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# **Diffusion of car ownership and use in Paris metropolitan area since the mid-70's**

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## **ABSTRACT**

In France, the growth of car ownership has slowed down and individual car traffic has stagnated since the beginning of the 2000's, especially in most urbanized areas. Indeed, in Paris metropolitan area, the saturation is older, car ownership has saturated during the 90's and the individual mileage reached a maximum during the 80's, so earlier to the rise in fuel price. Thus, this trend seems to show a precursor movement in urbanized areas. In the mid-70's, car ownership and use were quite low for the poorest income quartile, but the gap has much decreased with the three higher income groups. However, inequality index stabilized and even increased in the 2000's for the inhabitants of Paris region, showing that the diffusion of cars in society seems to reach its limits.

As the curves representing car ownership (number of cars per adult) and car use (annual mileage per household) seem to become quite horizontal during the most recent period, logistic curves have been estimated for each quartile of the distribution of households by income per consumption unit, according to time, then to real income. We describe this process since 1974 in Paris region. Saturation thresholds are estimated, as well as the date (or the income) of inflexion. We can place the saturation between 0.4 and 0.6 cars per adult according to the standard of living, and the mileage between 9 800 km and 13 000 km per household. Fuel price has a significant impact on car use, while it is less important for car ownership.

Key-words: Saturation, car ownership, car use, panel, growth model, income inequalities, Paris metropolitan area

## 1. INTRODUCTION

After a rapid growth during the 60's and the 70's, average car use per person has slowed down and seems to reach a saturation threshold in several industrialized countries during the 2000's (Millard-Ball & Schipper, 2010). The Australian Bureau of Infrastructure, Transport and Regional Economics, which has gathered time series in 25 countries, explains this recent evolution by the change in fuel price, the economic situation (unemployment rate, global financial crisis).

In France, the evolution is similar. Indeed, National Accounts (Commission des Comptes des Transports de la Nation) show a clear slowing down or even a stagnation of car traffic since 2003 (CCTN, 2012) that correspond to an upward trend for fuel price (SOeS, 2012). This change with regard to previous trend has been highlighted by recent household travel surveys in Lyon, Lille, Rouen, Reims, Rennes or Strasbourg (Hivert and al., 2008) and in the 2007-2008 National Travel Survey which shows diverging behaviors for the inhabitants of the largest urban areas and of lower density zones (Hubert, 2009). In Paris region (STIF 2012), trips are less oriented towards car (1.46 trips by car person per day in 2010 versus 1.54 in 2001) and public transport mobility is increasing (0.78 trips per person per day in 2010 versus 0.68 in 2001).

If the downturn in the growth of individual mobility is influenced by the increase of fuel price, it is not the only one factor. Indeed, Newman and Kenworthy (2011) have listed several possible causes of the saturation: the growth in public transport infrastructures, the densification of city-centers and suburbs to the detriment of outer-urban areas, the ageing of population in cities, the diffusion of an urban culture and the Marchetti constant (Marchetti, 1994). In parallel to the slowing down of individual automobile traffic, we also see a slowing down of car ownership and a decrease in center of London or Paris (STIF, 2012) where new forms of trips are developing: revival of bicycle with self-service bike, two-wheeled motorized vehicles and new automobile services (Autolib...).

At national level, while the slowing down of individual car traffic has emerged in the 2000's, the phenomenon is earlier in Paris region, especially for car use. A descriptive analysis is done in section 3. Assuming that the observed slowing down of car mobility is the precursory sign of an automobile saturation, we propose to determine its level for car ownership and use. In order to estimate levels of car saturation, we represent thresholds in adjusting logistic curves (Roed-Larsen, 2006) as a function of time and income. This function tends to an asymptote that depends on fuel price to capture its effect on mileage and car ownership (section 4). Our analyses are based on data provided by two samples of households partially renewed each year since 1974 for each quartile of income (description in section 2).

Finally, we tackle the subject from inequalities point of view in showing the diffusion of car ownership and use from the highest quartile of income to the lowest (Choquet, 1983). Do richer households, middle classes, or poor people follow the same trend? Or have they separated trajectories?

## 2. DATA

### 2.1 More than 30 years of rotating panel survey data

This research is based on two annual nationwide (representative for the largest regions) household surveys describing both car ownership and use:

- the Household Continuous Survey ("Enquête de Conjoncture Auprès des Ménages" (ECAM)) conducted by the National Institute of Statistics (INSEE) among a sample of dwellings drawn from the census: 10,000 to 13,000 households responding by interview each year, of which about one third had been also interviewed one year before; the period from 1974 to 1994 (end of this survey) is covered by the data files available at IFSTTAR;
- the "Parc-Auto" (Car Fleet) panel survey is a postal survey conducted by the private marketing research company TNS-Sofres; each annual wave includes 6,000 to 7,000 volunteer respondent households, of which about 3/4 have already responded the year before (even if having moved, contrary to ECAM survey); data files are available at IFSTTAR for all waves since 1984 and this survey is still on-going (Hivert and Pean de Ponfilly, 2000; Hivert et al., 2006). For a short description of these data, see also Hivert (2013) or Papon and Hivert (2008).

Despite differences in survey methodology, we have checked that these data sources show consistent results for the period 1984-94, when both datasets are available at IFSTTAR.

