
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-Cohorts. In view of the over-determination generated by the mechanical link between these three factors, we propose a Life Expectancy-Period-Cohort model (EPC), replacing age by life expectancy at this age and at each date makes it possible to directly estimate the model by keeping three components, while making the approach more consistent with the extension of life cycle stages (extension of 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. We will compare the results with the various previous models.

We consider the adult population (i.e., of driving age) and consider 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 models are estimated on the data of the Parc-Auto Kantar-SOFRES 1994-2015 (often 2016) panel survey, we treat an example of medium-term projection of the annual mileage knowing that in the long term the technical innovations (autonomous vehicle, electric and hybrid engines) and organizational (car sharing, carpooling, ...) are likely to fundamentally change the conditions of use of the car.

UN MODÈLE ESPÉRANCE DE VIE-PÉRIODE-COHORTE POUR PROJETER L´ÉQUIPEMENT EN VOITURE PARTICULIÈRE ET LA CIRCULATION AUTOMOBILE

Mots-clés : Motorisation individuelle, utilisation de l'automobile, espérance de vie, facteurs démographiques et économiques, prospective

Résumé :
Dans la plupart des pays industrialisés, après des décennies de croissance progressivement ralentie, la circulation automobile a stagné dans les années 2000. Ce phénomène a été attribué non seulement aux facteurs économiques classiques (stagnation des revenus, volatilité à la hausse du prix des carburants) et à une certaine ré-urbanisation liée à la métropolisation, mais aussi à des facteurs démographiques (vieillissement de la population, allongement des étapes du cycle de vie conduisant notamment à différer le passage du permis de conduire dans les jeunes générations). Nous avons déjà traité ces questions via des modèles Age-Période-Cohorte, et plus souvent Âge-Cohorte. Nous proposons un modèle Espérance de vie-Période-Cohorte (EPC) calibré sur les données du panel Parc-Auto Kantar-SOFRES 1994-2016 en remplaçant l'âge par l'espérance de vie à cet âge. Les effets de période sont spécifiés en introduisant le revenu et le prix des carburants comme variables explicatives. Enfin, nous comparons les résultats des différents modèles.

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].
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 in 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 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).
After a brief literature review (section 2), our individual based nested approach (holding a driving license / being the main user of a car / annual mileage) will be presented (section 3). Then, after a descriptive analysis (section 4) an example of middle term forecasts will be presented based on EPC modelling (section 5).

1. 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 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. Using Parc-Auto panel survey data for France from 1994 to 2016, we will investigate the behavior of the youngest generations and their impact on traffic growth, being aware that the context is quite specific: 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.

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 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 2400 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 parents' 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 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¨.

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 population growth, changes in behavior through generations, as well as period effects represented by real income per consumption unit and fuel price.

2. 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 life cycle has been split into 16 age brackets (from “18-22 years old” to “93-97 years old”).

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

Car use at individual level has been decomposed into three rather independent steps [Grimal, 2015] :

- Driving license holding,
- Car ownership, i.e. the proportion of individuals holding a driving license, 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.

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.

3. 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 (tables 1 and 2), with a dummy variable for the years 2004 to 2006 taking into account the slight heterogeneity of data for this period; in fact, this dummy is significant only for driving license holding and for the proportion of main users among license 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 license

Towards the end of life cycle, the proportion of driving license holders seems to decline in each cohort (Table 3) but very late in the life-cycle. 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 license than men. Considering separately each gender, there are quite few significant declines of license holding at old age : indeed, almost no women have lost their license, 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 license 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 license 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 license 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.

Up to the cohort 1986-89, there is an important decrease of the proportion of licensed people between 18 and 22 years. But when getting older, these cohorts tend to catch up with those born before. This makes questionable the main hypothesis on which relies the Age-Cohort model, i.e. that the trajectories of each cohort are parallel all along their life cycle.

The Age-Cohort model (Table 1) shows that after 30 years old, the rate of driving license owners is not significantly different from 96% for men, and from 88% for women (up to 75 years old). Over the whole period 1994-2015, around 20 years old it is 76% for men and 67% for women, while around 25 it has almost reached its maximum (94% for men and 85% for women).

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. Men born after 1980 are significantly less licensed, while this phenomenon is less marked and appears later for women.

4.2. Car ownership

According to the Age-Cohort model (Table 1), more than 80% of licensed men (resp. 60% for women) are the main user of a car when they are between 35 and 85 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 people born till the 1920's to over +30 points for those born in the 1980's. Thus, for the most recent generations, there is a kind of compensation between a low license rate and a high proportion of people having their own car among licensed individuals.

