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A life Expectancy-Period-Cohort model to project private car fleet and traffic applied to France

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Abstract

In most industrialized countries, after decades of gradually slowed growth, car traffic stagnated in the 2000s. This phenomenon has been attributed not only to conventional economic factors (stagnation of incomes, upward volatility in fuel prices) and to re-urbanization linked to metropolisation, but also to demographic factors (ageing of the population, longer life cycle stages leading in particular to delay the passage of the driving license in the younger generations). The economic recovery, albeit rather slow, and a significant drop in the price of oil in 2014 favored a certain revival of traffic growth in several countries (U.S.A., Germany, France, ...); but what about the structural factors and how to predict medium-term developments? We have already dealt with these questions via Age-Period-Cohort models, and more often Age-Cohort (AC). In view of the over-determination generated by the mechanical link between these three factors, we propose a Life Expectancy-Period-Cohort model (EPC); indeed, by replacing age by life expectancy at this age and at each date, the model can be directly estimated keeping the three components, while making this approach more consistent with the extension of life cycle stages (longer studies, women having their children in their thirties, postponement of retirement age, ...). Period effects are specified by introducing the income of the household and a fuel price index as explanatory variables. The results are compared with those of various previous models.

The scope is the adult population (i.e., of driving age), considering three phases for automobile behavior:
- to pass the driver’s license,
- to be the main user of a vehicle,
- to ride (annual mileage) or frequency of use of the vehicle.

Once the model is estimated on the data of the Parc-Auto Kantar-SOFRES 1994-2016 panel survey, an example of medium-term (horizon 2030) projection of the annual mileage is presented, being aware that in the long term the technical innovations (autonomous vehicle, electric and hybrid engines) and organizational evolution (car sharing, carpooling, ...) are likely to fundamentally change the conditions of use of the car.

Keywords : Individual motorization; use of the automobile; life expectancy; demographic and economic factors; prospective

1. Introduction

After expanding rapidly in the 1960s and 1970s, growth in car driving per capita slowed in the early 2000s in a number of industrialized countries. Is it an interruption in long term growth due to economic circumstances (high fuel price, then recession)? a peak due to saturation? a turning point before a long-term decline? (Goodwin, 2010-11). This “peak car travel” has been attributed both to structural factors (population ageing, new generations less addicted to automobile, metropolisation i.e. more and more people living in large urban areas, etc.) and to economic factors (lower income growth, upward volatility of fuel price, etc.).

Most papers on this phenomenon (Litman, 2009; Millard-Ball and Schipper, 2010; Newman and Kenworthy, 2011, Madre et al., 2012) are based on data collected before 2010. However, at least in the US, Germany and

France, car traffic has notably increased since 2015 (CGDD, 2017) as well as in Canada (e.g. in Montreal). Is it only a short-term phenomenon due to a cheaper fuel since 2014? Are structural (mainly demographic) factors still active for moderating the growth of car traffic?

These questions will be investigated using the data of Parc-Auto Kantar-SOFRES panel survey for France from 1994 to 2016, using a new demographic approach, (i.e. the Life Expectancy-Period-Cohort model proposed by d'Albis and Badji (2017). We will investigate the behavior of successive cohorts and their impact on traffic growth, being aware that the context is quite specific, i.e. the most numerous cohort in the U.S. is the millennial generation, while in France it is that born in the 1960's at the end of the baby-boom, because of less immigration and of a lower fertility rate, even if, except Ireland, it is in France that the fertility rate is the highest in Europe.

After a literature review (section 2), our individual based nested approach (holding a driving license / being the main user of a car / annual mileage) is presented (section 3). Then, a descriptive analysis is given (section 4). Follows estimations of different models, with comparison of forecasts for the annual mileage per adult (section 5). Finally, a conclusion (section 6).

2. Literature Review

The Australian Bureau of Infrastructure, Transport and Regional Economics, which has compiled long time-series for 25 countries, explains the slowing down of car driving per capita as a reflection of fuel prices and economic activity, as well as a time-related saturation effect for which a deeper understanding is needed (BITRE, 2012). A comprehensive analysis of global transport demand trends over the next 40 years was presented by the JTRC/ITF in May 2011 in Leipzig (OECD/ITF, 2011 and 2013) and regularly updated in "Outlooks" (see ITF website).

Most papers on this topic were focused on economic factors taking into account changes in behavior (economic growth and fuel price), but the demographic factors were neglected for explaining peak car (Mannering and Winston, 1985 ; Hensher et al., 1990 ; Goodwin et al., 2004 ; Pirotte et Madre, 2012).

During the diffusion of private cars, successive generations of men and women have increased their motorization along their life cycle. However, car ownership and use is specific for each generation cohort (Gallez, 1994 ; Dargay et al., 2000 ; Dejoux et al., 2009). Recent cohorts have grown in a society where the private car tends to become an individual good because of the diffusion of driver's license (Roux, 2012). Age cohort modelling has already allowed to anticipate phenomena such as decreasing car ownership of the inhabitants of the City of Paris starting in 1990, which has spread to inner suburbs in the 2000's (Bussière, Madre et al., 1996). Using continuous data, the introduction of period effects shows the influence of income growth and fuel price on peak car (Berri et al., 2005). Bastian and Börjesson (2015) explain the peak car in Sweden by GDP and fuel price. They conclude that most of the aggregate trends in car distances driven per adult, as much as 80% over the years 2002 to 2012 with elasticities higher among urban populations and in municipalities with high density, low average income and high share of foreign born residents. They stress the importance of accurate predictions of economic growth and fuel prices for accurate transport forecasts. Also, price elasticities tend to increase at high price levels and during periods of rapid price increases (Bastian, Börjesson, Eliasson, 2016). A vast review of econometric literature concerning mainly aggregate time-series in developed countries showed that income elasticities tend to be greater than price by a factor 1.5-3 and long-run elasticities are greater than short-run elasticities by a factor of 2-3 (Goodwin et al, 2004).

A study of over 15 developed countries, then extended to 14 additional countries, shows a decrease, in the past 25 years, in the percentage of young people with a driver´s license, but an increase for older people (Sivak & Schoettle, oct. 2011). Data on Paris region confirm these tendencies with a threshold around 2001 and a significant growth in mobility by car by the retired population (Courel & Bouleau, April 2013).

Other authors argue that the observed trends in car use imply a paradigm shift in what constitutes a good city (Newman and Kenworthy, 2011) as well as a series of other factors as road congestion and travel time in the cities (Metz, 2010).

