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Is there a limit to traffic growth ? Potential demand and convergence paths towards saturation

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Abstract

Traffic growth has temporarily stopped during the 2000's, before coming back to growth after 2010, in relation with economic recovery and decreasing fuel prices. However, there are strong reasons to believe that traffic growth is potentially limited, among which close completion of the diffusion process for car ownership, limited travel time budgets in relation with stable or declining travel speeds, decreasing marginal returns of additional car travel and infrastructure capacity restrictions. Representing car ownership as the result of an equilibrium between potential demand and economic constraints, and assuming additional car travel to be of decreasing marginal utility, one can implement a model to estimate saturation thresholds and describe the convergence path towards saturation. The model is disaggregated by household type and vehicle rank to account for heterogeneous choice sets and structural change in demographics and activity rates. It highlights the existence of an incomplete diffusion process for some groups and allows to break down potential demand between negotiable and non-negotiable needs. Projection results prove the existence of residual potential growth for car equipment among non-working adults which is nonetheless limited, while population ageing and changing cohabitation patterns will have a downwards effect on demand. By combining these results with car mileage projections, we find average car traffic per adult to increase gently until 2040, and remain almost stable afterwards. From this date, traffic trends would be essentially determined by demographic factors.

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Keywords: car equipment ; traffic growth ; potential demand ; saturation.

1. Introduction

Car traffic was long expected to increase indefinitely in direct relation to economic growth. From 1990 to 2003, the total amount of car traffic generated by personal vehicles still rose by 30 %. Likewise, the number of personal cars increased from 24 to 32 million between 1990 and 2016 (CGDD, 2017). Though car traffic growth was partially caused by demographic expansion, it also resulted from increasing car ownership and car mileage per adult, doubling

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between 1974 and the early 2000's (Grimal et al., 2013). However, after decades of continuous growth, the average car mileage per adult temporarily levelled off during the 2000's, in France like in other developed countries (CGDD, 2012a ; Millard-Ball and Schipper, 2011). This break-in-trend raised the issue of future traffic growth in a situation of increasing uncertainty. Goodwin (2010-11) suggested three foreseeable scenarios corresponding to different readings of the events : (a) the « business-as-usual » scenario assumes the current stagnation to be a temporary break caused by difficult economic circumstances (rising fuel prices, economic crisis after 2008…), within a long-run trajectory of growth ; (b) another plausible explanation is that car traffic would have reached a saturation point as the main travel needs would now be satisfied ; (c) finally, one might assume this plateau to be the prelude to a future decline, caused by multiple convergent transitions in the way of life and the comeback of alternatives to the car (Newman and Kenworthy, 2011). Since 2010 though, car traffic gradually came back to growth, even accelerating after 2013 in relation with economic recovery and decreasing fuel prices, following the peak of 2012 (Maurin, 2017). Traffic comeback was also noticed in other countries such as Germany and the USA, highlighting the key contribution of economic drivers (fuel prices, GDP…) to recent traffic trends, including the 2000's plateau (BITRE, 2012 ; Bastian et al., 2016). This recovery does not imply, however, that the very concept of saturation is irrelevant and that it is not to be expected in a more or less distant future. More, prospects of coming saturation are made very credible by a number of trends, such as decreasing levels of car ownership and car mileage from the early 1990's in the largest French metropolitan areas such as Ile-de-France (Cornut et al., 2014), national vehicle fleet growth slowing down from the early 2000's (CGDD, 2017), and the gradual decoupling between traffic growth and the economy (Madre et al., 2002 ; OCDE/ITF, 2011), which is also manifested through decreasing income elasticities of car traffic (Pendyala et al., 1995 ; Goodwin et al., 2004). Though hardly accounted for in official models - for instance through decreasing income elasticities - ideas of saturation appear as an interesting subject to explore, notably in relation with issues of forecasting accuracy and traffic externalities. In section 2, we present different arguments supporting the theory of saturation for car ownership and car traffic. They can be synthesized within a conceptual framework based on the idea of potential demand, where the gap between realized and potential demand is assumed to come from a set of technical, economic, environmental and regulatory constraints. The notion of pseudo-saturation is also introduced for car mileage. This paper will essentially focus on the role of economic drivers by estimating saturation thresholds and modelling the convergence path towards saturation with the relaxation of financial constraints. In section 3, the relation between car ownership, car mileage and income is analyzed by household categories and vehicle rank. Different household groups can indeed be interpreted as different classes of travel needs, being characterized by heterogeneous choice sets for the number of vehicles, while vehicle ranks can be understood as goods of different status and in more or less advanced diffusion stage. Model specification is also exposed. Estimation results are displayed in section 4, while section 5 is devoted to forecasting. Finally, in section 6, the main results of this study are reminded, before we draw up research tracks for the future, underlining some uncertainties and possible model improvements.