### 2.2 Homogenizing the description of households and their automobile behaviors

Both questionnaires contain similar variables:

- The annual income of the household in about 10 brackets,
- A description of the household (socio-economics, demographic structure, place of residence, etc.),
- A description of cars (age, type of fuel, main driver, etc.) which are at permanent disposal of the household (up to 2 cars in ECAM, up to 3 cars in Parc-Auto),
- An estimate of the annual mileage for each car described, which is rounded and heaped (Hivert, 2001; Yamamoto, 2009), as well as some information on the main purposes for which the vehicle is used.

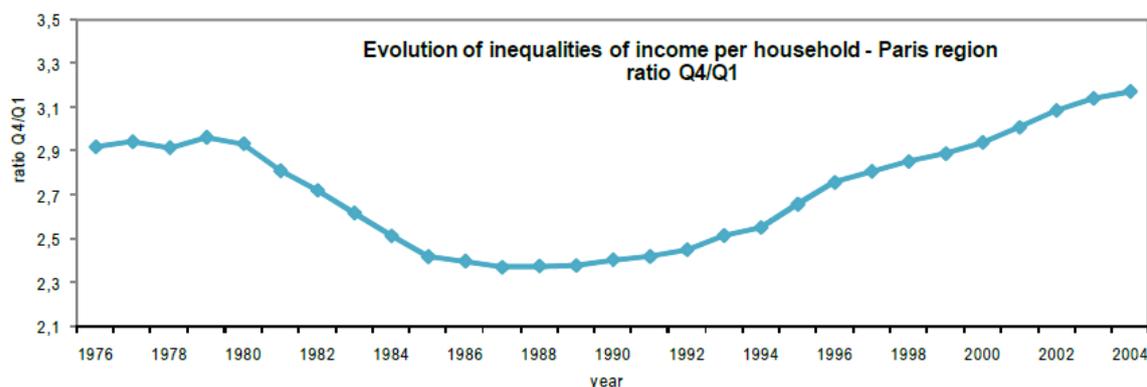
Thus, this information has to be homogenised mainly for income, which has been coded in brackets using different grids of nominal income over time.

We characterize motorization of a household by the average number of cars per adult (i.e. aged > 18, which is the minimum age in France to hold a driver licence). The number of cars per household (or per capita) would have been more homogeneous with the other variables, but isolating the population concerned gives generally better estimates in modelling. To characterize car use by a household, we compute the sum of annual mileages travelled by each private car at disposal. The sum is equal to zero for households without car.

To build quartiles of income per household, rather than conventional methods (Bhat, 1994) like simulated residuals (Lollivier and Verger, 1989), we have interpolated quantiles from the middle of each bracket by the number of consumption unit of the household (Madre and Purwanto, 2003). As we had no more access to raw data for ECAM surveys, the number of consumption units is calculated by using the ancient Oxford scale (the weight is equal to 1 for the head of the household, 0.7 for the other adults > 14 years old, and 0.5 for children). For estimating time-series accurately enough despite of the small sample size of our panel survey data, Referring to Cochran (1977), we have implemented the method optimising the accuracy of the time series for the most recent periods. This optimisation is crucial for the estimation of models using variables affected with small annual changes (often 1 or 2%). However, we had to smooth the time-series by moving averages over three consecutive years at national level and over five years for Paris region.

### 3. DESCRIPTIVE ANALYSIS: MOTORIZATION AND USE SINCE THE MID-70'S

#### 3.1 Income trends



Source: INSEE Household Continuous Survey 1974-94, SOFRES Parc-Auto panel survey 1994-2010

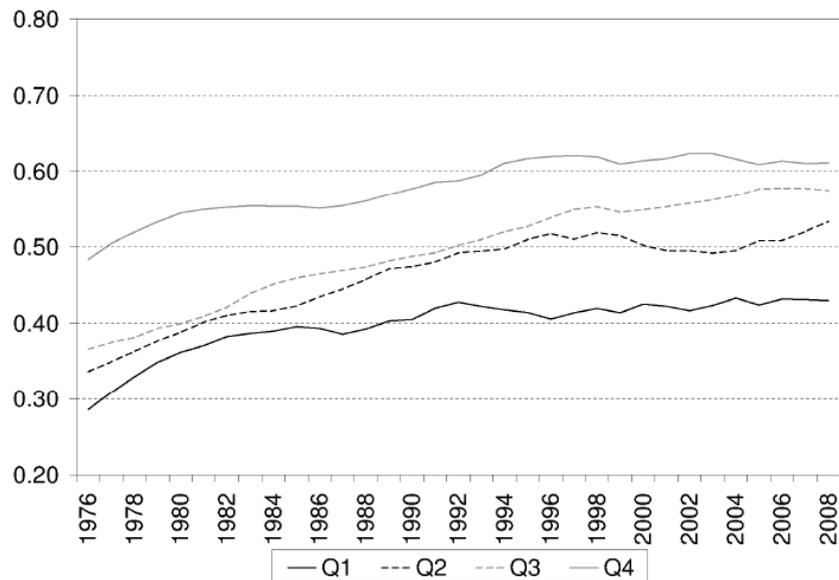
**Figure 1: Evolution of inequalities of income per household (ratio of extreme quartiles Q4/Q1) – Paris region**

For the measurement of inequalities, we have adopted the “Q4/Q1” ratio, which is the ratio between the means of the variable of interest for the extreme quartiles (Q1 representing the poorest and Q4 the richest).