Using Family Expenditure and Travel Surveys for different points in time, Yoann Démoli (2015) shows the influence of socio-professional characteristics, in particular the differences between white collars from public and private sectors. Through qualitative surveys conducted in Lyon and Montreal, Ortar et al. (2017) show, in the context of a longer access of young adults to be autonomous, that acquiring a license is less important than leaving their parents' household and having a job; environmental consciousness is emerging when a longer upper education period is present ; finally, the younger generation plans much less to move towards outer suburbs, but prefers to remain in a dense built environment, offering much more multimodal opportunities (bike and car sharing, public transport, etc.), but where car use is more and more considered as a costly constraint.

Based on the National Travel Surveys 1995-2009, conducted continuously in the Netherlands, and on qualitative surveys conducted at only one point in time, KiM (2014) makes the hypothesis that Dutch people will not have less cars, but will have them later, a tendency confirmed - the number of private cars went up by 15% between 2005 and 2015 (KiM, 2016).

According to a longitudinal analysis of the 2003-2013 American Time Use Surveys (Garikapati et al., 2016), compared to recent generations: millennials (born between 1979 and 2000) are found, in early adulthood, to travel less, own fewer cars, have lower driver's licensing rates, and use alternative modes more. Older millennials are showing activity-time use patterns similar to their prior generation counterparts as they age, although some differences persist, particularly in time spent as a car driver. But to what extent will it still be the case as millennials move through various phases of their life cycle? Millennials appear to exhibit a lag in adopting the activity patterns of predecessor generations due to delayed lifecycle milestones (e.g., completing their education, getting jobs, marrying, and having children) and lingering effects of the economic recession, suggesting that car travel demand could resume growth in the future.

Chatterjee, K., Goodwin et al (2018) recall that the downward trend for young adults in UK began approximately 25 years ago, explained by differences in life circumstances (demographics, living and socio-economic situation, precarious economic situation, rise in motoring costs), in contrast with baby boomers who represented rapid and prolonged growth in driver´s license holding, car ownership and car use. They predict only a modest change towards greater car ownership for millennials in the next 10-15 years, and only for those who secure stable, full-time employment.

Giovanni Circella, et al. (May 2016 & March 2017) in a study based on an online survey in California to a sample of 2,400 residents, including millennials show the importance of changes in attitudes and that the differences associated with the location where the respondents live are remarkably larger than differences observed among age groups:

- urban dwellers consistently report stronger pro-environmental policy attitudes than non-urban residents;
- urban millennials are heavy adopters of technology, smartphone apps in particular, and on average use these services more often for various purposes, including accessing information about the means (or combination of means) of transportation to use for a trip, finding information about potential trip destinations (e.g. a café, or a restaurant), or navigating in real time during a trip;
- large differences are also observed in the adoption of shared mobility across both age groups and urban vs. non-urban populations; not surprisingly, millennials tend to adopt these technological services more often than Gen Xers (i.e. born in the 1970s), particularly in urban areas.
-

They further analyzed the relationships between accessibility and the adoption of multiple modes of transportation (*multimodality*, and/or *intermodality*) among the various sub-segments of the population. For this analysis, they classified millennials in two groups of independent and dependent millennials based on their living arrangements and household composition. In fact, the residential location where dependent millennials live has likely been the result of their parent`s choices, and not of the millennials themselves. Accessibility and multimodality are usually positively correlated. Dependent millennials are found to make the most of their built environment potential, either due to individual choices, or the presence (or lack) of travel constraints. They are less likely to be mono-drivers and more likely to be multimodal commuters, even if they often live in neighborhoods that are less supportive of such behaviors. Independent millennials more often choose to live in accessible locations and tend to adopt non-motorized and multimodal travel options more often. The model for millennials compared to the model for other generations explains the lowest amount of variance in the data. A finding which signals the higher heterogeneity and variation among the members of this group, and the increased difficulty in explaining their behaviors through the estimation of econometric and quantitative models.

Laitian Zhong and Bumsoo Lee (2017) from a study in the Puget sound region in Washington state explains most of the decline of driving since the mid-2000s by socioeconomic factors, reduction of car ownership due to location, especially in compact neighborhoods.

Stapleton et al. (2017) shows results for Great Britain, which are consistent with the claim that economic recovery and low fuel prices could encourage renewed traffic growth – particularly since the income short-term elasticity of car travel is found to be significantly larger than the price elasticity. These results also suggest that the rebound effect from improved fuel efficiency averaged 26% over this period – which is consistent with the literature.

Bastian, A., Börjesson, M., & J. Eliasson (2016) show that the traditional variables GDP and fuel price are sufficient to explain the observed trends in car traffic in all the countries included in their study (USA, France, UK, Sweden, Australia, Germany). Price increases in the early 2000s has been underappreciated in many studies. They remind us that:

> ¨finding correlations between variables in times series does not prove causality, of course, so we should be precise with what our conclusion is. The logic is this: if economic variables could not explain recent downward trends in aggregate car use, then that would have meant that the trends must have been caused by something else, and this ‘‘something else” could be changes in lifestyles and attitudes. What we show is simply that the first part of this syllogism is not true: economic variables can in fact explain these recent trends. Of course, this does not rule out the existence of alternative explanations (this is true for any econometric model); nor does it imply that there are no changes in lifestyles or attitudes (of course there are), or that other variables do not affect travel patterns as well (of course they do). However, we can conclude that economic variables are sufficient to explain the aggregate trends in car use¨.

Barbara Noble (2005) shows that in Great Britain young people aged up to 24 with full car driving licences has been falling since about 1993 and that for those aged 25-29 there appears to be a more recent fall for young men and around 2002/04 a small decrease in the 30-34 age group. But in this age group licence holding continued to increase, though still lower than among men. Among other factors, the main cause of the decrease of licence holding is the cost of driving and the increased difficulty to pass the driving test. She mentions falling rates in Sweden, Norway, USA and Finland but no evidence of falling rates in Denmark, Netherlands and West Germany.