2. Discussion on the idea of saturation

The idea that car traffic growth would sooner or later come to an end is not entirely new : in the early works of Tanner and Tulpule (1973), it was usually believed that car traffic growth would come to an end once everyone who wants and needs a car would have one (Goodwin, 2013). By chance, these works also anticipated saturation to come during the first decade of the 2000's, where car traffic indeed levelled off, though probably because of economic circumstances (cf. supra). Since then, a number of studies attempted to estimate empirical saturation thresholds for car ownership and/or car use, such as works by Bussière et al. (1996), Schafer and Victor (2000), BITRE (2012), Madre et al. (2013), Collet et al. (2013), based on different types of econometric and demographic models. From a more theoretical point of view, the idea of saturation was justified by different arguments. Following Goodwin (2013), we expose some of these, before synthetizing them into a generalized concept :

(a) One of them is based on the diffusion process of durable goods, which can be incorporated within the general framework for the diffusion of innovations (Rogers, 2003). The diffusion of equipment goods can usually be modelled through an S-shaped sigmoid-curve tending towards an asymptote that will represent the saturation level for this type of asset. The diffusion process can be complete, if every agent is destined to be equipped with the gradual relaxation of constraints, or incomplete, as definitive limitations to diffusion might persist, related either to the lack of need or to remaining constraints, for instance the permanence of disabilities or inequalities resulting in insufficient financial resources for some population groups. In particular, the diffusion of car ownership could attain its limits, and therefore represent one of the major reasons for traffic stagnation (NSTPRC, 2008 ; Metz, 2010 ; Metz, 2013). However, this observation implies to determine the exact nature of the relation between car ownership and traffic growth. One possible statement is to consider that the increasing number of cars available would result in traffic growth through the increasing number of autonomous drivers owning their personal car. In turns, one could assume the increasing number of cars per household to result just in lowering the average car mileage per vehicle for an unchanged total distance travelled. Though both observations may be relevant within their own scope, the first one seems to be more decisive in shaping traffic trends over a long-run period. In a previous paper, we indeed found average car traffic per adult to increase proportionally to the number of cars per adult from the early 1970's, while the average car use per vehicle has been remaining roughly stationary during the same period, though with mid-term fluctuations related to fuel price volatility (Grimal et al., 2013). As already stated, one could therefore expect average car traffic per adult to reach saturation once every one would be equipped with a personal car, or even before if the diffusion process remains incomplete because of limitations to potential needs or the persistence of financial constraints. For instance, car-related costs along with driving and parking difficulties may be perceived as exceeding the advantages of the car for households living in dense urban areas well-provided with alternative transport supply.

However, the relevant level of analysis for the diffusion process of the car is ambivalent. While some equipments have always been considered as individual, such as the mobile phone or the personal computer, and others always remained household equipments such as most domestic electrical assets (fridge, washing-up machine…), the status of the car has changed over time from a household to an individual good with the growing diffusion of a second vehicle among households, notably related to increasing women activity rates (Papon and Hivert, 2008). As a result, the estimation of saturation thresholds was frequently revised upwards over time (Ingram and Liu, 1999). In addition, the relevant level for modelling the diffusion process of an equipment is directly related to its function which, in the case of the car, appears to be hybrid between common, shared and individual usage. Especially, the main vehicle household is rather multipurpose, being simultaneously used for the commuting needs of the household head, and common leisure/holiday trips of the family, for instance. Within mono-motorized households, the single vehicle is also to be shared between its adult members for their daily travel needs. In contrast, the second vehicle is rather of individual use as being devoted principally to the partner's daily travel needs. The status of the third vehicle is more uncertain as it may correspond, either to an individual equipment devoted to a third adult household member - for instance an adult child still living at the parental home - or to a specialized vehicle - for instance devoted to long-distance trips. By the way, vehicle specialization may also have changed over time : with the increasing availability of a second vehicle, the first vehicle may have become less universal and more focused on the household head's travel needs along with a lesser need of shared usage between adult household members. Given the hybrid status of the car between an individual and collective equipment, either individual or household-based models can be implemented, though most of them are household-based, in part for reasons of survey design and data availability (De Jong et al., 2004), but also for theoretical reasons, in particular the amount of common and shared vehicle use making difficult to utterly assign a car to a given individual. On the other side, an individual approach to auto-mobility might present several advantages, which we exposed in a previous paper (Grimal, 2017).

