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Evidence for an endogenous rebound effect impacting long-run car use elasticity to fuel price

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Abstract

This paper presents a structural equation model of household fleet fuel efficiency and car use. It allows to weigh the contribution of car equipment changes and car use adjustments to the price elasticity of household demand for fuel. This model is implemented using a panel dataset of 322 households that were present in each annual wave of the French Car Fleet survey from 1999 to 2007. The longitudinal dimension of this dataset enables to assess the short and long-run adjustments at the household level over a period of fuel price increase. The estimated price elasticities of the demand for fuel are fully consistent with the literature: -0.30 in the short run and -0.76 in the long run. Regarding car use elasticities, accounting for an endogenous rebound effect allowed a striking finding: the sensitivity of household car use to fuel price changes is lower on the long run than on the short run. This paper thus not only provides the latest estimations of elasticities for France, in the early 2000's, it also shows that, on the long run, French households have managed to mitigate the impact of increasing fuel prices on their car mobility by using more fuel efficient cars.

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1. Introduction

While the elasticities of automobile demand have been widely discussed over the past thirty years (e.g., see Espey 1998, Graham and Glaister 2002 or Goodwin *et al.* 2004 for reviews and meta-analyzes), a new topic has recently emerged, dealing with the impact of energy policies on a national car fleet efficiency and use. Improving the fuel efficiency does not generally induce a proportional decrease in the demand for fuel. Actually, if the fuel price remains the same, a better efficiency also reduces the cost per mile of car use. This makes the car mobility and the demand for fuel increase, thus limiting the energy saving gained from an improvement in the fuel efficiency. In the literature, this counter-effect defines the so-called *rebound effect*. Most studies assessing the rebound effect aim at capturing the impact of the energy efficiency on the fuel consumption, but independently from the evolution of fuel prices (Greene 1992, Small and Van Dender 2007).

Improvements in the fuel efficiency of a national car fleet do not necessary result from public policies, and can also derive from household adjustments to fuel price changes. The rebound effect can thus be endogenously induced from fuel price changes, and its role on fuel price elasticities is evaluated in this paper. In this perspective, both the fuel efficiency and use of household cars are explained by the fuel price, among other covariates, in a structural equation model.

Our approach is similar to the one applied by Johansson and Schipper (1997), Greene *et al.* (1999) and Small and Van Dender (2007) in so far as it aims at factorizing the price elasticity of household fuel demand into two components: a price elasticity of the car mobility and a price elasticity of the car fuel efficiency. Nonetheless, examining how households adjust their car efficiency and use to fuel prices requires ideally to follow the same entities over a period of changing prices. To the best of our knowledge, this condition is rarely satisfied in the existing literature literature, which is almost exclusively based on aggregated, semi aggregated, or disaggregated cross sectional datasets. Using a 1999-2007 panel dataset of 322 continuously present and motorized French households, we propose a disaggregated analysis that enables to capture the dynamics of adjustments, for the short and long runs. Consequently, this paper not only provides the most recent estimations of elasticities for France, it also brings an original contribution to the literature by assessing the dynamics that are at play, at the household level, during a 9-year period of almost continuous fuel price increase.

2. The Data

The data used in this paper are drawn from the French "Car Fleet"[1] survey. This survey has been conducted annually since the mid-80's by the polling institute TNS-Sofres[2], and aims at providing a good description of household car ownership and use in France. Every year, a representative sample of 10 000 households is surveyed by mail with a return rate of the self-administered questionnaire around 2/3. Particularly, it includes questions about the number of cars owned and some of their characteristics, such as the type of fuel used (either

[1]Literal translation of the French name: "*Parc Automobile*".
[2]Taylor-Nelson-Sofres, where Sofres stands for "*Société Française d'Etudes par Sondage*".

gasoline or diesel fuel), the fuel efficiency (in kilometers per liter of fuel), the annual mileage and the odometer value (in kilometers) for example. In addition, some information relative to the households themselves are also available, such as annual income, location area, and the gender, the age, the activity status for each of the members. Every year, the renewal rate of the sample is about 1/3. This survey methodology allows a longitudinal follow-up of a large part of the sample over time, and household panels can be built from successive waves of the survey.

