To Rebate or Not to Rebate: Fuel Economy Standards vs. Feebates*

Isis Durrmeyer[†] Mario Samano[‡]

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VERY PRELIMINARY, Please do not circulate.

Abstract

In this paper, we compare the effects of two different environmental policies on the automobile market that incentivize purchases of fuel efficient vehicles thus decreasing the new car fleet's average fuel consumption. Specifically, we compare standard-type policies and feebate policies. Conditional on maintaining the environmental benefit constant, we simulate the implementation of a standard-type policy and a feebate-type policy in France and in the United States. To do so, we consider a differentiated products model for the automobile market and estimate the demand and supply primitives of the American and French markets. We then use these estimates to simulate and compare the effects of the alternative policies in each of the markets. Preliminary results show that if a standard-type policy was to be implemented in France, manufacturers' profits decrease more than under a feebate scheme. However, the number of manufacturers negatively affected by the policy can be larger in the feebate case than in the standard policy case for relatively lenient regulations.

Keywords : Environmental regulation, automobile market, structural model, policy evaluation

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[†]University of Mannheim. E-mail: isis.durrmeyer@gmail.com

[‡]HEC Montreal. E-mail: mario.samano@hec.ca

1 Introduction

This paper compares alternative environmental regulation instruments in the automobile market. Environmental regulations have been introduced in most of the developed countries in the past ten years to reduce carbon dioxide related to new cars.[1] In the case of the United States, the Corporate Average Fuel Economy (CAFE) standards have been in place since 1978 and strengthened gradually. The CAFE standard policy imposes a fuel efficiency minimal threshold that manufacturers' sales must meet on average and a fine is paid if this is not the case. In Europe, on the other hand, incentives usually target consumers directly through a tax or a subsidy. In France, the "bonus/malus" policy was introduced in 2008. It is a scheme of tax/rebate (feebate) according to CO_2 emissions of new cars. This system was initially designed to be revenue-neutral: taxes should subsidize rebates.

Our research question is why different countries choose different instruments for the same main objective. In particular, we would like to understand how much this choice is related to different initial market conditions or to different implicit additional objectives on distributional effects across agents (manufacturers, consumers). We do a transatlantic comparison of two instruments: the feebate and the standard approach. It is an important and new question to compare the efficiency of different environmental regulation instruments focusing on their impacts on agents and the distributional implications. Furthermore, this is an empirical question since to do this evaluation is necessary to understand the American and French initial market conditions which, not surprisingly, are significantly different. We will focus on short-run effects of such environmental policies assuming that manufacturers do not modify the characteristics of car models they offer but only react through prices. That is, technology is fixed.

We simulate and analyze the effects of the two alternative instruments (standard and feebate) on each market keeping the environmental benefits constant. For the American case we find a feebate scheme that is environmentally equivalent to the given CAFE standard and then

[1] Recent examples include the modifications to the CAFE standard policy in the US using footprints-based thresholds, the Cash-for-Clunkers program in the US, a feebate program in France, and the Running on Green Power rebate program in Canada.

we simulate the reactions of agents (consumers and manufacturers) to this alternative policy. Then we compare the effects on consumer surplus and profits under each policy. For the French case, we calibrate a hypothetical CAFE standard policy such that its environmental benefits are equivalent to those of the feebate policy. When the CAFE policy goes into effect, we compare consumer and producer surplus between the two programs.

The data we have include all sales of new cars in France and the US by car model and their main characteristics. We are able, using a structural model of demand à la Berry et al. [1995] to recover parameters of preferences such as price sensitivities and valuations of car attributes. Using a structural model of supply and assuming that market outcomes correspond to those of a Bertrand-Nash equilibrium, we are able to recover estimates of marginal costs for all the products offered. Once we have estimated the structural parameters defining market conditions we are able to run the counterfactual simulations.

There have been a number of previous studies on the effects of CAFE standards and gasoline taxation (Goldberg [1998a], West [2004], Kleit [2004], Austin and Dinan [2005], Jacobsen [2013], Busse et al. [2009]) and on the European feebate programs (Huse and Lucinda [2013], D'Haultfoeuille et al. [2013], and D'Haultfoeuille et al. [2014]) but none on the empirical cross-policy comparison between the two. To the best of our knowledge, the closest study to ours is Gillingham [2013]. He uses the National Energy Modeling System (NEMS) to simulate CAFE policies and contrast them with a feebate policy. Our study differs from it in that we use market data from two different countries where each policy was actually implemented.

Our preliminary results show that if a CAFE standard type policy was implemented, short-run responses from manufacturers would not be negligible and that final market outcomes are indeed contingent to the form of the policy even though the environmental benefits are kept constant across the different implementations. Furthermore, the effects in France and US are very different, US manufacturers would be less willing to comply and more manufacturers would rather violate the regulation and pay the penalty than in the French scenario.

The rest of paper is as follows. In Section 2 we describe the two environmental policies. In Section 3 we introduce the model for each policy, for the demand system, and for the comparison of market outcomes. Section 4 describes the data and estimation results, as well as the simulations. We conclude with Section 5.

