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DIFFUSION OF CAR OWNERSHIP AND USE IN FRANCE SINCE THE MID-70'S

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Abstract

For each quartile of income per consumption unit, annual time-series have been estimated from panel surveys, with annual waves of observations since 1974:

- INSEE² Households' Continuous survey from 1974 to 1994,
- Sofres³ "Parc-Auto"⁴ panel survey since 1994.

In these data sources, household behaviour is described through:

- car ownership (percentages of households with at least one car, and of multi-car households, average number of cars per adult over 18, which is the minimum age for obtaining a driving license in France),
- car use (annual mileage per household or per car).

The repeated sample structure of data has been used for improving the accuracy of time-series of variables highly correlated for successive years.

In 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, which have a more homogeneous behaviour. Thus, multi-car ownership, which is mainly structured by geographic and demographic determinants, has slowed -but not reversed- the social diffusion of automobile. After a period of stability between the mid-80's and the early 90's, the social diffusion of automobile has started again like in the 70's, especially for low-income groups and in low-density areas where no alternative to car use is available. However, the Q4/Q1 index has almost stabilised in the 2000's, at national level as well as in Paris region, showing that this diffusion 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. Saturation thresholds are estimated, as well as the date of the point of inflection. The relationship between temporal elasticities (for each quartile) and cross-sectional income elasticities, which could be considered as a measurement of inequality at each point in time, will be discussed (Gardes and Madre, 2005).

Keywords: panel, automobile, car ownership, car use, income inequalities, saturation, France.

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³ TNS-Sofres: Taylor-Nelson, *Société Française d'Etudes par Sondages*, a French private polling institute.

⁴ "Car fleet" panel.

1. INTRODUCTION

In many countries like in France, most taxes on automobile were progressive when they had been decided. They have become neutral or even regressive because of the social diffusion of car ownership and use (Madre, 1985 ; Purwanto et al., 2002). Has multi-car ownership made this evolution slower? The answer to this question is probably different in low-density areas, where there is no alternative to automobile, and in large conurbations, where several destinations can be reached by foot or by bicycle and where public transport are available. Expenditure for car purchase are still concentrated in high income groups, as well as for toll motorways or parking, because cheaper (e.g. second hand cars) or free alternatives exist (Madre, 1991 ; Berri, 2005 ; Berri et al., 2009).

First, the data from two panel surveys, on which relies the calculation of annual time-series since 1974 for each quartile of income distribution, will be presented in section 2. Then, the methodologies used for the calculation of these time-series (interpolated quartiles, optimised estimate of time-series from panel surveys) and the inequality indicators will be described in section 3. A descriptive overview will give the first results (section 4). Finally, modelling in terms of logistic curves (Røed-Larsen, 2006) will be implemented in section 5: do poor/medium/rich households follow the same trajectories for car ownership and use according to the evolution of their income? What results can be derived in terms of relationship between cross-sectional and longitudinal income-elasticities (Madre and Gardes, 2005)?

2. MORE THAN 30 YEARS OF ROTATING PANEL SURVEY DATA

This research is based on two annual nationwide 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 French 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 (year of 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 Kalinowska and Hivert (2005) or Papon and Hivert (2008).

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

- 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.) at permanent disposal of the household (up to 2 cars in ECAM, to 3 cars in Parc-Auto),
- an estimate of the annual mileage for each car described (rounded and heaped (Hivert, 2001 ; Yamamoto, 2009), but unbiased according to odometer reading), as well as some information on the main purposes for which the vehicle is used (yes/no).

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

3. CALCULATION OF TIME-SERIES FOR EACH QUANTILE OF INCOME, METHODOLOGICAL ASPECTS

For the ECAM surveys conducted by the National Institute of Statistics, about 70% of households give for each person detailed information on their resources, including different sources of income (wages, retirement pensions, social benefits, etc.). About 25% give global information on a pre-coded grid, and 5 to 10% refuse. Thus, we chose to use these grids, particularly because the rate of non-response is much lower when using this pre-coded information.

Most of models rely on quantitative variables, but responses given by households are often rounded for income as well as for annual mileage. Moreover, inflation was important before mid-80's, and makes comparisons difficult over time. That is why income grids have been revised in 1977, 1983, 1987 and 1997. The grids have been also typically revised in 2002 in order to be converted from Franc to Euro.

Rather than conventional methods (Bhat, 1994) like simulated residuals (Lollivier and Verger, 1989), we have preferred a more robust method: interpolated quantiles from the middle of each bracket (Madre and Purwanto, 2003). It could be any quantiles (e.g. terciles or quintiles) but we have first to check that the number of brackets is much larger than the number of quantiles.

Let us consider the distribution of a variable of interest (e.g. the number of cars in the household) by income bracket. In order to locate the limits of each income quantile, the distribution is interpolated, and the average number of cars per household is calculated in each quantile with the rather strong hypothesis that car ownership is constant inside each bracket containing a limit between two quantiles (e.g. lowest quartile Q1, median or third quartile Q3).

This method has been tested on the respondents of the 1993-94 French National Travel Survey, which gave precise information in terms of income. The result is obviously better, when the upper and lower limits of a quantile are nearer to the thresholds of brackets on the grid. But surprisingly enough, splitting the sample into a larger number of brackets when dividing the middle of each class by the number of consumption units does not improve the

quality of the interpolation, because even inside a bracket the income level is correlated with the composition of the household. Thus, the interpolation is more precise for total household income than for the income per consumption unit, which is a more adequate measurement of the standard of living.

