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On the relevance of differentiated car purchase taxes in light of the rebound effect

Bénédicte MEURISSE*

Abstract

The significant weight of CO_2 emissions resulting from car use in the total of CO_2 emissions is enough of a signal to set up policy tools aiming at reducing such emissions. This paper investigates the effects of setting a penalty on the purchase of high emitting cars (*i.e.* a Malus). With static comparative analyses of a basic model of consumer's behaviour facing two alternatives: a clean and a dirty vehicles, we essentially find that a rebound effect does not necessarily accompany the reduction in the average fuel consumption per kilometre resulting from the implementation of a differentiated car purchase tax such as a Malus scheme. This is because the improvement of the fuel-efficiency is observed at the aggregate scale and not at the individual level. Thereby, it happens that we observe a rebound effect only under certain conditions pertaining to the characteristics of the vehicles that make up the fleet. We also show that, from the moment that a rebound effect occurs, the higher the amount of Malus, the higher the rebound effect. It implicitly means that because of the rebound effect, the higher the pricing scheme, the less efficient the purchase tax.

Key words: car purchase decision, car use, CO_2 emissions, rebound effect, penalty on car purchase.

JEL Classification Codes: D11, H31, Q58.

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1. Introduction

The high probability of the anthropic origin of climate change has been confirmed by the fifth report of the Intergovernmental Panel on Climate Change. Transportation activities do contribute to climate change through their CO_2 emissions (38% of the total of CO_2 emissions in France in 2010; European Commission, 2013). Furthermore, rapidly increasing traffic and a high dependency on fossil fuels have made transportation activities a crucial issue with regard to the action required to fight climate change. In France in 2010, passenger vehicles contributed to 57% of road transport CO_2 emissions, when the latter transport mode accounted for 80% of transport CO_2 emissions (European Commission, 2013). Therefore, this paper focusses on passenger vehicles.

With reference to the Schipper's ASIF scheme, transport GHG emissions can be tackled through four main levers: the transport **A**ctivity, the modal **S**hare, the energy **I**ntensity and the carbon intensity of **F**uel (Schipper and al., 2000). We will consider in this work only two levers, namely the transport Activity and the energy Intensity. This choice is motivated by the fact that car demand involves both a discrete decision with respect to the purchase of the car (including the choice of the vehicle's energy performances; see "I" in ASIF) and, conditional on the purchase decision, a continuous decision in terms of consumption of kilometres (see "A" in ASIF). Both decisions are decisive factors in reducing CO_2 emissions from passenger vehicles (Schipper, 2011).

Unlike congestion or safety issues associated with road transport, global pollution particularly affects car owners' welfare as well as non-car owners' welfare. It follows that the level of pollution from vehicles – without an adapted policy to internalise this externality – has no impact on the car ownership probability (De Borger, 2001). Therefore, charging the vehicle purchase is warranted in the context of fighting air pollution. Nonetheless, there seems to be no reason to charge the purchase of a clean vehicle, all the more so because consumers derive utility from owning a vehicle – thanks to values of freedom or success attached to car ownership – regardless of the car use (Dubois and Moch, 2006). The implementation of a differentiated purchase tax or subsidy (*i.e.* based on the vehicle's CO_2 emissions) is thus more relevant. This acknowledgment has motivated the adoption of a feebate scheme in France, and justifies the large emerging literature focusing on such schemes (see for instance d'Haultfoeuille and al., 2013 and 2014 for the French case). Actually, a differentiated car purchase charge falls, to some extent, within the so-called environmental taxation in that it aims at deterring the production and the consumption of high-carbon goods in order to improve the environmental quality, perceived as a public good (Bovenberg and Goulder, 2001).

However, vehicle purchase pricing schemes are claimed not to convey the correct incentive for mileage choice to the car driver (Santos and al., 2010). Furthermore, the trend that low fuel-consuming vehicles are more intensively used than high fuel-consuming ones leads us to envision that implementing a differentiated purchase tax could result in a rebound effect. This is because the latter tool precisely targets a new repartition of vehicles in favour of low fuel-consuming vehicles. Indeed, an initial reduction in consumption resulting from an improvement in energy efficiency – measured in our case over the whole fleet – as an effect from the scheme, will lead to an effective decrease in the average price per kilometre. As a result, car use may increase, partially offsetting the impact of the efficiency gain in fuel use. This phenomenon is referred to in the literature as the "*rebound effect*".

In this paper, we study the effects of a Malus scheme using the framework of static comparative analysis of a basic model of consumer's behaviour. Specifically, we question the relevance of a differentiated car purchase tax in light of the rebound effect.

The remainder of this paper is structured as follows. Section 2 briefly presents the consumer's behaviour, and the way we compute the total of CO_2 emissions from car use. Following that, we discuss in Section 3 the effects of a penalty on the purchase of the dirty vehicles. In section 4, we illustrate the theoretical findings using a numerical version of the model based on French data. Finally, section 5 presents conclusion.

2. Model formulation

2.1. The consumers' behaviour

Herein, the car purchase decision (*i.e.* which vehicle to purchase?) – and not the car ownership decision (*i.e.* to purchase or not a car?) – is investigated, meaning that we consider a fixed vehicle-purchasing population. Either this is the first consumer's car purchase and the utility derived from owning a car regardless of car use (Dubois and Moch, 2006) is assumed to be high enough to bypass the alternative "do not purchase a car"[1]; or this is a car replacement decision that is at focus, and the higher quality of cars for sale is supposed to be high enough compared to that of the consumer's current car to bypass the alternative "keep the current car"[2]. In this latter scenario, we further assume that once the consumer has opted for replacing his car, the consumer's purchase history does not affect the consumer's car choice (contrary to what Liberali and his co-authors claim to be true for any repeated purchase decisions; see Liberali and al., 2011). In contrast, our model is not intended to investigate a scenario wherein a consumer purchases a second (or a third) car[3].