2 Environmental Policies

The CAFE standard regulations, implemented in the US and Canada consist of, in their most general form, a threshold of fuel economy that each manufacturer's fleet of cars sold in the country should meet in average. In Canada the regulation uses the car's fuel consumption, measured in litres per 100 kilometers, whereas in the US, the fuel economy, measured in miles per gallon is used. This regulation has already a long history starting as a response to the Arab oil embargo in 1973-1974. The CAFE is the weighted harmonic mean of miles per gallon of all the cars in a manufacturer's fleet for a given year. The weights come from the number of vehicles sold during that year. Compliance occurs when the manufacturer's CAFE is above the standard for that year, that is, the manufacturer's fleet is in average more fuel efficient than a hypothetical manufacturer with an average equal to the standard.[2]

When a manufacturer's CAFE is below the standard, it incurs a penalty of $55 per mile per gallon under the target value times the total volume of vehicles sold in a given year. Since 1983, manufacturers have paid more than $500 million in penalties. It is not possible to know for a consumer how much the price of a new car was affected by the manufacturer's response to the policy. The CAFE standard is a policy that only affects the supply side of the automobile market. Moreover, this policy only affects the extensive margin, but once the vehicle has been purchased, the policy has no direct effect on the intensive margin.[3]

In Europe, on the other hand, policies to incentivize reduction in the consumption of gasoline usually target consumers directly. In France, the "bonus/malus" policy was introduced in 2008. It is a scheme of taxes and rebates (feebate) according to CO_2 emissions of new cars. Initially, this system was designed to be revenue-neutral: taxes should subsidize rebates. Its

[2]Although the US regulation involves fuel efficiency which is measured in miles per gallon, all of our estimations and simulations involve a transformed measure of this into fuel consumption, i.e. the reciprocal of fuel efficiency. This allows us to map in a more transparent way the policy in Europe to the one in North America and vice-versa.

[3]Only a gasoline tax could have a direct effect on the intensive margin of all vehicles, old and new.

purpose was to lower average CO_2 emissions produced by cars from 176 grams to 130 grams of CO_2 per kilometer by 2020.[4]

In France, the scheme consisted of a financial rebate, from 200 to 1,000 euros. It was given to consumers purchasing low CO2 emissions level vehicles (less than 130g/km), whereas consumers buying polluting cars (more than 160g/km) were taxed, from 200 to 2,600 euros. The exact amount of the rebate or the fee depended on the class of emissions of the vehicle. This feebate was received or paid once, at the time of the sale of the vehicle. It only applied to all new cars, including those purchased abroad or manufactured abroad. Thus, unlike the CAFE standards regulation, the feebate affects the demand side and modifies the system of prices faced by consumers. However, its effects on the intensive and the extensive margins are similar to those of the CAFE standard policy.

3 The Equilibrium Model

To analyze the effects of environmental policies, we first estimate the primitives of the US and the French car markets separately. We rely on a structural model of demand and supply for new cars. For the demand system we use a nested-logit estimation. These demand parameters for new cars are identified from the consumers' heterogeneous tastes for car characteristics and the supply parameters from the price competition between manufacturers with differentiated products.

3.1 Demand Model

We first present the demand model. Each consumer chooses either to purchase one of the J products or not to buy any, which is the outside option denoted by 0. The set of products is segmented in $G+1$ groups. First, consumer chooses a group g, and then given this choice consumer chooses a specific car model from within this group. As usual, each product is assimilated to the bundle of its characteristics. Consumers are utility maximizers, and the utility of choosing j is assumed to be a linear function of characteristics following the nested

[4]California had a proposed feebate program in the late 2010s which eventually was merged with the new structure of the CAFE standards that went into effect in the US at the federal level in 2011.

logit model of Berry [1994]:

$$\begin{aligned} U_{ij} &= \delta_j + \zeta_{ig} + (1-\sigma)\epsilon_{ij} \\ \delta_j &= X_j\beta + \xi_j \end{aligned}$$

where X_j corresponds to observed characteristics of products, including the price and ξ_j represents the valuation of unobserved characteristics. The term $\zeta_{ig}+(1-\sigma)\epsilon_{ij}$ represents the idiosyncratic preference shock where ϵ_{ij} is extreme-value distributed, ζ_{ig} is the group specific random shock, and it allows for correlation of preferences over cars within the groups. By construction $0 \leq \sigma \leq 1$, if σ is close to 1, all the car models within each group become perfect substitutes. Berry [1994] discusses how $\zeta_{ig} + (1-\sigma)\epsilon_{ij}$ is extreme-value distributed.
Because of this logistic assumption, the probabilities of purchasing the good j conditional on segment g take the closed-forms

$$\begin{aligned} s_{j|g}(\delta,\sigma) &= [\exp(\delta_j/(1-\sigma))]/D_g \\ D_g &= \sum_{j\in\mathcal{J}_g} \exp(\delta_j/(1-\sigma)) \end{aligned}$$

where $\mathcal{J}_g$ is the set of car models in group g. The probability of choosing group g is

$$s_g(\delta,\sigma) = D_g^{1-\sigma} \Big/ \sum_g D_g^{1-\sigma}.$$

Then the final market share of choosing car model j from group g is

$$s_j(\delta,\sigma) = s_{j|g}s_g = \frac{\exp(\delta_j/(1-\sigma))}{D_g^{\sigma}\left[\sum_g D_g^{1-\sigma}\right]}.$$

Dividing the expression above by the market share for the outside good and taking logs on both sides we obtain

$$\log s_j = \delta_j/(1-\sigma) - \sigma \log D_g + \log s_0$$

by using a normalization for the outside good such that $\delta_0 = 0$ and $D_0 = 1$. And finally by substituting the expression for D_g from above,

$$\log s_j = \delta_j/(1-\sigma) - \sigma \log\left(\frac{\exp(\delta_j/(1-\sigma))}{s_{j|g}(\delta,\sigma)}\right) + \log s_0$$

which reduces to

$$\log s_j - \log s_0 = \delta_j + \sigma \log s_{j|g}.$$

and this is the equation to take to the data. We use an instrumental variable approach to address the potential endogeneity of prices and the market share conditional on the group. Following the literature, we construct instruments based on functions of exogenous characteristics of other products. These are valid instruments since we are assuming competition only occurs by choosing prices and the characteristics of other products are correlated with the price of the good through the substitution patterns. If a product has several close substitutes will have less ability to increase its price.