After obtaining homogenised income groups through quantiles, how to estimate 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. Because we could not access again roar data from ECAM surveys, we have adopted Oxford scale for the calculation of consumption units, which was generally used in the 80's.

For the measurement of inequalities, we have adopted three indicators (see also Bureau et al., 2009):

- the Gini index (Gini, 1921),
- the ratio "Q4/Q1", i.e. between the means of the variable of interest for the extreme quartiles (Q1 representing the poorest and Q4 the richest), which is the only indicator presented here, but the other could be added in a future version,
- the cross-sectional income-elasticity, with usual references (1 when the variable of interest is proportional to income and 0 when it is not influenced by income).

More sophisticated indicators could be considered, for example those proposed by Atkinson (1970) ; Atkinson and Stiglitz (1980) ; Atkinson and Bourguignon (1982) (also cited in Madre, 1985 ; Berri, 2005). In order to avoid heterogeneity over time due to different income grids, these indicators have been calculated from only four points, which are the mean values for each quartile.

4. DESCRIPTIVE ANALYSIS

For each quartile of the distribution of income per consumption unit, time-series have been estimated since 1974 for:

- income per household (income per consumption unit would have been homogeneous with the criteria used to define the quartiles, but this variable, which presents a quite similar trend, was not available in the database kept from ECAM surveys,
- the average number of cars per adult (i.e. aged > 18, which is the minimum age in France to hold a drivers 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 (see section 5),
- the proportion of equipped and of multi-car households,
- the average annual mileage per household or per car,

separately nationwide, and for the Metropolitan Area of Paris (Paris region) in order to show the specificity of the inhabitants of a high population density region, where the diffusion of

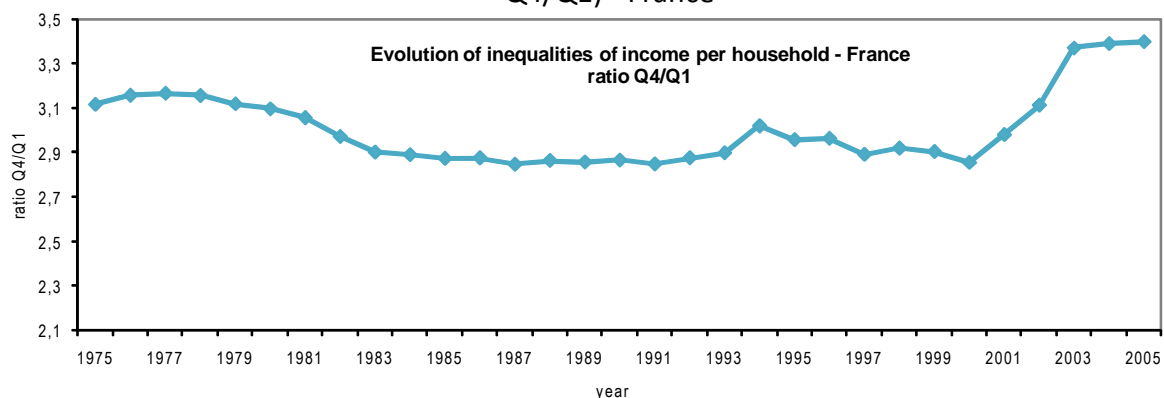
automobile has started earlier than elsewhere in France.

4.1. Income Trends

Nationwide (figure 1), the inequalities of income per household have decreased between mid-70's and mid-80's, then have remained almost constant till 2000 except a temporary increase during the 1993-94 recession. Since 2001, income is growing faster for the highest quartile than for medium or low-income groups.

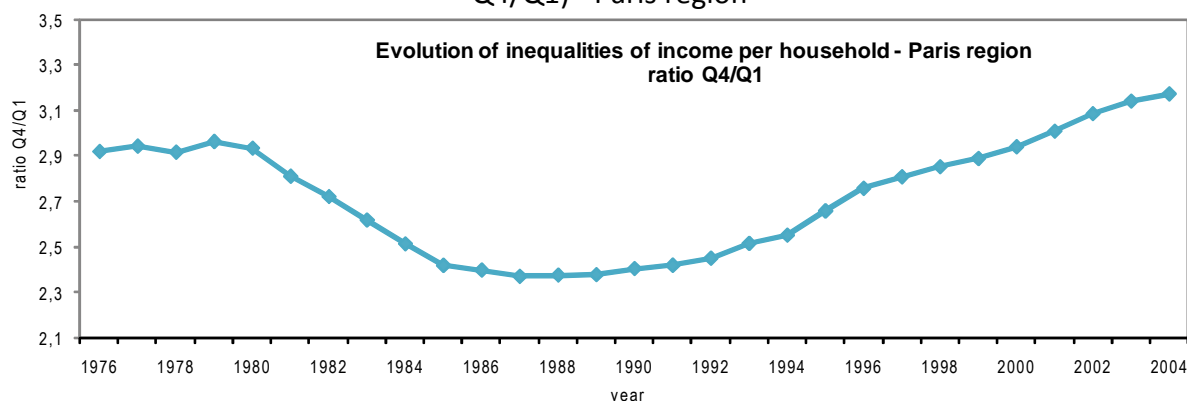
In Paris region (figure 2), inequalities have decreased more rapidly during the first period, then have remained constant only from mid-80's to early 90's, and increase since the 1993 recession. Because of the relative stability of household structures, the evolutions of income per consumption unit follow the same patterns, as shown since 1994 on Parc-Auto data.