In Switzerland (Patrick Rérat, 2018), as in several western countries, the proportion of young people aged between 18 and 24 who have a driving licence fell from 70.7% in 1994 to 58.7% in 2010, before increasing slightly to 61.0% in 2015 (OFS, and ARE 2017). Between 1994 and 2015, there was a very slight decrease among people aged 25–44 (88.9% vs. 87.8%) and a 10-point increase among those aged 45–64 (79.5% vs. 89.8%). There are significant changes among people aged 65–79 (50.6% vs. 79.0%) and those aged over 80 (from 19.7% to 45.0%). These increases of nearly 30 points are explained by the arrival in these age groups of women who have had greater access to cars than in previous generations. Thus, since 2005, there are proportionately more people in their 60s and 70s who have a driving licence than young adults. The symbolic meaning of the car that may declining. Rérat identifies four main factors explaining these tendencies: 1-complex administrative and pedagogical steps to obtain the driver´s licence, 2- age, mainly 18 years old, the difference being not significant at the age of 22, 3-possession of a public transport pass, 4-the residencial context: fewer licences in large or medium cities. Ages seems the determinant factor and, overall, young adults get their licences later and a catch-up effect occurs.

There is no consensus on the causes of peak travel except that it is multifactorial, and on whether it will persist. The final issue will depend of a combination of factors: demography, urban density, income, price, policies, technology, accessibility, mentalities. We don´t pretend to be able to take into account all these factors but propose a demographic approach which takes into account at national level, population growth, changes in behavior through generations, as well as period effects represented by real income per consumption unit and fuel price.

3. Data and Methodology

3.1. An individual based approach

The household is the traditional sampling unit for surveys. However, a household-based approach doesn’t allow a clear understanding of individual’s behavior, especially for young adults, who play a crucial role for peak car; they experience a longer and longer transition from the household of their parents to their own one.

Our analysis is based on 23 waves of TNS-SOFRES Parc-Auto panel survey (from 1994 to 2016). For comparability, a datafile of adults (individuals 18 or more years old, i.e. old enough to have a driving license in France) has been built from the household files, which contain a description of up to 6 adult members of the household; from 2004 to 2006 they are directly extracted from the datafile of individuals, which introduces a slight heterogeneity for this short period. The resulting datafile contains 284,286 observations (i.e. individuals*years). The analysis has been broken down into 16 age brackets (from “18-22 years old” to “93-97 years old”), which allows a detailed analysis of the life cycle.

3.2. A nested approach from driving license holding to annual mileage

Car use at an individual level has been split into three rather independent steps (Grimal, 2015) :

- Driving licence holding.
- Car ownership, i.e. the proportion of individuals holding a driving licence, who are the main user of a car; in the rare case of a vehicle with 2 or 3 main users, only the car with the highest annual mileage is retained;
- The annual mileage of the car.
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Thus, car use, i.e. the average annual mileage per adult, is the product of license holding, by individual motorization per license owner, by annual mileage per car.

4-Descriptive analysis

We will start by analyzing each component of automotive behavior by cohort along the period of their life cycle for which the 1994-2016 data is available. This is synthetized through the estimation of Age-Cohort models (see Dejoux et al., 2009; Bussière, Madre et al., 1996).This simplified model relies on the hypothesis that there is a constant lag between different cohorts along their life cycle for their automotive behavior (e.g. % of driver`s licence owners or annual mileage per adult). A dummy variable for the years 2004 to 2006 is introduced to take into account the slight heterogeneity of data for this period; in fact, this dummy is significant only for driving licence holding and for the proportion of main users among licence owners. Then, forecasting issues will be discussed according to the hypothesis that can be made on the gap between the different cohorts in the future.

4.1. Driver's licence

Towards the end of life cycle, the proportion of driving licene holders seems to decline in each cohort (Table 1) but very late in the life cycle. If we average 5 cohorts of people born between 1974 and 1993, we observe a peak at 33-47 years with 94% and then diminishes very slowly. It is still at 88% between 63-67 years and remains at 68% between 88-92 years. This is mainly due to a longer life expectancy of women; indeed, those born during the first half of the XXth century had notably less often a driving licence than men. If we considered separately each gender, we would observe that there are quite few significant declines of licence holding at old age : in the cohort 1918-21, from 78 years onward 90% of men have their licence, while 60% of women have it around 80 and only 55% around 90. However, almost no women loose their licence, while for men the maxima of cancelled licenses is around 30, 60 and 85 years old, but never exceeds 1% of individuals in each age bracket.

At an early stage of life cycle (i.e. in the 18-22 years bracket following the minimum age to be licensed), the licence rate is minimal (56%) for the individuals born during the late 1980's (cohort 1986-89), but notably higher for those born in the early 1990's (66% for the cohort 1990-93), with no more significant difference between genders. For the cohort 1986-89, the licence rate has increased rapidly, reaching 85% around 25 years old. Between 23 and 27 years, women have a higher rate than men since the cohort 1982-85 (86% for women, compared to 81% for men). Between 25 and 30 years old, the increase of licence rate is lower for people born during the early 1970's than for those born later. Around 35 years old, there are few significant differences between the cohorts born in the 1960's and 1970's, with a slightly higher rate for men.

The Age-Cohort model (explained in Box 1) shows that after 30 years old, the rate of driving licence owners is not significantly different by gender, from 96% for men, and from 88% for women (up to 75 years old; in all age groups until 88-92 the rate of driving licence owners is high for both men (up to 97% in 28-32 for men) and women (up to 93% for the same age group) and very slightly higher for men, from 3% to 7.5% until the age of 87 and rises at the ages of 88 an over (Table 2).

Concerning cohort effects, men born before the 1920's are significantly less licensed than those born later, while it is before the 1940's for women with a larger gap (Table 1). Men born after 1980 are significantly less licensed, while this phenomenon is less marked and appears later for women.

Finally, up to the cohort 1986-89, there is an important decrease of the proportion of licensed people between 18 and 22 years (Table 3). But when getting older, these cohorts tend to catch up with previous cohorts. This shows that in some instances the trajectories of each cohort may diverge and makes questionable the simplified hypothesis used in the Age-Cohort Model that the trajectories of each cohort are parallel all along the life cycle.

Box 1 : Age-Cohort Model

For a demographic analysis, three inter-related dimensions have to be considered:
•Age for identifying different stages in the life cycle,
•Cohort, considering that people borna round the same date share a similar experience,
•Period, i.e. socio-economic factors influencing everyone at the same time (e.g. fuel price) - date of observation.