3.2 Supply Model

We now turn to the supply-side model. We consider an oligopolistic market with a finite number of firms selling differentiated products. These manufacturers are multi-products and set prices taking into account the demand. Profit of firm $m = 1, \ldots, M$ producing the set of good $\mathcal{M}$:

$$\Pi_m = \sum_{j \in \mathcal{M}} N\left(p_j - c_j\right) s_j$$

N is the number of potential buyers, s_j is the market share of product j that depends, among others, on prices of all other products. c_j is the marginal cost. The optimal price p_k derived from the profit maximization is such that:

$$\sum_{j \in \mathcal{M}} (p_j - c_j) \frac{\partial s_j}{\partial p_k} + s_k = 0 \;, \quad \forall k \in \mathcal{M}$$

Let Ω be the matrix of derivatives of market shares according to prices, and it is such that:

$$\Omega(k, j) = \begin{cases} \frac{\partial s_j}{\partial p_k} \;, & \text{if } k \text{ and } j \in \mathcal{M} \\ 0 \;, & \text{otherwise} \end{cases}$$

Then the optimal vector price is satisfies

$$p_j^* = c_j - [\Omega^{-1} S]_j$$

where $[\Omega^{-1} S]_j$ represents the j^{th} element of the mark-up vector defined by $[\Omega^{-1} S]$.

3.3 Introducing Environmental Policies

Fuel Economy Standard

The first policy considered is the introduction of a standard on fuel efficiency levels. In the US, a manufacturer's CAFE is defined by the harmonic mean of the cars fuel efficiency, measured in miles per gallon, over its car sold.

$$f_m = \frac{\sum_{j \in \mathcal{M}} s_j}{\sum_{j \in \mathcal{M}} \frac{s_j}{\bar{e}_j}}$$

where f_j is a car's fuel economy measured in miles per gallon. The rationale behind the use of the harmonic mean can be best understood through an example. Suppose two different cars, with different fuel efficiencies travel the same distance. Imagine one car traveling that distance using the arithmetic mean of the two cars gasoline consumption. Then this hypothetical car must have traveled at a fuel efficiency equal to the harmonic mean of the two cars fuel efficiencies.[5] Equivalently, we can measure fuel consumption which is the inverse of the fuel efficiency. In this way the CAFE for each manufacturer becomes the weighted arithmetic mean of the *fuel consumption* of each car model. In this analysis, we use this measure which allows for simplification as it is often done in the literature (see for example Goldberg [1998b] and Roth [2012]). Thus the policy we analyze sets a maximum on the average fuel consumption of the manufacturers' fleet which is defined by

$$e_m = \frac{\sum_{j \in \mathcal{M}} s_j e_j}{\sum_{j \in \mathcal{M}} s_j} \tag{1}$$

and it is measured in gallons per 100 miles.

To comply, manufacturers can only modify the prices, as we assume other characteristics, in particular fuel consumption, to be exogenous and thus fixed. Let $\bar{e}$ be the fuel consumption standard imposed by the regulation, the problem of a manufacturer m selling the set of cars $\mathcal{M}$ is

$$\begin{aligned} & \max_{p_{j, j \in \mathcal{M}}} \Pi_m(p_1, \ldots, p_J) \\ \text{s.t.} \quad & e_m \leq \bar{e} \end{aligned} \tag{2}$$

[5]To fix ideas, consider two cars with fuel efficiencies 20 mpg and 60 mpg. The arithmetic mean of gasoline consumption to travel 120 miles is 4 gallons. A fictitious vehicle traveling the same distance using 4 gallons of gas would have a fuel efficiency equal to the harmonic mean of 20 and 60, i.e. 30 mpg.

where e_m is the manufacturer's specific average fuel consumption as defined by equation (1). These changes in prices may lead to large decreases in manufacturers' profits up to the point where it is preferable to pay the penalty and leave e_m above the standard. This cost of not complying is set by the regulation as

$$F = N\phi \sum s_j(e_m - \bar{e})$$

where ϕ is the unit penalty imposed by the regulation, and e_m is the manufacturer's fuel consumption average as defined above. The manufacturer has to pay the penalty for every car sold and for each unit of fuel consumption below the threshold. Then the program of a manufacturer m that does not comply to the regulation is

$$\max_{p_{j,j\in\mathcal{M}}} \Pi_m(p_1, \ldots, p_J) - N\phi \sum s_j(e_m - \bar{e}) \tag{3}$$

There are three types of manufacturers, (i) the ones that change prices in order to comply and do not pay the penalty (the *compliers*), (ii) the ones that have an average above the standard but prefer to pay the penalty and remain above the standard (the *payers*), and (iii) the ones whose fleet average is already below the standard and are not affected by the regulation (the *non-affected*). For each type of manufacturers, we solve the profit maximization problem to obtain the expression for optimal car prices after the regulation is introduced. Note that even the non-affected manufacturers modify their prices after the regulation is introduced as a strategic reaction to the prices of the affected manufacturers.

(i) The complier case.
We consider the following Lagrangian to represent manufacturer's m problem defined by the system of equations (2).

$$\mathcal{L}(\{p_{j,j\in\mathcal{M}}\}, \lambda_m) = \sum_{j\in\mathcal{M}} (p_j - c_j)s_j - \lambda_m (e_m - \bar{e}).$$

This Lagrangian takes into account the shadow costs of the policy through the last term of the expression above. The optimality conditions for prices are

$$\begin{cases} \frac{\partial \mathcal{L}}{\partial p_k} = \sum_{j \in \mathcal{M}} \left(p_j - c_j - \lambda_m \left(e_j - \bar{e}\right)\right) \frac{\partial s_j}{\partial p_k} + s_k = 0 \\ \frac{\sum_{j \in \mathcal{M}} s_j e_j}{\sum_{j \in \mathcal{M}} s_j} - \bar{e} = 0 \\ \lambda_m > 0 \end{cases}$$

Optimal price of car j with the CAFE standard regulation satisfies

$$p_j^* = \left(c_j + \lambda_m \frac{(e_j - \bar{e})}{\sum s_j}\right) - \left[\Omega^{-1} S\right]_j$$

where $[\Omega^{-1}S]_j$ represents the j^{th} element of the vector $[\Omega^{-1}S]$. In this case, a decrease in the standard has a direct effect that is similar to an increase in the marginal cost of production. If the car model has a higher (lower) fuel consumption than the standard, then decreasing the standard has the same effect of an increase (decrease) of the marginal cost of production of this car. As a consequence, prices of cars with fuel consumption below the standard decrease and prices of cars above the standard increase. The magnitude of this direct effect depends on λ_m, which reflects how constrained the manufacturer is by the regulation. It can be interpreted as an implicit or shadow cost (per unit of fuel consumption) of the regulation, and it is manufacturer specific. The CAFE standard as an indirect effect on prices through the term $[\Omega^{-1}S]_j$ that is modified by the regulation. However it is not possible to predict the sign and the magnitude of the indirect effect which depends on substitution patters across products and market power.