For young adults (18-22 years) the proportion of license holders who are the main user of a car (Table 4), is increasing from 34% for those born around 1975 to 56% for those born in the late 1980's, and 47% for those born in the early 1990's, while the rate of main users per adult along the life cycle (Table 5) is rather flat, showing the compensation mentioned before. But around 35 years old, the differences between adults born in the 1960's and 1970's are much smaller. The Age-Cohort model gives, for car ownership, a flat maximum around 2040 for the average number of main users per adult, and around 2050 for the total number of vehicles (Table 8).

Does it mean that the following generations will catch up with them when they will reach 35 years?

Table 1: Age-Cohort Models by Gender

	Drivers' License				Main users/drivers' license			
	Men		Women		Men		Women	
Age	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
18-22	0.75805	0.00520	0.67207	0.00760	0.39573	0.00887	0.10271	0.01110
23-27	0.93502	0.00482	0.85343	0.00698	0.62251	0.00796	0.32873	0.00988
28-32	0.96863	0.00430	0.88382	0.00637	0.76235	0.00704	0.47143	0.00897
33-37	0.96483	0.00398	0.88860	0.00597	0.79710	0.00652	0.54549	0.00840
38-42	0.96585	0.00370	0.88512	0.00559	0.81153	0.00606	0.58903	0.00789
43-47	0.96272	0.00323	0.89360	0.00493	0.83638	0.00529	0.60499	0.00698
48-52	0.95243	0.00317	0.88376	0.00474	0.82501	0.00520	0.63540	0.00674
53-57	0.95208	0.00320	0.87912	0.00465	0.84654	0.00525	0.62437	0.00663
58-62	0.95286	0.00321	0.87258	0.00466	0.87570	0.00526	0.60963	0.00667
63-67	0.95471	0.00357	0.87782	0.00522	0.88906	0.00585	0.62793	0.00753
68-72	0.95358	0.00395	0.87034	0.00581	0.88198	0.00646	0.64662	0.00847
73-77	0.94575	0.00439	0.85390	0.00648	0.86121	0.00717	0.65512	0.00961
78-82	0.94065	0.00512	0.84004	0.00764	0.81285	0.00838	0.64945	0.01161
83-87	0.92278	0.00660	0.79436	0.01009	0.69590	0.01088	0.57617	0.01590
88-92	0.90238	0.01181	0.62413	0.01606	0.54512	0.01913	0.43582	0.02901
93-97	0.88582	0.02735	0.32115	0.03079	0.39575	0.04577	0.14971	0.07242
YEARS 2004-2006*	-0.01464	0.00192	-0.01858	0.00278	0.00823	0.00321	0.03086	0.00410
COHORT born in:								
1914-1917	-0.07727	0.01042	-0.32367	0.01749	-0.07351	0.01749	-0.37726	0.03089
1918-1921	-0.02686	0.00636	-0.23537	0.01024	-0.03239	0.01045	-0.33958	0.01630
1922-1925	0.01761	0.00513	-0.19686	0.00794	0.02039	0.00837	-0.30861	0.01224
1926-1929	0.00525	0.00466	-0.17027	0.00697	0.01391	0.00763	-0.29923	0.01051
1930-1933	0.01588	0.00424	-0.11193	0.00627	0.01260	0.00692	-0.22620	0.00927
1934-1937	0.02295	0.00404	-0.06191	0.00592	0.03853	0.00660	-0.20484	0.00865
1938-1941	0.02552	0.00388	-0.02858	0.00568	0.01602	0.00634	-0.15257	0.00823
1942-1945	0.02622	0.00371	-0.00294	0.00542	0.03200	0.00605	-0.09586	0.00778
1946-1949	0.01731	0.00339	0.00467	0.00498	0.01967	0.00555	-0.05039	0.00712
1950-1953	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
1954-1957	-0.00241	0.00349	0.03962	0.00524	-0.00522	0.00573	0.09181	0.00741
1958-1961	0.00156	0.00363	0.04326	0.00544	0.02109	0.00596	0.10001	0.00768
1962-1965	0.00167	0.00385	0.05309	0.00572	0.03663	0.00630	0.15711	0.00806
1966-1969	0.00677	0.00405	0.04410	0.00603	0.03911	0.00663	0.20456	0.00850
1970-1973	-0.00145	0.00430	0.05662	0.00633	0.03641	0.00705	0.25904	0.00890
1974-1977	-0.00948	0.00458	0.04508	0.00678	0.03439	0.00752	0.26486	0.00958
1978-1981	-0.01494	0.00499	0.04414	0.00719	0.06206	0.00826	0.34056	0.01019
1982-1985	-0.08135	0.00558	0.01410	0.00807	0.07373	0.00945	0.36919	0.01158
1986-1989	-0.11642	0.00655	-0.02945	0.00912	0.12105	0.01152	0.39704	0.01350
1990-1993	-0.08952	0.00779	-0.01049	0.01110	0.06821	0.01406	0.35834	0.01690
Adj.R^2	0.94640		0.86300		0.84210		0.65110	