Specifically, we consider a continuum of consumers who have two options: purchasing a clean vehicle – termed "vehicle c" in what follows – or purchasing a dirty vehicle – termed "vehicle d". At that stage, we attract the reader's attention to the fact that we do not put 'green' and 'grey' vehicles facing each other in that we do not define what is a 'green vehicle'. We content ourselves with comparing two vehicles with the same motorisation (and thus the same CO_2 emissions factor) which consume a different amount of fuel per kilometre. And this is for ease of exposition that, with a slight abuse of language, we speak about a "clean" and a "dirty" vehicles. More specifically, the fuel consumption figures are such that $f^c < f^d$ with f^j being the vehicle j's fuel consumption per kilometre.

All consumers derive utility from the consumption of vehicle-kilometres-travelled (VKT termed k), and from the consumption of a composite good (termed C) treated as numeraire. Our most restrictive assumption lies actually in the fact that consumers are supposed not to be

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[1] Consider for instance freshly driving licensed persons or freshly parents for whom this assumption is correct from a specific date – and is not before.

[2] Indeed, it is often observed that consumers replace a durable good to gain greater performance, not because of failure (Liberali and al., 2011). More generally, the quality variable refers to the performance, the reliability, the durability and so on (see Garvin, 1987).

[3] This is above all a simplifying assumption in that consumers do not have to choose to what extent the new car will be used compared to the used one. A further reason to bypass the 'multi-equipment' scenario is the fact that multi-equipment is based on second-hand car purchases (Prieto, 2006) while second-hand markets deserve a specific analysis as such (see *e.g.* Gavazza and al., 2012).

able to consume kilometres with public transports. What is more, all consumers are supposed to have the same preferences in terms of VKT[4] (see θ that does not depend on consumer i in equation 1 below). In sum, we have the following utility function[5]:

$$U(k, C) = C^{1-\theta} k^{\theta} \quad (1)$$

As stated in the neo-classical theory, consumers maximise their utility under a budget constraint. In that light, we assume that consumers earn annually the same income, termed y.

Expressly, we proceed by backward induction in order to find the consumer's optimal behaviour in terms of car purchase and use:

- First, for each vehicle j (with $j = c, d$), the consumer chooses the consumption levels of the composite good (C^j) and of VKT (k^j) that maximise his utility. Not surprisingly, this income allocation between the two utility function's attributes is the same for all consumers insofar as it is only a function of the preference parameter θ, and of the annual income y which are common to all consumers.

- Then, each consumer chooses the vehicle type that provides the maximum of utility. At this stage[6], we introduce the consumer i's taste for vehicle j, that reflects the preferences for vehicle characteristics (*e.g.* colour, comfort, and so on). Precisely, let η_i^j denote this additional utility which varies both with the vehicle type and across consumers[7]. In accord with the economic theory whereby the consumer's behaviour is utility-maximising, the decision rule of consumer i underlying the car choice is thus written as follows:

[4] Differences in preferences in terms of VKT may have translated into differences in preferences for vehicles' characteristics (*e.g.* comfort). In contrast, the absence of any difference in preferences for VKT does not determine whether individuals have – or not – the same preferences for the different vehicle's characteristics (see η_i^j in equation 2).

[5] Transport is often a "derived demand", *i.e.* it is generally not requested for its own sake but is very largely associated with the consumption of other goods (Crozet and Lopez-Ruiz, 2013). This is why VKT and composite good are treated as complementary goods within the utility function.

[6] Consumers derive utility from the consumption of the service provided by the durable good, not from the possession of the durable good as such. "*The utility associated with a consumer durable is then best characterized as indirect*" (Dubin and McFadden, 1984). This is why the utility derived from the vehicle characteristics regardless of the car use does not enter the direct utility function (equation 1), but also enters the indirect utility function (equation 2).

[7] Within transport economics, and more particularly for comparison purposes with mode choice models, this additional utility is tantamount to the 'alternative-specific constant' which is a constant that is added to the utility function of a mode and whose numerical value may be different for different modes. It actually represents the average effects of variables not present in the model.

If $V_i^c > V_i^d$ he/she chooses to purchase vehicle c

(DR1)

If $V_i^c < V_i^d$ he/she chooses to purchase vehicle d

with:

$$V_i^j = U^j + \eta_i^j \quad (2)$$

In all evidence, we can also write the decision rule in the following manner:

If $U^c - U^d > \eta_i^d - \eta_i^c$ he/she chooses to purchase vehicle c

(DR1bis)

If $U^c - U^d < \eta_i^d - \eta_i^c$ he/she chooses to purchase vehicle d

Interestingly, the left-hand term of the inequality is the same for all households, and varies solely with the vehicles' market price and fuel consumption per kilometre. The value of this gap in utility is typically behind the repartition of households between the two vehicles. We note $U^* = U^c - U^d$. That said, whether $\eta_i^d - \eta_i^c$ is below or above U^* makes household i purchases respectively vehicle c or vehicle d.

2.2. Towards computing the total of CO_2 emissions

Intuitively, public authorities implement policy tools provided that they effectively help reduce CO_2 emissions. The annual total of CO_2 emissions due to the use of both vehicles is given by:

$$E = Ne\left(\varphi^c k^c f^c + \varphi^d k^d f^d\right) \quad (3)$$

where N is the size of the vehicle-purchasing population, e is the CO_2 content of fuel (expressed in kilograms of CO_2 per litre of fuel), and φ_c and φ_d are the shares of vehicles c and d at the aggregate level. The latter shares are obtained by summing the choice of the individuals constituting the whole vehicle-purchasing-population. Considering a given distribution of the households for the different values of $\eta_i^d - \eta_i^c$, we have:

$$\varphi^c = P\left(\eta_i^d - \eta_i^c < U^*\right), \text{ and } \varphi^d = 1 - \varphi^c \quad (4)$$

3. Effects of the Malus scheme

In this Part, we investigate the effects of a Malus scheme. To this purpose, we differentiate two public policy regimes:

- a "no-policy regime" (all variables referring to this regime are termed with a tilde symbol in the remainder of the paper); and
- a "penalty regime" (the variables are termed with an over bar).

