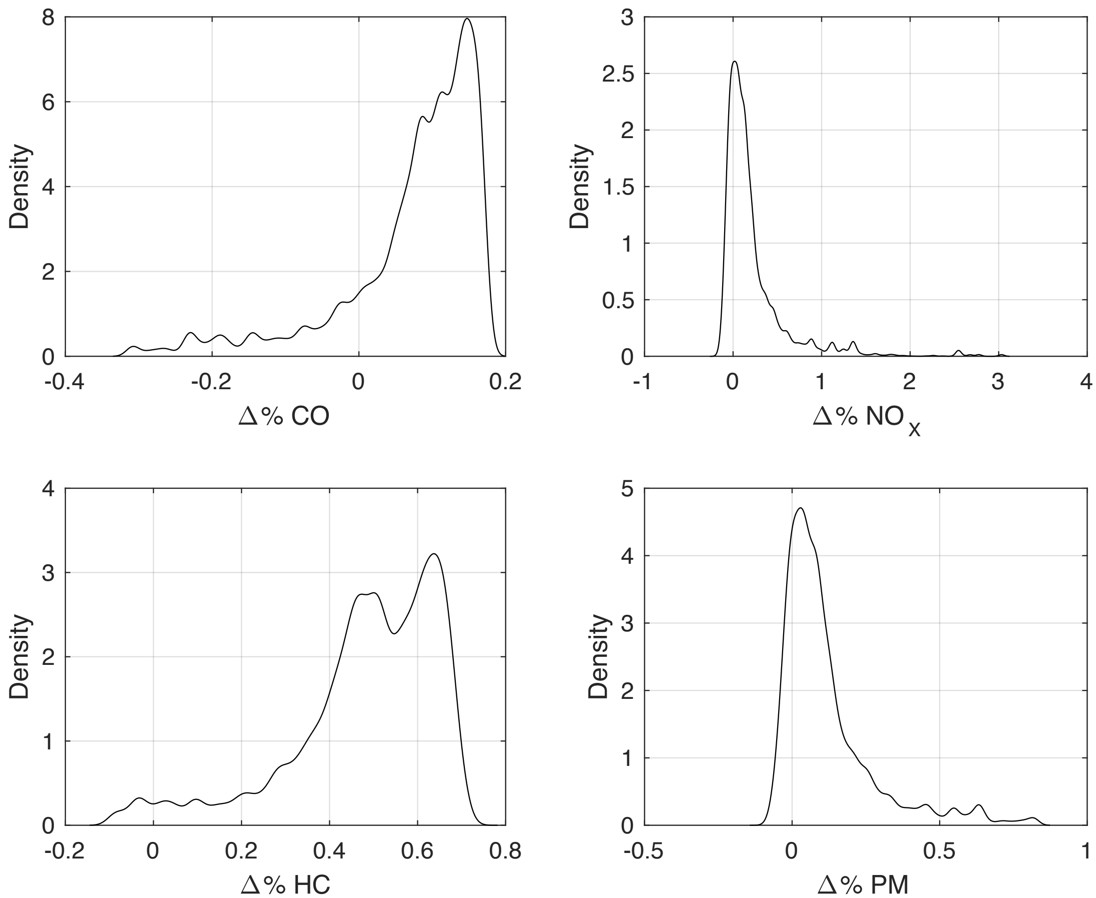
The changes in average NO_X appear to be quite heterogeneous across municipalities. The variation in NO_X emissions lies between -0.17% and 3.1%. The emissions decreased in 43% of the municipalities, which represent 23% of the households. Unlike CO emissions, the level of NO_X mainly decreased in small cities.

In contrast, the distribution of the variation of PM emissions is very concentrated around low values with an important tail. Similar to the emissions of NO_X, PM emissions decrease in a large percentage of the municipalities (34%), but only a small proportion of individuals benefited from the decrease (17% of the households).

I now investigate how the heterogeneity of the feebate effect on emissions relates to the demographic characteristics of the municipalities. I first examine the average variation in emissions by income decile. As Table 13 shows, there is a clear relation between the variations in emissions and income deciles but with very differentiated patterns across pollutants. Emissions of CO and HC increased more in poor municipalities than rich ones, while the opposite occurred for NO_X and PM. The average emissions of CO even decreased in the two highest income deciles. Conversely, in the first two income deciles, the emissions of NO_X decreased and those of PM decreased only in the first one. The feebate, therefore, appears progressive for NO_X and PM but regressive for CO and HC. Provided that NO_X and PM are much more harmful than HC and CO for individuals, I can conclude that the feebate induced some redistribution for the rich households to the poor ones.

Next, I compute the average variation in emission levels by municipality size. A clear pattern emerges: CO and HC emissions increased the most in rural areas while NO_X and PM emissions increased the most in dense municipalities. In Paris, the feebate caused a decrease of 0.19 mg/km in the average emissions of CO but increased the average emissions of NO_X by 0.85 mg/km and those of PM by 0.16 mg/10 km. The opposite occurred for rural municipalities: NO_X emissions increased by less than 0.1% in cities with fewer than 20,000 inhabitants, while the emissions of HC increased by 0.6%, and those of CO by 0.13%. The increase in PM emissions was lower than 0.1% in municipalities with fewer than 100,000 inhabitants but reached 0.31% in the Paris area.