Unfortunately :
PERIOD (date) = COHORT (birth year) + Age - which makes model identification problematic.
However, making the hypothesis that curves are parallel for successive cohorts, a “profile-type” can be computed from observations collected for a long enough period of time:
•K(a,t) = gAGE + cGEN
With :
•K(a,t) indicator of car ownership or use for age a at date t,
•AGE dummy variable for Age
•GEN dummy variable for Cohort

4.2. Car ownership - main user of a car

For young adults (18-22 years) the proportion of licence holders who are the main user of a car (Table 3), is increasing from 34% for those born around 1975 to 56% for those born in the late 1980’s, but drops to 47% for those born in the early 1990’s. The rate of main users per adult along the life cycle is low in the 18-22 age group, doubles for the 23-27 which reflects the financial capacity to own a car (Table 4), then is rather flat until the early 60´s and then diminishes significantly with ageing. For the most recent generations, there seems to be a kind of compensation between a low licence rate and a high proportion of people having their own car among licensed individuals. But around 35 years old, the differences between adults born in the 1960’s and 1970’s are much smaller.

Does it mean that the following generations will catch up with them when they will reach 35 years? According to the Age-Cohort model (Table 2), more than 80% of licensed men (resp. 67% for women are the main user of a car when they are between 35 and 75 years old. There are almost no cohort effects for men except a slight one for extreme generations, which is negative for the individuals born before 1920 and positive for those born in the 1980’s. For women, it varies widely from over -30 points for those born till the 1920’s to over +30 points for those born in the 1980’s (Table 2b). Thus, for the most recent generations, there is a kind of compensation between a low licence rate and a high proportion of people having their own car among licensed individuals.

4.3. Car use

For each age bracket, with almost no significant exception, the annual mileage per car is decreasing when considering more recent generation cohorts (Table 2). For example, the 18-22 years had an annual mileage of 13,023 km for those born in 1974-1977 and of 10,711 for those born in 1990-1993, a diminution of 18%. In the age groups where the mileage was the highest, 23-27 years, the annual mileage was 16,800 km for those born in 1970-1973 and of 13,600 km for those born in 1986-1989, a reduction of 19% (Table 5). This may be partly due to a higher fuel price after 2005 as well as changes in travel habits.

The resulting annual km per adult according to age is bell shaped, with a flat maximum moving slightly from the mid-twenties to the early fifties (Table 6). People born in the 1920’s and before drive less, as well as those born in the 1990’s, while the maximum is observed for those born from the 1960’s to the early 1980’s according to the Age-Cohort model.

These changes correspond clearly to delayed steps in the life cycle for the most recent generations. For instance, more than 80% of the 18-22 years lived with their parents (i.e. were more than 20 years younger than the head of household), and less than 70% were students among those born in the late 1970’s, while it is less than 60% (and more than 80%) for those born in the 1980’s.

5. Forecasting the annual mileage per adult

5.1. Forecasting using fixed behavior by age with an Age-Cohort model

Demography is an important factor explaining peak car travel. Indeed, we have just shown that the curve of drivers' mobility according to age is bell shaped. A straightforward combination of fixed mobility by age group at date t° with the evolving number of inhabitants suggests that the demographic transition (i.e. a slower growth of the number of inhabitants with population ageing) implies a slow decrease of the annual mileage as car driver per adult.

Whatever trends in socioeconomic transformation in the country and users' expectation and preferences towards using cars, the choice of the reference date t° shows some influence: indeed, because of a generation effect, the mobility of the elderly is higher nowadays than it was before (e.g. people 68 to 72 years old drove 2,300 km annually in 1984-86, 5,000 km in 1994-96, 5,700 km in 2004-06 and 6,000 km in 2014-16).

Table 7 summarizes various projections with the Age-Cohort model and the Life Expectancy-Period Cohort model. The resulting forecast of the annual mileage driven by the whole population for 2032 compared to 2007 is a decrease of 8.3% with the 1984-86 reference, while it is only around 5% with a reference period after 2000. Figure 1 illustrates projections up to the horizon 2057 even though uncertainties of the future diminishes reliability in long term forecasting.

The Age Cohort model combines life cycle and generation effects. For car ownership, it gives a flat maximum around 2040 for the average number of main users per adult, and around 2050 for the total number of vehicles. For the annual mileage per adult, it shows a cohort coefficient increasing till the generation born around 1970, then a decrease. For forecasting, we made two simulations :

- -"constant lag" means that we have maintained for "future generations", the coefficient of the cohort born in the early 1990's (i.e. the most recent cohort surveyed),
- -"reversed lag" means that we have extrapolated an increase of the generation coefficient after that of the cohort 2000-04, symmetrically to the decrease observed for previous generations, assuming that the generation gap could increase after its minimum observed around 1990.

Between 2007 and 2032, there is not much difference between these simulations (-8% for "constant lag" vs. -7% for "reversed lag"). Between 2007 and 2032, there is not much difference between these simulations (-8% for "constant lag" vs. -7% for "reversed lag").