(ii) The payer case.

Solving the program represented by (3) leads to the following first order conditions :

$$\sum_{j \in \mathcal{M}} (p_j - c_j - \phi(e_j - \bar{e})) \frac{\partial s_j}{\partial p_k} + s_k = 0.$$

Optimal price of car j with the CAFE standard regulation for a payer satisfies

$$p_j^* = (c_j + \phi(e_j - \bar{e})) - \left[\Omega^{-1} S\right]_j$$

The penalty has the same effect of an increase (decrease) in marginal cost for the cars which fuel consumption is above (below) the standard.

(iii) The non-affected case.

The expressions for the first order condition associated to profit maximization satisfy, as usual

$$\sum_{j\in\mathcal{M}} (p_j - c_j)\frac{\partial s_j}{\partial p_k} + s_k = 0.$$

And the optimal price of car j with the CAFE standard regulation for the non-affected manufacturer satisfies

$$p_j^* = c_j - \left[\Omega^{-1}S\right]_j$$

The manufacturer's problem remains unchanged by the introduction of the standard. However, because of strategic interactions, optimal prices will be different after the introduction of the standard since the term $[\Omega^{-1}S]_j$ is modified.

The vector of equilibrium prices and λ_ms after the regulation must satisfy simultaneously the first order conditions of all manufacturers. We provide details on how to solve, in practice, this system of equations in a separate section below.

Feebate

The second environmental policy studied here is the introduction of a purchase tax/subsidy. Specifically, we consider a *feebate* scheme which introduces a tax for all the vehicles with fuel consumption above a certain threshold and a subsidy for the car models with fuel consumption below that same threshold. This policy is parameterized by the rate $\tau > 0$ of taxation or rebate per unit of fuel consumption (in gallons per 100 miles) with respect to the threshold, and by the threshold itself, $\tilde{e}$. We consider a simple feebate scheme that is linear in the fuel consumption so that, the final price faced by consumers is given by[6]

$$p_j^f = p_j + \tau(e_j - \tilde{e}).$$

[6] In the French and California cases the feebate schemes were not linear but we need to restrict our model to a linear approximation since otherwise we could get multiple schemes that reach the environmental outcome and the revenue neutrality property. We can only identify two parameters from the revenue neutrality condition and the policy objective level condition.

Higher values of τ make the policy more stringent. Among all the possible feebate schemes $(\tilde{e}, \tau)$, we focus on the ones that have the revenue neutrality property. Thus, the regulator sets a pair $(\tilde{e}, \tau)$ such that the policy transfers the collected money from the taxes towards the rebates to be paid and such that the average fuel consumption does not exceed the level $\bar{e}$. The revenue neutrality condition is then

$$\frac{\sum_{j=1}^{J} s_j \tau(e_j - \tilde{e})}{\sum_{j=1}^{J} s_j} = 0$$

together with the policy objective level

$$\frac{\sum_{j=1}^{J} s_j e_j}{\sum_{j=1}^{J} s_j} = \bar{e}.$$

From the revenue neutrality condition we see that any value of τ makes this restriction to hold. Then we can solve for $\tilde{e}$ and conclude that

$$\tilde{e} = \bar{e},$$

thus the exogenously imposed policy target must equal the threshold defining the sign of the transfer.

The manufacturers' objective is modified because all the final prices faced by consumers are different except for the vehicles with fuel inefficiency exactly equal to the threshold. The profit under the feebate regulation is

$$\Pi_m = \sum_j (p_j - c_j) s_j(p^f).$$

It is useful to rewrite the manufacturer's problem as

$$\begin{cases} \max_{p^f_{j, j \in \mathcal{M}}} \sum_j \left(p^f_j - (c_j + \tau(e_j - \bar{e}) \right) s_j(p^f) \\ p^f_j = p_j + \tau(e_j - \bar{e}), \end{cases}$$

the feebate scheme has the same effect as a cost increase (reduction) when the fuel consumption is above (below) $\bar{e}$. The optimal final price vector p^f and the policy parameter τ that implements a given environmental outcome are the solution to the system of equations

$$\begin{cases} p^f_j = (c_j + \tau(e_j - \bar{e})) + \left[\Omega^{-1} S\right]_j \\ \frac{\sum_{j=1}^{J} s_j e_j}{\sum_{j=1}^{J} s_j} = \bar{e}. \end{cases}$$

Policies Comparison

Our objective is to compare the effects of the two policies described above by keeping the environmental outcome fixed. We accomplish this by fixing an average level of fuel consumption $\bar{e}$ and then solving for the equilibrium prices and market shares for each policy separately. For the simulation of the CAFE standard policy, we also need to set a value for the penalty ϕ. For the feebate case, we need to solve for the parameter τ that implements the environmental objective.

When we introduce the CAFE standard regulation, we need to solve for the shadow prices of the policy for the compliers λ_m's and new prices. There are two challenges arising from solving the system. The first one is that the choice of complying or paying the penalty is not known ex-ante. Second, the systems of equations defining optimal solutions for new prices are non-linear because prices enter the market share function, which has a logit form, and its derivatives. Thus, there is no closed form solution for prices and we have to use numerical methods to solve for them.