Figure 4: Distribution of the variation in average emissions across municipalities in percentage of the emissions without the feebate.



Note: The kernel estimators are the densities of the variation in emissions with Gaussian kernels. The estimation includes 31,584 municipalities, which are weighted by the number of households.

Table 13: The average variation in emissions by income decile.

Income decile		ΔCO		ΔNO_X		ΔHC		ΔPM	
		Level	%	Level	%	Level	%	Level	%
≤ d1	14,629	0.41	0.15	-0.11	-0.057	0.18	0.62	-0.016	-0.024
d1-d2	15,666	0.4	0.14	-0.025	-0.013	0.18	0.6	0.002	0.004
d2-d3	16,356	0.38	0.13	0.027	0.016	0.18	0.58	0.013	0.021
d3-d4	17,059	0.35	0.12	0.085	0.049	0.17	0.56	0.025	0.039
d4-d5	17,661	0.32	0.11	0.15	0.087	0.16	0.53	0.037	0.06
d5-d6	18,412	0.28	0.097	0.21	0.12	0.16	0.51	0.049	0.08
d6-d7	19,475	0.25	0.084	0.28	0.16	0.15	0.5	0.063	0.1
d7-d8	20,954	0.16	0.055	0.42	0.25	0.14	0.44	0.09	0.15
d8-d9	23,589	-0.005	0	0.66	0.42	0.11	0.35	0.14	0.24
d9-d10	50,696	-0.55	-0.16	1.4	1.1	0.035	0.1	0.25	0.51
Average		0.2	0.073	0.31	0.22	0.15	0.48	0.066	0.12

Note: In the second column, I provide the upper bound of the income decile. Variations by level are in mg/km, except for PM, which are in mg/10 km. Variations by percentage are relative to the emissions without the feebate.

Table 14: Variations in the average emissions of pollutants and municipality size.

Municipality size	ΔCO		ΔNO_X		ΔHC		ΔPM	
	Level	%	Level	%	Level	%	Level	%
< 2,000	0.37	0.13	0.095	0.062	0.18	0.6	0.027	0.046
2,000-4,999	0.36	0.13	0.11	0.068	0.18	0.59	0.03	0.051
5,000-9,999	0.36	0.13	0.11	0.068	0.18	0.59	0.03	0.051
10,000-19,999	0.37	0.13	0.077	0.052	0.18	0.6	0.024	0.041
20,000-49,999	0.23	0.078	0.26	0.16	0.14	0.46	0.057	0.096
50,000-99,999	0.24	0.084	0.23	0.14	0.15	0.47	0.051	0.086
100,000-199,999	0.21	0.071	0.29	0.18	0.14	0.45	0.063	0.11
200,000-1,999,999	0.16	0.055	0.36	0.23	0.13	0.42	0.076	0.13
Paris area	-0.19	-0.045	0.83	0.66	0.085	0.27	0.16	0.31

Note: Variations in absolute terms are in mg/km for all pollutants except for PM, which is in mg/10 km. Variations by percentage are relative to the value of the emissions without the feebate.

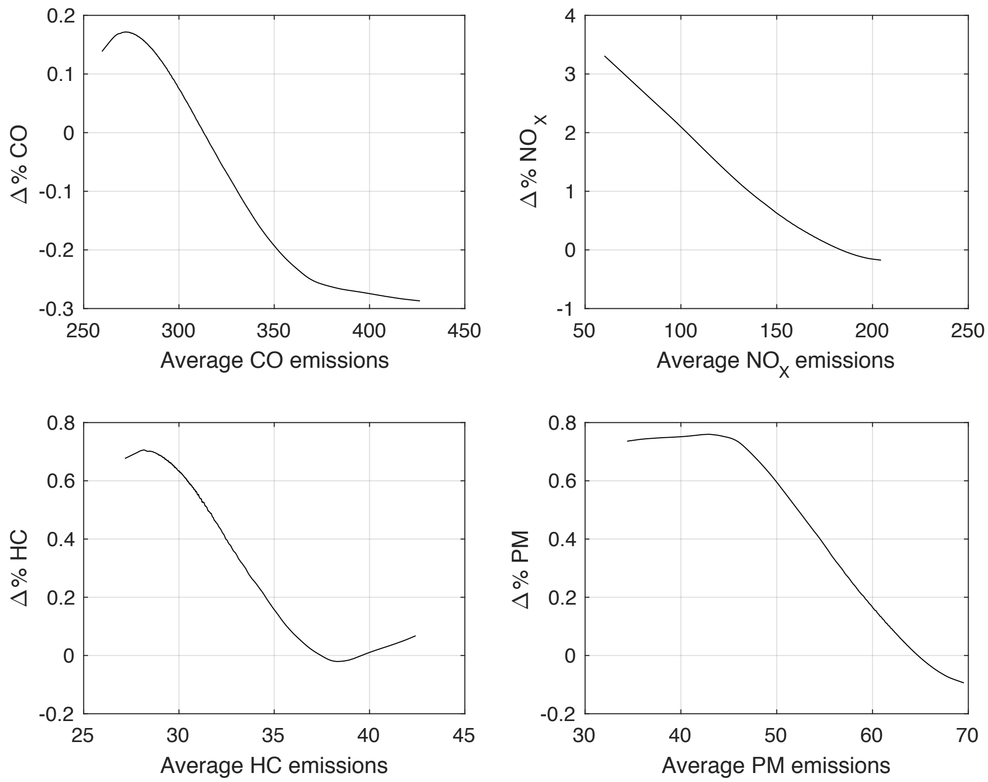
Finally I investigate whether emissions increased the most where they are the highest or the lowest. For this, I group municipalities according to their emission decile and compute average emissions by emission decile. I use the emissions in 2008 without the feebate to construct these emission deciles. Like for the income, I weight each municipality by the number of households to obtain the distribution of emissions across individuals. As Table 15 suggests, the emissions increased the most in the municipalities where they are the lowest. The negative correlation between changes in emissions and emission deciles is consistent across all the local pollutants. This is because the feebate caused an increase in average emissions in urban and rich municipalities which are those with initially low average emission levels of local pollutant. It implies that the feebate achieved some redistribution in terms of emissions of local pollutants from the high emission municipalities to the low emission ones. I graphically illustrate this in Figure 5 where I plot the variations of average emissions in percentage as function of the average emission levels without the feebate using local polynomial regressions. These graphs basically confirm the analysis by emission deciles and reveal that the relations between the variation of emissions and the emission level are not linear. Similar conclusions hold when analyzing the changes in emissions in levels (see Figure 7 in Appendix C).