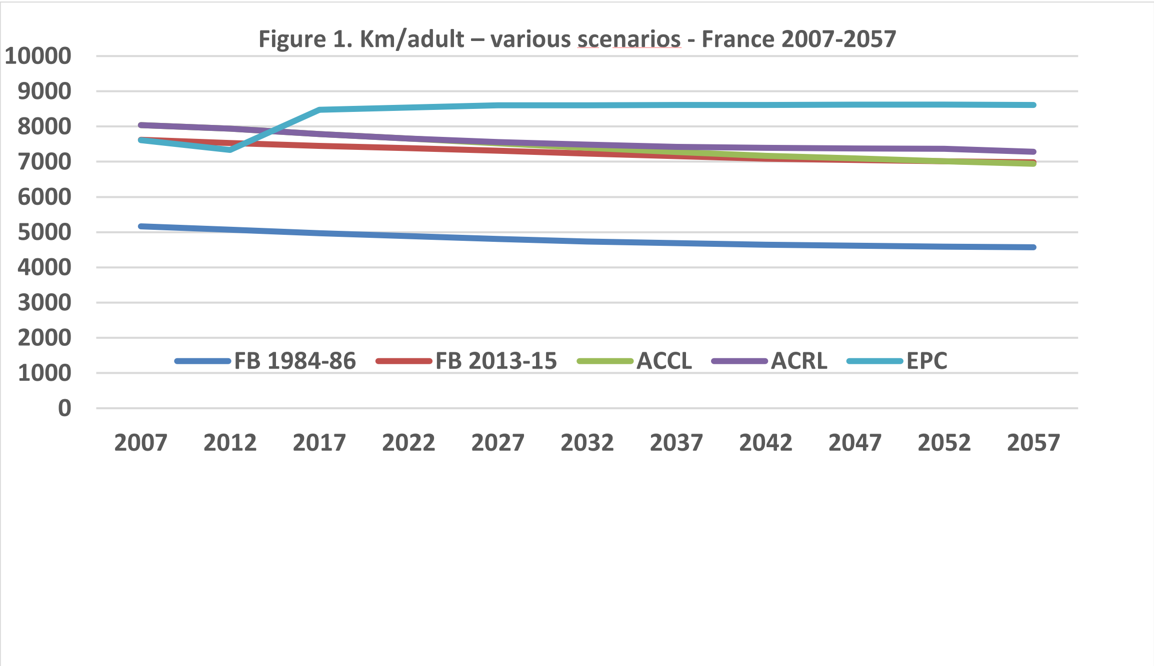

Figure 1: FB: Fixed Behavior: ACCL Age-Cohort with Constant Lag: ACRL: Age-Cohort with reversed Lag; EPC: Life Expectancy-Period-Cohort model with constant lag.

5.2. Forecasting using the Life Expectancy-Period-Cohort (EPC) model

Taking into account longer stages in the life cycle (i.e. not only the perception that death will occure later but also that more time is available at each stage of life cycle), shown in the literature review as well as in the descriptive analysis, the Life Expectancy-Period-Cohort model see Box 2) seems quite attractive. Moreover, contrary to Age-Period-Cohort, it is not subject to collinearity problems for estimation (d'Albis and Badji, 2017) - see Box 1.

Box 2 : Life Expectancy-Period-Cohort Model

Let us take the example of KMA as dependent variable, which is the annual mileage of the car at date t for which the individual i (at age a and date t) is the main user; KMA=0 when this individual is not the main user of a vehicle.

•KMA(i,t) = aLE(a,t) + ble(a,t)² + cGN + Dcuinc(i,t) + EPFUEL(t)

With :
- LE, the Life Expectancy of the individual at the date t when he/she is surveyed, deduced from his/her age;
- LE² to take into account that the curve of annual mileage as a function of age is bell shaped, with a maximum for individuals in their forties;
- dummy variables – (GN: Generation: BF: Before; AF: After) –
GNBF1955 to GN1995 for cohorts (GNBF1955 for individuals born before 1955, GN196579 for those born between 1965 and 1979,…, GNAF1989 for those born after 1989); the reference cohort, for which the coefficient is set to 0, corresponds to individuals born from 1955 to 1964 ; quinquennial cohorts have been grouped in order to obtain coefficients which are significantly different from one another.
-And for period effects, the economic variables:
-* CUINC, real income of the household per consumption unit,
-* PFUEL, the national index of fuel price, taking inflation into account (2015=100).

Table 7 compares provisional forecasting results with both models. The Age-Cohort model gives for the period 2007-2032 a fall in km/adult ranging from -8.3% to -5.2% depending of the fixed behavior hypothesis chosen which reflects the observed tendencies of fall of car use without price effects.

The LEP model gives quite different results with a 13% increase of the annual mileage per adult between 2007 and 2032; it is only +8.5% when keeping the real fuel prices of 2007 constant instead of taking for 2032 its value of 2016 which was 4% lower after the drop in 2014. Indeed, the economic factors have a strong influence. Neutralizing them after 2017 by keeping fuel price and income constant, it appears that demographic factors have a positive influence till about 2030, which is due to cohort effects (the life expectancy effect is negative). Combined with a stagnation in population growth, total traffic saturates after 2032. Table 8 gives the estimation of coefficients for average km per adult in the EPC model.

In a further research we could diversify scenarios including various price variations in both models to estimate its influence versus demographic factors

5.3 Comparison between forecasts obtained from different methods (Figure 1)

Driver`s license holding for young adults (aged 18 to 22), whose decline was the first advanced signal of peak car travel in Great Britain in the 1990's (Noble, 2005), seems to have reached a minimum after 2010 in France for the generation cohort born in the late 1990's. But the proportion of license owners being the main user of their car has compensated the differences between successive cohorts, resulting in a quite uniform distribution by age of the annual mileage per adult, despite an increasing proportion of students and individuals living with their parents in the new generations of young adults.

What consequences can be derived from the behavior of the younger generation-cohorts in terms of forecasting? Postulating a fixed behavior by age, we obtain quite similar results for the period 2007 to 2032 (-8% based on 1980's behavior vs. -5% based on behaviors observed after 2000). Using the Age-Cohort model and maintaining for future generations the lag observed for the cohort 1990-1994, a slight downward trend (-8% between 2007 and 2032) is obtained for the annual mileage per adult, and a slightly positive trend (+5% on the same period) for car traffic (total number of kms driven) till a flat maximum after 2032. Supposing that after a minimum reached for the cohort born in the 1990's, the lag for new (not yet observed) cohorts increases, reaching for the individuals that will be born around 2025 the lag observed for those born around 1970, the annual mileage per adult is still decreasing (-7% between 2007 and 2032), and it is only after 2030 that the rate of decrease is halved (-6% between 2032 and 2057) compared to that obtained with a constant lag (-3% on the same period).

In the life Expectancy-Period-Cohort model we added economic factors and consequently the model gives less stable forecasts because it exhibits a strong influence of these factors (mainly fuel price), which can explain the renewal of traffic growth since 2015. Maintaining constant the generation lag of people born in the 1990s, shows that its demographic components have a positive effect till about 2030, unlike a simple Age-Cohort model.

Scenarios with both methodologies show that, even in the case of younger generations catching up with their predecessors, the annual mileage per adult would hardly resume growth because of a rapidly increasing proportion of old drivers, with lower mobility, due to population ageing.

6. CONCLUSIONS

In a context of longer stages of life cycle (having a job and children later, retiring at older age), it makes sense to replace age by life expectancy among the three components of an Age-Period-Cohort model; moreover, this approach avoids the collinearity between these components. Indeed, in the context of volatility of economic factors (income growth and fuel price), it is important to take into account their impact as period effects, at least in the medium term.