In order to obtain an initial guess for the λ_m's and prices, and to identify the type of each manufacturer we use an approximated solution for optimal prices that only depends on initial prices and the car's fuel consumption.

$$
\begin{aligned}
p_j^* &= p_j^0 + \lambda_m \frac{(e_j - \bar{e})}{\sum s_j} && \text{If the manufacturer is a complier,} \\
p_j^* &= p_j^0 + \phi(e_j - \bar{e}) && \text{if the manufacturer is a payer,} \\
p_j^* &= p_j^0 && \text{if the manufacturer is non-affected,}
\end{aligned}
$$

where p_j^0 is the initial price of car model j. This amounts to make the following approximation:

$$
\left[\Omega^{*-1} S^*\right]_j = \left[\Omega^{0^{-1}} S^0\right]_j .
$$

In other words, this approximation implies that the mark-up term does not change and the cost of the regulation is entirely passed-through to the prices. We can also use this approximation to identify whether a manufacturer prefers complying than paying the fines. Since the cost of the regulation is entirely passed through to consumers prices, we only have to compare the variation of market shares. Furthermore, it is clear that the market share s_j is strictly decreasing with p_j. Then, a manufacturer prefers the solution that leads to the lowest price variation. In the end, a simple rule allowing to identify the manufacturers who decide to pay the fine is $\lambda_m > \phi$. [7]

In practice, we first solve for the equilibrium where all manufacturers comply and get initial λ_m's using the approximated solution for prices. From this, it is possible to identify the manufacturers that are going to pay the penalty and solve for the full problem. We check ex-post that the manufacturers paying the penalty do not have an unilateral incentive to be complying.

For the simulation of the feebate policy, we get an initial guess for τ and prices by using the following approximated expression for optimal prices

$$p_j^* = p_j^0 + \tau(e_j - \bar{e}).$$

It amounts, as before, to assume a total pass-through of the feebate on consumer prices, or in this case to neglecting strategic reaction to the introduction of the feebate. By substituting these prices in the objective function through the market shares equations, we obtain an equation in τ only, which is easy to solve. Similarly to the previous case, we use this first

[7] In order to identify the type of a manufacturer, it is useful to express the profit function under compliance and penalty.
Under compliance, we obtain

$$\begin{aligned} \Pi_m^c &= N \cdot \textstyle\sum_{j\in\mathcal{M}} \left(p_j^c - c_j\right) s_j^c \\ &= N \cdot \textstyle\sum_{j\in\mathcal{M}} \left(p_j^0 + \lambda_m \frac{(e_j - \bar{e})}{\sum s_j^c} - c_j\right) s_j^c \\ &= N \cdot \left[\textstyle\sum_{j\in\mathcal{M}} \left(p_j^0 - c_j\right) s_j^c + \lambda_m \sum_{j\in\mathcal{M}} \frac{(e_j - \bar{e})}{\sum s_j} s_j\right]. \\ &= N \cdot \textstyle\sum_{j\in\mathcal{M}} \left(p_j^0 - c_j\right) s_j^c. \end{aligned}$$

If the manufacturer pays the penalty, we have

$$\begin{aligned} \Pi_m^p &= N \cdot \textstyle\sum_{j\in\mathcal{M}} \left(p_j^p - c_j - \phi(e^m - \bar{e})\right) s_j^p \\ &= N \cdot \textstyle\sum_{j\in\mathcal{M}} \left(p_j^0 + \phi(e_j - \bar{e}) - \phi(e^m - \bar{e}) - c_j\right) s_j^p \\ &= N \cdot \textstyle\sum_{j\in\mathcal{M}} \left(p_j^0 + \phi(e_j - e^m) - c_j\right) s_j^p. \\ &= N \cdot \left[\textstyle\sum_{j\in\mathcal{M}} \left(p_j^0 - c_j\right) s_j^p + \left(\sum s_j^p\right) \sum \frac{\phi(e_j - e^m) s_j^p}{\sum s_j^p}\right]. \\ &= N \cdot \textstyle\sum_{j\in\mathcal{M}} \left(p_j^0 - c_j\right) s_j^p. \end{aligned}$$

Which shows that a manufacturer chooses to pay the penalty if $\sum_{j\in\mathcal{M}} \left(p_j^0 - c_j\right)\left(s_j^p - s_j^c\right) > 0$. The case of a one-product manufacturer yields the inequality we use as a first approximation for this optimal decision between the two strategies.

solution as our initial guess when solving for the full model without the approximation.

4 Data, Estimation, and Simulations

4.1 Data and estimation

To simulate the effect of the two alternative regulations, we use demand parameters (price sensitivity and the cross-price elasticities) and marginal costs as inputs. We estimate the demand for automobile for France and the United States separately using the nested logit specification presented in section 3.1. We then recover marginal costs assuming the prices observed come from the competitive equilibrium described in 3.2.

We use a dataset from the association of French automobile manufacturers (CCFA, Comité des Constructeurs Français d'Automobiles) that records all the registrations of new cars purchased by households in France between 2003 and 2008. Each year, we observe a sample of about one million vehicles. For each registration, the following attributes of the car are reported: brand, model, fuel energy, car-body style, number of doors, horsepower, CO_2 emissions, cylinder capacity and weight. These characteristics have been complemented with average fuel prices and the average exchange rate between euro and dollar over years to compute the cost of driving in dollars for 100 miles. Prices are also converted from euros to dollars. The monetary variables are deflated to be expressed in constant 2008 dollars.

For the American data we use car characteristics from J.D. Power and Associates (JDPA) and from Wards Communications covering the period of 2000 through 2007.[8] Gasoline prices come from the Energy Information Administration. All prices are converted into 2007 dollars using the CPI published by the Bureau of Labor Statistics.