Table 15: Variations in the average emissions of pollutants by emission decile.

Emission	ΔCO		ΔNO_X		ΔHC		ΔPM	
decile	Level	%	Level	%	Level	%	Level	%
$\leq$ d1	0.45	0.16	1.4	1.1	0.19	0.66	0.26	0.51
d1-d2	0.43	0.15	0.69	0.44	0.19	0.63	0.14	0.24
d2-d3	0.4	0.14	0.43	0.26	0.18	0.61	0.092	0.15
d3-d4	0.36	0.13	0.31	0.18	0.17	0.57	0.068	0.11
d4-d5	0.32	0.11	0.23	0.13	0.16	0.54	0.052	0.084
d5-d6	0.27	0.092	0.15	0.085	0.15	0.5	0.037	0.059
d6-d7	0.22	0.074	0.084	0.047	0.15	0.46	0.024	0.039
d7-d8	0.14	0.046	0.013	0.007	0.13	0.42	0.011	0.017
d8-d9	-0.029	-0.009	-0.056	-0.03	0.11	0.33	-0.003	-0.005
d9-d10	-0.57	-0.16	-0.15	-0.079	0.031	0.09	-0.022	-0.034

Note: Variations in absolute terms are in mg/km for all pollutants except for PM, which is in mg/10 km. Variations by percentage are relative to the value of the emissions without the feebate.

Figure 5: Emission variations in percentage as function of emission levels without feebate.



Note: Local polynomial regressions using second order polynomials. Emissions are in mg/km except PM emissions are in mg/10km.

4.3 Performance of the feebate

I assess the performance of the actual feebate scheme in terms of the redistribution and limitation of the emissions of local pollutants. I investigate alternative feebate schemes that achieve the same average CO_2 emissions and have the same monetary cost. Since, potentially, there is an infinity of different feebate schemes defined by thresholds and the amounts of the fees and rebates, I consider only simple linear feebate schemes of the form:

$$\lambda_j = r \times (e_j - \bar{e})\mathbb{1}(e_j \leq \bar{e}) + t \times (e_j - \bar{e})\mathbb{1}(e_j \geq \bar{e}).$$

where λ_j represents the rebate (fee) associated with car model j, e_j represents the CO_2 emissions of the car, and $\bar{e}$ is the pivot point that separates the positive and negative feebates. r (t) is the marginal rebate (tax) rate for each unit of CO_2 emission below (above) the pivot point. Basically, I consider linear feebates that can have different slopes for the rebates and fees. This restriction is necessary because I have two outcomes to match: average CO_2 emissions and the monetary cost of the policy. Therefore, for a given pivot point, I solve for the marginal tax and rebate rates such that these two outcomes match those of the current feebate.

I compare the current feebate scheme to optimal feebates and consider several outcomes and objective functions. I consider the consumer surplus, the national manufacturers' profits and the emissions of local pollutants as outcomes. For each of these outcomes, I consider different objective functions: a simple average, a weighted average, the individual (car manufacturer) with the minimal surplus (profits) or municipality with the maximum level of emissions and the difference between the maximum and the minimum (as a measure of inequality). The different outcomes, objectives and corresponding formalized objective functions are summarized in Table 16.

Table 16: Description of the objective functions and outcomes of interest.