For forecasting, the specification adopted here which should be improved, is flexible enough to allow:

- In the long run, to take into account the saturating effect of demographic factors using the life expectancy forecasts at each age up to 2060 delivered by the *Institut national de la statistique et des études économiques* (INSEE), and based on hypothesis on generation gaps for cohorts whose automotive behavior has not yet been surveyed; a conservative hypothesis consists in keeping the coefficient estimated for the cohort born in the 1990s.
- In the medium term, to build differentiated scenarios for income growth at different stages of the life cycle (e.g. slower growth at retirement age, as shown by the changes of taxation rate (*contribution sociale généralisée - CSG*) for retirement pensions in 2018.
- To elaborate contrasted scenarios concerning fuel price at an aggregate level, and fuel efficiency for taking into account of rebound effects, possibly by age.

However, major uncertainty comes from changes in economic factors (mainly fuel price and a carbon tax) and political factors (restraints of car use) , and more research is needed for calibrating their influence in the context of major technical and organizational innovations (autonomous car, carpooling, short term car rental membership, rent a bike, new services, etc.). Moreover, spatial factors e.g. density, are not explicitly taken into account by our approach, despite of their important influence on automotive behavior. Let us suggest that they should be integrated by implementing the life Expectancy-Period-Cohort model separately on contrasted types of zones for which demographic forecasts are available (e.g. a longer life expectancy for the inhabitants of Paris region than for the rest of France as well as a higher supply of public transportation and consequently less private car use), then to aggregate the results.

Table 1. License holding along the life cycle by cohort (%)

Age	18-22	23-27	28-32	33-37	38-42	43-47	48-52	53-57	58-62	63-67	68-72	73-77	78-82	83-87	88-92
Individuals born in:															
All	67%	87%	92%	94%	94%	94%	92%	91%	90%	88%	85%	81%	78%	74%	68%
1914-1917	,	,	,	,	,	,	,	,	,	,	,		68%	61%	46%
1918-1921	,	,	,	,	,	,	,	,	,	,	,		74%	71%	68%
1922-1925	,	,	,	,	,	,	,	,	,	,		77%	76%	76%	73%
1926-1929	,	,	,	,	,	,	,	,	,		79%	76%	77%	76%	
1930-1933	,	,	,	,	,	,	,	,		85%	81%	80%	81%		,
1934-1937	,	,	,	,	,	,	,		88%	87%	85%	87%		,	,
1938-1941	,	,	,	,	,	,	,		88%	89%	90%		,	,	,
1942-1945	,	,	,	,	,	,		92%	91%	91%	91%		,	,	,
1946-1949	,	,	,	,	,		92%	90%	89%	91%		,	,	,	,
1950-1953	,	,	,	,		92%	90%	91%	91%		,	,	,	,	,
1954-1957	,	,	,		94%	94%	92%	92%		,	,	,	,	,	,
1958-1961	,	,	,		92%	93%	94%		,	,	,	,	,	,	,
1962-1965	,	,		95%	94%	94%	94%		,	,	,	,	,	,	,
1966-1969	,		93%	94%	94%	95%		,	,	,	,	,	,	,	,
1970-1973		90%	93%	93%	94%		,	,	,	,	,	,	,	,	,
1974-1977	74%	87%	92%	94%		,	,	,	,	,	,	,	,	,	,
1978-1981	75%	87%	92%		,	,	,	,	,	,	,	,	,	,	,
1982-1985	64%	84%	90%		,	,	,	,	,	,	,	,	,	,	,
1986-1989	56%	85%		,	,	,	,	,	,	,	,	,	,	,	,
1990-1993	66%		,	,	,	,	,	,	,	,	,	,	,	,	,

Source : ParcAuto panel survey 1994-2015.

Table 2a. Age-Cohort Models by Gender, 1994-2017

	Drivers' License				Main users/drivers' license				Annual mileage/adult (km)			
	Men		Women		Men		Women		Men		Women	
Age	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
18-22	0.748	0.004	0.705	0.006	0.439	0.008	0.250	0.009	5954.08	182.78	1176.33	140.65
23-27	0.929	0.004	0.891	0.005	0.656	0.007	0.479	0.008	11353.00	168.54	6063.03	127.17
28-32	0.970	0.003	0.927	0.005	0.785	0.006	0.613	0.007	13614.00	141.82	7853.96	110.22
33-37	0.968	0.003	0.931	0.004	0.810	0.005	0.672	0.006	13052.00	120.43	8204.79	96.19
38-42	0.967	0.003	0.926	0.004	0.815	0.005	0.712	0.006	12176.00	120.26	8393.03	95.89
43-47	0.963	0.003	0.932	0.004	0.829	0.005	0.727	0.006	11856.00	124.22	8404.25	96.71
48-52	0.955	0.003	0.923	0.004	0.809	0.005	0.754	0.006	10877.00	129.41	8080.17	99.31
53-57	0.954	0.003	0.916	0.005	0.824	0.006	0.742	0.007	10389.00	144.52	7120.36	108.73
58-62	0.955	0.004	0.909	0.005	0.846	0.006	0.727	0.007	9449.60	157.55	6223.74	119.55
63-67	0.957	0.004	0.918	0.005	0.859	0.007	0.741	0.008	8698.57	165.54	5868.35	125.66
68-72	0.957	0.004	0.916	0.006	0.851	0.007	0.760	0.009	7338.99	177.69	5571.10	134.75
73-77	0.950	0.004	0.902	0.006	0.828	0.008	0.776	0.010	5696.88	194.58	5293.05	148.53
78-82	0.944	0.005	0.898	0.007	0.778	0.009	0.773	0.011	3806.81	221.94	5036.25	170.43
83-87	0.937	0.007	0.871	0.010	0.665	0.012	0.743	0.015	2080.76	286.40	4639.95	217.58
88-92	0.909	0.011	0.748	0.015	0.524	0.019	0.623	0.027	948.61	461.31	3959.19	333.41
93-97	0.894	0.025	0.441	0.029	0.346	0.045	0.424	0.069	1373.32	1067.18	2673.28	624.35
YEARS 2004-2006*	0.015	0.002	-0.020	0.003	-0.012	0.003	0.015	0.004	-215.58	83.537	81.0764	63.54004