Tables 1 and 2 present the results for the demand estimation for respectively the French and US markets. As expected, the price coefficient is negative and the intra-segment correlation (σ) is between 0 and 1. However, the within-segment substitution appears to be more important in the US than in France. Fuel cost has a negative and statistically significant coefficient in France but turns out to be insignificant in the US. It is a well-known fact that Americans

[8]We thank Adam Copeland for sharing this data set

are less sensitive to gasoline prices and fuel economy than Europeans that are facing much higher gasoline prices. Weight and horsepower also have coefficients different from zero and have positive signs showing positive preferences for these attributes in the French market. Unfortunately, we do not observe these characteristics in the US market.

Table 1: Demand parameters for the French market

Variable	Parameter	Std-error
Price	-0.67**	0.12
$\log(\bar{s})$	0.28**	0.05
Weight	0.7*	0.32
Horsepower	0.24**	0.04
Fuel cost	-0.23**	0.02
Station Wagon	-0.13	0.08
Coupe	0.02	0.12
Three doors	-0.16†	0.1
Intercept	-6.16**	0.43
R^2	0.62	

Significance levels : † : 10% ∗ : 5% ∗∗ : 1%

Notes: The price variable is in 10,000 $, the weight is in 1,000 kilograms and fuel cost is in dollar per 100 miles. Year and brand fixed effects are included. The demand model is estimated using 3,651 car-model observations.

Table 2: Demand parameters for the US market

Variable	Parameter	Std-error
Price	-0.09**	0.01
$\log(\bar{s})$	0.93**	0.02
Fuel cost	0.01**	0.002
Intercept	-2.92**	0.18
R^2	0.97	

Significance levels : † : 10% ∗ : 5% ∗∗ : 1%

Notes: The price variable is in 10,000 $. Year and brand fixed effects are included. The demand model is estimated using 5,010 car-model observations.

The demand parameters imply an average mark up rate of 36% in the US and 57 % France which is quite high but consistent with the fact that the industry has to finance large investment in research and development. It reflects a difference in market power across the two countries, French manufacturers are able to get a higher margin on the average car. It probably comes from a lower degree of competition in France.

The initial fuel economy is 40.5 miles per gallon in France while it is only 19.4 in the US in 2007 when including light trucks (pickups and SUVs). We consider the year 2007 which is the year before the feebate policy was introduced in France and 2007 for the US as that is the last year in our dataset. At the end, the two markets we analyze here differ in multiple dimensions: in terms of market power, of consumers' preferences and in initial fuel efficiency. Introducing the environmental regulations is likely to be different in the two markets because of the intrinsic difference in market conditions. This is what we explore by conducting simulations in the next section.

4.2 Simulations

We simulate the introduction of the two environmental policies in France and in the US following the strategy mentioned above. At this time, we observe 18 different manufacturers in France and 17 in the US.[9] The manufacturer list and their characteristics are provided in Table 11 in the Appendix. We identify slightly above 600 different car models (625 for the US and 649 for France). Products are defined by a brand, model and class of CO_2 emissions in France; as a consequence we consider two versions of the same model to be different if their fuel efficiency differ so much that the two versions belong to different classes of CO_2 emissions.[10] Typically, this allows to differentiate between the basic version of a car model from the sport version of the same model. For the US, cars are defined by their brand and model name since we only have data on aggregate market shares at the model level.

Table 3 shows the benchmark parameter values for the simulation. From this benchmark, we explore separately the effect of modifying the threshold and the penalty. The threshold $\bar{e}$ and the penalty ϕ were set while the parameter of the feebate τ is estimated so that the average fuel consumption is equal to the threshold and the revenue neutrality property is achieved. We set the value of $\bar{e}$ to achieve an increase average fuel efficiency by two miles per gallon

[9] Note that manufacturer groups are different in Europe and US.

[10] In France, cars are classified according to CO_2 emissions. Classes typically cover a range of 10 grams of CO_2 emissions.

and then transform into fuel consumption standard (in gallon per 100 miles). We set the unit penalty to be equal to 600 dollars per mpg above the standard. In the US, the penalty was set to 55 dollars per mpg which is much lower. We set a higher value of the penalty to account for other costs of not complying such as the negative brand image associated to not-complying. Furthermore, the unit penalty has always been considered to be too low to discourage manufacturers to violate the regulation. We explore different values of the standard and the penalty later. We then convert this penalty in terms of fuel consumption.

Table 3: Benchmark parameters

Country	Parameter	Value	Description
Both	ϕ	600	Penalty per mpg per vehicle sold
US	$\bar{e}$	21.4	CAFE standard (in mpg)
US	τ	1,690	Equivalent feebate parameter (in mpg)
France	$\bar{e}$	42.5	CAFE standard (in mpg)
France	τ	474	Equivalent feebate parameter (in mpg)

We first compare the effect of introducing the CAFE standard regulation in the US and France. The main results are presented in Table 4. Two manufacturers cannot comply with the regulation in France since they do not produce any vehicle with fuel economy above the standard of 42.5. These manufacturers are automatically going to be payers, whatever the value of the penalty is. On the other hand, four manufacturers are ex-ante complying to the regulation and are non-affected in the US. The benchmark parameters correspond to the introduction of a moderate policy, with a significant improvement in average fuel efficiency and a relatively low penalty so some manufacturers prefer to pay the penalty than to comply.

Table 4: Comparison of the effects of the CAFE standards with benchmark parameters.

	US	France
# non-affected	4	1
# payers	12	14
# compliers	1	3
Tax revenue	8,887	429
Δ mpg	0.38	1.39

Notes: The tax revenue is in million of dollars.

