Distributional effects of a carbon tax on car fuels in France

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Abstract

This paper analyses the distributional effects of alternative scenarios of carbon taxes on car fuels using disaggregated French panel data from 2003 to 2006. It incorporates household price responsiveness that differs across income groups into a consumer surplus measure of tax burden. We show that carbon taxation is more detrimental to high-income households when welfare changes are expressed in euros. But the reverse is true when welfare changes are expressed in percentage of income. We find also that carbon taxation combined with simple mechanisms of revenue recycling can make poorest households better off. For example, an additional carbon tax may be progressive when revenues are returned in equal amounts to every household.

1. Introduction

On March 2007, European Union committed to reduce greenhouse gases by at least 20% by 2020, compared to 1990 levels, and to extend this reduction to 30% if other developed countries commit themselves to comparable emissions reductions[1]. The transport sector is one of the main sources of CO_2 emissions in Europe. For instance, transports accounted for 34% of French CO_2 emissions in 2006, half of which come from private vehicles. Transport is also the sector where emissions increased the most in France between 1990 and 2006 (CDC, 2009). Therefore, an ambitious climate strategy should include an ambitious plan for transports.

Carbon pricing is increasingly considered by policymakers as a credible instrument to tackle climate change. A tax on vehicle carbon emissions essentially is equivalent to a fuel tax. Rising fuel taxes may give rise to concerns over the effects of additional taxation on low-income households. For instance, it is often argued in France that low-income households cannot afford to live in city centres where the supply of public transport is abundant, and have then no choice but using their car to travel. Beyond equity concerns, the acceptability of a new carbon tax clearly depends on the proportion of the population that benefit from it. This paper then analyses the distributional effects of alternative scenarios of carbon taxes. The methodology is based on a car use model that is estimated using disaggregated panel data from 2003 to 2006. To the best of our knowledge, this is the first time panel data methods are used to study the distributional impacts of car use taxation. Earlier papers only had access to single or pooled cross-sections. As is well-known, panel data allows controlling for unobserved time-invariant individual effects, then reducing potential estimation biases.

Another characteristic of the paper is that we use French data. Many studies dealing with the distributional effects of car use taxation utilize North-American data (e.g., Bento et al. 2005, 2009, Poterba, 1991, Røed Larsen, 2006, Walls and Hanson, 1999, West, 2004, 2005). Their results are not easily transferable to Europe as the geography of urban areas, the spatial distribution of income and the relative importance of public transport are completely different. For example, OECD (2006) shows that

[1] Conclusions of the European Council of 8-9 March 2007.

private car use, measured in passenger-kilometres per capita, is twice higher in the US than in France. A meta-analysis by Goodwin et al. (2004) showed also that USA has lower fuel consumption elasticities than Europe with respect to both price and income. European studies on the distributional effects of fuel taxation do exist but they often do not model the changes of behaviour induced by taxes (e.g., Aasness and Roed Larsen, 2003). Their results are then only valid for marginal tax shifts. In contrast we explicitly model and simulate individual changes in kilometres travelled induced by modifications in fuel taxation. In this regard, our paper is closer to Blow and Crawford (1997) or Santos and Catchesides (2005) who assess the regressive effects of gasoline taxation in the United Kingdom considering the behavioural response of drivers to the increased cost of driving.

The paper also simulates simple scenarios of carbon tax revenue recycling. This is of most interest since such scenarios change the conclusions about the distributive impacts of the carbon tax. Most available studies do not consider revenue recycling scenarios.

As all available studies – except Bento et al. (2005, 2009) for the US – we focus on short run effects of fuel taxation. In particular, we assume that households respond to the additional taxation by reducing the number of kilometres they drive, but not by changing the size or composition of their fleet[2].

The paper is organized as follows. Section 2 presents the model of car use that will provide the basis for the simulations. Section 3 presents our approach for simulating scenarios of carbon taxation. Section 4 discusses the data. Section 5 presents and interprets the results. The last section concludes.

2. Model of car use

This section presents the model of car use. Estimates of the model will then be used to simulate changes in fuel taxation. We consider the following standard expression for kilometres demand:

[2] Bento et al. (2005, 2009) do consider changes in motorisation as well as adjustments on the supply side of the car market. More generally, a full evaluation would ideally require a general equilibrium framework. It would also require a precise knowledge of the distribution of non-market benefits between income groups. Such a task is beyond the scope of the paper.

$$KM_{it} = \alpha + \beta_1.p_{it} + \beta_2.(p_{it} \times y_{it}) + \gamma.two_{it} + V'.\delta_1 + H'.\delta_2 + X'.\delta_3 + T_t'.\zeta + a_i + \varepsilon_{it} \quad (1)$$

where i indexes households, t indexes years, KM is the annual number of kilometres the household drives, *p* is the price per kilometre, *y* is income per consumption unit, *two* indicates if the household holds two cars, *V* is a vector of vehicle attributes, *H* is a vector of household characteristics, *X* is a vector of other control variables, *T* is a vector of year dummies, a_i is the household fixed effect, ε_{it} is the usual error term, and the remaining Greek letters denote parameters.