Outcome	Objective	Function
CS	Simple average	$\max_{\lambda_j} \sum_m \phi_m CS_m(\lambda_1, ..., \lambda_J)$
CS	Weighted average	$\max_{\lambda_j} \sum_m \frac{\phi_m}{I_m} CS_m(\lambda_1, ..., \lambda_J)$
CS	Min	$\max_{\lambda_j} \min_m CS_m(\lambda_1, ..., \lambda_J)$
CS	Max - min	$\min_{\lambda_j} (\max_m CS_m(\lambda_1, ..., \lambda_J) - \min_m CS_m(\lambda_1, ..., \lambda_J))$
French profits	Simple average	$\max_{\lambda_j} \sum_f \Pi_f(\lambda_1, ..., \lambda_J)$
French profits	Weighted average	$\max_{\lambda_j} \sum_f \frac{1}{s_f} \Pi_f(\lambda_1, ..., \lambda_J)$
French profits	Min	$\max_{\lambda_j} \min_f \Pi_f(\lambda_1, ..., \lambda_J)$
French profits	Max - min	$\min_{\lambda_j} (\max_f \Pi_f(\lambda_1, ..., \lambda_J) - \min_f \Pi_f(\lambda_1, ..., \lambda_J))$
Pollutant	Simple average	$\min_{\lambda_j} \sum_m \phi_m \eta_m(\lambda_1, ..., \lambda_J)$.
Pollutant	Weighted average	$\min_{\lambda_j} \sum_m \tilde{\eta}_m \eta_m(\lambda_1, ..., \lambda_J)$
Pollutant	Max	$\min_{\lambda_j} \max_m \eta_m(\lambda_1, ..., \lambda_J)$
Pollutant	Max - min	$\min_{\lambda_j} (\max_m \eta_m(\lambda_1, ..., \lambda_J) - \min_m \eta_m(\lambda_1, ..., \lambda_J))$

Note: "CS" stands for consumer surplus. The consumer surplus weights are inversely proportional to the income I_m. The profit weights are inversely proportional to the market share of the car manufacturer s_f. The emissions weights are proportional to the average level of emissions $\tilde{\eta}_m$ in 2008, with the feebate.

In practice, I solve for the optimal feebate scheme associated with an objective function and an outcome by performing a grid search. For each value of the pivot point between 89 and 219 g/km, I solve for the slope parameters r and t such that average CO_2 emissions and the cost of the policy are the same as those with the actual feebate.[15] Then, I select the optimal scheme associated with the given objective function and the objective outcome. I jointly solve for the slope parameters of the feebate and the new market equilibrium (optimal prices

[15] I also performed the same exercise matching this time the annual CO_2 emissions instead of the average CO_2 emissions. The results are available upon request; the insights do not fundamentally change.

and market shares). The computation of each feebate scheme solves for a system of 1,012 non-linear equations (1,010 car prices and 2 feebate parameters). I increase the computation speed by imputing relevant initial values for the feebate parameters. These initial values are the solutions of a simplified problem that assumes car manufactures do not react and entirely pass the feebate through to the consumers. Second, I find that the optimal feebates are always lower than the value of 146 g/km for the pivot point, so I perform the search on a sparser grid from 160 g/km (every 10 g/km instead of every g/km). I check the robustness of the results to the use of a finer grid on the sample of 3,000 municipalities. The results of the robustness check are displayed in Table 22 in Appendix C. These results are consistent with the results using all municipalities and indicate that the findings are not driven by a grid-search that is too coarse.

Table 17 displays the potential gains from replacing the 2008 feebate scheme by the optimal one (optimal simple feebate for a defined outcome and objective function). I provide in parenthesis the parameters of this optimal feebate: the pivot point (in g/km), the tax rate and the rebate rate (both in €). The first row suggests that the actual feebate performs very well for consumer surplus maximization. In fact, the best simple linear feebates have lower performance than the actual feebate for maximizing the average surplus and the minimal surplus. The inequalities across individuals could be reduced with a simple linear feebate but the gains would be moderate (1.6%). The optimal feebate for inequality reduction pivot point of 130 g/km and provides large rebates and imposes low taxes on a large percentage of the cars (the slope is €10 g/km for fees and €61 g/km for rebates).

On the other hand, there is room to increase profits for the French manufacturers by a large amount. Total French profits could be increased by almost 10%, and the weighted average could be increased by 15% (the weights are inversely proportional to the manufacturers' market shares, giving more importance to Renault than to PSA). There are also large potential gains when the objective is to favor the weakest manufacturer: Renault's profits could be increased by 20.7%. The feebates that achieve this performance have a pivot point between 115 and 117 g/km, slopes for fees between €6.8 and €7 and slopes for rebates between €367 and €504. Such optimal schemes result in very large rebates for a few vehicles and low taxes for many cars. The gains in terms of reducing the inequalities between the two car manufacturers are small (2%). This result occurs because both car manufacturers offer similar car ranges, so the feebate cannot be manipulated too much to stimulate one manufacturer at the expense of the other one.