Table 1 below summarizes the analytical expressions of: the distance covered with each vehicle, the consumption of composite good, the indirect utility, the shares of vehicles and the total of CO_2 emissions in the "no-policy regime" (first column) and in the "penalty regime" (second column). The two first listed variables are simply obtained by maximising the utility (equation 1) under a budget constraint which expression is given in the first row in Table 1. It is worth noting that the differences between both regimes result from the penalty that is introduced in the budget constraint in the second regime (see M for 'Malus' in the budget constraint in the second regime). Notations are detailed below.

Table 1: Analytical expressions of our model

	"No-policy regime" (for both vehicles, indexed by *j*)		**"Penalty regime" (for vehicle *c* or vehicle *d*)**
Budget constraint	$y-\frac{P^j}{T}=\widetilde{C^j}+pf^j\widetilde{k^j}$	Or	$y-\frac{P^c}{T}=\overline{C^c}+pf^c\overline{k^c}$ $y-\frac{P^d+M}{T}=\overline{C^d}+pf^d\overline{k^d}$
Distance travelled	$\widetilde{k^j}=\frac{\left(y-\frac{P^j}{T}\right)\theta}{pf^j}$	Or	$\overline{k^c}=\frac{\left(y-\frac{P^c}{T}\right)\theta}{pf^c}$ $\overline{k^d}=\frac{\left(y-\frac{P^d+M}{T}\right)\theta}{pf^d}$
Consumption of composite good	$\widetilde{C^j}=(1-\theta)\left(y-\frac{P^j}{T}\right)$	Or	$\overline{C^c}=(1-\theta)\left(y-\frac{P^c}{T}\right)$ $\overline{C^d}=(1-\theta)\left(y-\frac{P^d+M}{T}\right)$
Indirect utility	$\widetilde{V_i^j}=\left[(1-\theta)\left(y-\frac{P^j}{T}\right)\right]^{1-\theta}\left[\frac{\left(y-\frac{P^j}{T}\right)\theta}{pf^j}\right]^{\theta}+\eta_i^j$	Or	$\overline{V_i^c}=\left[(1-\theta)\left(y-\frac{P^c}{T}\right)\right]^{1-\theta}\left[\frac{\left(y-\frac{P^c}{T}\right)\theta}{pf^c}\right]^{\theta}+\eta_i^c$

		$\overline{V_i^d} = \left[(1-\theta)\left(y - \frac{P^d+M}{T}\right)\right]^{1-\theta} \left[\frac{\left(y-\frac{P^d+M}{T}\right)\theta}{pf^d}\right]^{\theta} + \eta_i^d$
Shares of clean and dirty vehicles	$\widetilde{\varphi^c} = P(x < \widetilde{U^*})$, and $\widetilde{\varphi^d} = 1 - \widetilde{\varphi^c}$	$\overline{\varphi^c} = P(x < \overline{U^*})$, and $\overline{\varphi^d} = 1 - \overline{\varphi^c}$
Total of CO_2 emissions	$\tilde{E} = Ne(\widetilde{\varphi^c}\widetilde{k^c}f^c + \widetilde{\varphi^d}\widetilde{k^d}f^d)$	$\overline{E} = Ne\left(\overline{\varphi^c k^c}f^c + \overline{\varphi^d k^d}f^d\right)$

The budget constraint is function of the following variables:

- y is the annual income, P^j is the vehicle j's market price, and T is the length of car ownership[8];
- M is the amount of penalty charged on the purchase of a dirty vehicle;
- C^j is the expenditure on composite good (the price of the composite good is normalized to one);
- pf^jk^j is the expenditure on fuel, with p being the fuel price (expressed in euros per litre), and f^j the vehicle j's fuel consumption (expressed in litre per kilometre).

Finally, recall that N is the size of the vehicle-purchasing population, and e is the CO_2 content of fuel.

The effects of the Malus scheme can be easily deduced from Table 1. They are:

- a reduction in the distance covered with a dirty vehicle ($\overline{k^d} < \widetilde{k^d}$) because of a lower disposable income after the car purchase, on the one hand; and
- a decrease of the share of dirty vehicles ($\overline{\varphi^d} < \widetilde{\varphi^d}$) on the other hand. This reduction in the share of dirty vehicles due to the Malus scheme translates into a higher average energy efficiency of vehicles over the whole fleet.

Given the higher energy efficiency of the fleet in the Malus scheme regime, tackling the issue of the rebound effect takes on its full meaning. To some extent, the rebound effect measures

[8] Introducing the length of car ownership enables us to reflect the tendency to keep one's car for several years, while avoiding introducing a pure preference rate, although this is the common practice in the 'durable goods' literature. Our reasoning is tantamount to considering first equally weighted years and second identical years over the total length of car ownership. We are well aware that our "identical years" assumption holds only with myopic (or risk-neutral) consumers who do not anticipate fuel price or income changes over the length of car ownership. Regarding the "equally weighted years" assumption, we may consider that cars are financed by credit (with a zero interest rate), even if such an assumption is more relevant for studying a car ownership tax than for studying a car purchase tax (as we do in the next subsection).