In Paris region (figure 1), income inequality has decreased rapidly between mid-70’s and mid-80’s, then it has remained constant from mid-80’s to early 90’s, and since the 1993 recession, income is growing faster for the highest quartile than for medium and low-income groups. So, for about two decades, inequality has raised in Paris region.

### 3.2 Diffusion of motorization

The social diffusion of a good is defined by the temporal process in which this good comes into all social levels, especially in different income levels. In the case of automobile, richer households and those living in metropolitan areas were the first equipped (e.g. till the mid-60's, car ownership was higher in the conurbation of Paris than in the rest of France).



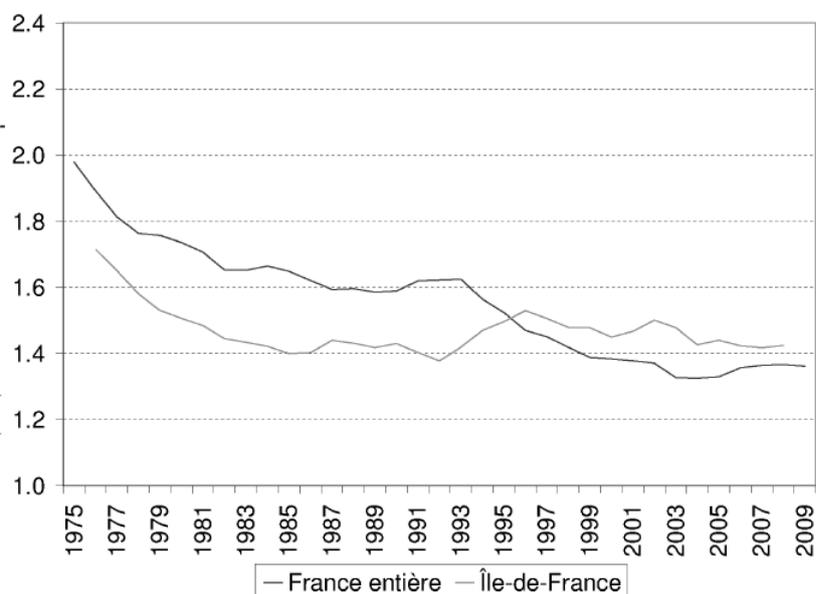
Sources : INSEE Household Continuous Survey 1974-94, SOFRES Parc-Auto panel survey 1994-2010.

**Figure 2: Evolution of car ownership with time - average number of cars per adult by quartile of income per consumption unit (smoothed MA5) – Paris region**

Does the automobile motorization follow the same trends for upper, middle or lower class? In France and in Paris region, the curves showing the evolution of car ownership per adult (figure 2) are growing and concave in each quartile of income. In the different quartiles, the curves follow the same patterns.

Nowadays, car ownership in Paris region is lower than in the rest of France, especially because of high population density (i.e. traffic congestion and scarce parking space) and an easier access to public transport, so a less car dependency (Dupuy, 1999). In Q1, there is a stagnation of car ownership since the beginning of the 90's at above 0.4 cars per adult. For Q2 and Q3, from the mid-70's to the end of the 90's, their car ownerships were approximately the same. But the curve of Q2 seems to stabilize then (above 0.5), whereas the Q3 curve seems to reach the Q4 one (at 0.6 cars per adult). Car ownership in Paris region seems to reach thresholds at above 0.6 for Q4 and Q3, 0.5 for Q2 and 0.4 for Q1; whereas for whole France, all curves are upper than in Paris region and the potential saturation thresholds seem not to be reached yet. So Paris region seems to be a precursory area for this break in trend.

At last, we see a positive link between growth of income and growth of car ownership. But, there is not a catching up effect between quartiles (there are separate thresholds between income groups). We will estimate these saturation levels in section 4.



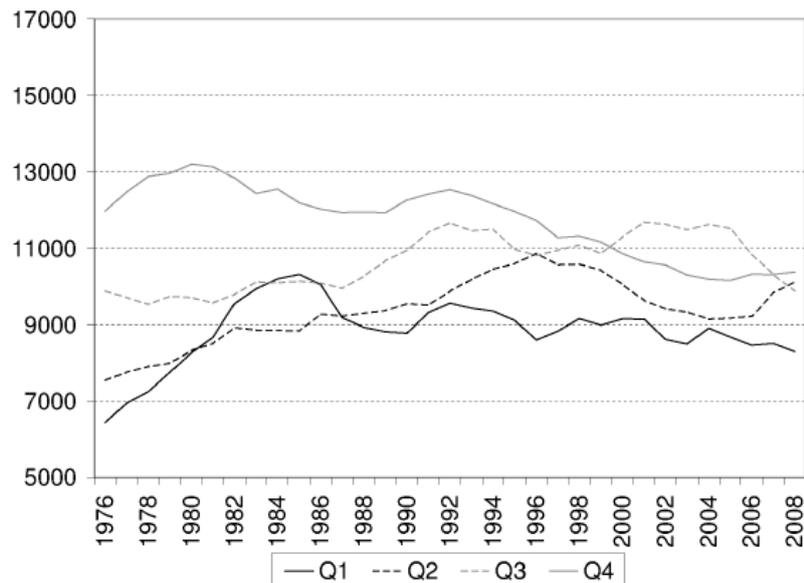
Sources : INSEE Household Continuous Survey 1974-94, SOFRES Parc-Auto panel survey 1994-2010.