There are small potential gains in terms of limiting the average emissions of local pollutants. The potential gains reach 2.4% for the average emissions of NO_X. When the objective is the weighted average of emissions, the gains from the alternative feebates are slightly lower, consistent with the mild increase in emissions in municipalities with relatively high emissions. If the objective is to reduce emissions in the municipalities where they are the highest, the potential gains are heterogeneous across the pollutants. The gains are large for the emissions of CO (15%) and HC (13%) but very small for NO_X and PM (0.4% and 0.34%, respectively). The reduction in the maximal levels of NO_X and PM is achieved through a feebate with asymmetric feebate schemes with a pivot point of 114 or 115 g/km, a low marginal tax rate (€7) and a medium rebate rate (between €500 and €600), but the gains are small. There are large potential gains in terms of inequality reduction. For instance, the current feebate achieves only slightly more than 50% of the maximal reduction in the difference between the lowest and highest emissions of CO. The performance of the current feebate is slightly better for NO_X and PM, with potential gains of 19% and 25%, respectively. The feebate scheme that decreases inequalities is the same for all pollutants: the pivot point is minimal (89 g/km), and the tax rate is very low (€8), which basically amounts to a tax on 99.8% of the cars. This feebate scheme is also optimal for limiting the emissions of CO and HC for all the objective functions. But this feebate scheme would not be optimal to imporve redistribution across consumers.

Finally, the optimal feebates are heterogeneous across outcomes and objectives, revealing that a regulator would have to make an arbitrage between the different feebate aftereffects to select the optimal regulation.

Table 17: Potential gains from the optimal simple feebates (in % of potential outcomes).

Outcome/Obj.	Simple average	Weighted average	Min or max	Max - min
CS	-1.06	-1.03	-0.668	1.61
	(146/19/21)	(142/16/26)	(137/13/36)	(130/10/61)
Fr. profits	9.68	15.36	20.67	2.09
	(117/7/367)	(116/7/428)	(115/7/504)	(89/8/23,760)
CO	1.77	1.52	15.1	49.71
		(89/8/23,760)		
NO_X	2.38	2.03	0.401	18.65
		(114/7/593)		(89/8/23,760)
HC	1.83	1.6	13.21	45.83
		(89/8/23,760)		
PM	1.77	1.55	0.339	25.18
		(115/7/504)		(89/8/23,760)

Note: "CS" represents consumer surplus. The weights are inversely proportional to income for consumer surpluses, inversely proportional to market shares for manufacturers' profits and proportional to average emissions for the pollutants."Min or max" represents the minimal consumer surplus and manufacturer profits and the maximal average emission levels. Values that appear in parentheses are the parameters of the optimal feebate scheme and are in the following order: pivot point/tax rate/rebate rate. The optimal feebates are selected from 78 feebate schemes that reach the same average CO_2 emissions and have the same monetary cost. A grid search was conducted for the pivot points between 89 and 160 g/km, with an increment of 1 g/km, and between 160 and 219 g/km, with an increment of 10 g/km. I use all the 31,584 municipalities.

5 Conclusion

In this paper, I quantify both the direct effects and the aftereffects of the feebate policy and find that the policy increased global welfare. Consumers are globally worse off, but their loss is more than offset by an increase in the profits of French manufacturers. With a flat tax rate, the feebate appears to be favorable to middle-income class, while it is progressive with a tax that is proportional to income. The policy decreased average CO_2 emissions but increased the emissions of all local air pollutants. The emissions of local pollutants increased the most where they are the lowest, limiting this pervasive effect f the feebate. The feebate increased the local emissions of NO_X and PM in rich and dense municipalities achieving more redistribution from the rich individuals to the poor ones. Finally, the performance of the implemented feebate is good in terms of consumer surplus, but French manufacturers profits could be further increased. The emissions of local pollutants could be limited with alternative feebate schemes. However, there is not a single optimal feebate scheme that improves all the outcomes at the same time. The design of an optimal feebate scheme would require the regulator to define her objective and to specify the weight associated with each outcome.

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A Predicting the emissions of local pollutants

Table 19 displays the main estimation results of the regressions of the emissions on car characteristics. First, note that the difference in sample sizes comes from non-uniform missing values across pollutants. I obtain rather good fits for the regressions with R^2 between 0.32 and 0.90. Car characteristics best explain the within-car model variation in the emissions of NO_X, while they have less explanatory power for CO and PM emissions.

Table 18 presents the limits on the emissions of CO, NO_X, HC and PM imposed by Euro 4, Euro 5, and Euro 6 standards. The year refers to the introduction of the new standard for the certification of vehicles. Note that for diesel cars, HC is not regulated per se, but there is a limit on the amount of total emissions of HC and NO_X. Since the limits on HC and NO_X together follows exactly the limits on NO_X, I assume there is no change in the limit on HC for diesel engines between Euro 4 and Euro 5. This assumption is also consistent with the constant limit on HC for gasoline cars. PM started to be regulated for gasoline cars with Euro 5. However, it was only applied to vehicles with direct injection engines, which did not represent the majority of vehicles sold before 2008.

Table 18: Emission standards under Euro 4, Euro 5 and Euro 6 and the estimated and predicted coefficients.