the decision-maker's error of assessment of the efficiency of the Malus scheme, due to the fact they do not anticipate the response of motorists in terms of car use. This is also a loss of efficiency of the policy instrument. In concrete terms, the rebound effect corresponds to the total of CO_2 emissions resulting from the fact that the distance covered with the clean vehicle in the "penalty regime" by the motorists who would have purchased a dirty vehicle in the absence of the penalty does not equal (more precisely, it exceeds) the distance they would have covered with the dirty vehicle in the "no-policy regime". Expressed in absolute terms, that is to say in kilograms of CO_2 per household and per year, the rebound effect (RE) amounts to[9]:

$$RE = Ne\left(\overline{\varphi^c} - \widetilde{\varphi^c}\right)\left(k^c - \widetilde{k^d}\right)f^c \tag{5}$$

where $\left(\overline{\varphi^c} - \widetilde{\varphi^c}\right)$ is the share of motorists who change their car purchase decision because of the Malus scheme, and $\widetilde{k^d}$ is the distance the public decision-makers think it will be travelled by the latter motorists, while they cover k^c kilometres in reality (with a vehicle consuming f^c litres of fuel per kilometre). It is noteworthy that this specific way of computing the rebound effect is tantamount to considering that the policy stakeholders do not anticipate the effect of the Malus amount on the distance travelled with the dirty vehicle. Indeed, we use $\widetilde{k^d}$ instead of $\overline{k^d}$. We attract the reader's attention to the fact that this reasoning explains why we can observe some situations in which the rebound effect is higher than 100% while the CO_2 emissions in the "penalty regime" are still lower than the emissions in the "no-policy regime". In fact, conventionally, when the rebound effect is higher than 100%, the CO_2 emissions are higher after the improvement of the energy efficiency. This particular situation is referred to in the literature as the Jevons Paradox. In the present analysis, we slightly differ from this traditional result because the improvement of the energy efficiency is due to the implementation of a Malus scheme – and not because of technological progress – which effect is not limited to the improvement of the energy efficiency: this public intervention also leads to a reduction in the distance covered with the dirty vehicle. This is the reason why there is no interest in computing the rebound effect in relative terms in the remainder of this Part.

That said, and from equations (5), we derive the following Proposition:

[9] It results from the following difference between the two decreases in CO_2 emissions caused by the Malus scheme (when taking into account or not the change in the motorists' car use): $Ne\left(\overline{\varphi^c} - \widetilde{\varphi^c}\right)\widetilde{k^d}\left(f^d - f^c\right) - Ne\left(\overline{\varphi^c} - \widetilde{\varphi^c}\right)\left(\widetilde{k^d}f^d - k^c f^c\right)$.

Proposition.

a) *There is a rebound effect provided that* $\frac{yT-P^c}{f^c} > \frac{yT-P^d}{f^d}$*;*

b) *The rebound effect (in absolute terms) increases with the Malus amount.*

Proof.

a) Using equation (5), the rebound effect is positive from the moment that $k^c > \widetilde{k^d}$. We obtain the condition under which this is verified by using the expressions of the distances covered k^c and $\widetilde{k^d}$ given in Table 1 above.

a) We have $\frac{\partial RE}{\partial M} = Ne\left(k^c - \widetilde{k^d}\right)f^c \frac{\partial \overline{\varphi^c}}{\partial M}$. The latter derivative is positive since $\frac{\partial \overline{\varphi^c}}{\partial M} > 0$ (see $\overline{\varphi^c}$ in Table 1) and $k^c - \widetilde{k^d} > 0$ (condition under which a rebound effect does exist).

First of all, since the improvement of the fuel-efficiency is observed at the aggregate scale and not at the individual level, it happens that we observe a rebound effect only under certain conditions pertaining to the characteristics of the vehicles that make up the fleet. Indeed, the order of magnitude of the gap in market prices of the dirty and clean vehicles compared to that of the gap in fuel consumptions of both vehicles determines whether a less fuel-consuming vehicle is effectively more used than a more fuel-consuming vehicle. Besides, when a rebound effect occurs, its amount in absolute terms increases with the level of Malus because the higher the penalty, the higher the number of consumers who purchase a clean vehicle in the Malus scheme regime while they would have purchased a dirty vehicle in the "no-penalty" regime.

4. Numerical illustration in France

4.1. Data used

This numerical illustration is carried out with data from 2013.

For ease of explanation, the size of the vehicle-purchasing population is normalized to one. This way, the total of emissions is exactly the amount of kilograms of CO_2 emissions that results from the distances travelled by private car by an average household over one year[10].

[10] The totals of emissions obtained in this numerical exercise are between 960 and 990kg CO_2 per household and per year. We attract the reader's attention to the fact that such a total is not directly comparable to the figure given by the French General Commission on Sustainable Development (*i.e.* on average, a French person emits 2

Note that we solely consider petrol vehicles as penalties particularly target petrol vehicles because of their higher level of CO_2 emissions per kilometre. The fuel consumption per kilometre of the clean vehicle corresponds to the average level in France in 2013, namely 5.2L/100km (ADEME, 2014) (*i.e.* $f^c = 0.052L/km$). The market price of the clean vehicle is €18,918 (*i.e.* $P^c = €18{,}918$). This is approximately the average price of petrol vehicles in France in 2013[11].

Besides, since the amount of Malus varies with the vehicle's fuel consumption, we will consider different dirty vehicles. More specifically, based on the minimum amount of fuel above which a Malus is charged in France in 2013 (*i.e.* 5.8L/100km), and on the amount of fuel above which the amount of Malus does not change (8.6L/100km) (see Appendix for a description of the French Malus scheme), we will consider two gaps in the fuel consumptions of our two types of vehicles, namely +0.6L/100km (*i.e.* the dirty vehicle consumes 5.8L/100km) and +3.4L/100km (*i.e.* the dirty vehicle consumes 8.6L/100km). And for reasons of clarity of charts, we will consider only three gaps in market prices of both vehicles, namely -3,000€ (*i.e.* the dirty vehicle is €3,000 less expensive); +0€ (*i.e.* both vehicles have the same market prices), and +3,000€ (*i.e.* the dirty vehicle is €3,000 more expensive).