The linear specification of the demand function allows the demand response to *p* to vary with the level of demand. This is a key issue in assessing the distributional effects of a rise in *p*. In contrast, a log-log specification would impose the restriction that the price elasticity is the same for all households. Besides, to allow the price effect to vary with income, we include an interaction between income and the price per kilometre. In the estimations, *p* and ($p \times y$) are also interacted with specific dummy variables to allow the price effect to vary between one and two-vehicle households.

When estimating a model of car use, a standard econometric problem deals with the endogeneity of the variables describing the number and the attributes of cars held by households. This is due to the joint nature of the demands for vehicles and kilometres. The choices of vehicle and kilometres are related because characteristics that influence a household to purchase a certain number and type of vehicles may also influence that household's choice of kilometres. For example, as Mannering and Winston (1985) point out, the individual characteristics that tend to increase usage (e.g., pleasure of driving) will adversely affect the probability of selecting an old, decrepit vehicle from which little driving pleasure can be derived. In econometric terms, such correlation implies that vehicle specific attributes, which are included as explanatory variables in (1), will be correlated with the error term. In this context, the use of Ordinary Least Squares (OLS) may lead to biased and inconsistent estimators of parameters. A standard procedure to deal with this problem is to adopt a two step approach. A discrete choice model is first used to estimate the probabilities of choosing different fleet sizes and compositions; these probabilities are then used in the estimation of kilometres demand to control for endogeneity (e.g., Berkowitz et al., 1990, Goldberg, 1998, Hensher et al., 1992, Mannering and Winston, 1985, Train, 1986, West, 2004)[3]. The use of panel data allows us to adopt a more straightforward approach to deal with endogeneity. Indeed, the use of a fixed effect estimator permits to purge the effects of a_i, i.e., all unobserved and time invariant determinants, from (1). At last, the sole condition for the estimator to be consistent is that the indiosyncratic error ε_{it} is uncorrelated with explanatory variables. We consider this assumption as a reasonable one in our case[4].

3. Simulation strategy

3.1. General approach

Having described how we model the demand for kilometres, we now describe how we simulate the different scenarios. We proceed in four stages. First, we estimate econometrically the parameters of equation (1) using panel data from 2003 to 2006. Second, we simulate the changes in kilometres driven by households induced by the changes in fuel taxation. Third, we calculate individual welfare changes. Finally, we examine the distribution of welfare changes among households. The data used in the simulations refer to 2006.

3.2. Calculation of individual welfare changes

As stated in the introduction, we restrict the analysis to short-run partial equilibrium incidence of the tax. We assume that households respond to the additional taxation solely by reducing the number of kilometres they drive. We use the change in household consumer surplus to measure the change in household welfare due to the tax. Assuming a linear demand curve for kilometres, the change in consumer surplus for household *i* induced by an additional tax can be expressed:

$$\Delta CS_i = (p_{i1} - p_{i0}).KM_{i1} + \tfrac{1}{2}\,[(p_{i1} - p_{i0}).(KM_{i0} - KM_{i1})] \qquad (2)$$

[3] This approach derives from the seminal work of Dubin and McFadden (1984) who propose models to estimate the joint demand for durables and energy use.
[4] Exceptions may concern two of our variables: *ADD* and *SEP*. We come back to this issue in the next section.

where p_{i0} is the initial price per kilometre for household *i*, p_{i1} is the price per kilometre with the additional tax, KM_{i0} is the initial number of kilometres, and KM_{i1} is the number of kilometres after the tax.

It is important to note that not considering behavioural response of drivers amounts to taking into account twice the second term of (2), leading to an over-estimation of the welfare impact of taxation.

3.3. Scenarios

Table 1 describes the six scenarios. As a benchmark, we consider an additional carbon tax of €0.071 per litre of gasoline and €0.081 per litre of diesel. Those values refer to a cost of CO2 of €31 per tonne (in 2006€). It is the official figure to be considered in France (by 2010) when evaluating public investment choices or, more generally, when making environmental evaluation of public policies (CAS, 2008). It was determined in order to achieve the European political objectives of March 2007 and lies at the high end of the spectrum of international evaluations of external costs of carbon (see e.g., CE Delft, 2008)[5]. Then we consider several variations of this reference scenario. First, a higher taxation of carbon: €0.124 per litre of gasoline and €0.140 per litre of diesel. It corresponds to €54 per tonne of CO2 (in 2006€), which is the official figure to be considered in France by 2020. The idea is to investigate if the level of taxation impacts the distribution of burdens among households. We also consider two alternative ways of recycling the additional revenues from the tax increase:

- *"flat" recycling*: revenues are returned in equal amounts to every household;
- *"size-based" recycling*: revenues are allocated according to the number of consumption units[6] in the household.