		Euro 4 (2005)	Euro 5 (2009)	Euro 6 (2014)	Coef. Euro 4/5 (predicted)	Coef. Euro 5/6 (estimated)
Diesel	CO	500	500	500	0	0
	NO_X	250	180	80	70.2	100.2
	HC+NO_X	300	230	170	0	0
	PM	250	50	45	63.3	1.6
Gasoline	CO	1,000	1,000	1,000	0	0
	NO_X	80	60	60	20	0
	HC	100	100	100	0	0
	PM		50*	45*	3.1	1.5

*Note: All emissions are in mg/km, except PM, which is in mg/10 km. *Only engines with direct injection are subject to the regulation on the emissions of PM.*

Table 19: Regression of the emissions of local pollutants on car characteristics.

	NO_X	CO	HC	PM
Horsepower × Gasoline	1.4 **	2.5 **	0.75**	−0.5**
	(0.02)	(0.11)	(0.01)	(0.01)
Horsepower × Diesel	3.7 **	32.2**	2.2 **	1.2 **
	(0.039)	(0.21)	(0.019)	(0.013)
Weight × Gasoline	−0.026	−8.2**	2.2 **	−0.35**
	(0.11)	(0.59)	(0.052)	(0.051)
Weight × Diesel	−1.2**	−5.4**	−0.16**	−0.28**
	(0.05)	(0.28)	(0.024)	(0.015)
CO_2 × Gasoline	−0.26**	0.54 **	−0.27**	0.12 **
	(0.006)	(0.035)	(0.003)	(0.004)
CO_2 × Diesel	0.29 **	−1.1**	−0.18**	−0.008**
	(0.006)	(0.03)	(0.003)	(0.002)
Wagon × Gasoline	2.8 **	10.6**	3.4 **	0.44**
	(0.47)	(2.6)	(0.23)	(0.13)
Wagon × Diesel	−4 **	−26.1**	−1.5**	−0.86**
	(0.38)	(2.1)	(0.18)	(0.18)
Convertible × Gasoline	9.6 **	−8.9**	5.2 **	−0.51**
	(0.46)	(2.6)	(0.23)	(0.14)
Convertible × Diesel	−7.6**	−55.1**	−4.5**	−0.28
	(0.56)	(3.1)	(0.27)	(0.29)
Euro 6 × Gasoline				−1.5**
				(0.15)
Euro 6 × Diesel	−100.2**			−1.6**
	(0.36)			(0.14)
Trend × Gasoline	−0.27	−8.1**	−1.3**	−0.7 **
	(0.21)	(1.2)	(0.1)	(0.072)
Trend × Diesel	−0.016	−3 **	−0.22**	−0.057
	(0.16)	(0.9)	(0.079)	(0.051)
2014	0.35	10.1**	0.66 **	0.11
	(0.27)	(1.5)	(0.13)	(0.087)
2015	2.7 **	27.5**	0.51 *	−0.95**
	(0.47)	(2.5)	(0.22)	(0.15)
Diesel	56.2**	−126.8**	−13.8**	−4.7**
	(1.1)	(6.3)	(0.55)	(0.62)
Intercept	67.2**	265.1**	47.6 **	11.6 **
	(1.4)	(7.9)	(0.69)	(0.66)
No. observations	75,687	75,687	75,628	35,420
R^2	0.90	0.32	0.51	0.38

Note: NO_X, CO and HC are in mg/km, while PM is in mg/10 km. Weight is in 100 kg. All the regressions include model-name fixed effects. R^2 represents the share of the within-car model variance that is explained by the model.

B Sample selection

I consider a representative sample of 3,000 municipalities that are randomly drawn from all the municipalities in France for which I observe all the relevant demographic characteristics.

I use the number of households in the municipality as the weight. The restricted sample is used only for the estimation, while the counterfactual simulations are conducted at the national level, and the estimated parameters of the preferences are used to compute the market share for all the municipalities.

Table 20 shows the average demographic characteristics of the municipalities in both the exhaustive sample and the sample used for the estimation. The sample is very representative of the entire territory, except that the urban and very urban areas are over-represented compared to rural areas. This result is a direct consequence of drawing a representative sample since rural areas have a lower population density.

The sample of the municipalities selected shows important variations in the demographic characteristics, which is crucial for identifying the parameters of heterogeneity. For instance, the median income in the sample is between approximately €4,000 and €44,000. Note that the variation in income is due to variations across municipalities and variations over time, while the other demographic characteristics are fixed over time. The frequency of the different professional activities have a large range from 0 to between 46% and 93%.

Table 20: Descriptive statistics for the exhaustive dataset and the sample dataset.