Figure 1: Evolution of inequalities for income per household (ratio of extreme quartiles Q4/Q1) - France



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

Figure 2: Evolution of inequalities for income per household (ratio of extreme quartiles Q4/Q1) - Paris region



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

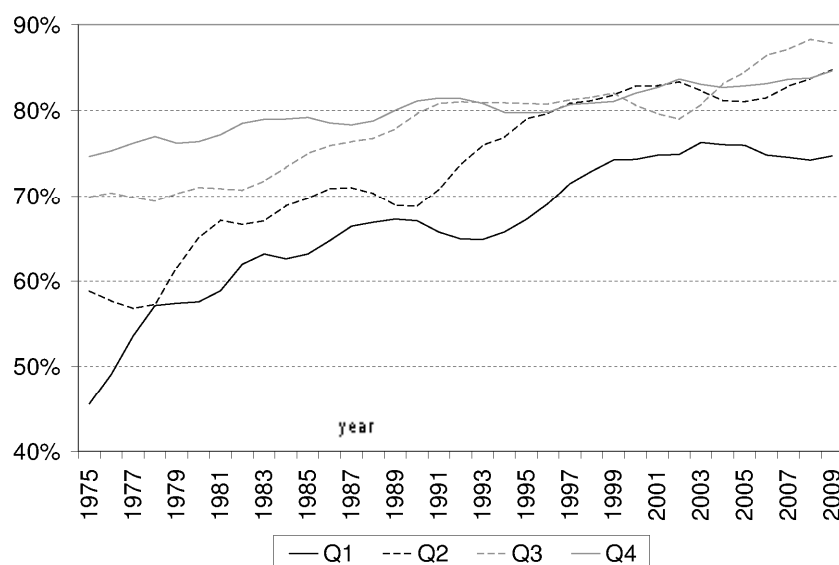
4.2. Nowadays, Multi-car ownership plays the main role in the diffusion of automobile

Concerning the proportion of motorised households (Figure 3), Q2 and Q3 have caught up with the highest quartile in the early 90's. The gap between the lowest and the highest quartile has also decreased till the early 2000's, then has remained almost constant :for the lowest quartile the percentage of households without car has dropped from 55% in mid-70's to 25% around 2002, while it has diminished only from 25% to 15% for the highest quartile.

The proportion of multi-car ownership has increased quite linearly for the two lowest quartiles, while it has remained almost constant during the 90's for the upper quartiles (Figure 4). Multi-car ownership was indeed an increasing function of income till 1990 ; hereafter, Q3 then Q2 have over-passed Q4, because well-off households live in more densely populated areas (e.g. in the Metropolitan Area of Paris).

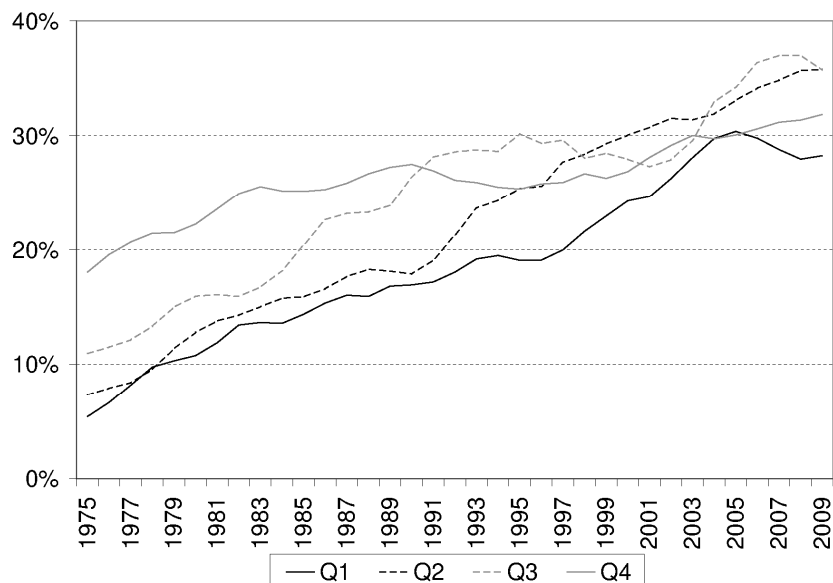
At national level, the average number of cars per adult is a concave function of time for all quartiles and, at any point in time, an increasing function of income per consumption unit (figure 5), which is also true for the inhabitants of Paris region (Figure 6). In this region, car ownership has been almost constant for the lowest quartile since the early 90's, for Q2 and Q4 since the mid-90's, while Q3 has almost caught-up with Q4.