In terms of consumers' behaviour, we assume that each consumer makes his car purchase decision based on the total revenue of the household rather than on his own income. We also assume that the car purchase decision is based on the average income earned the year before the time of observation because of the uncertainty on the level of income during the current year. In 2012, the French average annual income per household amounted to €36,190 (INSEE). Similarly, because of the uncertainty about the fuel price level, consumers are supposed to consider the fuel price the year before the car purchase decision, namely €1.5753[12] per litre of petrol in 2012 (DGEC). A further consideration in terms of consumers' behaviour is that households keep on average their vehicle for 5.3 years (CCFA, 2014). Finally, the value of the preference parameter associated to driving θ is chosen such that the

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tonnes of CO2 emissions per year because of its trips, CGDD, 2010) since we consider only the private car and not the other modes of transport.

[11] In 2013, the average vehicle market price amounts to €23,407 in France (L'Argus). Yet, diesel vehicles are claimed to be 5% to 20% more expensive than petrol vehicles. Since we consider quite large vehicles (cf. the range of fuel consumptions per kilometre above), we use the lowest gap in market prices between petrol and diesel vehicles (*i.e.* 5%, since the relative advantage of petrol vehicles in terms of purchase cost is lower for large vehicles). We also take into account the distribution of registrations between diesel (about 69%) and petrol vehicles (about 31%) in 2013 to estimate the average market price of petrol vehicles in 2013. We have approximately $P^c = €22{,}600$. This means €18,918 when taxes are excluded.

[12] Weighted (according to the national annual total consumption, see DGEC) average of annual prices of Super SP95 and Super SP98.

model roughly reflects realistic orders of magnitude in terms of annual distance covered with a petrol vehicle (*i.e.* 7,751km in 2013; CCFA, 2014). We conduct a sensitivity analysis on this parameter in Appendixes.

Finally, we will consider the following range for the amount of Malus: $M \in [€0, €6{,}000]$ with €6,000 being the maximum amount of Malus charged in France in 2013 (see Appendixes).

All values used in our simulations are summarized in Table 2. below.

Table 2: Exogenous variables in our numerical illustration

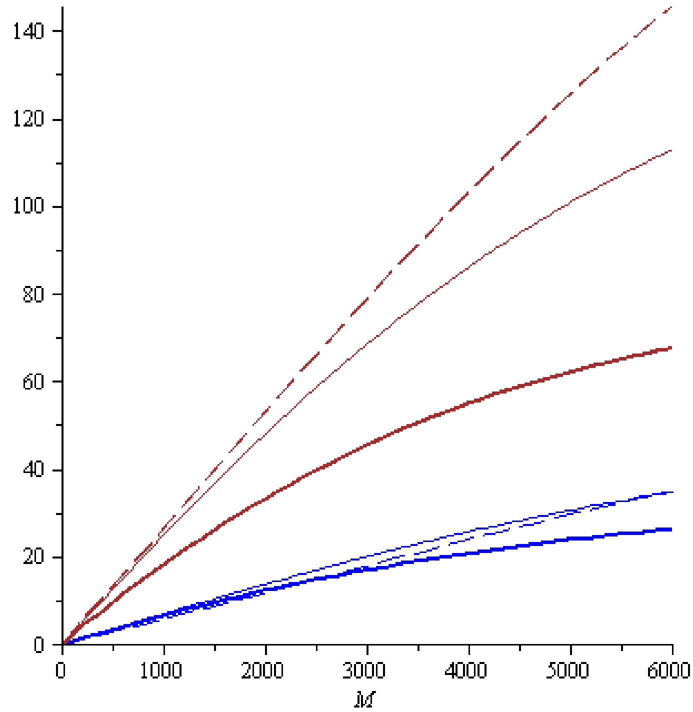
Exogenous variables	**Value in 2013**
Household's average income ($\boldsymbol{y}$) (€)	36,190
Length of car ownership ($\boldsymbol{T}$) (years)	5.3
Preference parameter ($\boldsymbol{\theta}$)	0.027
Clean vehicle's fuel consumption ($\boldsymbol{f^c}$) (L/km)	0.052
Dirty vehicle maximum purchase price ($\boldsymbol{P^d}_{\boldsymbol{max}}$) (€)	21,918
Fuel price ($\boldsymbol{p}$) (€/L)	1.5753
CO_2 content of fuel ($\boldsymbol{e}$) ($kgCO_2$/L)	2.346
Malus amount ($\boldsymbol{M}$) (€)	From 0€ to €6,000

Lastly, note that we consider a standard normal distribution of households for the different values of the relative preferences for dirty vehicle's characteristics. A sensitivity analysis regarding the distribution law is given in Appendixes.

4.2. Effects of the Malus scheme on the total of CO_2 emissions

We start by plotting the rebound effect (in absolute terms) that accompanies the implementation of the Malus scheme in Figure 1 below, while considering the two gaps in fuel consumptions of our dirty and clean vehicles $f^d - f^c$: +0.6L/100km (in blue) and +3.4L/100km (in brown), and for the three different gaps in market prices of both vehicles $P^d - P^c$: -3,000€ (dashed curves), +0€ (thine curves), and +3,000€ (bold curves).