	Exhaustive				Sample			
	Mean	Std. dev.	Min	Max	Mean	Std. dev.	Min	Max
No. of households	15,611	30,317	15	194,661	28,212	37,875	44	194,661
Income	16,888	3,590	5,601	50,696	17,295	4,241	7,229	43,849
Household size								
Single	0.33	0.1	0.043	0.63	0.38	0.1	0.083	0.59
Couple	0.3	0.055	0.067	0.71	0.28	0.044	0.15	0.53
Family	0.37	0.087	0	0.78	0.35	0.089	0.14	0.68
Professional activity								
Farmer	0.012	0.026	0	0.47	0.0033	0.0091	0	0.33
Entrepreneur	0.046	0.024	0	0.46	0.04	0.015	0	0.2
Executive	0.1	0.07	0	0.51	0.13	0.087	0	0.45
Intermediate	0.15	0.043	0	0.52	0.15	0.032	0	0.46
Employee	0.12	0.041	0	0.47	0.13	0.031	0	0.26
Manual laborer	0.18	0.069	0	0.69	0.16	0.064	0	0.5
Retired	0.34	0.084	0	0.93	0.31	0.077	0.071	0.86
Other activity	0.06	0.043	0	0.58	0.077	0.044	0	0.25
Municipality size								
Rural	0.44	0.5	0	1	0.17	0.38	0	1
Urban	0.21	0.41	0	1	0.27	0.44	0	1
Very urban	0.36	0.48	0	1	0.56	0.5	0	1

Note: The statistics are weighted by the number of households.

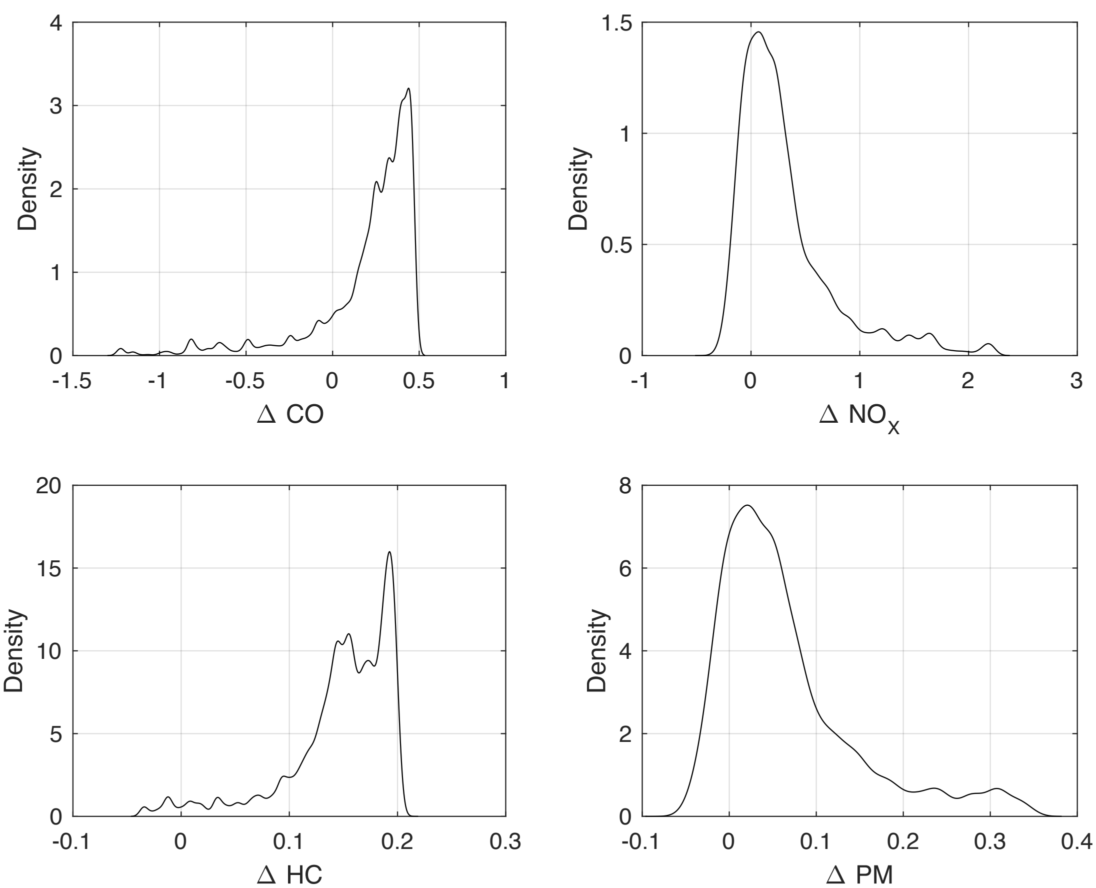
C Additional Tables and Figures

Table 21: Influence matrix for the the heterogeneity parameters and the micro moments.

Moment /parameter	Income, fuel cost	Income, price	Urban, fuel cost	Urban, weight	Couple, cylinder	Income	Urban	Couple
Income×fuel cost	-0.368	1.08	0.058	-0.029	0.071	0.06	-0.019	-0.31
Income×price	1.07	-3.77	-0.118	0.068	-0.213	-0.124	0.095	0.866
Urban×fuel cost	0.125	-0.019	-0.857	0.49	-0.383	-1.04	0.148	0.329
Urban×weight	-0.077	0	0.511	-0.336	0.306	0.739	-0.046	-1.02
Couple×cylinder	-0.189	-0.545	-0.246	-0.47	4.38	3.41	4.61	-72