Figure 3: Evolution of car ownership with time: share of equipped households by quartile of income per consumption unit (smoothed by mobile averages over 3 years) – France



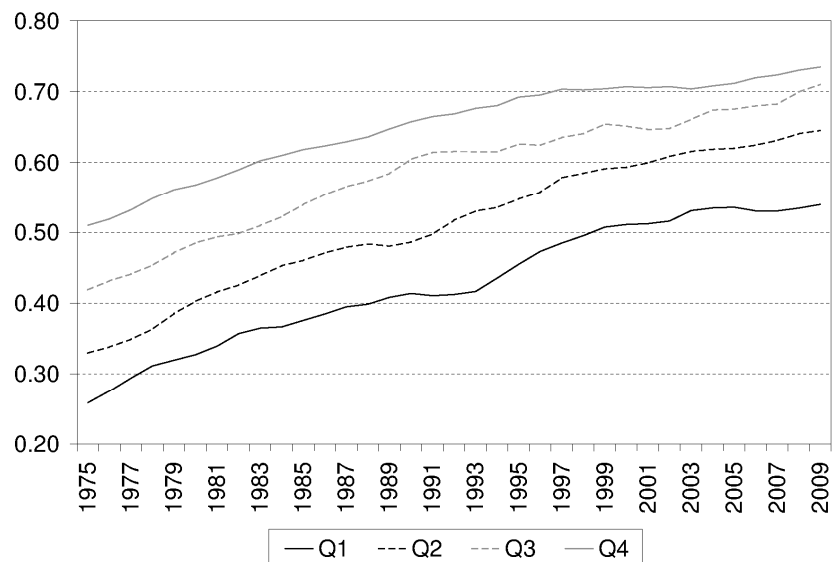
Sources : INSEE Household Continuous Survey 1974-94, SOFRES Parc-Auto panel survey 1994-2010.

Figure 4: Evolution of car ownership with time: share of multi-equipped households by quartile of income per consumption unit (smoothed by mobile averages over 3 years) – France



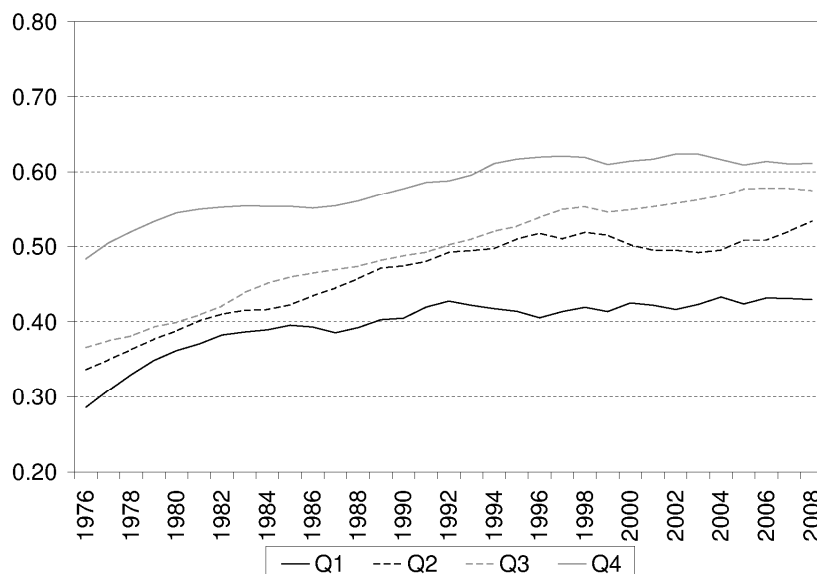
Sources : INSEE Household Continuous Survey 1974-94, SOFRES Parc-Auto panel survey 1994-2010.

Figure 5: Evolution of car ownership with time: average number of cars per adult by quartile of income per consumption unit (smoothed MA3) - France



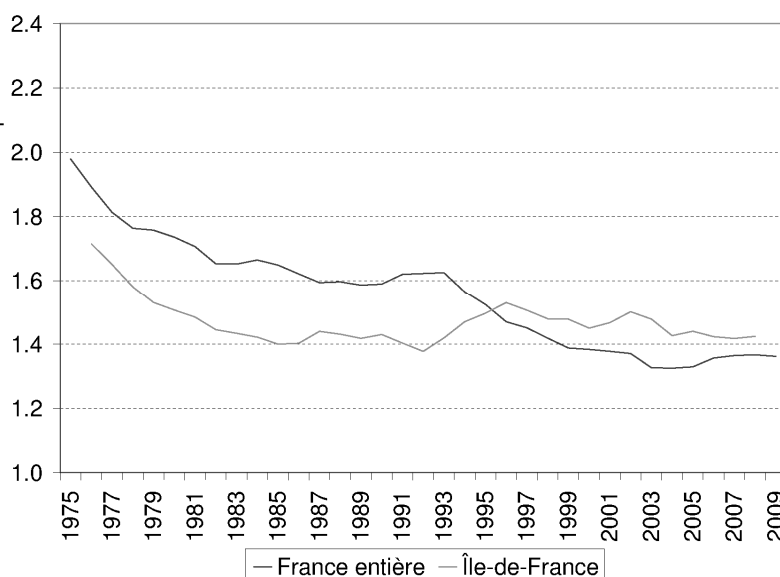
Sources : INSEE Household Continuous Survey 1974-94, SOFRES Parc-Auto panel survey 1994-2010.