Figure 1: Rebound effect (in Y-axis, in $kgCO_2$/household/year) as a function of the Malus amount (X-axis, in €)



Legend:

$f^d - f^c = 0.6L/100km$, and $P^d - P^c = -3000€$

$f^d - f^c = 3.4L/100km$, and $P^d - P^c = -3000€$

$f^d - f^c = 0.6L/100km$, and $P^d - P^c = 0€$

$f^d - f^c = 3.4L/100km$, and $P^d - P^c = 0€$

$f^d - f^c = 0.6L/100km$, and $P^d - P^c = 3000€$

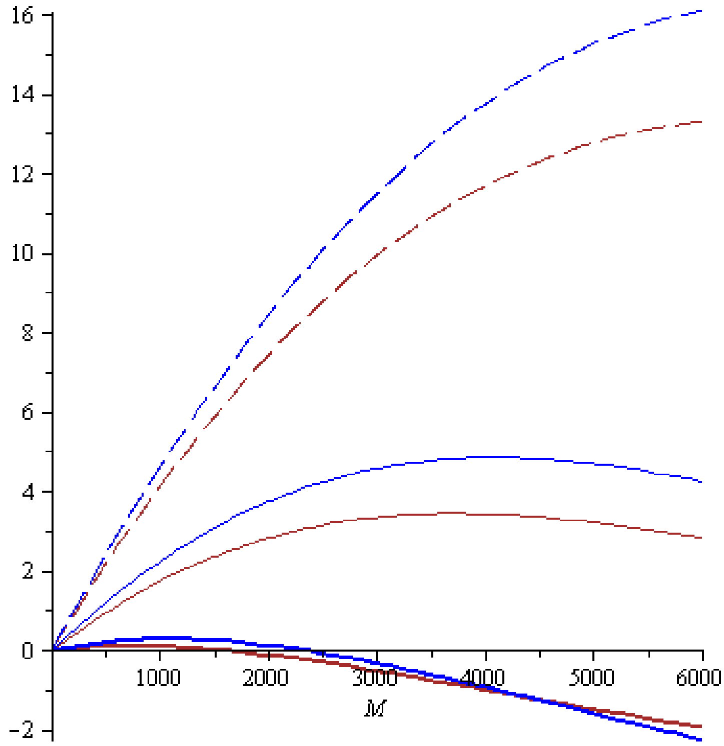
$f^d - f^c = 3.4L/100km$, and $P^d - P^c = 3000€$

First of all, for the latter characteristics of both vehicles, we always observe a rebound effect with the implementation of the Malus scheme, such as shown in Figure 1. Furthermore, Figure 1 shows that the higher the amount of Malus, the higher the rebound effect. In addition, as expected, the higher the gap in the fuel consumption of both vehicles, the higher the rebound effect (compare the blue curves with the brown ones in Figure 1 below). In contrast, the role played by the gap in market prices of vehicles on the order of magnitude of the rebound effect is more ambiguous: for a large gap in fuel consumptions (+3.4L/100km, in brown), the higher the gap in market prices, the higher the rebound effect, whereas when the gap in fuel consumptions is low (+0.6L/100km, in blue), whether the rebound effect is higher with a larger gap in market prices depends on the amount of the Malus.

Despite the rebound effect, the Malus scheme is able to reduce the CO_2 emissions from car use, as illustrated in Figure 2 below. This Figure plots the gap in CO_2 emissions between the two policy regimes we consider – *i.e.* CO_2 emissions without policy tools minus CO_2

emissions with a Malus scheme – while keeping considering two gaps in fuel consumptions (+0.6L/100km (in blue) and +3.4L/100km (in brown)), and for three gaps in market prices (-3,000€ (dashed curves), +0€ (thine curves), and +3,000€ (bold curves)). Clearly, the Malus scheme helps mitigate emissions provided that the gap we chose to plot is positive.

Figure 2: Emissions without policy tools minus Emissions with a Malus scheme (Y-axis, in $kgCO_2$/household/year) as a function of the amount of Malus (X-axis, in €)



Legend:

$f^d - f^c = 0.6L/100km$, and $P^d - P^c = -3000€$ | $f^d - f^c = 3.4L/100km$, and $P^d - P^c = -3000€$

$f^d - f^c = 0.6L/100km$, and $P^d - P^c = 0€$ | $f^d - f^c = 3.4L/100km$, and $P^d - P^c = 0€$

$f^d - f^c = 0.6L/100km$, and $P^d - P^c = 3000€$ | $f^d - f^c = 3.4L/100km$, and $P^d - P^c = 3000€$

Figure 2 shows that increasing the amount of Malus reinforces the effects of the Malus scheme in the first instance, but there exists an amount of Malus above which the reduction in CO_2 emissions attained with the Malus scheme decreases with the Malus amount. More specifically, the lower the gap in the vehicle market prices (in dashed lines compared to the thine lines), the higher the effects of the Malus scheme on the one hand, and the higher the malus threshold above which the efficiency of the Malus deteriorates with the Malus amount on the other hand. More astonishing is the effect of the Malus scheme when the dirty vehicle costs more to purchase than the clean vehicle (cf. the curves in bold that correspond to a gap in market prices of +3,000€). Indeed, in that case, it happens that the effects of the Malus scheme are counterintuitive above a certain level of Malus: the CO_2 emissions are higher in the Malus scheme regime (cf. points below the X-axis in Figure 2 above). This particular situation is referred to as the *Jevons Paradox*.

The latter results highlights the importance of designing the Malus scheme appropriately. In the same vein, and as a remark, d'Haultfoeuille and al. (2014) also argue "*while feebates may be efficient tools for reducing CO_2 emissions, they should thus be designed carefully to achieve their primary goal*" (F444). In their analysis, the potential increase in CO_2 emissions coming with the feebate results from two effects: the rebound effect and a large scale effect (*i.e.* a rise of total sales of new cars).