However, and the same applies to all the surveys that attempt to follow the same respondents for several years, the "Car Fleet" survey has to cope with an attrition phenomenon. Whether it be because of demographic reasons or because bad respondents are expelled from the next survey, the number of same households present in all the waves since a given reference date decreases with time. Therefore, a trade-off has to be made: many households observed on a short period, or fewer on a longer period. Since our study focuses on long-run adjustments of motorized households, a good compromise was to consider the sub-sample of 322 households that were continuously motorized and present in the survey over the period 1999-2007. This panel has been weighted by applying the propensity score method[3], which has made this sub-sample in 1999 representative[4] of all the motorized households surveyed in the wave 1999.

Petrol and diesel cars are not using the same energy, and their fuel efficiency cannot be directly compared. This problem can be fixed by converting gasoline and diesel fuel into a common unit. In this paper, their energy is expressed in kilograms of oil-equivalent ($kgoe$), given that 0.75 kg (resp. 0.84 kg) of oil have, in average, the same calorific value as one liter of gasoline (resp. diesel) fuel[5]. Thus, the fuel efficiency is evaluated in $km/kgoe$ for both petrol and diesel cars. Regarding multi-motorized households, the fuel efficiencies of their cars have been averaged using the harmonic mean, and weighting each one by its annual mileage. For each of these households, the result can be interpreted as the fuel efficiency of their "representative car"[6]. Last, the fuel price was also converted in constant euros per $kgoe$.

3. The Model

3.1. The structural equation model

Let $C_{i,t}$ represent the annual demand for fuel expressed in $kgoe$ of household i at period t, and allocated to its car mobility. It is given by:

$$C_{i,t} = KM_{i,t} \times E_{i,t}^{-1}, \quad \text{and} \quad ln(C_{i,t}) = ln(KM_{i,t}) - ln(E_{i,t}) \tag{1}$$

where $KM_{i,t}$ is the annual mileage in kilometers and $E_{i,t}$ is the fuel efficiency of the representative car. Both terms in the right side of (1) are assumed to be explained by the following

[3]See Battistin *et al.* (2003) for an application.

[4]In terms of income, age of the household chief, number of adults and children, location, and car ownership.

[5]These values are usually taken in French energy studies, as in Gallez *et al.* (1998) and Hivert (2007) for example.

[6]For mono-motorized households, this representative car is simply the only one they own.

specifications:

$$ln(E_{i,t}) = \sum_{s=1}^{S_E} \gamma_{E_s} ln(E_{i,t-s}) + \alpha_E X_{i,t} + \beta_E ln(FP_t) + u_i + \epsilon_{i,t} \quad (2)$$

$$ln(KM_{i,t}) = \sum_{s=1}^{S_{KM}} \gamma_{KM_s} ln(KM_{i,t-s}) + \alpha_{KM} X_{i,t} + \beta_{KM} ln(KP_i) + v_i + \eta_{i,t} \quad (3)$$

where X refers to the household characteristics, FP is for the fuel price, as defined in the previous section, KP stands for the "kilometric price" (defined below), u_i and v_i are time-invariant and unobserved specific effects[7], and last, $\epsilon_{i,t}$ and $\eta_{i,t}$ are normally distributed errors. α, β and γ are the parameters to be estimated, as well as S_E (resp. S_{KM}), the number of relevant lags in each equation.

Although the current fuel price is the same for all the households at a given period, the current kilometric price depends on the fuel efficiency of the household cars, and varies over i. It defines the cost for each household to achieve 1 km with its representative car, that is $KP_{i,t} = FP_t \times E_{i,t}^{-1}$. Substituting this expression in (3) makes the structural nature of our model appear:

$$ln(KM_{i,t}) = \sum_{s=1}^{S_{KM}} \gamma_{KM_s} ln(KM_{i,t-s}) + \alpha_{KM} X_{i,t} + \beta_{KM}[ln(FP_t) - ln(E_{i,t})] + v_i + \eta_{i,t} \quad (4)$$