Figure 6: Evolution of car ownership with time: average number of cars per adult by quartile of income per consumption unit (smoothed MA5) - Paris region



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

Figure 7 : Evolution of the ratio Q4 / Q1 for the average number of cars per adult - France (smoothed MA3) and Paris region (smoothed MA5)



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

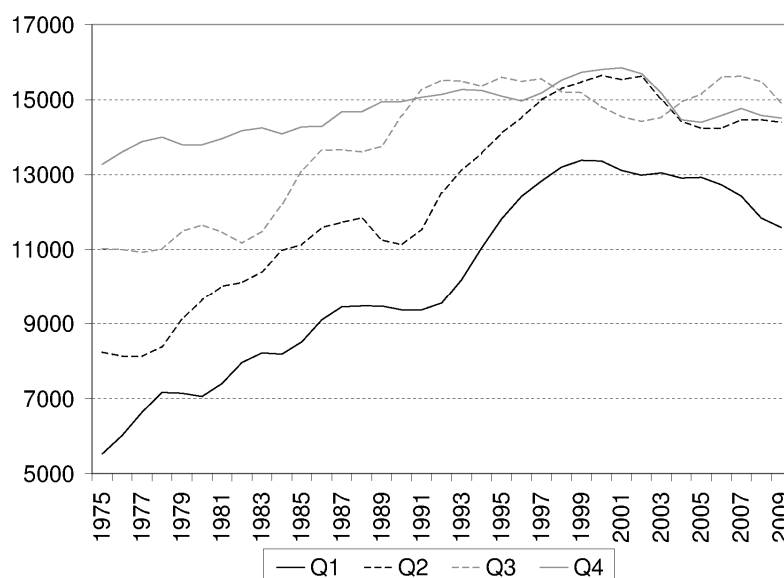
What is resulting in terms of inequality? At national level, the ratio Q4/Q1 for the average number of cars per adult has fallen from 2.0 in the mid-70's to less than 1.4 in the 2000's, somewhat stagnating with an intermediate plateau during the second half of the 80's (Figure 7). For the proportion of multi-car ownership, this ratio has been divided by 3 during the same three decades, falling from 3.3 to 1.1 . Since the second half of the 90's, the gap

between Q1 and Q4 remains almost constant in terms of the proportion of equipped households, and in the 2000's, the gap has almost closed between Q1 and Q4 in terms of multi-car ownership. Thus, after the first equipment, the second car has contributed to the social diffusion of automobile, but with an almost uniform distribution of multi-car ownership, this diffusion process seems to reach its limits. 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.

4.3. A Diffusion of Car Use determined by changes in Fuel Price

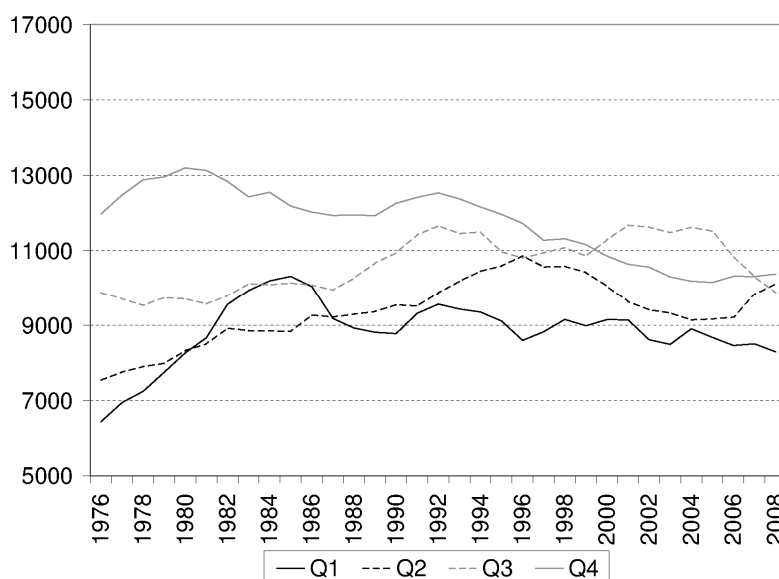
After two oil shocks in 1973 and 1979-80, fuel price has remained at a high level during the first half of the 80's. It has sharply fallen between mid-1985 and mid-1986, and has remained at a low level during the 90's, taking into account of the substitution of petrol fuel by diesel fuel (which was 40% cheaper). After a first peak in 1999-2000, fuel price has risen constantly from 2003 to mid-2008, and is quite volatile since then, with a new record in 2012. Thus, the average mileage per car has declined. With a still increasing car ownership, the average mileage per household is declining since 2000 at national level ; this new trend has started earlier for the highest quartile (Figure 8), as well as in high density areas. For instance, in Paris region, where car ownership and use has developed earlier than elsewhere in France and 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 and in the 80's for the highest quartile (Figure 9). The three highest income groups are converging, while the lowest quartile is remaining below.

Figure 8 : Evolution of car use with time: average mileage per adult by quartile of income per consumption unit(in kilometres, smoothed MA3) – France



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

Figure 9: Evolution of car use with time: average mileage per adult by quartile of income per consumption unit (in kilometres, smoothed MA5) - Paris region



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

In terms of inequality at national level, the ratio Q4/Q1 for the annual mileage per household has declined from 1.7 mid-80's to 1.3 mid-90's (i.e. in a context of cheap fuel), because of a slower increase for the highest income groups. In the 2000's with a rising fuel price, low income groups have been reluctant to drive less ; indeed, they often live in low-density areas with no alternative to an already low car use.

In summary, after a period of stability between the mid-80's and the early 90's, the social diffusion of automobile has started again like in the 70's, especially for low-income groups and in low-density areas where no alternative to car use is available. However, the Q4/Q1 index has almost stabilised in the 2000's, at national level as well as in Paris region, showing that this diffusion seems to reach its limits.