Tables 5 and 6 show the effects of implementing the two alternative policies for different values of the threshold. We compute the average fuel consumption actually achieved, and the variation of sales, profits and consumer surplus. We also provide the repartition of winners and losers across manufacturers. Under both policies the mean gpm, the total sales, and total profits decrease as the threshold becomes more stringent (lower expected mean gpm). This shows that both policies achieve a reduction in the mean fuel consumption and that this has a negative effect on profitability. This last effect is stronger with the CAFE policy than with the feebate policy for lenient levels of the policies, but as the threshold diminishes, the two policies seem to converge in their negative effects on profits. The last two columns present the number of manufacturers that see their profits increase or decrease, respectively.

Table 5: Simulation results for the French market, for different values of the environmental objective

Threshold	Policy type	Mean mpg	ΔSales	ΔSales (in %)	ΔProfit	ΔProfit (in %)	ΔConsumer Surplus	ΔCS (in %)	# Winners	# Losers
No	No policy	40.47	-	-	-	-	-	-	-	-
40.5	Standard	41.46	-20.06	-1.87	-356.5	-1.78	-363.8	-4.06	7	11
40.5	Feebate	40.5	-0.02	0	0.6	0	-1.2	-0.01	5	13
41	Standard	41.61	-24.2	-2.26	-429.1	-2.15	-437.6	-4.88	7	11
41	Feebate	41	-1.61	-0.15	-12.8	-0.06	-43.7	-0.49	4	14
41.5	Standard	41.89	-29.47	-2.75	-520.2	-2.6	-535.5	-5.98	6	12
41.5	Feebate	41.5	-5.56	-0.52	-70.8	-0.35	-127.6	-1.42	3	15
42	Standard	42.2	-36.21	-3.38	-636.5	-3.19	-658	-7.34	4	14
42	Feebate	42	-11.83	-1.11	-172.8	-0.87	-251.8	-2.81	3	15
42.5	Standard	42.49	-44.41	-4.15	-777	-3.89	-805.4	-8.99	3	15
42.5	Feebate	42.5	-20.37	-1.9	-318.1	-1.59	-414.7	-4.63	1	17
43	Standard	42.91	-54.27	-5.07	-946.7	-4.74	-981.1	-10.95	1	17
43	Feebate	43	-31.15	-2.91	-505.8	-2.53	-614.2	-6.86	1	17

Notes: The sales are in 1,000 of units and profits and consumer surplus in million dollars.

Table 6: Simulation results for the US market, for different values of the environmental outcome objective

Threshold	Policy type	Mean mpg	ΔSales	ΔSales (in %)	ΔProfit	ΔProfit (in %)	ΔConsumer Surplus	ΔCS (in %)	# Winners	# Losers
No	No policy	18.88	-	-	-	-	-	-	-	-
19.5	Standard	19.65	-98.66	-1.3	-1406.6	-2.02	-31200	-2.22	5	12
19.5	Feebate	19.5	-14.82	-0.2	118.5	0.17	-5853.5	-0.42	4	13
20	Standard	19.74	-131.99	-1.75	-1843	-2.65	-41442.2	-2.95	6	11
20	Feebate	20	-44.53	-0.59	440.2	0.63	-16347.5	-1.16	3	14
20.5	Standard	19.83	-166.48	-2.2	-2190.5	-3.15	-52271.3	-3.72	5	12
20.5	Feebate	20.5	-86.67	-1.15	1029.4	1.48	-30742.6	-2.19	3	14
21	Standard	19.94	-205.88	-2.72	-2267	-3.26	-64524.9	-4.59	5	12
21	Feebate	21	-139.21	-1.84	1930.7	2.78	-48334.7	-3.44	3	14
21.5	Standard	20.04	-245.02	-3.24	-2285.9	-3.29	-77323	-5.5	5	12
21.5	Feebate	21.5	-200.8	-2.66	3172.5	4.56	-68671.2	-4.88	3	14
22	Standard	20.15	-286.78	-3.79	-2112.5	-3.04	-90953.4	-6.47	5	12
22	Feebate	22	-270.49	-3.58	4765.5	6.85	-91436	-6.5	3	14

Notes: The sales are in 1,000 of units and profits and consumer surplus in million dollars.

In Table 7 we present additional results for the standard-type policy. We provide, for each threshold considered the number of manufacturers that are going to comply, to pay the penalty or not affected. We also report here the total revenue raised by the government from the penalties. As the threshold becomes more stringent it is more difficult to comply and thus the number of manufacturers that have to pay a fine increases.

Table 7: Behavior of manufacturers with a CAFE standards in the French market

Threshold	# compliers	# payers	# non-affected	Penalties
40.5	10	3	5	31.3
41	10	4	4	32.1
41.5	10	6	2	40.2
42	10	6	2	60.2
42.5	9	8	1	108.5
43	10	8	0	157.4

Notes: Penalties represent the revenue from payers, in million dollars.

Table 8: Behavior of manufacturers with a CAFE standards in the US market

Threshold	# compliers	# payers	# non-affected	Penalties
19.5	3	5	9	4,533.1
20	3	6	8	7,475
20.5	1	8	8	10,136
21	4	9	4	13,146.7
21.5	2	11	4	15,585.6

Notes: Penalties represent the revenue from payers, in million dollars.

Alternatively, we can fix the threshold $\bar{e}$ and vary the penalty ϕ from 600 to 2,400 dollars. Tables 9 and 10 show that as the penalty increases the number of payers decreases in both markets and the number of non-affected manufacturers is constant in both. Total amount of money paid in fines increases with the level of the fine in the US case but not in the French market.

Table 9: Effect on increasing the penalty associated to the CAFE standard policy in France.

Penalty	# compliers	# payers	# non-affected	ΔProfit (in %)	Total Penalties
600	3	13	2	-2.23	357.5
1,200	6	10	2	-2.98	239
1,800	10	6	2	-3.19	60.2
2,400	12	4	2	-3.22	30.3

Notes: Penalties represent the total revenue from penalties, in million dollars.

Table 10: Effect on increasing the penalty associated to the CAFE standard policy in the US.