[5] We consider an additional fuel tax that fully internalise the external cost of carbon as defined by CAS (2008). One may argue that social costs of carbon are already internalised in existing fuel (or car) taxation. Assessing the economic optimality of such an additional tax is out the scope of the paper. We wish merely to feed the debate on additional fuel taxation on equity grounds.

[6] In the whole paper, the "OECD modified scale" is used to define consumption units, i.e., the first adult gets the weight 1, other members aged 14 or more get 0.5, children aged less than 14 get 0.3.

Both alternatives can be handled in our methodological framework as they involve lump sum transfers to all households. It is reasonable to assume that such transfers do not modify significantly households' demand for kilometres[7]. In our calculations, lump sum transfers are then simply added to individual surplus variations induced by the carbon tax to obtain the overall individual welfare changes. We consider that recycling is accomplished on an annual basis and assume that it does not involve additional costs to the government.

Table 1: Description of the six scenarios

Scenario name	**Carbon tax**	**Redistribution of carbon tax revenues**	**Redistributed amount (per annum)**
Reference	Gasoline: €0.071/L. Diesel: €0.081/L.	No	–
Reference – Flat recycling	Gasoline: €0.071/L. Diesel: €0.081/L.	Yes	€64
Reference – Size-based recycling	Gasoline: €0.071/L. Diesel: €0.081/L.	Yes	€41 per consumption unit
High	Gasoline: €0.124/L. Diesel: €0.140/L.	No	–
High – Flat recycling	Gasoline: €0.124/L. Diesel: €0.140/L.	Yes	€110
High – Size-based recycling	Gasoline: €0.124/L. Diesel: €0.140/L.	Yes	€71 per consumption unit

4. Data and summary statistics

4.1. General data description

The "Panel Parc Auto TNS-Sofres" (hereafter "Parc Auto") is the main component of the data. This survey has been carried out annually in France for twenty-five years. We use the last four waves of the panel: 2003 to 2006. "Parc Auto" describes the number of vehicles held by households, the technical attributes of those vehicles (e.g., age, type, fuel) and their usage. It also includes the socio-economic and geographical characteristics of the surveyed households. About 6,500 households are surveyed each year. On average, two-thirds are re-interviewed the following year while the others drop out of the panel and are replaced by new ones.

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[7] As we will see it in section 5, our estimations show that the impact of income on demand for kilometres is small and hardly significant.

Our estimations are limited to motorized households who hold one or two cars. As stated above, we are only concerned with the response of households in terms of usage, not in terms of car ownership. So we do not consider non-motorized households in our estimations[8]. Besides, not enough three-or-more-vehicle households remained in our sample after cleaning to produce sound estimates. Those households were then systematically dropped out. Note however that they represent less than 7% of French households in 2006. Because we use a fixed effect estimator, households who are just present once in the panel are not included in our sample. Careful examination of data also revealed obvious measurement errors in the variable "number of kilometres driven" for households who replaced one of their cars within the year of survey. Those observations are not included in the sample. Finally, observations with missing values for key explanatory variables also drop out. Overall this leaves us with an unbalanced panel of 2,956 households with 7,915 observations over the period 2003-2006[9].

To construct a price per kilometre variable fuel prices and the fuel efficiency of each vehicle are needed. For fuel prices, we use annual average prices provided by the French Ministry in charge of energy. "Parc Auto" contains data on fuel efficiency. Households are asked to give an estimation of the fuel efficiency of each of their vehicle. We do not consider this information directly but use it to estimate average fuel efficiencies per type of vehicle[10]. The idea is that some households may over-estimate or under-estimate the fuel efficiency of their fleet but we assume that, on average, households' estimations are correct. For two-vehicle households, the price per kilometre considered in the estimation is the average of the price per kilometre of the two vehicles.

4.2. Summary statistics

[8] However, non-motorized households are taken into account when measuring the welfare impacts of additional taxation, considering their welfare change to be zero.

[9] 49% of households are surveyed two years, 34% are surveyed three years and 17% are surveyed four years.

[10] On total, more than 180 types of vehicles are considered according to fuel type, engine size, market segment, and age. Fuel efficiencies vary also according to the year of survey. Estimation is carried out by OLS. Results are available upon request.

Table 2 presents the main descriptive statistics of the sample and the variables used for the estimation. For example, it can be seen that households drive 14,601 kilometres a year on average, 26% hold two vehicles and 35% live in peri-urban or rural areas.