**Figure 3: Evolution of the ratio Q4/Q1 for the average number of cars per adult – France (smoothed MA3) and Paris region (smoothed MA5)**

What is resulting in terms of inequality? At national level, the ratio Q4/Q1 (figure 3) for the average number of cars per adult has fallen from 2.0 in the mid-70's to less than 1.4 in the 2000's, somewhat stagnating with an intermediate plateau during the second half of the 80's. In Paris region, the ratio Q4/Q1 for the average number of cars per adult has decreased from 1.7 in the mid-70's to 1.4 around 1993, but has risen to 1.5 hereafter, which exceeds its value at national level; it is due in part to the raise of inequalities of income in this region for two decades. Thus, the social diffusion of car ownership seems to reach its limits in the capital region.

### 3.3 Diffusion of car use

In France, the average mileage per household raised until 2000 and then decreased particularly because of the increase in fuel price. Indeed, fuel price has increased from mid-70s to mid-80s with two oil chocks, then decreased (sharply in 1985-86, then more slowly with the diffusion of diesel cars using a cheaper fuel). It has peaked in 2000, and then increased continuously from 2004 to the peak of mid'08, followed by a quite volatile period.



Sources : INSEE Household Continuous Survey 1974-94, SOFRES Parc-Auto panel survey 1994-2010.

**Figure 4: Evolution of car use with time – Average mileage per household by quartile of income per consumption unit (in kilometers, smoothed MA5) – Paris region**

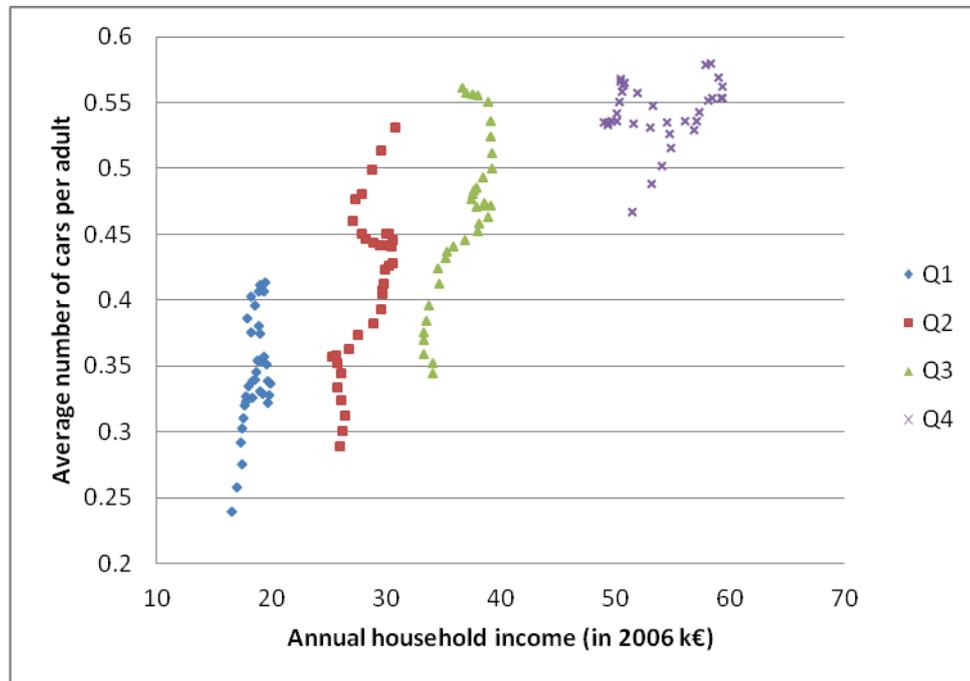
However, the limit to the growth of car mileage has happened earlier than the rise in fuel price in larger cities. In Paris region, where traffic congestion is important but where public transport is attractive for local as well as for long distance trips, the decline has started in the late 90's for Q2, in the early 90's for Q3 but in a less homogenous manner and in the 80's for the highest quartile (Figure 4). The three highest income groups are converging, while the lowest quartile is remaining below. So, Figure 4 shows precursory trends for the decline of car use.

A plausible explanation why the saturation has happened before for Q4 is the location of richest people: they often live in city center where access to Public Transport is the best; thus they have less needs for car. Indeed, the number of cars registered in the city of Paris is decreasing since 1990, and car traffic inside the city of Paris is decreasing since the early 90's, with less space for cars due to the development of reserved lanes for buses and tramways.

In terms of inequality, the Q4/Q1 ratio for the annual mileage per household has declined between the mid-90's and 2005 in the less densely populated areas whereas this ratio has increased in Paris region since because poor people can only change their behavior if they have alternatives to car (i.e. walk or bike for shorter distances and public transport for longer trips).

### 3.4 Evolutions according to income growth

The two next figures present, for each quartile by consumption unit, the evolution of car ownership per adult and car use per household, according to income levels, in constant 2006 Euros (considering all the annual waves together).