Source : Parc-Auto panel survey 1994-2015. *Years for which the file of adults has been built directly from the individuals`, not from the households`datafile.

Table 2: Age-Cohort Models for the annual mileage per adult		
Age	Coef.	Std. Err.
18-22	3168	144
23-27	8261	133
28-32	10388	119
33-37	10469	110
38-42	10182	102
43-47	10025	89
48-52	9380	87
53-57	8439	87
58-62	7498	88
63-67	7022	100
68-72	6202	111
73-77	5195	125
78-82	4028	147
83-87	2875	197
88-92	1826	319
93-97	1236	646
YEARS 2004-2006*	69	55

COHORT individuals born in:		
1910-1914	-617	329
1915-1919	-664	249
1920-1924	-557	150
1925-1929	-474	129
1930-1934	-214	115
1935-1939	45	106
1940-1944	374	101
1945-1949	-41	90
1950-1954	0	0
1955-1959	81	93
1960-1964	419	99
1965-1969	525	108
1970-1974	572	116
1975-1979	326	128
1980-1984	403	140
1985-1989	-46	166
1990-1994	-449	205
1995-1999	-1258	346
Adj.R^2	0.4661	

Source : Parc-Auto panel survey 1994-2015,
* Years for which the file of adults has been built directly from the individuals', not from the households' datafile.

Extrapolated coefficients	constant lag	reversed lag
2000-2004	-449	-449
2005-2009	-449	-46
2010-2014	-449	403
2015-2019	-449	326
2020-2024	-449	572
2025-2029	-449	525
2030-2034	-449	419
2035-2039	-449	81

Table 3: 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 4: Main user of a car per license holder 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	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 5: Main user of a car per adult 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	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 6: Annual mileage per vehicle along the life cycle by cohort (km)

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 7: Annual mileage per adult along the life cycle by cohort (km)

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 8: Forecasting car use and ownership - France 2007-2057

Fixed behavior of:	variable	Type of model	2007	2012	2017	2022	2027	2032	2037	2042	2047	2052	2057	2032/2007	2057/2032	2057/2007
CAR USE																
1984-86	km/adult	FB	5165	5068	4973	4885	4804	4736	4685	4643	4613	4590	4571	-8.32%	-3.47%	-11.5%
1994-96	km/adult	FB	7187	7104	7030	6930	6825	6731	6657	6593	6545	6509	6486	-6.34%	-3.65%	-9.8%
2004-06	km/adult	FB	7654	7592	7524	7450	7369	7276	7212	7160	7121	7094	7070	-4.95%	-2.82%	-7.6%
2013-15	km/adult	FB	7623	7532	7453	7384	7310	7227	7154	7090	7045	7010	6983	-5.20%	-3.38%	-8.4%
Age-Cohort with:																
Constant lag	km/adult	ACCL	8039	7937	7782	7655	7525	7392	7274	7171	7091	7015	6941	-8.05%	-6.11%	-13.66%
	Total Traffic (bilion km)	ACCL	387	394	397	400	403	406	407	407	407	407	407	4.91%	0.28%	5.20%
Reversed lag	km/adult	ACRL	8039	7937	7782	7655	7555	7485	7422	7391	7380	7366	7282	-6.89%	-2.71%	-9.41%
	Total Traffic (bilion km)	ACRL	387	394	397	400	405	411	415	420	424	427	430	6.23%	4.58%	11.10%
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	8.08%	-0.59%	7.44%
	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	23.31%	6.17%	30.92%

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.

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 7). This is partly due to a higher fuel price after 2005.

The resulting annual mileage per adult according to age is bell shaped, with a flat maximum moving slightly from the thirties to the forties (Table 7). 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 Age-Cohort model (Table 2).

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.