Most of the variables used for the estimation are standard in car use modelling. Some deserve specific attention: "Parc Auto" classifies vehicles into nine market segments. In order to have enough observations for each variable, some were grouped together so that we finally consider four market segments: downmarket (e.g., Renault Clio, VW Polo), mid-range (e.g., Peugeot 307, VW Golf), upmarket or SUVs (e.g., Mercedes-Benz E-Class, BMW 7 Series) and utility vehicles. Note also that "Parc Auto" describes the use – in the last twelve months – of each vehicle the household holds at the end of the year. As the fleet size may vary during the year, two control variables are included in the estimation: *ADD* which indicates that the household bought an additional car during the year and *SEP* which indicates that the household parted with one car. We expect the former to decrease the number of kilometres the household drives – because it does not hold the additional vehicle for twelve months. Conversely, we expect SEP to increase the number of kilometres the household drives with the remaining vehicle – reflecting some kind of inertia in household's activity pattern. Note that the two variables may be endogenous even after controlling for time-invariant unobserved effects. As non-regular choices made by households they may indeed be correlated with ε_{it}. No valid instruments being available, we ran the estimation without including households with *ADD* and *SEP* equal to one. This robustness check did not change significantly the estimates of other key variables.

Finally, even if the information is available in "Parc Auto", we choose not to include in the estimation a variable describing fuel type (i.e., gasoline or diesel) as one may expect at first glance. Such an inclusion is not necessary because we believe that the sole influence of fuel type on kilometres is via fuel efficiency (diesel vehicles are more fuel efficient on average) which is reflected in the price per kilometre. Another characteristic of diesel cars is that they are usually considered to have a more important longevity. A priori, such information is not correlated with any of our explanatory variables, so there is no harm to let the fuel type information in the error term.

Table 2: Descriptive statistics

Variable	Definition	Mean	Std. Dev.
KM	Total kilometres driven	14601	9127
p	Price per kilometre	0.0791	0.0157
p*INCOME	Price per kilometre*income per capita	1523	930
ONE	=1 if household holds one vehicle	0.74	0.44
TWO	=1 if household holds two vehicles	0.26	0.44
DOWNMARKET	=1 if a 1-vehicle household holds a downmarket vehicle	0.31	0.46
MIDRANGE	=1 if a 1-vehicle household holds a mid-range vehicle	0.39	0.49
UTILITY	=1 if a 1-vehicle household holds a utility vehicle	0.01	0.08
DOWN_DOWN	=1 if a 2-vehicle household holds two downmarket vehicles	0.03	0.17
DOWN_MID	=1 if 2-vehicle household holds a downmarket and a mid-range vehicle	0.13	0.34
DOWN_UP	=1 if a 2-vehicle household holds a downmarket and a upmarket vehicle	0.03	0.16
MID_MID	=1 if a 2-vehicle household holds two mid-range vehicles	0.04	0.19
MID_UP	=1 if a 2-vehicle household holds a downmarket and a mid-range vehicle	0.01	0.10
UTILITY_2V	=1 if a 2-vehicle household holds a least one utility vehicle	0.02	0.15
NEW	=1 if a 1-vehicle household holds a new car (less than 2 years)	0.07	0.25
OLD_NEW	=1 if a 2-vehicle household holds one new car	0.04	0.19
NEW_NEW	=1 if a 2-vehicle household holds two new cars	0.00	0.05
NB_ADULTS	Number of adults (18 years old or more)	1.8	0.7
Q_j	=1 if household belongs to the j-th quintile of income per capita (j=2,..., 5)	_	_
SUBURB[a]	=1 if household lives in a suburban area	0.34	0.47
PERIURBAN[a]	=1 if household lives in a periurban area	0.33	0.47
RURAL[a]	=1 if household lives in a rural area	0.02	0.16
ADD	=1 if fleet size increased during the year	0.02	0.13
SEP	Equals one if fleet size decreased during the year	0.01	0.10
YEAR-j	Year dummies (j=2004, 2005, 2006)	_	_
FEMALE	=1 if head of household is female	0.19	0.39
AGE	Age of household head	58	15
NB_DL	Number of household members with a driving licence	1.6	0.5
NORTH	=1 if household lives in the North	0.07	0.26
EAST	=1 if household lives in the East	0.10	0.30
WEST	=1 if household lives in the West	0.14	0.34
SOUTH_WEST	=1 if household lives in the South West	0.10	0.30
SOUTH_EAST	=1 if the household lives in the South East	0.24	0.43

[a] Four types of location are considered: city centres, suburbs, peri-urban zones and rural areas. This coding was developed by the French National Institute for Transport and Safety Research (INRETS).

4.3. Test of sample selection bias

When filling the survey questionnaire of “Parc Auto”, households are asked to give details on the attributes and usage of all their cars. So it is clearly more tedious to fill in when a multi-motorized household. As a consequence, multi-motorized households are less likely to stay in the panel than mono-motorized ones. In other words, the decision to rotate households out of the panel is not fully random, so that a sample selection problem can result. Wooldridge (2002, p. 581) provides a simple test for sample selection bias in the context of fixed effect estimation with unbalanced panel. The test relies on the fact that sample selection in a fixed effects context is only a problem when selection is related to the idiosyncratic errors, ε_{it}. So Wooldridge suggests adding the lagged selection indicator, $s_{i,t-1}$, to the equation ($s_{i,t-1}$ equals one if household *i* is present in the panel at time *t-1*, 0 otherwise), estimate the model by fixed effects and do a *t* test for the significance of $s_{i,t-1}$. Under the null hypothesis, ε_{it} is uncorrelated with s_{ir} for all *r*, and so selection in the previous time period should not be significant at time *t*.[11] In our case, a robust *t* test strongly supports the hypothesis of no sample selection bias.