4.4. Evolutions according to income growth

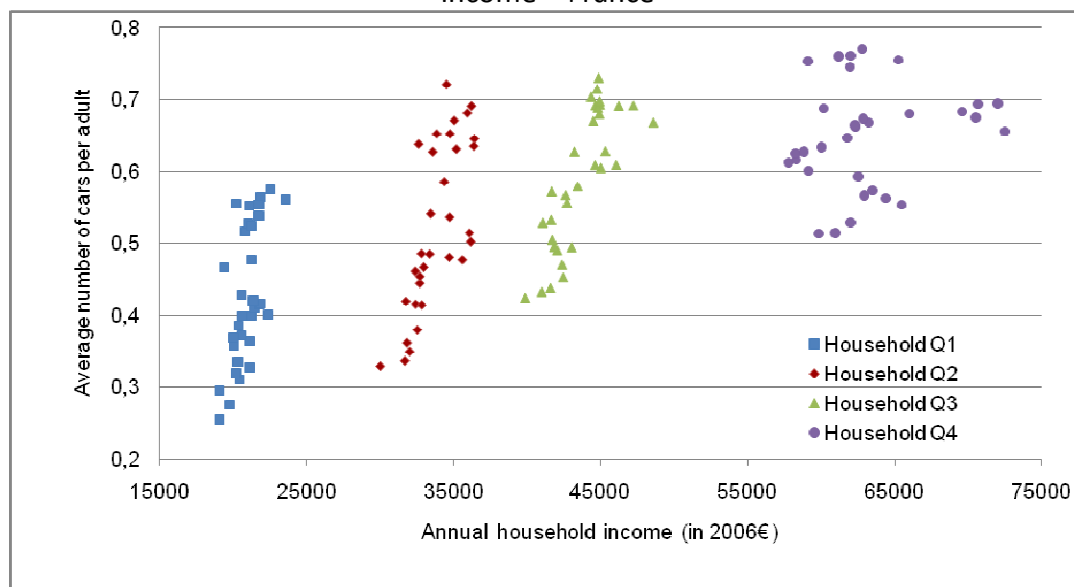
The two next figures present, for each quartile by consumption unit, the evolution of car ownership (per adult) and car use by household, according to income, in constant 2006 Euros (considering all the annual waves together).

Globally, the scatter of points on figure 10 shows that, as expected, household car ownership has increased with their income. Indeed, the number of cars per adult has been about 0.45 for a real annual income of €20,000 while it is about 0.7 for incomes over €65,000 (constant 2006 Euros). 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. Indeed, it is decreasing when the household has a higher social position. Particularly, car ownership is increasing faster with real income for the household Q1 than for the household Q4. Over the years, this has induced a reduction of social inequalities for car ownership, as shown on figure 5.

Considering car use on figure 11, analogous conclusions roughly emerge. The average mileage of households has been about 10,000 km/year for an annual income of €20,000. Over €65,000, it has globally ranged between 15,000 and 17,000 km/year. As on figure 10, the scatter of points on figure 11 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.

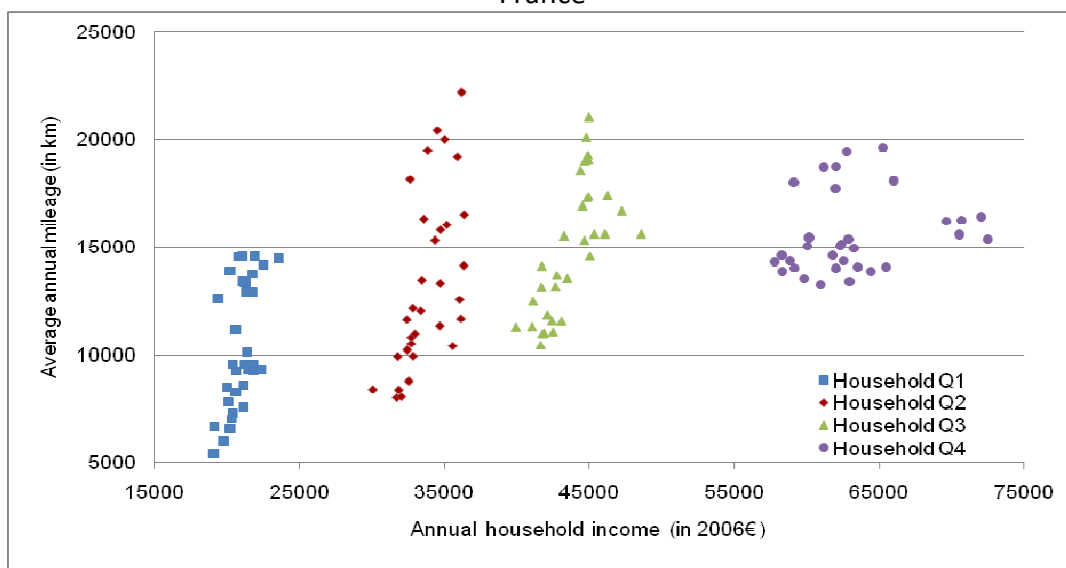
The apparently concave relations of figures 10 and 11 suggest that the diffusion of automobile can reach saturation thresholds for both car ownership and use when the households are getting wealthy. Theoretically, the social diffusion of a good (either in time or in the income scale) can be represented 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.