Penalty	# compliers	# payers	# non-affected	ΔProfit (in %)	Total Penalties
600	1	12	4	-1.94	9,275.3
1,200	2	11	4	-2.93	13,029.1
1,800	4	9	4	-3.26	13,146.7
2,400	5	8	4	-2.69	9,793.4

Notes: Penalties represent the total revenue from penalties, in million dollars.

5 Conclusions

We estimate and simulate a structural model that captures the main characteristics of a standard-type policy and a feebate policy for the car industry. We show the effects on the distribution of manufacturers' profits and consumers' surplus of being in a market regulated with one of those two regulatory instruments. Even though the two policies can be calibrated to have the same environmental outcome, the distributional impacts on firms and consumers are not the same.

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Appendix

Derivation of first order conditions

We provide here the details of the derivation of the first order conditions associated to profit maximization for affected manufacturers. (i) Manufacturer decides to comply to the regulation. The Lagrangian associated to the problem is then :

$$\mathcal{L}_m(\{p_{j,j\in\mathcal{M}}\},\lambda_m) = \sum_{j\in\mathcal{M}}(p_j - c_j)s_j + \lambda_m\left(e_m - \bar{e}\right))$$

Given that

$$\frac{\partial e_m}{p_k} = \frac{\sum \frac{\partial s_j}{\partial p_k}(e_j - e_m)}{\sum s_j}$$

and $e_m = \bar{e}$ since the manufacturer complies to the regulation, the first order conditions are then :

$$\frac{\partial \mathcal{L}}{\partial p_k} = \sum_{j\in\mathcal{M}}\left(p_j - c_j + \lambda_m(e_j - \bar{e})\right)\frac{\partial s_j}{\partial p_k} + s_k = 0$$

$$\frac{\sum_{j\in\mathcal{M}} s_j e_j}{\sum s_j} - \bar{e} = 0$$

$$\lambda_m > 0,$$

(ii) Manufacturer decides to pay the penalty : Then the manufacturer's profit is :

$$\sum_{j\in\mathcal{M}}\left(p_j - c_j - \phi\left(e_m - \bar{e}\right)\right)s_j$$

The first order condition associated to the profit maximization is:

$$\sum_{j\in\mathcal{M}}\left(p_j - c_j + \phi\left(\frac{\sum_{j\in\mathcal{M}} e_j s_j}{\sum_j s_j} - \bar{e}\right)\right)\frac{\partial s_j}{\partial p_k} + \left[s_k + \phi\sum_{j\in\mathcal{M}} s_j\cdot\left(\frac{\sum e_j \frac{\partial s_j}{\partial p_k}.(\sum s_j) - \sum e_j s_j.\sum(\frac{\partial s_j}{\partial p_k})}{(\sum s_j)^2}\right)\right] = 0$$

$$\sum_{j\in\mathcal{M}}\left(p_j - c_j + \phi\left(\frac{\sum_{j\in\mathcal{M}} e_j s_j}{\sum_j s_j} - \bar{e}\right)\right)\frac{\partial s_j}{\partial p_k} + s_k + \left[\phi\left(\sum s_j \frac{\partial e^m}{\partial p_k}\right)\right] = 0$$

where: $\frac{\partial e^m}{\partial p_k} = \frac{\sum e_j \frac{\partial s_j}{p_k}}{\sum s_j} - \frac{(\sum e_j s_j)\sum \frac{\partial s_j}{\partial p_k}}{(\sum s_j)^2}$

$$\sum s_j \frac{\partial e^m}{\partial p_k} = \sum e_j \frac{\partial s_j}{\partial p_k} - \frac{\sum e_j s_j}{\sum s_j}\sum \frac{\partial s_j}{\partial p_k}$$

It simplifies to : $\sum_{j\in\mathcal{M}} (p_j - c_j + \phi(e_j - \bar{e}))\frac{\partial s_j}{\partial p_k} + s_k = 0$

Additional tables

Table 11: Manufacturers' initial characteristics in the French market.

Manufacturer	Sales (in 1,000)	Market share (in %)	Av. fuel consumption (in gallon/100 miles)	Nb. of car models
P.S.A.	364.26	34.04	2.34	39
Renault	254.59	23.79	2.43	26
Toyota	65.48	6.12	2.49	10
Ford	65.32	6.1	2.44	47
Volkswagen	60.17	5.62	2.49	42
Gm	54.4	5.08	2.46	67
Daimler	39.7	3.71	2.77	45
B.M.W.	39.05	3.65	2.74	13
Fiat	30.96	2.89	2.38	52
Suzuki	23.46	2.19	2.85	17
Hyundai	21.36	2	2.71	25
Nissan	20.85	1.95	2.78	6
Honda	10.31	0.96	2.57	76
Mazda	9.53	0.89	2.75	45
Chrysler	6.97	0.65	3.42	11
Porsche	1.96	0.18	5.1	19
Daihatsu	0.92	0.09	2.93	29
Subaru	0.86	0.08	4.4	75

Table 12: Manufacturers' initial characteristics, US market. Means at the car-model level in 2007.

Manufacturer	Sales (in 1,000)	Market share (in %)	Av. fuel consumption (in gallon/100 miles)	Nb. of car models
B.M.W	19.4	2.0	5.6	16
Chrysler	35.1	13.0	5.8	58
Ford	22.9	15.5	5.7	105
Subaru	14.9	1.1	4.9	11
General Motors	27.4	24.0	5.8	137
Honda	38.0	9.7	4.6	40
Hyundai	20.3	2.9	4.7	22
Isuzu	1.5	0.04	6.2	5
Kia	15.2	1.9	5.1	20
Mazda	12.9	1.7	4.9	21
Mercedes	9.5	1.5	6.4	24
Mitsubishi	8.2	0.7	5.4	14
Nissan	24.7	6.5	5.7	41
Porsche	3.6	0.2	5.4	8
Suzuki	7.8	0.7	4.9	13
Toyota	41.4	16.0	4.8	60
Volkswagen	10.5	2.0	5.2	30