Table 2b. Age-Cohort Models by Gender (continued) – Generation gap with the Reference Cohort 1960-1964												
	Drivers' License				Main users/drivers' license				Annual mileage/adult (km)			
	Men		Women		Men		Women		Men		Women	
COHORT born in:												
1910-1914	-0.082	0.012	-0.336	0.018	-0.017	0.021	-0.583	0.031	1869	494	-3991	386
1915-1919	-0.040	0.008	-0.375	0.014	-0.033	0.015	-0.472	0.024	1348	360	-4060	309
1920-1924	-0.007	0.005	-0.260	0.008	0.027	0.009	-0.462	0.012	2090	230	-4128	181
1925-1929	0.005	0.005	-0.224	0.007	0.036	0.008	-0.420	0.010	2365	202	-3985	156
1930-1934	0.014	0.004	-0.150	0.006	0.039	0.007	-0.343	0.009	2637	186	-3390	142
1935-1939	0.022	0.004	-0.092	0.006	0.046	0.007	-0.305	0.008	2777	175	-3011	133
1940-1944	0.028	0.004	-0.043	0.006	0.029	0.007	-0.235	0.008	2672	168	-2419	127
1945-1949	0.014	0.003	-0.035	0.005	0.016	0.006	-0.183	0.007	1358	151	-1876	115
1950-1954	0.002	0.003	-0.020	0.005	-0.001	0.006	-0.105	0.007	720	141	-1302	109
1955-1959	-0.004	0.003	0.006	0.004	-0.007	0.005	-0.037	0.006	-186	130	-459	103
1960-1964	0	0	0	0	0	0	0	0	0	0	0	0
1965-1969	0.005	0.003	0.006	0.004	0.000	0.005	0.057	0.006	-479	130	664	101
1970-1974	0.000	0.003	0.016	0.005	-0.007	0.005	0.110	0.006	-1287	137	1394	106
1975-1979	-0.014	0.004	0.003	0.005	-0.007	0.006	0.133	0.007	-1866	154	1574	119
1980-1984	-0.035	0.004	-0.007	0.006	0.028	0.007	0.199	0.008	-2185	172	2195	130
1985-1989	-0.097	0.005	-0.043	0.007	0.061	0.009	0.243	0.010	-2686	212	2052	156
1990-1994	-0.064	0.006	-0.038	0.009	0.011	0.012	0.212	0.013	-3193	267	1640	201
1995-1999	-0.105	0.008	-0.078	0.013	0.028	0.017	0.239	0.021	-3551	353	1437	293
Adj. R^2	0.946		0.866		0.818		0.647		0.549		0.414	

Source : Parc-Auto panel survey 1994-2017.

* years for which the file of adults has been built directly from the individuals', not from the households' datafile.

Table 3. Main user of a car per license holder along the life cycle by cohort (%), 1994-2015

Age	18-22	23-27	28-32	33-37	38-42	43-47	48-52	53-57	58-62	63-67	68-72	73-77	78-82	83-87	88-92
Individuals born in:															
All	45%	64%	75%	78%	78%	77%	75%	73%	70%	70%	68%	65%	59%	50%	38%
1914-1917	,	,	,	,	,	,	,	,	,	,	,		48%	46%	33%
1918-1921	,	,	,	,	,	,	,	,	,	,	,		53%	40%	22%
1922-1925	,	,	,	,	,	,	,	,	,	,		64%	56%	53%	48%
1926-1929	,	,	,	,	,	,	,	,	,		63%	63%	61%	51%	
1930-1933	,	,	,	,	,	,	,	,		66%	68%	64%	61%		,
1934-1937	,	,	,	,	,	,	,		66%	68%	68%	67%		,	,
1938-1941	,	,	,	,	,	,	,		68%	69%	71%		,	,	,
1942-1945	,	,	,	,	,	,		68%	70%	73%	73%		,	,	,
1946-1949	,	,	,	,	,		69%	71%	73%	75%		,	,	,	,
1950-1953	,	,	,	,		73%	72%	74%	72%		,	,	,	,	,
1954-1957	,	,	,		73%	74%	75%	78%		,	,	,	,	,	,
1958-1961	,	,	,		72%	77%	79%		,	,	,	,	,	,	,
1962-1965	,	,		74%	79%	81%	81%		,	,	,	,	,	,	,
1966-1969	,	67%	70%	76%	82%	82%		,	,	,	,	,	,	,	,
1970-1973		59%	76%	81%	84%		,	,	,	,	,	,	,	,	,
1974-1977	34%	61%	75%	82%		,	,	,	,	,	,	,	,	,	,
1978-1981	41%	65%	81%		,	,	,	,	,	,	,	,	,	,	,
1982-1985	50%	68%	77%		,	,	,	,	,	,	,	,	,	,	,
1986-1989	56%	67%		,	,	,	,	,	,	,	,	,	,	,	,
1990-1993	47%		,	,	,	,	,	,	,	,	,	,	,	,	,

Source : ParcAuto panel survey 1994-2015.

Table 4. Main user of a car per adult along the life cycle by cohort (%), 1994-2015

Age	18-22	23-27	28-32	33-37	38-42	43-47	48-52	53-57	58-62	63-67	68-72	73-77	78-82	83-87	88-92
Individuals born in:															
All	30%	56%	69%	73%	73%	72%	69%	66%	63%	62%	58%	52%	46%	37%	26%
1914-1917													32%	28%	15%
1918-1921													39%	28%	15%
1922-1925												49%	43%	40%	35%
1926-1929											50%	48%	47%	38%	
1930-1933										57%	55%	51%	50%		
1934-1937									58%	59%	58%	58%			
1938-1941									60%	61%	64%				
1942-1945								62%	63%	66%	67%				
1946-1949							64%	64%	65%	68%					
1950-1953							65%	67%	66%						
1954-1957						69%	68%	71%							
1958-1961					67%	71%	74%								
1962-1965				70%	74%	76%	76%								
1966-1969			65%	71%	77%	78%									
1970-1973		53%	70%	75%	79%										
1974-1977	25%	53%	70%	76%											
1978-1981	30%	56%	74%												
1982-1985	32%	57%	69%												
1986-1989	32%	57%													
1990-1993	31%														

Source : Parc-Auto panel survey 1994-2015.