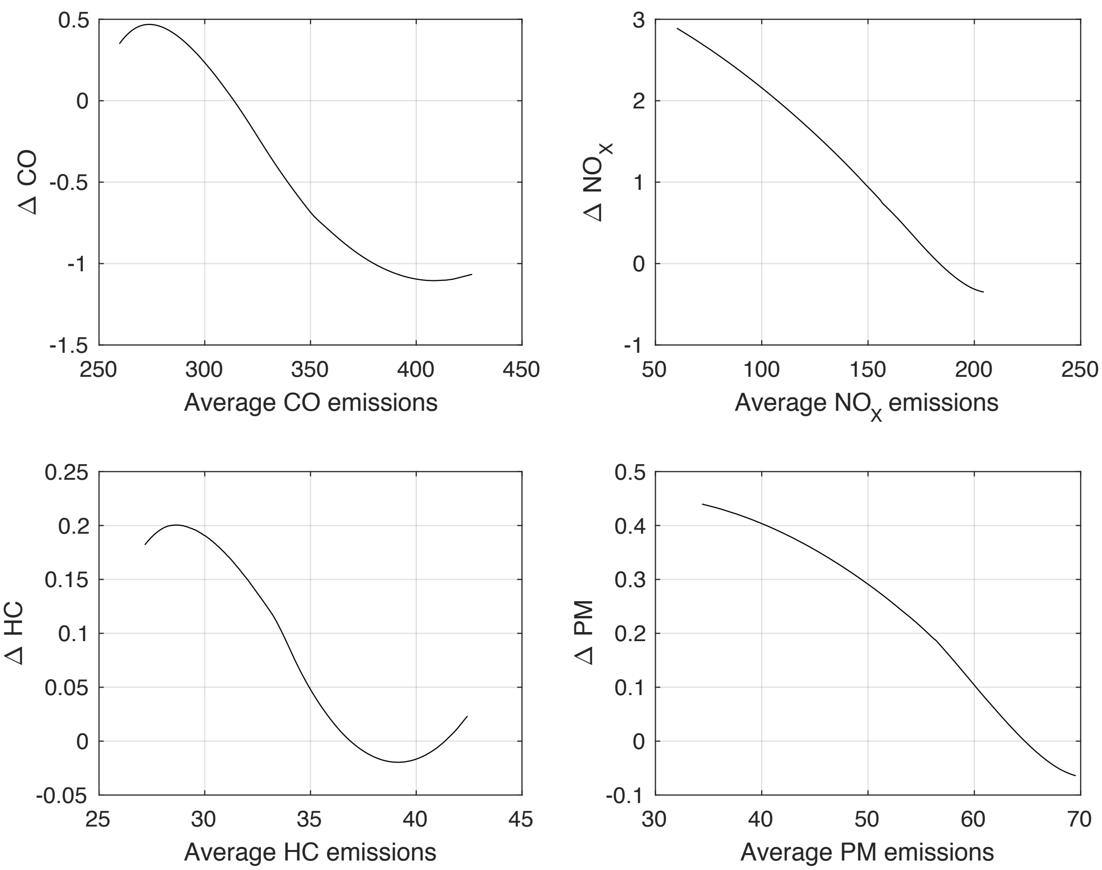
Table 21 provides the influence matrix for the micro moments and the parameters of heterogeneity. This table reveals which moments are the most crucial for parameter identification. Most of the time, the largest influence comes from the moments constructed from the covariance between the corresponding demographic and product characteristics. This is, however, not the case for the parameters of income that are interacted with the fuel cost, which is most influenced by the covariance between income and price. The parameter for urban areas interacted with the fuel cost is most influenced by the average income. Perhaps even more surprising, the coefficient of urban areas interacted with weight is not influenced the most by the moment constructed from the covariance between urban areas and weight but by the average percentage of couples, the average income and the covariance between urban areas and the fuel cost.

Figure 6: Distribution of the variations in average emissions by level across municipalities.



Note: The kernel estimator of the density of the variation of average pollutants uses a Gaussian kernel. I use the 31,584 municipalities weighted by the number of households.

Figure 7: Average variation of average emissions of pollutant in level and average emissions without feebate.



Reading notes: Local polynomial regressions of the variation of pollutants as function of average emissions without feebate using 2^{nd} degree polynomials. Emissions are in mg/km except PM emissions are in mg/10 km.

Table 22: Potential gains from the optimal simple feebates (based on the % of the potential outcomes) for the sample of 3,000 municipalities.

Outcome / Objective	Simple average	Weighted average	Min/Max	Max - Min
Consumer surplus	0.028	0.01	-0.007	0.124
French manuf. profits	2.96	11.27	18.61	9.88
CO	1.67	1.39	10.56	35.35
NO_X	2.64	2.18	0.651	11.18
HC	1.7	1.45	9.71	34.48
PM	1.94	1.64	0.528	17.32

Note: Weights are inversely proportional to income for consumer surplus, inversely proportional to market share for manufacturers' profits and proportional to average emissions for the pollutants. "Min/Max" represents the minimal surplus and manufacturer profits and the maximal average emission levels. Optimal feebates are selected from 651 feebate schemes that reach the same average CO_2 emissions and have the same monetary cost. The grid search was conducted over 651 pivot points between 89 and 219 g/km, with an increment of 0.2 g/km. I use the sample of 3,000 municipalities.