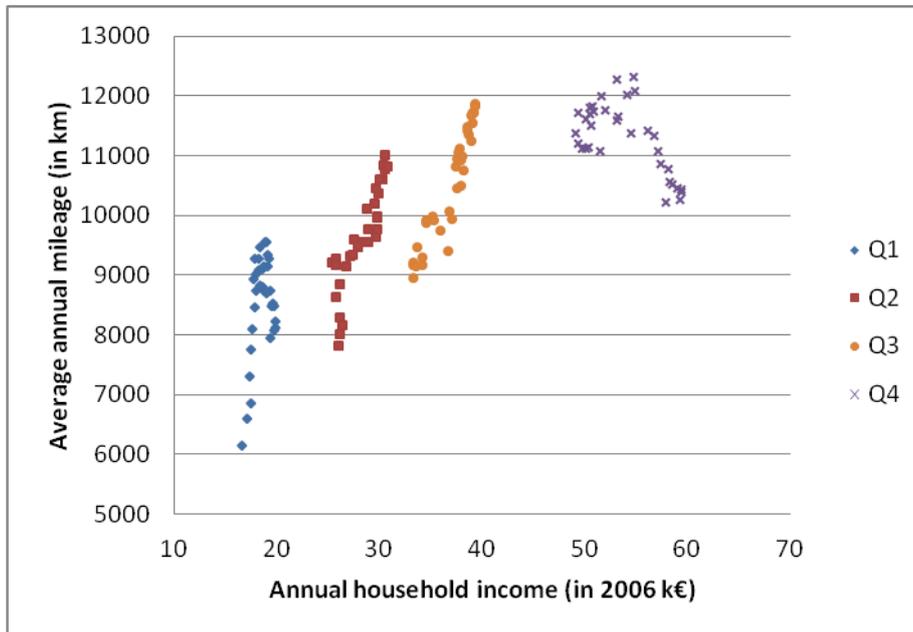
Source: INSEE Household Continuous Survey 1974-94, SOFRES Parc-Auto panel survey 1994-2010

**Figure 5: Evolution of car ownership (average number of cars per adult) with household income – Paris region**

Overall, the scatter of points on figure 5 shows that, as expected, household car ownership has increased with their income. The shape of the scatter of points suggests a concave increase of car equipment with income. However, the slope seems different when comparing each of the four quartiles. The relation between raise of income and raise of car ownership seems to be well correlated for Q1 to Q3. For Q4, the relation is diffuse. Car ownership is increasing faster with real income for Q1 than for Q4. Over the years, this has induced a reduction of social inequality for car ownership, as shown on figure 3. Thus, a saturation threshold could be contemplated over a certain level of income.

Considering car use on figure 6, analogous conclusions roughly emerge. The average mileage of households has been between 8000 and 9000 km/year for an annual income of €20,000. Over €65,000, it has globally ranged between 10,000 and 12,000 km/year. Like on figure 5, the scatter of points on figure 6 could also suggest a concave growth of household car use with their real income. Regarding the quartile specific households, the slope of the annual mileage over real income also seems to decrease with their position in

the standard of living scale. As for the previous figure, the relation between income and mileage is diffuse for Q4.



Source: INSEE Household Continuous Survey 1974-94, SOFRES Parc-Auto panel survey 1994-2010

**Figure 6: Evolution of car use (annual mileage per household) with household income - Paris region**

The apparently concave relations of figures 5 and 6 and the decorrelation in Q4 between income and car ownership or use suggest that the diffusion of automobile can reach saturation thresholds when the households are getting wealthy. Theoretically, the social diffusion of a good (either in time or in the income scale) can be represented using a sigmoid curve, ended by a saturation level. It is modelled in the following section for car ownership and use (dependent variables), using time or income as explanatory variables.

#### **4. ESTIMATION OF LOGISTIC CURVES FOR MODELLING CAR OWNERSHIP AND USE**

The average household for each of the four quartiles of annual income per consumption unit are observed annually, during 33 years from 1974 to 2006. Let Q1, Q2, Q3 and Q4 refer to these households by increasing order of resource. In this section, we assume that car ownership and use can be represented by logistic functions which approach an asymptote: the level of saturation. The logistic model, which is exposed below, is applied on the data of each quartile specific household.

## 4.1 The model

Let  $Y_{it}$  refer either to the number of cars per adult or to the annual mileage in  $10^4$  kilometers for the household  $Q_i$  at period  $t$ . Both these variables are modelled separately assuming a logistic specification. The explanatory variable is denoted  $X_{it}$  and stands successively for time (section 4.2) and for real income (section 4.3). Thus, the model is given by:

$$Y_{it} = Y_{it}^* + \varepsilon_{it} = \frac{\exp(\gamma)}{1 + \exp(-\alpha X_{it} + \beta)} + \varepsilon_{it} \quad (1)$$

Where  $\varepsilon_{it}$  is assumed to be *i.i.d.* along a  $N(0, \exp(\sigma))$ , and where  $\{\alpha, \beta, \gamma, \sigma\}$  are the parameters to be estimated. For  $\alpha$  positive, the formulation (1) implies that  $Y_{it}^*$  is increasing with  $X_{it}$  along a symmetrical sigmoid, bounded by two horizontal asymptotes: the lower plateau is fixed at  $Y_{it}^* = 0$  while the upper plateau, corresponding to a saturation level, is located at  $Y_{it}^* = \exp(\gamma)$ . The inflection point, for which the second derivative of

$Y_{it}^*$  with respect to  $X_{it}$  is zero, is located at  $\left( X_{it} = \frac{\beta}{\alpha} ; Y_{it} = \frac{\exp(\gamma)}{2} \right)$ .