Table 5. Annual mileage per vehicle along the life cycle by cohort (km), 1994-2015

Age	18-22	23-27	28-32	33-37	38-42	43-47	48-52	53-57	58-62	63-67	68-72	73-77	78-82	83-87	88-92
Individuals born in:															
All	11778	15512	15377	14851	14416	14349	13901	13106	12058	11319	10183	8874	7379	6099	5642
1914-1917	.	.	.	.	.	.	.	.	.	.	.		7886	8066	6500
1918-1921	.	.	.	.	.	.	.	.	.	.	.		7504	6004	3837
1922-1925	.	.	.	.	.	.	.	.	.	.		9321	7648	5904	4577
1926-1929	.	.	.	.	.	.	.	.	.		10391	9499	7473	5969	
1930-1933	.	.	.	.	.	.	.	.		11972	10587	8584	6983		.
1934-1937	.	.	.	.	.	.	.		12770	12028	10399	8555		.	.
1938-1941	.	.	.	.	.	.	.		13102	11924	10009		.	.	.
1942-1945	.	.	.	.	.	.		14911	13012	11099	9682		.	.	.
1946-1949	.	.	.	.	.		14880	13551	11505	10227		.	.	.	.
1950-1953	.	.	.	.		15405	14785	12880	11040		.	.	.	.	.
1954-1957	.	.	.		14813	14907	13342	11703		.	.	.	.	.	.
1958-1961	.	.	.		15315	14605	13116		.	.	.	.	.	.	.
1962-1965	.	.		15416	14428	13884	13447		.	.	.	.	.	.	.
1966-1969	.		16648	15451	14069	12938		.	.	.	.	.	.	.	.
1970-1973		16799	16213	14589	13839		.	.	.	.	.	.	.	.	.
1974-1977	13023	16107	15341	14214		.	.	.	.	.	.	.	.	.	.
1978-1981	12384	15657	14119		.	.	.	.	.	.	.	.	.	.	.
1982-1985	12265	14661	14114		.	.	.	.	.	.	.	.	.	.	.
1986-1989	11220	13607		.	.	.	.	.	.	.	.	.	.	.	.
1990-1993	10711		.	.	.	.	.	.	.	.	.	.	.	.	.

Source : ParcAuto panel survey 1994-2015.

Table 6. Annual mileage per adult along the life cycle by cohort (km), 1994-2015

Age	18-22	23-27	28-32	33-37	38-42	43-47	48-52	53-57	58-62	63-67	68-72	73-77	78-82	83-87	88-92
Individuals born in:															
All	3509	8640	10631	10845	10577	10344	9564	8647	7614	6998	5860	4615	3374	2239	1451
1914-1917													2547	2268	980
1918-1921													2932	1697	582
1922-1925												4568	3262	2378	1603
1926-1929											5196	4561	3477	2294	
1930-1933										6773	5791	4380	3486		
1934-1937									7369	7099	5989	5003			
1938-1941									7846	7310	6399				
1942-1945								9305	8243	7349	6495				
1946-1949							9514	8623	7478	6949					
1950-1953						10343	9567	8586	7235						
1954-1957					10118	10339	9127	8367							
1958-1961					10234	10382	9736								
1962-1965				10831	10694	10508	10195								
1966-1969			10749	11023	10892	10093									
1970-1973		8955	11387	11005	10924										
1974-1977	3282	8497	10662	10855											
1978-1981	3751	8800	10489												
1982-1985	3899	8340	9717												
1986-1989	3550	7786													
1990-1993	3295														

Source : Parc-Auto panel survey 1994-2015.

Table 7. Forecasting car use and ownership with Age Cohort model and Life Expectancy-Period-Cohort model - France 2007-2057

CAR USE

Fixed behavior of:	Variable	Type of model	2007	2012	2017	2022	2027	2032	2037	2042	2047	2052	2057	2032/ 2007	2057/ 2032	2057/ 2007
1984-86	km/adult	FB	5165	5068	4973	4885	4804	4736	4685	4643	4613	4590	4571	-8.3%	-3.5%	-11.5%
1994-96	km/adult	FB	7187	7104	7030	6930	6825	6731	6657	6593	6545	6509	6486	-6.3%	-3.7%	-9.8%
2004-06	km/adult	FB	7654	7592	7524	7450	7369	7276	7212	7160	7121	7094	7070	-5.0%	-2.8%	-7.6%
2013-15	km/adult	FB	7623	7532	7453	7384	7310	7227	7154	7090	7045	7010	6983	-5.2%	-3.4%	-8.4%
Age-Cohort with:																
Constant lag	km/adult	ACCL	8039	7937	7782	7655	525	7392	7274	7171	7091	7015	6941	-8.1%	-6.1%	-13.7%
	Total Traffic (bilion km)	ACCL	387	394	397	400	403	406	407	407	407	407	407	4.9%	0.3%	5.2%
Reversed lag	km/adult	ACRL	8039	7937	7782	7655	7555	7485	7422	7391	7380	7366	7282	-6.9%	-2.7%	-9.4%
	Total Traffic (bilion km)	ACRL	387	394	397	400	405	411	415	420	424	427	430	6.2%	4.6%	11.1%
Life Expectancy -Period-Cohort with:																
Constant lag	km/adult	EPC	7615	7334	8477	8543	8603	8605						13%		
	Total Traffic (bilion km)	EPC	366	364	432	447	461	472						29%		
CAR OWNERSHIP																
Age-Cohort with constant lag	Main users per adult	ACCL	0.664	0.679	0.692	0.703	0.711	0.717	0.721	0.722	0.723	0.723	0.713	8.1%	-0.6%	7.4%
	Car fleet (milions)	ACCL	31.9	33.7	35.3	36.8	38.1	39.4	40.3	41.0	41.5	41.9	41.8	23.3%	6.2%	30.9%

FB: Fixed Behavior; ACCL : Age-Cohort with Constant Lag; ACRL : Age-Cohort with Reversed Lag; EPC : life Expectancy-Period-Cohort with constant lag.

Source : Calculations by IFSTTAR from Parc-Auto panel surveys.

Table 8. Model EPC for average km per adult					
Effect	Variable name	Estimated value of parameters	Error	Value of test t	Pr > |t|
Real Income Effect	CUINC	0.12135	0.00165	73.57	<.0001
Fuel Price Effect	Pfuel	-29.12967	0.72406	-40.23	<.0001
Life expectancy Effect	LE	641.00293	5.15904	124.25	<.0001
	LE^2	-9.47999	0.08867	-106.92	<.0001
Cohort Effect					
Individuals born:					
-before 1955	gnbf1955	-753.74337	53.16550	-14.18	<.0001
- between 1955 and 1964	Reference	0	0		
- between 1965 and 1979	gn196579	2459.66101	68.24797	36.04	<.0001
- between 1980 and 1989	gn198089	3542.75796	109.53351	32.34	<.0001
- after 1989	gnAF1989	2371.30057	175.64685	13.50	<.0001
Source : Estimated from Parc-Auto 1994-2016.					

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