3.2. Elasticities

It is well known that a "log-log" specification allows to interpret the coefficients directly as elasticities of the endogeneous variable. The use of this structure should not bring any loss of generality since Graham and Glaister (2004) did not identify any systematic impact of the specification on the measured elasticity values. Regarding equation (2), the short-run elasticity of the car fuel efficiency with respect to the fuel price is simply given by $e^{SR}_{E/FP} = \beta_E$, while the long-run elasticity writes $e^{LR}_{E/FP} = (1 - \sum_s \gamma_{E_s})^{-1} \times \beta_E$. Similarly for the car use model in (3), the short-run elasticity of the household car mobility with respect to the kilometric-price is $e^{SR}_{KM/KP} = \beta_{KM}$. The long-run elasticity is given by $e^{LR}_{KM/KP} = (1 - \sum_s \gamma_{KM_s})^{-1} \times \beta_{KM}$. Using these notations, we can write from equations (1) to (4) that:

$$e^H_{C/FP} = -e^H_{E/FP} + e^H_{KM/FP} = -e^H_{E/FP} + e^H_{KM/KP} \times (1 - e^H_{E/FP}) \quad (5)$$

where $e^H_{KM/FP}$ is the fuel price elasticity of car use and where H is the temporal horizon, either SR or LR for the short run or the long run respectively. Here, improving fuel efficiency and reducing car mobility when the fuel price increases are the two behaviors ruling

[7] These effects refer to a combination of unobserved and constant factors impacting the modeled variables in equations (2) and (3). For example, they can derive from the generation, the gender and the education level of the household head.

the household demand for fuel. Equation (5) shows that the price elasticities of the fuel demand can be expressed as functions of the fuel price elasticities of the fuel efficiency and the kilometric price elasticities of the car mobility. This gives a structural explanation for the statement that price elasticities of the fuel demand are generally found to be higher (in absolute value) than traffic ones, that is, $|e^H_{C/FP}| \geq |e^H_{KM/KP}| \geq |e^H_{KM/FP}|$.

According to Greening *et al.* (2000), the rebound effect defines the impact on the demand for energy resulting from the decrease in the utilization cost which is caused by an improvement in the energy efficiency. In our notations, it is simply defined by $|e^H_{KM/KP}|$. Indeed, if the fuel efficiency increases by 1%, the fuel demand should also decrease by 1%, keeping the car mileage unchanged. However, it also makes the kilometric price reduce by 1%, inducing an increase (the "rebound") in the car mileage and in the fuel consumption by $|e^H_{KM/KP}|$. Therefore, the crossed term $|e^H_{KM/KP} \times e^H_{E/FP}|$ appearing in equation (5) can be interpreted as *the induced rebound effect*, that is, the rebound of the demand for fuel and car use induced by the sensitivity of the fuel efficiency to the fuel price.

3.3. Estimation strategy

Regarding estimation techniques, recursive types of structural equation models do not necessitate particular precautions. In our case, the Blundell-Bond estimator (Blundell and Bond 1998) is fully adapted to estimate the dynamic equations (2) and (3) sequentially. However, two difficulties may arise. First, the error terms $\epsilon_{i,t}$ and $\eta_{i,t}$ in these models might be serially correlated, and the Blundell-Bond estimator remains consistent if there is no correlation of the time-differenced errors at the second order (and over). This hypothesis has to be examined, using the Arellano-Bond testing procedure (Arellano and Bond 1991). Secondly, household declarations of car use and fuel efficiency can be affected by related errors. For example, households that are more environmentally-minded could be likely to under-report their annual mileage and over-state the fuel efficiency of their cars. Therefore, current $\epsilon_{i,t}$ and $\eta_{i,t}$ might be correlated. In this case, the car use equation (4) shows that $ln(E_{i,t})$ has to be instrumented for $\hat{\beta}_{KM}$ not to be biased. Taking these elements into consideration, equations (2) and (3) have been sequentially implemented using the Blundell-Bond estimator, which is currently available in Stata using the package *xtabond2* (Roodman 2006).

4. Results

This section presents the estimates of the structural equation model, and focuses on the dynamics of household sensitivity to changes in the fuel price. Table 1 displays the results for equation (2) modeling the fuel efficiency of the household representative car. The estimates for the household car mileage equation (3) are reported in Table 2.

For each of these equations, the Hansen test (Hansen 1982) cannot reject the hypothesis that the set of instruments that has been used is exogenous. Moreover, the Arellano-Bond test fails to reject the null hypothesis of no correlation at the second order of the time-differenced errors (Arellano and Bond 1991). Thus, the estimates provided in Tables 1 and 2 are consistent.