In this model estimated for the four income quartiles, if we show that the saturation levels don't significantly differ between  $Q_i$  but that the dates or the levels of income at inflexion are significantly different, we can estimate a fixed effects model by introducing a specific constant in each quartile:

$$Y_{it} = Y_{it}^* + \varepsilon_{it} = \frac{\exp(\gamma)}{1 + \exp(-\alpha X_{it} + \beta_1 Q_1 + \beta_2 Q_2 + \beta_3 Q_3 + \beta_4 Q_4)} + \varepsilon_{it} \quad (2)$$

With  $Q_1 + Q_2 + Q_3 + Q_4 = 1$ ,  $Q_i$  being a dummy variable of the quartile  $i$  ( $i=1,2,3$  or  $4$ ).  $\varepsilon_{it}$  are assumed to be *i.i.d.* along a  $N(0, \exp(\sigma))$ ;  $\{\alpha, \beta_1, \beta_2, \beta_3, \beta_4, \gamma\}$  are the parameters to be estimated.

## 4.2 Time as explanatory variable

Time is seen as a proxy, which captures several structural effects, for instance the trend to urban sprawl, the diffusion of driving licence for women or the ageing of population being more equipped. These three elements have facilitated the development of car market and the growth of demand.

To be more relevant, the saturation threshold is expressed as a linear function of fuel price. The saturation threshold of the models (1) and (2),  $\exp(\gamma)$ , is written now  $\exp(\gamma + \delta \cdot p_t)$ , where  $p_t$  is the fuel price index at year  $t$  (base 1 in 2006).

The dependent variable is the number of cars per adult in the household. The explanatory variables are time and fuel price index (base 1 in 2006). All the parameters are significant at the 90% level				
	quartile Q1	quartile Q2	quartile Q3	quartile Q4
log-likelihood	177,49	181,82	135,28	198,98
Number of observations	33	33	33	33
$\Upsilon$ (Standard deviation $\Upsilon$ )	-0,783 (0,007)	-0,487 (0,007)	-0,540 (0,020)	-0,406 (0,004)
$\delta$ (Standard deviation $\delta$ )	-0,060 (0,009)	-0,038 (0,006)	-0,190 (0,023)	-0,017 (0,003)
Statistical significance of $\delta$	<0,0001	<0,0001	<0,0001	<0,0001
$\beta$ (Standard deviation $\beta$ )	-0,663 (0,006)	-0,178 (0,006)	-0,827 (0,027)	-1,020 (0,006)
$\alpha$ (Standard deviation $\alpha$ )	0,115 (0,001)	0,072 (0,001)	0,133 (0,006)	0,061 (0,001)
Saturation threshold with price of 2006 (number of cars per adult)	0,43	0,59	0,48	0,65
Saturation threshold with price of 2006 multiplied by 2	0,40	0,57	0,40	0,64
Saturation threshold with price of 2006 multiplied by 1.5	0,42	0,58	0,44	0,65
Saturation threshold with price of 2006 divided by 2	0,44	0,60	0,53	0,66
year of inflexion	1968	1972	1968	1957

**Table 1: Estimates for each quartile, of the car ownership model as a function of time with introduction of fuel price**

As expected, the results show that car ownership has increased over time (table 1). Indeed, the parameter  $\alpha$  is found to be positive and significant in each quartile. Car ownership has developed in Paris region earlier than elsewhere in France: the inflexion has occurred around 1970 for Q1 to Q3 and at the end of the 50's for Q4. The thresholds are between 0.43 and 0.65 for the different quartiles. The saturation threshold of Q3 seems particularly sensitive to future fuel price while the impact is not significant on the other quartiles. This model determines separated thresholds of saturation between quartile, so differential behaviors between levels of income.

For car use, the confidence intervals for the saturation level overlap around an annual mileage of 11.000 km per household (table 2). Thus, adopting a parsimonious approach, a pooling model should give more accurate results, assuming a common saturation threshold and quartile-specific inflexion points (i.e. quartile fixed effects).

The saturation threshold is between 9800 km per year per household if fuel price double from the level of 2006 and 13200 km/year if fuel price is divided by 2. As expected, saturation of use is more influenced by fuel price than saturation of car ownership. Indeed, in Paris region, people can change their behavior because of an easier access to public transport.

The inflexion has occurred around 1970 for Q1, around 1960 for Q2, 1950 for Q3. The date of inflexion cannot be precisely estimated for Q4, because the curve of the annual mileage had no phase of growth since 1974 (figure 5). So, the sigmoid component is not identifiable in this case.

The dependent variable is the annual mileage per household in kilometers. The explanatory variable are time and fuel price index (base 1 in 2006). All the parameters are significant at the 90% level				
	quartile Q1	quartile Q2	quartile Q3	quartile Q4
log-likelihood	243,24			
Number of observations	132			
$\Upsilon$ (Standard deviation $\Upsilon$ )	0,380 (0,053)			
$\delta$ (Standard deviation $\delta$ )	-0,200 (0,048)			
Statistical significance of $\delta$	<0,0001			
$\beta$ (Standard deviation $\beta$ )	-0,244 (0,055)	-0,500 (0,078)	-1,076 (0,219)	-5,273 (6,852)
$\alpha$ (Standard deviation $\alpha$ )	0,047 (0,004)			
Saturation threshold with price of 2006 (yearly kilometers)	12000			
Saturation threshold with price of 2006 multiplied by 2	9800			
Saturation threshold with price of 2006 multiplied by 1.5	10800			
Saturation threshold with price of 2006 divided by 2	13200			
Year of inflexion	1969	1963	1951	1863

**Table 2: Estimates for the car use model as a function of time with introduction of fuel price, pooling**

### 4.3 Income as explanatory variable

In this section, household car ownership and use are modelled using real income as explanatory variable.  $X_{it}$  in the model (1) refers to the real annual income of the household  $Q_i$  at time  $t$ , expressed in euros of 2006.