5. Conclusion

This research examines the impacts of a car purchase charge in terms of a reduction in CO_2 emissions. Precisely, we start by modelling the consumer's behaviour in two stages: first, for each vehicle type (in fact we consider a clean vehicle and a dirty vehicle), the consumer determines the optimal distance to travel by car; second, he chooses the vehicle that yields the highest utility. Then, we run this two-stage model in two situations: a no-policy regime and a regime with a penalty charged on the purchase of high-emitting vehicles. Interesting and not trivial is that a rebound effect does not necessarily accompany the reduction in the average fuel consumption per kilometre resulting from the implementation of a differentiated car purchase tax such as a Malus scheme. In fact, since the improvement of the fuel-efficiency is observed at the aggregate scale and not at the individual level, it happens that we observe a rebound effect only under certain conditions pertaining to the characteristics of the vehicles that make up the fleet, namely the gaps in market prices and fuel consumptions of the dirty and clean vehicles. Additionally, from the moment that a rebound effect occurs, we show that the higher the amount of Malus, the higher the rebound effect. It means that because of the rebound effect, the higher the pricing scheme, the less efficient the purchase tax. Thereby, the Malus scheme should be designed carefully to achieve its primary goal. This is moreover without taking account two other feedback effects of a differentiated purchase tax, or more precisely of the increase in the share of energy-efficient vehicles: the reduction in fuel price – that accentuates the rebound effect – caused by the lower fuel demand on the one hand; and the reduction of the car lifespan due to a more intensive use on the other hand (Stepp and al., 2009).

Ways of improving the model so that it betters mirrors the real life could be to take into account the normative component of a penalty, that is to say the psychological connotation of punishments so that the effects of a an increase in the market price on the one hand and in the amount of penalty on the other differ. Furthermore, considering the particular higher sensitiveness to losses when facing losses and gains of the same magnitude (De Hann and al., 2009) would be of a great interest for conducting the same static analysis in a policy scenario with a feebate scheme.

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Appendixes

A – Malus amounts according to the vehicle's CO_2 emissions or fuel consumption

Table 3: Malus amounts in 2013 in France

CO_2 Emissions (g/km)	Fuel consumption (L/100km)	Malus amount in 2013 (€)
135 < x < 140	5.8 ≤ x < 6.0	100
140 < x < 145	6.0 ≤ x < 6.2	300
145 < x < 150	6.2 ≤ x < 6.4	400
150 < x < 155	6.4 ≤ x < 6.6	1,000
155 < x < 175	6.6 ≤ x < 7.5	1,500
175 < x < 180	7.5 ≤ x < 7.7	2,000
180 < x < 185	7.7 ≤ x < 7.9	2,600
185 < x < 190	7.9 ≤ x < 8.1	3,000
190 < x < 200	8.1 ≤ x < 8.5	5,000
> 200	≥ 8.5	6,000

Source: Author from the French General Tax Code
and using the CO_2 content of petrol (*i.e.* 2.346kgCO_2/L; EPA, 2011)

B – Sensitivity analysis on the preference parameter

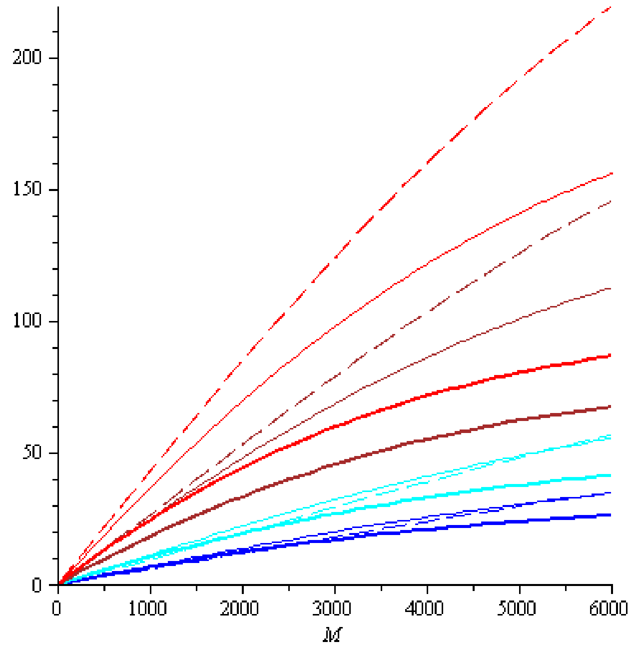
This Appendix aims at highlighting the extent to which the preference parameter plays on our results. With this aim in view, we plot in Figure 3 the rebound effect (cf. left-hand chart) and the gap in CO_2 emissions between a regime without policy tools and a regime with a Malus Scheme (cf. right-hand chart) for two different values of the parameter: $\theta = 0.02$ and $\theta = 0.033$. These values are chosen because they give a distance covered with respectively the clean vehicle and with the dirty vehicle (when the latter car costs €21,918 and consumes 8.6L/100km) relatively close to the average distance covered with a petrol car in France in 2013, namely 7,751km (CCFA, 2014) (see Table 4 below).

Table 4: Distances covered by car depending on the preference parameter

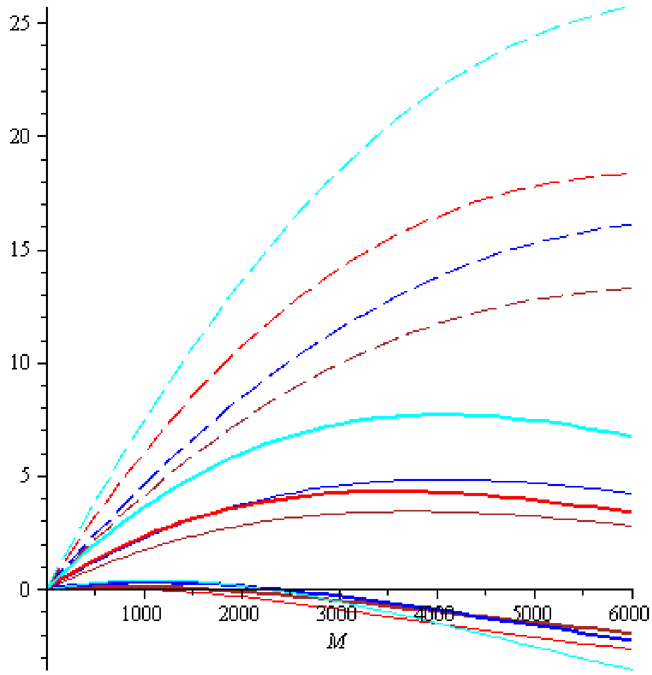
	k^c	k^d
$\theta = 0.02$	7,964km	4,732km
$\theta = 0.033$	13,141km	7,808km