5. Estimation and results

5.1. Estimation of the model of car use

The results from the estimation of the car use model are reported in Table 3. As mentioned earlier, a fixed effect estimator is used to control for the potential endogeneity of the explanatory variables describing fleet size and composition. For comparison purpose, Table 3 also reports estimation results with pooled OLS and random effects (RE). We know that those methods will generally lead to inconsistent estimators if the (unobserved to the econometrician) household-specific effects a_i are correlated with any of the explanatory variables. As expected, pooled OLS and RE produce substantially different results than FE indicating correlation between a_i and the explanatory variables. Formally, a standard Hausman test strongly rejects the assumption of similar RE and FE estimates. Besides, we ran an *F* test to test the null hypothesis that the constant terms are equal across households. The hypothesis is strongly rejected, implying that pooled OLS would be inappropriate. For the rest of the paper with then focus on FE estimates.

The price coefficients are significant[12] and of expected sign. Households drive less as price per kilometre increases but richer households are less price sensitive. As expected, households with two cars drive more, as those holding a recent car – though

[11] This approach was first suggested by Nijman and Verbeek (1992) in the context of random effects estimation.
[12] Because of the interaction effects, one may take care not to look separately at the price coefficients. Then, even if the coefficient of *p*INCOME*TWO* is not significant at the 10% level (it is though at the 13% level), a F-test strongly rejects the joint hypothesis that *p*TWO* and *p*INCOME*TWO* equal zero.

this last result is only significant for one-vehicle households. On the contrary, market segment dummies have very little explanatory power[13,14].

Unsurprisingly, households with more adults drive more, as those living in peri-urban or rural areas. Interestingly, the effect of income per capita is negative though only just significant[15]. This is so because our model produces estimates holding the number of cars constant. In their extensive review of demand elasticity studies, Goodwin et al. (2004) note that when income increases, the number of vehicles increases relatively more than the volume of traffic. Such a result implies that use per vehicle should decline as income increases.

As expected, households that hold one of their vehicles for less than 12 months drive less. Conversely, two-car households who part with one of their vehicle drive more with the remaining one, reflecting some kind of inertia in their activity pattern.

[13] Tests on coefficients exhibit only two exceptions: the 3% of households that own a downmarket and an upmarket vehicle drive more than most of the other two-vehicle households. Moreover, one-vehicle households owning a mid-range vehicle drive more than the 0.7% of households owning a utility vehicle.

[14] Such a general absence of significativity is also found in Goldberg (1998) for the US.

[15] The negative sign holds whatever the specification of income: continuous or dummy variables, total or per consumption unit income, but not the significativity.