The car ownership estimates with the model (1) give saturation thresholds (table 3) which do not differ significantly from those given by the model with time. However, confidence intervals are larger than in the case of the model as function of time. The confidence intervals are smaller for upper classes, which are nearer to saturation. As the confidence intervals overlap each other, we estimate the model by pooling the whole sample. The estimation of the saturation threshold is now much accurate. The threshold is 0.6 cars per adult. The incomes reached at the inflexion point raise when quartiles increase. Contrary to the model with time, we don't have clear separated trends between quartile but rather a convergent trend towards a common threshold.

Dependent variable = Average number of cars per adult ; explanatory variable = annual income (in Euros 2006)				
	quartile Q1	quartile Q2	quartile Q3	quartile Q4
log-likelihood	273,19			
Number of observations	132			
Y (Standard deviation Y)	-0,518 (0,020)			
$\beta$ (Standard deviation $\beta$ )	2,643 (0,362)	3,568 (0,511)	5,064 (0,706)	5,556 (0,818)
$\alpha$ (Standard deviation $\alpha$ )	1,265 (0,160)			
Saturation threshold (Number of cars per adult)	0,60			
[Confidence interval at 90%]	[0,57;0,62]			
Inflexion income (euros 2006)	20900	28200	40000	43900

**Table 3: Estimates for the car ownership model as a function of real income, pooling**

The estimation of car use saturation threshold (table 4) is much more accurate for higher income group, which are currently nearer to their estimated asymptote. So, for Q4, changes in income seem to have less influence on car use than for lower classes. The results are close to those of the model as a function of time. The saturation threshold is maximum for Q2, then Q4. One of the explanations is the fact that many middle class people don't live in city center so they have a more important need to car. The incomes reached at the inflexion point raise when quartiles increase. As in table 2, the inflexion income of Q4 cannot be precisely estimated, because the curve of the annual mileage had no phase of growth since 1974 (figure 5). So, the sigmoid component is not identifiable in this case.

Dependent variable = Annual mileage (km) per household ; Explanatory variable = Annual Income (euros 2006)				
	quartile Q1	quartile Q2	quartile Q3	quartile Q4
log-likelihood	43,34	64,20	67,48	90,77
Number of observations	33	33	33	33
Y (Standard deviation Y)	-0,046 (0,050)	0,250 (0,122)	0,131 (0,036)	0,227 (0,002)
$\beta$ (Standard deviation $\beta$ )	16,270 (8,793)	3,769 (1,341)	7,298 (4,180)	-32,780 (25,932)
$\alpha$ (Standard deviation $\alpha$ )	7,518 (3,801)	1,299 (0,493)	2,015 (0,963)	-3,418 (3,026)
Saturation threshold (yearly kilometers)	9500	12800	11400	12500
[Confidence interval at 90%]	[8800;10400]	[10400;15800]	[10700;12200]	[12400;12600]
Income at inflexion (euros 2006)	21600	29000	36200	94200

**Table 4: Estimates for each quartile, of the car use model as a function of real income**

The model assumes the symmetry of the adjusted logistic curves with respect to the inflexion point. This can be viewed as a strong hypothesis and asymmetric curves might be more relevant in our context. However, the assumption of symmetry is useful when considering our data. As shown on figures 2 and 4, the data do not cover the lower part of a presumed sigmoid, at the left side of the inflexion point and near to the lower asymptote (in zero). As there is no empirical information about this part, its representation has to rely

on some assumptions. A solution would have been to extend the observation period farther in the past, back to the end of World War II. Unfortunately, detailed yearly data about car use and equipment between 1945 and 1973 are not available.

Chapman-Richards curve (Richards, 1959; Chapman, 1961; Draper and Smith, 1981) could give a more flexible functional form, with no left asymptote but a starting point at a chosen date (e.g. 1920) and no symmetry.

## 5. CONCLUSION

The social diffusion of automobile has been one the driving factors of the economic growth after World War II. If, poorest people have gradually equipped, this diffusion seems to reach its limits in Paris region. Indeed, inequality index of car ownership has saturated since mid-90's and the index for use has even raised during the 2000's. In less urbanized areas, automobile dependence remains important even in low income groups because there is no alternative to cars.

The introduction of fuel price in the model permit to modulate the saturation threshold according to different assumptions, especially concerning the rise in fuel price. This information is important to create prospective scenarios of sustainable development. Rise in fuel price does not have a significant impact on car ownership contrary to car use. Indeed, evolution of car ownership is a long term decision and the adjustment is longer to emerge whereas people can more easily change their car use behavior in short term.