Figure 10: Evolution of car ownership (average number of cars per adult) with household income – France



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

Figure 11: Evolution of car use (annual mileage per household) with household income - France



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

5. ESTIMATION OF LOGISTIC CURVES TO MODEL CAR OWNERSHIP AND USE

The average households 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. The logistic model, which is exposed below, is applied on the data of each quartile specific household.

5.1. The model

Let Y_{it} refer either to the number of cars per adult or to the annual mileage in 10^4 kilometres 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 the time (section 5.2) and the real income (section 5.3). 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 ε_{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 α 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 $(X_{it} = -\beta / \alpha ; Y_{it}^* = \exp(\gamma) / 2)$.

5.2. Time as explanatory variable

In this section, the explanatory variable of model (1) is the time. Precisely, X_{it} is given by the index t, with t=0 for the year 1974, t=1 for 1975... and t=32 for 2006. Tables 1 and 2 report the estimates for car ownership and use respectively.

Table 1: Estimates for the car ownership model as a function of time

Parameters	Hh.Q1	Hh.Q2	Hh.Q3	Hh.Q4
α	0.06	0.06	0.08	0.10
β	-0.66	-0.52	0.04*	0.66
γ	-0.27	-0.17	-0.26	-0.31
σ	-7.58	-7.03	-7.84	-6.98
Mean log-likelihood	2.37	2.09	2.40	2.07
Nb. of observations	33	33	33	33
Saturation threshold (# of cars per adult) [90% conf. interval]	0.76 [0.61; 0.96]	0.84 [0.72; 0.98]	0.77 [0.73; 0.81]	0.74 [0.71; 0.77]
Date of inflexion	1986	1982	1973	1967

*Note: the dependant variable is the number of cars per adult in households. The explanatory variable is time. All the parameters are significant at the 90% level, except those indicated by *.*

As expected, the results show that car ownership and use have increased along time, despite a slight decrease in the mileages after 2001 caused by an increasing fuel price⁵. Indeed, the parameter α is found to be positive and significant in every case on tables 1 and 2. For both car ownership and use, the inflection has occurred in the mid 80's for the two lower quartiles (Q1 and Q2), in the 70's for Q3 and in the 60's for the higher income quartile Q4. Although confidence intervals overlap, the highest saturation level seems to be for Q2, then it decreases till Q4 because higher income groups live in more densely populated areas. Saturation thresholds are quite low for Q1.

Considering the car ownership model, the confidence intervals for saturation level overlap around 0.74 cars per adult (table 1). For car use, the confidence intervals for the saturation level in table 2 overlap around an annual mileage of 20,000 km per household (table 2). Thus, a pooling data model should fit better assuming quartile-specific inflection points, that is, quartile fixed effects. Assuming a common saturation level, it allows estimates of inflexion dates for each quartile, which do not differ much from those obtained through separate estimations for each income group.

⁵ This factor has not yet been taken into account in the model.

Table 2: Estimates for the car use model as a function of time

Parameters	Hh.Q1	Hh.Q2	Hh.Q3	Hh.Q4
α	0.07	0.07	0.07	0.05
β	-0.83	-0.79	-0.19*	0.66
γ	0.56	0.81	0.74	0.65
σ	-4.75	-3.27	-3.94	-4.27
Mean log-likelihood	0.95	0.21	0.55	0.71
Nb. of observations	33	33	33	33
Saturation threshold (km/year) [90% conf. interval]	17500 [14600; 21100]	22600 [16800; 30200]	21100 [17800; 24900]	19300 [15600; 24000]
Date of inflexion	1985	1985	1977	1961

*Note: the dependant variable is the annual mileage of households in 10⁴ kilometres. The explanatory variable is time. All the parameters are significant at the 90% level, except those indicated by *.*

However, income is a more robust factor than time to explain the diffusion of automobile. Let's now consider income growth as determinant in model (1).

5.3. Real income as explanatory variable

In this section, household car ownership and use are modelled using real income as explanatory variable. Particularly, X_{it} in model (1) refers here to the real annual income of the household Q_i at period t , expressed in 10⁴ constant 2006 Euros.

The saturation levels obtained from the income model do not differ significantly from those given by the time model, even if they seem lower for car use. Confidence intervals are wider for low income groups. Indeed, the estimation of the saturation threshold is much more accurate for higher income groups, which are currently near to their estimated asymptote. The poor fit for car ownership in Q4 is an exception: for this group with a quite high standard of living, changes in income seem to have less influence on the number of cars per adult.

Here again, confidence intervals for saturation levels overlap. Concerning income level at the inflection point, it is higher at higher standards of living (except for Q4 in the car ownership model). Pooling the data in a fixed effect model could show if each quartile follow the same trajectory of car ownership and use, but for specific levels of income of inflection.

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

Parameters	Quartile Q1	Quartile Q2	Quartile Q3	Quartile Q4
log-likelihood	48,92	53,73	72,10	45,30
α	5,37*	2,74	2,99	2,07*
β	10,28*	8,58	11,62	10,48*
γ	-0,49	-0,21*	-0,28	-0,34
Nb. of observations	33	33	33	33
Saturation threshold (# of cars per adult) [90% conf. interval]	0,61 [0,37 ; 0,99]	0,81 [0,51 ; 1,28]	0,76 [0,69 ; 0,82]	0,71 [0,57 ; 0,88]
Income of inflexion (in 2006 Euros)	19200	31300	38800	50600

Note: the dependant variable is the number of cars per adult in households. The explanatory variable is their income expressed in 10^4 constant 2006 Euros. All the parameters are significant at the 90% level, except those indicated by *.