Table 3: Kilometre demand results

	OLS		RE		FE	
p*ONE	-128,233***	(8444)	-109,804***	(7559)	-40,989***	(15501)
p*TWO	-246,077***	(23795)	-187,422***	(18083)	-78,174***	(26906)
p*INCOME*ONE	0.258	(0.24)	0.463***	(0.16)	0.466***	(0.17)
p*INCOME*TWO	0.313	(0.37)	0.345	(0.26)	0.531	(0.35)
TWO	15,423.9***	(2729.3)	12,498.1***	(2518.0)	11,550.6***	(3222.8)
DOWNMARKET	-3,876.6***	(558.1)	-3,020.4***	(484.6)	-504.4	(1098.6)
MIDRANGE	-1,252.0**	(530.4)	-817.6*	(458.1)	247.3	(936.2)
UTILITY	-863.9	(951.7)	-1,792.0**	(901.5)	-1,628.4	(1258.4)
DOWN_DOWN	-2,544.4	(1827.4)	-1,088.3	(2146.9)	-636.1	(2934.5)
DOWN_MID	-603.5	(1704.7)	642.7	(2033.2)	104.3	(2748.2)
DOWN_UP	740.7	(1653.6)	2,921.2	(2039.5)	2,933.7	(2805.0)
MID_MID	684.5	(1814.4)	1,128.1	(2095.7)	-166.0	(2828.8)
MID_UP	3,181.7*	(1825.9)	3,349.0	(2143.0)	511.5	(3122.6)
UTILITY_2V	-419.9	(1609.2)	1,309.9	(2042.7)	2,123.0	(2799.4)
NEW	1,679.8***	(276.7)	612.5***	(178.2)	338.0*	(182.0)
OLD_NEW	946.7*	(557.4)	313.0	(377.3)	157.8	(397.4)
NEW_NEW	4,250.7*	(2490.1)	3,659.6*	(1989.8)	3,029.6	(2176.1)
NB_ADULTS	1,093.0***	(240.3)	925.8***	(231.6)	1,004.7**	(418.9)
QQ2	1,060.8***	(329.8)	81.9	(231.0)	-427.3*	(256.5)
QQ3	1,414.9***	(361.3)	323.5	(251.9)	-475.0	(294.3)
QQ4	2,275.0***	(420.4)	707.7**	(293.8)	-470.5	(346.4)
QQ5	2,701.4***	(586.1)	711.5*	(385.4)	-764.8*	(443.0)
SUBURB	-20.8	(262.4)	-45.9	(269.4)	-199.3	(953.7)
PERIURBAN	2,151.3***	(274.1)	2,088.9***	(281.0)	2,609.8**	(1058.9)
RURAL	1234.4	(921.5)	1,483.7**	(749.7)	6,096.8***	(1966.4)
ADD	-2,428.9***	(736.5)	-2,661.9***	(553.0)	-2,508.9***	(661.9)
SEP	279.3	(753.6)	1,101.4*	(589.6)	1,670.7**	(746.1)
YEAR04	532.4***	(150.2)	345.9***	(120.0)	-6.1	(123.1)
YEAR05	1,226.0***	(178.3)	867.7***	(136.4)	-168.8	(192.2)
YEAR06	1,322.5***	(194.6)	892.5***	(150.7)	-440.9**	(220.4)
FEMALE	-1,220.0***	(332.8)	-1,535.7***	(324.0)		
AGE	-141.4***	(7.3)	-145.5***	(7.7)		
NB_DL	709.0**	(277.8)	491.4*	(272.9)		
NORTH	290.7	(459.1)	177.6	(476.4)		
EAST	603.3	(397.2)	454.0	(398.1)		
WEST	1,045.6***	(353.1)	635.2*	(358.6)		
SOUTH_WEST	225.0	(406.3)	32.6	(426.6)		
SOUTH_EAST	176.3	(283.3)	179.9	(297.8)		
CONSTANT	26,179.8***	(1109.2)	26,414.7***	(1012.4)	12,616.5***	(1873.69)
Observations	7915		7915		7915	
R2	0.50		0.49		0.36	

Notes. Dependent variable is KM. Robust standard errors in parentheses. * indicate significance at the 10% level. ** Idem, 5%. *** Idem, 1%.

5.2. Elasticities

Results of the estimations are used to calculate the elasticity of demand for kilometres with respect to price per kilometre. Because vehicle choices are held constant, this elasticity corresponds to a short run response. Using FE results and sample means of kilometres, price per kilometre and income, yields an elasticity of -0.22, which is fairly in line with the literature (see e.g., Graham and Glaister, 2002, Goodwin et al., 2004). Table 4 lists elasticities of demand by income group. Demand elasticities clearly vary across quintiles. In absolute value, elasticity declines with income, which is a pretty intuitive result. A similar outcome is found in Blow and Crawford (1997) and Santos and Catchesides (2005) for the UK, and in West (2004) for the U.S.[16] Table 4 also presents elasticities of demand by income group and geographical location. Whatever the income group, peri-urban or rural households respond less to price change than urban households. This is mainly due to the reduced availability of alternative transport modes in peri-urban and rural areas. This is in line with the results of Blow and Crawford (1997) and Santos and Catchesides (2005) for the UK.

Table 4: Kilometres demand elasticities by quintile[a]

Quintile	All motorized households	Urban motorized households	Peri-urban or rural motorized households
1	-0.28	-0.30	-0.25
2	-0.25	-0.29	-0.22
3	-0.23	-0.25	-0.20
4	-0.21	-0.22	-0.19
5	-0.18	-0.19	-0.17

[a] Demand elasticities are calculated at the mean price per kilometre, kilometres, and income, by quintile, using FE results.

5.3. Results of the simulations

With the estimates of the car use model and the data on households' mobility and price per kilometre, we can now simulate the impact of various scenarios of carbon taxes on households' welfare. Table 5 presents the results for the reference scenario, i.e., an additional carbon tax of €0.071 per litre of gasoline and €0.081 per litre of diesel without recycling of the carbon tax revenues. Let us first consider variations of surpluses in euros per annum. Losses clearly increase with income: from €71 euros for lower income motorized households to €88 for the wealthiest motorized households (+23%). It is not surprising as richer households own more cars, drive more and are less price-sensitive.

[16] Though, in West (2004), the richest households (decile 9 plus decile 10) are slightly more elastic than the preceding income group (decile 7 plus decile 8).

The result is even stronger if one considers not only vehicle owners but all households. The richest households (quintile 5) lose 43% more than the poorest (quintile 1). This is so because the percentage of non-motorized households decreases with income: 25% in quintiles 1 or 2, 12% in quintile 5.

As expected, households living in peri-urban or rural areas lose more. This result holds even after controlling for income. The difference is striking for the poorest households. Households of quintile 1 that live in peri-urban or rural areas lose 90% more than other households of quintile 1 (€72 vs €38).