Mileage in Paris region has stagnated or even decreased long time ago, especially for the highest income group because of constraint of congestion and parking, and also a substitution of a good system of public transport. This supports the hypothesis of precursory behaviors of saturation in urbanized areas. The causes of behavioral changes need to be better highlighted by future research.

Concerning the saturation levels found with the model as a function of time, thresholds for car ownership are significantly higher for rich people but for car use each income group could reach the same level at above 12 000km per household. The introduction of income as an explanatory variable rather than time gives roughly similar estimates. Decoupling of car mobility from economic growth should be investigated, taking into account of residential location (e.g. population density).

At last, for a better econometric fit, we could introduce an alternative functional function, especially for car use in Paris region, and more especially for the higher income group, that shows no period of Growth since the mid-70's, which makes difficult the determination of an inflexion point. Moreover, a disaggregated analysis according to cohorts of households could be analysed. We could show the role of generational renewal on automobile behavior which is influenced by the succession of generations and events during life cycle.

## References

BITRE (Bureau of Infrastructure, Transport and Regional Economics). Traffic growth: Modelling a global phenomenon. Report 128, Canberra ACT, 2012.

BHAT, C.R. (1994). Imputing a continuous income variable from grouped and missing income observations. *Economics Letters* 46, pp. 311-319.

CCTN. Les transports en 2011 : 49ème rapport à la Commission des comptes des transports de la Nation. CGDD, Paris, 2012.

CHAPMAN, D. G. (1961). Statistical problems in population dynamics. *Proceedings of the fourth Berkeley symposium on mathematical statistics and probability, Vol. 4*. University of California Press, Berkeley.

CHOQUET, O. (1983). L'automobile, un bien banalisé, *Economie et Statistique* 154 (1), pp. 47-55.

COCHRAN, W.G. (1977). *Sampling Techniques*. John Wiley and sons, New York.

DRAPER, N. R., and SMITH, H. (1981). *Applied regression analysis*. John Wiley and Sons, New York.

DUPUY, G. (1999). *La dépendance automobile : symptômes, analyses, diagnostic, traitements*. Anthropos, Paris.

HIVERT, L. and PEAN DE PONFILLY, J. Inégalités d'accès à l'automobile, disparités d'équipement et d'usage entre les ménages les plus pauvres et les plus riches. Rapport INRETS pour l'ADEME, 2000.

HIVERT, L. Le parc automobile des ménages, étude en fin d'année 1999 à partir de la source "Parc Auto" SOFRES. Rapport sur Convention ADEME-INRETS, 2000.

HIVERT, L. L'automobile en Europe, Changements de comportements d'équipement et d'usage. PREDIT3 Go1 Rapport pour l'ADEME, 2006.

HIVERT L. (2013). Short-term break in the French love for Diesel?. *Energy Policy* 54, pp. 11-22.

HIVERT, L., OTTMANN, P., KRAKUTOVSKI, Z., LEGROS, D., CHLOND, B., MADRE J.-L. and ZUMKELLER D. (2008). Multimodalité et tendances démographiques - CADMIUM : Comparative Analysis of Demographic Modifications and Impact on the longitudinal Use of Modes. Deufrako-Predit3 pour ADEME, INRETS & IfV Karlsruhe Universität, 202p.

HUBERT, J.-P. (2009). Dans les grandes agglomérations, la mobilité quotidienne des habitants diminue, et elle augmente ailleurs. *Insee Première* (1252).

LOLLIVIER, S. and VERGER, D. (1989). *D'une variable discrète à une variable continue : Une application de la méthode des résidus simulés dans Mélanges Economiques, Essais en l'honneur d'Edmond Malinvaud*. Editions de l'EHESS, Paris.

MADRE, J.-L. et PURWANTO, A.J. (2003). Des quantiles interpolés pour suivre l'évolution des inégalités, XXXIXème colloque de l'ASRDLF, 1-3 September 2003, Lyon.

MARCHETTI, C. (1994). Anthropological invariants in travel behavior. *Technical Forecasting and Social Change* 47 (1), pp. 75-88.

MILLARD-BALL, A., SCHIPPER, L. (2010). Are we reaching peak travel? Trends in passengers transport in eight industrialized countries. *Transport Reviews* 31.

NEWMAN, P., KENWORTHY, J. (2011). 'Peak Car Use': Understanding the demise of automobile dependence, *World transport, Policy & Practice* 17(2), pp. 31-42.

PAPON, F., and HIVERT, L. (2008). Adulterous behaviour within the car-owner couple: Some analyses from French panel data on car rental and car sharing within households. *IATSS Research* 32(2), pp. 6-15.

RICHARDS, F. J. (1959). A flexible growth function for empirical use. *Journal of Experimental Botany* 10, pp. 290-300.

RØED-LARSEN, E. (2006). Distributional Effects of Environmental Taxes on Transportation: Evidence from Engel Curves in the United States. *Journal of Consumer Policy* 29(3), pp. 301-318.

SOeS. La circulation routière augmente à un rythme ralenti depuis 2003, Le Point sur n°118. Commissariat Général au Développement Durable, 2012.

STIF (2012). *Enquête Globale Transport, La mobilité en Ile-de-France*. no.1 Sept 2012.

YAMAMOTO, T. (2009). A random heaping model of annual Vehicle Kilometres Travelled considering heterogeneous approximation in reporting. *12th conference of the International Association for Travel Behaviour Research*, 13-18 December 2009, Jaipur.