4. Forecasting the annual mileage per adult

5.1- Forecasting from fixed behavior by age to the 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.

However, 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. between 68 and 72 years old, people drove 2300 km annually in 1984-86, 5000 km in 1994-96, 5700 km in 2004-06 and 6100 km in 2013-15). The resulting forecast of the annual mileage driven by the whole population for 2032 compared to 2007 is a decrease of 8% with the 1984-86 reference, while it is only 5% with a reference period after 2000 (Table 8).

For combining life cycle and generation effects, an Age-Cohort model is implemented [Dejoux et al., 2009]. It shows for the annual mileage per adult, 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 constant the coefficient of the cohort born in the early 1990's (i.e. gap with individuals born around 1960) for those whose behavior has not been observed (i.e. born after 1997),
- "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.

Between 2007 and 2032, there is not much difference between these simulations (-8% for "constant lag" vs. -7% for "reversed lag"), but between 2032 and 2057, the contrast could be higher (-6% vs. -3%).

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

Taking into account of longer stages in the life cycle shown in the literature review as well as in the descriptive analysis, the Life Expectancy-Period-Cohort model seems quite attractive. Moreover, contrary to Age-Period-Cohort, it is not subject to collinearity problems for estimation (d'Albis and Badji, 2017).

The dependent variable is KMA, the annual mileage of the car at date t for which the individual is the main user; KMA=0 when this individual is not the main user of a vehicle.

The explanatory variables are :

- - 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 GEN1920 to GEN1995 for cohorts (GEN1920 for individuals born before 1925, GEN1927 for those born between 1925 and 1929,…, GEN1995 for those born after 1989); the reference cohort, for which the coefficient is set to 0, is GEN1962;
- And for period effects, the economic variables:
- * CUINC real income of the household per consumption unit,
- * PFUEL the national index of fuel price, for the type of fuel (diesel or petrol) of the car, taking inflation into account (2015=100).

The dummy T200406 for years 2004 to 2006 takes into account the slight heterogeneity of Parc-Auto data for this short period, but it is not very significant. Table 9 gives the estimation of coefficients for average km per adult in the EPC model.

Table 9: Model E-P-C for average km per adult

Effect	Variable name	Estimated value of parameters	Error	Value of test t	Pr > |t|
Real Income Effect	CUINC	0.12058	0.00166	72.76	<,0001
Fuel Price Effect	Pfuel	-30.9933	0.80081	-38.7	<,0001
Life expectancy Effect	LE	659.97673	6.09057	108.36	<,0001
	LE²	-9.79638	0.10222	-95.84	<,0001
A typical Period Effect	t200406	107.63803	56.08353	1.92	0.055
Cohort Effect	gen1920	-396.16474	109.38118	-3.62	0.0003
	gen1927	-676.0384	100.14578	-6.75	<,0001
	gen1932	-621.67759	89.6495	-6.93	<,0001
	gen1937	-779.54723	87.52852	-8.91	<,0001
	gen1942	-796.43089	89.08777	-8.94	<,0001
	gen1947	-1114.2034	84.70436	-13.15	<,0001
	gen1952	-669.34957	86.54183	-7.73	<,0001
	gen1957	-13.19478	85.814	-0.15	0.8778
	gen1967	2204.90613	87.65336	25.15	<,0001
	gen1972	2694.24567	94.08728	28.64	<,0001
	gen1977	2714.27198	108.30902	25.06	<,0001
	gen1982	3746.23898	124.06348	30.2	<,0001
	gen1987	3696.87759	155.1281	23.83	<,0001
	gen1995	2685.17812	185.52984	14.47	<,0001

Source : Estimated from Parc-Auto 1994-2016.

For forecasting, the specification adopted here should allow:
- To take into account 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;
- 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.
- Provisional results give a 13% increase of the annual mileage per adult between 2007 and 2032; it is only +8.5% when keeping the fuel prices of 2007 constant instead of that of 2016 in 2032. 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).

5. Conclusion

Driver`s license holding for young adults (aged 18 to 22) seems to have reached a minimum 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 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 long term 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 2035. 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).

The life Expectancy-Period-Cohort model gives less stable forecasts, because it exhibits a strong influence of economic 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, its demographic components have a positive effect till about 2030, unlike to a simple Age-Cohort model.

Thus, 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 due to population ageing. However, major uncertainty comes from changes in economic factors (mainly fuel price), and more research is needed for calibrating their influence in the context of major technical and organizational innovations (autonomous car, new services, etc.).

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