When considering surplus variations in percentage of income, Table 5 shows that low-incomes lose more than richer households. Therefore, the scenario is regressive.

Table 6 presents the results of simulations for a heavier taxation of carbon: €0.124 per litre of gasoline and €0.140 per litre of diesel. Such a heavier taxation mechanically increases the magnitude of losses but not their distribution across income groups or geographical locations.

We now consider scenarios where the additional revenues from the carbon tax are returned in equal amounts to every household (*"flat" recycling*) or according to the number of consumption units in the household (*"size-based" recycling*). Table 5 and Table 6 exhibit dramatically different results than in scenarios without recycling.

First consider the reference scenario, i.e., a carbon tax of €0.071 per litre of gasoline and €0.081 per litre of diesel. Considering the whole population, the poorest households (quintiles 1 and 2) are net gainers whatever the recycling method. This is so because the proportion of non-motorized households – that benefit from the revenue distribution without incurring any cost – decreases with income. Then the two recycling scenarios are globally progressive. Comparing the two recycling scenarios, the *"size-based" recycling* scenario is the most progressive: low-incomes gain more and high-incomes lose more. The reason is that households of quintile 1 are bigger on average (1.77 consumption units vs. 1.58 for the whole population). If we focus on motorized households, the carbon tax is still progressive in the *"size-based recycling"* scenario but not in the *"flat" recycling* scenario.

Table 5 shows that on average households living in urban areas are net gainers while those living in peri-urban or rural zones are net losers. In other words, carbon taxation with recycling implies transferring welfare from peri-urban or rural areas to urban zones. However, within the whole population of peri-urban and rural households, carbon taxation with recycling remains progressive. If revenues are recycled according to households' size, this result also holds for the sub-population of vehicle owners.

We now compare the impact of the reference scenario with a heavier taxation of carbon (Table 6). Considering the whole population, the poorest households gain more on average with the heavier carbon taxation. The reason is the same than above: the percentage of non-motorized households is more important in quintiles 1 and 2. Also, the transfer from peri-urban and rural zones to urban areas increases with taxation.

6. Conclusion

This paper analyses the distributional effects of alternative scenarios of carbon taxes on private vehicle fuels in France. The methodology is based on a car use model that is estimated using disaggregated panel data from 2003 to 2006. Panel data is particularly suitable for estimating the car use model as it allows controlling for the inherent endogeneity of motorisation choices. Nevertheless, two methodological limits should be kept in mind when interpreting the results. Our analysis uses a partial equilibrium approach and is restricted to the short-run incidence of the tax.

That being said, our results show that conclusions about the distributional impacts of a carbon tax depend on whether the welfare losses induced by the tax are measured in absolute terms, i.e., in euros, or in relative terms, i.e., as a percentage of income. In absolute terms, the carbon tax is more detrimental to high-incomes because they drive more and are less price-sensitive. In relative terms, it is more detrimental to low-incomes, meaning that carbon taxation is regressive.

Considering geographical location, peri-urban and rural households lose more than households in urban areas, even after controlling for income. In our reference scenario, households of quintile 1 that live in peri-urban or rural areas lose 90% more than other households of the quintile 1 that live in urban areas. Considering various geographical locations is then crucial when assessing distributional effects of fuel taxation.

Our results also suggest that simple mechanisms of revenue recycling can make poorest households better off, namely returning revenues in equal amounts to every household or according to the number of consumption units in the household. In this context, we show that the average gains of the poor households increase with the level of carbon taxation.

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Table 5: Simulation results of the reference scenario[a]