Both past efficiencies at lags one and two emerge as significant to explain the current fuel efficiency of the household representative car. This result was expected since car ownership is probably not reassessed every year by every household. Indeed, the car generally represents a medium or long-term investment for households. It is not a flexible good for which they can frequently adjust the characteristics. This is illustrated in Table 1 by a sum of coefficients related to past endogenous variables close to one (0.91). This also implies that short-run effects are very low compared to long-run ones. The fuel price has a positive and significant impact on the fuel efficiency, as expected: the short-run elasticity $e^{SR}_{E/FP}$ is estimated at 0.05 and the long-run one $e^{LR}_{E/FP}$, at 0.57. Most of the other explanatory variables related to household characteristics appear to be significant, and have the expected sign.

Note that only the demand side of the car market is considered in our fuel efficiency model, although automobile manufacturers have tried to make regular efforts over the studied period to supply the automobile market with more and more efficient cars. As a matter of fact, the European Automobile Manufacturers' Association signed in 1998 a voluntary agreement which aimed at making the European car fleet more fuel efficient by 2008. In order to account for this attempt, a temporal trend in the energy efficiency model could be introduced among the explanatory variables[8]. However, the trend effect was found not to be significant when included, according to a Wald test ($p = 0.56$). This result is consistent with the fact that the 2008 target of the EAMA agreement was not reached. Actually, the efficiency gains were balanced by the development of heavier and more powerful vehicles (Cuenot 2009).

The household car mileage model also performs better when two lags of the endogenous variables are included among the covariates. Both have a positive and significant effect, revealing that habits also matter in car use behaviors. The sum of the estimates for the lagged endogenous variables is 0.39, which is much lower than in the previous efficiency model. This result was also expected, as car use behaviors are obviously more flexible in the short run than car ownership. The kilometric price is found to impact significantly and negatively the annual car mobility of households. The corresponding elasticities are estimated at -0.28 in the short run ($e^{SR}_{KM/KP}$), and -0.46 in the long run ($e^{LR}_{KM/KP}$). These results are fully consistent with those found by Greene *et al.* (1999) on disaggregated data. Other covariates, such as the income per consumption unit, also emerge as relevant determinants to explain household annual mileage.

Given equation (5), the estimates from the fuel efficiency and car use models enable to compute the price elasticity of the demand for fuel. It is estimated at -0.31 for the short run $e^{SR}_{C/FP}$, and -0.77 for the long run $e^{LR}_{C/FP}$. These estimates are in the range of the literature values.

On the short run, we observe that the elasticity of household car use with respect to the fuel price (-0.26) is left almost unchanged compared to the kilometric price elasticity (-0.28), due to a weak induced rebound effect (0.01). Things are very different regarding the long run, as households can more easily adjust their equipment to make their representative car more fuel efficient when fuel prices are increasing: the induced rebound effect is therefore much higher (0.26). Thus for this time horizon, the kilometric price elasticity of household car mileage (-0.46) is also much higher in absolute value than the fuel price elasticity (-0.20). Very interestingly, the induced rebound effect makes the sensitivity of household car use to

[8] As suggested by an anonymous referee.

the fuel price slightly lower in the long than in the short run. Clearly, during the 2000's, French households have largely looked to mitigate the effect of the long-run increase in the fuel prices on their kilometric price by getting and/or using more fuel efficient cars, in order to preserve their car mobility. All the elasticities mentioned above are summarized in Table 3.

5. Conclusion

This paper presents the estimation of a structural equation model in which the car use behavior of French households and their choice of car fuel efficiency are the explained variables. The model allows to factorize the price elasticity of the demand for fuel as the sum of the fuel price elasticities of car fuel efficiency and use. Moreover, it highlights the impact of the rebound effect induced by a change in the fuel price on the elasticities of household car use and demand for fuel.

Our overall results, obtained from a nine years long panel dataset made of French motorized households, are fully consistent with the literature. As a matter of fact, Graham and Glaister (2002, pp. 19–20) conclude their literature review asserting: "the overwhelming evidence from our survey suggests that long run price elasticities will typically tend to fall in the -0.6 to -0.8 range" and that "these same studies show that short-run price elasticities normally range from -0.2 to -0.3". On the short run, we estimated the price elasticity of the household demand for fuel at -0.31, and 84% of the fuel savings are due to the reduction in household car use when the fuel prices increase. Not the same stands on the long run. For this time horizon, we observe a price elasticity of the household demand for fuel at -0.77, and the share of household fuel savings which is due to the car use reduction drops to 26%.