Figure 3: Impact of the preference parameter

Rebound effect (in $kgCO_2$/household/year)



Emissions without policy tools minus Emissions with a Malus scheme (in $kgCO_2$/household/year)



Legend:

— — $f^d - f^c = 0.6L/100km$, and $P^d - P^c = -3000€$ — — $f^d - f^c = 3.4L/100km$, and $P^d - P^c = -3000€$

Same as above, but $\theta = 0.033$ instead of $\theta = 0.02$

$f^d - f^c = 0.6L/100km$, and $P^d - P^c = 0€$

Same as above, but $\theta = 0.033$ instead of $\theta = 0.02$

$f^d - f^c = 0.6L/100km$, and $P^d - P^c = 3000€$

Same as above, but $\theta = 0.033$ instead of $\theta = 0.02$

Same as above, but $\theta = 0.033$ instead of $\theta = 0.02$

$f^d - f^c = 3.4L/100km$, and $P^d - P^c = 0€$

Same as above, but $\theta = 0.033$ instead of $\theta = 0.02$

$f^d - f^c = 3.4L/100km$, and $P^d - P^c = 3000€$

Same as above, but $\theta = 0.033$ instead of $\theta = 0.02$

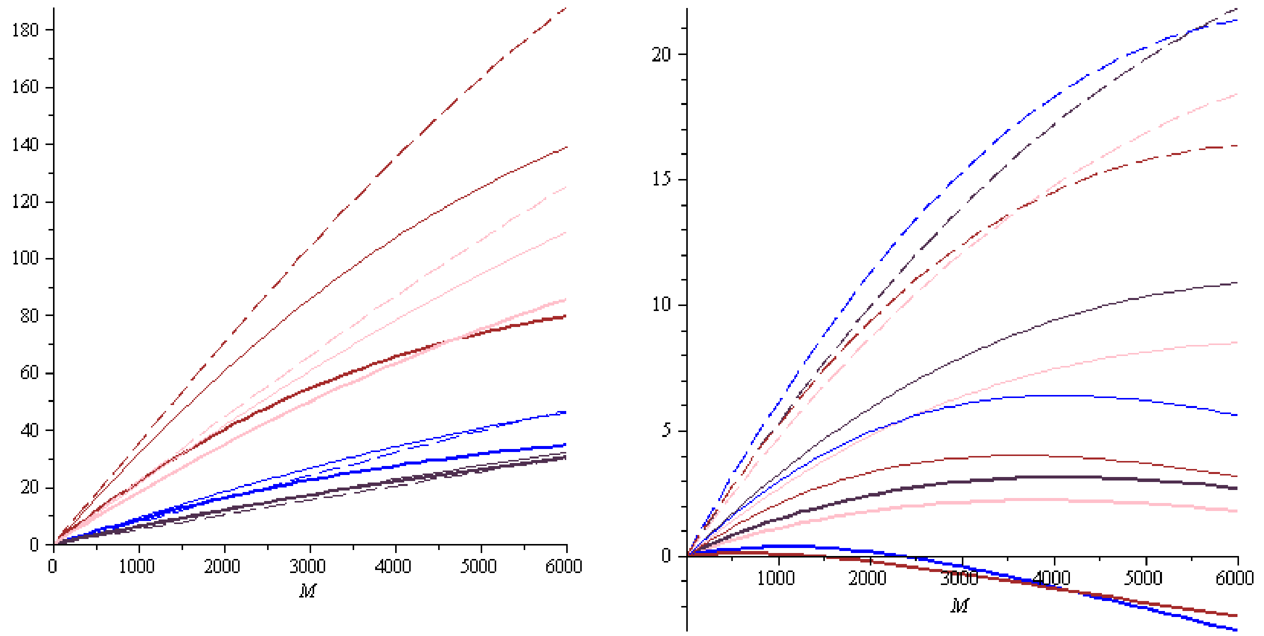
C – Sensitivity analysis on the distribution law

In our simulation, we use a standard normal distribution. To highlight the sensitivity of our results to the distribution law, Figure 4 below plots the rebound effect (cf. the left-hand chart) and the gap in CO_2 emissions due to the Malus scheme (cf. the right-hand chart) assuming either a standard normal distribution (*i.e.* N(0,1), in brown and blue) or a logit distribution with a scale parameter equal to 1 (*i.e.* L(1) in pink and violet).

Figure 4: Impact of the distribution law

Rebound effect (in $kgCO_2$/household/year)

Emissions without policy tools minus Emissions with a Malus scheme (in $kgCO_2$/household/year)



Legend:

$f^d - f^c = 0.6L/100km$, and $P^d - P^c = -3000€$

Same as above, but with L(1) instead of N(0,1)

$f^d - f^c = 0.6L/100km$, and $P^d - P^c = 0€$

$f^d - f^c = 3.4L/100km$, and $P^d - P^c = -3000€$

Same as above, but with L(1) instead of N(0,1)

$f^d - f^c = 3.4L/100km$, and $P^d - P^c = 0€$

Same as above, but with L(1) instead of N(0,1) | Same as above, but with L(1) instead of N(0,1)

$f^d - f^c = 0.6L/100km$, and $P^d - P^c = 3000€$ | $f^d - f^c = 3.4L/100km$, and $P^d - P^c = 3000€$

Same as above, but with L(1) instead of N(0,1) | Same as above, but with L(1) instead of N(0,1)

The left-hand chart of Figure 4 clearly shows that we overestimate the rebound effect when we consider a standard normal distribution. In a coherent manner, we underestimate the effect of the Malus scheme in terms of CO_2 emissions reduction, as shown in the right-hand chart in Figure 4 above.

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