Quintile	Change in consumer surplus (euros)		Change in consumer surplus/Income (%)		Change in consumer surplus (euros)				Change in consumer surplus/Income (%)			
	Vehicle owners only	All households	Vehicle owners only	All households	Vehicle owners only		All households		Vehicle owners only		All households	
					Urban	Peri. or rural	Urban	Peri. or rural	Urban	Peri. or rural	Urban	Peri. or rural
No recycling												
1	-71	-53	-0.63%	-0.47%	-60	-84	-38	-72	-0.56%	-0.71%	-0.36%	-0.61%
2	-71	-53	-0.41%	-0.30%	-66	-78	-44	-68	-0.38%	-0.44%	-0.26%	-0.38%
3	-79	-68	-0.32%	-0.28%	-68	-93	-55	-89	-0.28%	-0.38%	-0.23%	-0.36%
4	-84	-77	-0.26%	-0.24%	-74	-101	-66	-98	-0.24%	-0.31%	-0.21%	-0.30%
5	-88	-75	-0.19%	-0.16%	-79	-114	-65	-111	-0.16%	-0.25%	-0.13%	-0.24%
Avg.	-79	-65	-0.36%	-0.29%	-71	-92	-54	-84	-0.30%	-0.44%	-0.23%	-0.40%
"Flat" recycling												
1	-8	11	-0.07%	0.17%	4	-20	26	-8	0.04%	-0.18%	0.32%	-0.04%
2	-8	11	-0.04%	0.11%	-2	-15	20	-4	-0.01%	-0.08%	0.17%	0.00%
3	-15	-5	-0.06%	-0.01%	-4	-30	9	-25	-0.02%	-0.12%	0.05%	-0.10%
4	-20	-13	-0.06%	-0.04%	-11	-38	-2	-34	-0.03%	-0.12%	0.00%	-0.10%
5	-24	-12	-0.05%	-0.02%	-16	-50	-1	-47	-0.03%	-0.10%	0.00%	-0.10%
Avg.	-15	-1	-0.06%	0.04%	-7	-28	10	-20	-0.02%	-0.12%	0.10%	-0.06%
"Size-based" recycling												
1	5	19	0.05%	0.23%	14	-5	29	4	0.13%	-0.04%	0.34%	0.07%
2	-5	8	-0.03%	0.07%	-2	-11	14	-3	-0.01%	-0.06%	0.12%	0.00%
3	-11	-4	-0.05%	-0.01%	-2	-24	8	-21	-0.01%	-0.10%	0.04%	-0.08%
4	-20	-14	-0.06%	-0.04%	-12	-34	-5	-31	-0.04%	-0.11%	-0.01%	-0.10%
5	-27	-16	-0.06%	-0.03%	-19	-52	-7	-49	-0.04%	-0.11%	-0.01%	-0.10%
Avg.	-12	-1	-0.03%	0.05%	-6	-22	7	-16	0.00%	-0.08%	0.09%	-0.03%

[a] The tax is set to €0.071 per litre of gasoline and €0.081 per litre of diesel (2006€), and is imposed on top of existing taxes.

Table 6: Simulation results of the "High" scenario[a]

Quintile	Change in consumer surplus (euros)		Change in consumer surplus/Income (%)		Change in consumer surplus (euros)				Change in consumer surplus/Income (%)			
	Vehicle owners only	All households	Vehicle owners only	All households	Vehicle owners only		All households		Vehicle owners only		All households	
					Urban	Peri. or rural	Urban	Peri. or rural	Urban	Peri. or rural	Urban	Peri. or rural
No recycling												
1	-123	-91	-1.10%	-0.81%	-103	-145	-66	-125	-0.97%	-1.23%	-0.62%	-1.06%
2	-124	-92	-0.71%	-0.52%	-114	-136	-76	-117	-0.67%	-0.76%	-0.44%	-0.66%
3	-136	-118	-0.56%	-0.49%	-118	-162	-95	-154	-0.49%	-0.65%	-0.40%	-0.62%
4	-146	-133	-0.46%	-0.42%	-129	-176	-114	-169	-0.41%	-0.53%	-0.36%	-0.52%
5	-153	-131	-0.32%	-0.28%	-138	-197	-113	-192	-0.29%	-0.43%	-0.23%	-0.42%
Avg.	-137	-112	-0.62%	-0.51%	-122	-160	-93	-146	-0.53%	-0.76%	-0.40%	-0.69%
"Flat" recycling												
1	-14	19	-0.12%	0.28%	7	-35	44	-15	0.06%	-0.31%	0.55%	-0.07%
2	-14	18	-0.08%	0.18%	-5	-26	34	-7	-0.03%	-0.15%	0.29%	0.00%
3	-27	-9	-0.11%	-0.02%	-8	-52	15	-45	-0.03%	-0.21%	0.09%	-0.18%
4	-36	-23	-0.11%	-0.06%	-19	-66	-4	-60	-0.06%	-0.21%	0.00%	-0.18%
5	-43	-21	-0.09%	-0.04%	-28	-87	-3	-82	-0.06%	-0.18%	0.00%	-0.17%
Avg.	-27	-2	-0.10%	0.07%	-12	-50	17	-36	-0.03%	-0.22%	0.18%	-0.11%
"Size-based" recycling												
1	9	32	0.08%	0.39%	24	-9	50	7	0.21%	-0.08%	0.59%	0.12%
2	-10	13	-0.06%	0.12%	-3	-19	24	-7	-0.02%	-0.11%	0.21%	-0.01%
3	-20	-7	-0.08%	-0.02%	-4	-43	13	-37	-0.02%	-0.18%	0.07%	-0.15%
4	-35	-24	-0.11%	-0.07%	-21	-60	-9	-55	-0.07%	-0.19%	-0.02%	-0.17%
5	-48	-29	-0.10%	-0.06%	-34	-90	-13	-86	-0.07%	-0.19%	-0.02%	-0.18%
Avg.	-21	-2	-0.06%	0.08%	-11	-40	12	-29	-0.01%	-0.14%	0.15%	-0.06%

[a] The tax is set to €0.124 per litre of gasoline and €0.140 per litre of diesel (2006€), and is imposed on top of existing taxes.