Because of a higher induced rebound effect, the fuel price sensitivity of household car use is found to be smaller on the long run (-0.20) than on the short run (-0.26). This striking result can be explained as follows: when facing long-run rises in the fuel prices, households try to improve the fuel efficiency of their fleet to preserve their car mobility. Several strategies allow households such an adaptation. On the short run, they may gain efficiency by adapting their driving behaviors (Rouwendal 1996). When multi-equipped, they may also favor the use of the most efficient cars of their fleet. On a longer term, they can renew their fleet and choose more efficient vehicles. Cuenot and Papon (2007) show that on the 2000-2005 period, the increase in car fleet efficiency was mostly due to dieselization, rather than technological improvements. Estimating the relative contribution of each of these strategies to the sensitivity of households car fuel efficiency to the fuel prices is beyond the scope of this study but constitutes a direction for a future research. Whatever may be the reason of this sensitivity, our results suggest that fuel taxes, as long as they remain affordable and do not generate energy vulnerability, can be an efficient tool for reducing the negative externalities related to household fuel demand (such as local pollutants or greenhouse gas emissions), but have a weaker effect on those generated by car use (such as congestion).

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Tables

Table 1: Estimates of the household car fuel efficiency model

Dependent variable: $ln(E_t)$	Coefficient	Pr $> \|z\|$
$ln(E_{t-1})^*$	0.752	< 0.001
$ln(E_{t-2})^*$	0.159	< 0.001
$ln(FP_t)$	0.051	0.032
$ln(income\ per\ CU_t)$	0.008	0.062
$ln(\#\ of\ cars_t)$	0.015	0.143
$ln(\#\ of\ persons_t)$	-0.023	0.066
$ln(\#\ of\ adults_t)$	0.022	0.103
$\#\ of\ working\ persons_t$	0.007	0.035
Arellano-Bond test for second order correlation: $z = 0.42$; Pr $> \|z\| = 0.67$.		
Hansen test: $\chi^2(1) = 0.40$; Pr $> \chi^2 = 0.53$.		

Notes: $*$ *designates the instrumented variables.* $N = 322$ *households,* $T = 7$ *periods. Robust Blundell-Bond estimator (system GMM). Instruments:* $ln(E_{t-2})$ *for the differenced equation;* $\Delta ln(E_{t-1})$ *and* $\Delta ln(E_{t-2})$ *for the level equation. Intercept not reported.*

Table 2: Estimates of the household annual mileage model

Dependent variable: $ln(KM_t)$	Coefficient	Pr $> \|z\|$
$ln(KM_{t-1})^*$	0.256	< 0.001
$ln(KM_{t-2})^*$	0.138	0.005
$ln(KP_t)^*$	-0.278	0.021
$ln(income\ per\ CU_t)$	0.100	0.016
$ln(\#\ of\ cars_t)$	0.637	< 0.001
$ln(\#\ of\ persons_t)$	0.264	0.002
$ln(\#\ of\ adults_t)$	-0.126	0.113
$\#\ of\ working\ persons_t$	0.051	0.009
Arellano-Bond test for second order correlation: $z = 0.42$; Pr $> \|z\| = 0.68$.		
Hansen test: $\chi^2(2) = 2.79$; Pr $> \chi^2 = 0.25$.		

Notes: $*$ *designates the instrumented variables.* N=*322 households,* T=*7 periods. Robust Blundell-Bond estimator (system GMM). Instruments:* $ln(KM_{t-2})$, $ln(KM_{t-3})$, $\Delta ln(FP_t)$ *and* $\Delta ln(\hat{E}_t)$ *for the differenced equation;* $\Delta ln(KM_{t-1})$, $ln(FP_t)$ *and* $ln(\hat{E}_t)$ *for the level equation (*$\hat{E}_t$ *stands for expectation of* E *based on the household car fuel efficiency model estimates). Intercept not reported.*

Table 3: Summary of elasticities

Household elasticity of	Car Fuel Efficiency	Mileage	Demand for fuel	Mileage	Induced Rebound Effect
with respect to	Fuel price (1)	Price per km (2)	Fuel price (3)	Fuel price (4)	(5)
Short run	0.05	-0.28	-0.31	-0.26	0.01
Long run	0.57	-0.46	-0.77	-0.20	0.26

Notes: *Figures in* (1), (2) *and* (5) *are derived from Tables 1 and 2. According to equation (5), column* (3) *is given by* $(2) - (1) + (5)$, *and column* (4) *by* $(2) + (5)$.