Table 4: Estimates for the car use model as a function of real income

Parameters	Quartile Q1	Quartile Q2	Quartile Q3	Quartile Q4
α	4,59*	6,36	4,35	3,61*
β	-8,99*	-19,96	-17,53	-18,82*
γ	0,48*	0,53	0,64	0,48
σ	-2,82	-2,36	-3,25	-3,48
Mean log-likelihood	-0,01	-0,24	0,21	0,32
Nb. of observations	32	32	32	32
Saturation threshold (km/year) [90% conf. interval]	16100 [6500; 39600]	17000 [14200; 20400]	18900 [16700; 21400]	16100 [14800; 17400]
Income of inflexion (in 2006 Euros)	19500	31300	40300	52000

Note: the dependant variable is the annual mileage of households in 10^4 kilometres. The explanatory variable is their income expressed in 10^4 constant 2006 Euros. All the parameters are significant at the 90% level, except those indicated by *.

Let us discuss now the constraints implied by fitting logistic curves, which are symmetric around the point of inflection, and defined on R (i.e. for positive and negative values of the explanatory variable). Negative values can be admitted for time, but is more questionable for income. For a better representation in the left side of the logistic curves, the model (1) has also been fitted using the log of real income, $\ln(X_{it})$, instead of real income in level. The logistic adjustment does not seem to perform better using this alternative specification.

The model (1) assumes the symmetry of the adjusted logistic curves with respect to the

inflection 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 made necessary when considering our data. As shown on figures 10 and 11, the data do not cover the lower part of a presumed sigmoid, at the left side of the inflection 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 data about car use and equipment between 1945 and 1973 are not available.

Chapman-Richards curve (Richards, 1959 ; Chapman, 1961 ; Draper and Smith, 1981) gives a more flexible functional form, with no left asymptote but a starting point at a chosen date (e.g. 1920), no symmetry, and an upper asymptote which can depend on fuel price and/or income level (Collet et al., 2013; Grimal et al., 2013). But this sophistication is more forecasting oriented, and is not necessary for the analysis of inequality.

6. CONCLUSIONS

The social diffusion of car is a major feature of economic growth in Occidental Europe after World War II. This paper describes this phenomenon in France for four income groups from 1974 onward. Multi-car ownership has interrupted but not reversed this long term trend : after a period of status quo between mid-80's and mid-90's, the social diffusion of automobile continues like during the 70's, especially in low density areas, whose inhabitants are more car dependent even if their income is low.

However, the growth of car ownership becomes slower and slower, which shows that saturation levels are not far from already reached levels. In order to determine these thresholds, we have adjusted logistic curves separately for each income quartile. Geographic factors (as density, distance to city-centre, size of conurbation) probably explain why it is not for Q4 that saturation levels are the highest, which could be checked by estimating the same models only for the inhabitants of the Metropolitan Area of Paris.

For both car ownership and use, the confidence intervals of saturation level for each quartile overlap. These saturation thresholds depend more on the zone of residence than on the standard of living (Grimal et al., 2013) ; indeed, it seems to be lower for the highest income group, who lives generally in more densely populated areas.

However, the curves do not show monotonous changes towards saturation. Figure 8 indicate that car use has peaked around 2001 and have since declined significantly, The main factor that contributed to this trend is certainly fuel price, which could be introduced as explanatory variable. Additional factors could also include rising vehicle prices, tax policies, demographics (aging population and declining employment rates), improvements in alternative modes (walking, cycling and public transport), and changing consumer preferences.

This heterogeneity opens theoretical discussions about cross-sectional versus longitudinal

estimates. Another example is an important change over time of cross-sectional income elasticities, which makes impossible to consider them as a proxy for long-term longitudinal elasticities (Gardes and Madre, 2005). There is still much to do with these data. The first point is to plot various inequality indexes (Gini coefficient, elasticity, etc.) and to update the curves at least to 2010. Considering modelling, fixed quartile effect can be estimated on pooled data. At national level, it gives a more accurate estimate of saturation levels, which do not differ significantly between quartiles of the distribution of income per consumption unit. This yields a better estimation of the inflection points according to time and income, and allows to check whether each quartile follow the same trajectory. Moreover, introducing fuel price and/or real income as explanatory factor for car use should allow to derive saturation thresholds for the annual mileage in different economic conditions, which could give an important information for building scenarios for sustainable development. However, we should take into account that even fuel price elasticity depends on income level (Kemel et al., 2009).

Differences in vehicle ownership and mileage rates between different income classes are often presented as an inequity, with the implication that, as lower-income households own more vehicles and drive more annual miles, they are better off overall. Yet, these trends could be not as much positive as that. Indeed, lower-income households may have to spend an excessive portion of their budget for transportation, due to a lack of more affordable alternatives. Lower-income households might be better off, for example, if there were more affordable housing in urban neighbourhoods with good walking, cycling and public transit, which would reduce their vehicle ownership. These assumptions about what is considered equitable and desirable are still to be discussed.

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