Not only being halfway between an individual and a collective equipment, the car is also a good of intermediary status between an essential and a luxury item. While being simply motorized has become an essential for most households, upmarket models consist in luxury goods and remain symbols of social status (Coulangeon and Petev, 2013). In addition, while the main vehicle is often considered mandatory, ownership of a second vehicle is more subject to trade-offs depending on individual travel needs and financial constraints, though this status is moving over time along with the diffusion stage of the second vehicle. As a result, while the first vehicle market may already have attained maturity, reserves of potential growth may still exist for the second vehicle as its social diffusion remains incomplete. Therefore, either the collective or individual function of the car, its degree of necessity or social status depend much on vehicle rank. These considerations led us to model car ownership and mileage by vehicle rank, separating the first, second and third vehicle by considering them as distinct goods at different stages of their diffusion process.

(b) Another argument is based on the willingness to devote time to car travel. As daily travel time has remained remarkably stable over a long-run period (Metz, 2013), travel growth was mainly caused by higher travel speeds, allowing travel distances to increase, either for commuting or other purposes (Zahavi, 1974). Here again, this dynamic being itself principally caused by the broader availability of a personal car, one can expect car travel growth to come to an end once every adult would be equipped with a personal car. Also, car travel speeds have themselves increased, contributing to traffic growth by means of improved road infrastructures, both quantitatively and qualitatively. However, real car travel speeds may now be declining, both because of increasing congestion (IAURIF, 2013), infrastructure investment cuts, and due to policy sets going towards decreasing the efficiency of the car, through reducing authorized speeds, dedicated transit lanes, and parking restrictions (Jarrige and Raynard, 2003 ; Cairns et al., 1998 ; Fraser, 2014). One may assume these measures to moderate car travel distances in relation with the limited consent for additional travel time. Nonetheless, people are simultaneously subjected to opposite constraints, resulting from tensions on metropolitan housing markets (Rougerie and Friggit, 2010 ; Vanco, 2012), forcing them to handle increasing commuting distances by orientating residential choices away from employment areas (Le Breton, 2008). Greater commuting distances might also partially be a consequence of the growing conflict between professional and family obligations (Vignal, 2005 ; Vincent et al., 2010), with from one side the increasing injunction to job mobility, and from another side a rather low residential flexibility, resulting from the subscription of residential loans and the permanency of relational, educational and family links locally. While until now individuals have adapted through reducing other trips in order to control daily travel times, this strategy might also attain its own limits as some trips are mandatory, pushing individuals either to relocate, shift to transit where alternatives are attractive enough, or consent to increase daily travel time. Depending on opportunities, opposite constraints may therefore result in different trade-offs, leading either to reduced or increased travel distances and times, and therefore to travel growth or decline. Indeed, though Marchetti (1994) hypothesizes average daily travel time to be some kind of « anthropological invariant », nothing guarantees, however, that this apparent stability would not be broken under the pressure of opposite constraints, given a double binding between speed moderation policies and residential choices oriented by housing markets. Rather than assuming a constant travel time, a more general argument supporting saturation - though it doesn't give an operational criterion to estimate saturation thresholds - is that willingness to devote time to travel is necessarily bounded by other activities, within the framework of a trade-off between concurrent allocations of time budgets.

(c) The average car travel by agent – either the individual or the household - may also be limited by decreasing marginal returns of additional gains in terms of accessibility (trip distances) and/or mobility (trip frequencies) as these correspond to ever-less essential travel needs (Schafer and Victor, 2000 ; Metz, 2010 ; Metz, 2013). In addition, these potential benefits are themselves weakening as car travel speed is coming closer to its upper limit, or is even decreasing. More, the increasing value of time leads to transferring new trips to faster modes such as high speed train and plane (Schafer and Victor, 2000), allowing either substantial time cuts or accessibility benefits, while presenting a greater intrinsec utility, increasing the value of travel by allowing to realize different activities (Papon et al., 2008).

(d) Finally, road infrastructure capacity constraints may also hinder car travel growth, along with road investment cuts caused by the increasing scarcity of budgetary resources and the reorientation of public funds towards alternatives to the road (Papon and Madre, 2003).

Though arguments in favour of saturation may be different in nature, they can all be subsumed through the notion that some mechanisms are rather finite than infinite, and may have an upper limit which is determined by capacity constraints. If assuming the diffusion rate of a given item to result from an equilibrium between perceived needs[1] and a set of constraints hindering out their realization, the saturation level can also be described as the potential demand or market size for this type of good, being an indicator of demand in the absence of constraints. The notion of saturation, however, is imperfect when dealing with car mileage as, unlike the diffusion rate of a given equipment, there is no *a priori* reason to believe that its intensity of usage is limited by nature. At least, it seems very difficult to

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1 The notion of perceived needs corresponds to the idea that needs are not purely determined by objective factors but also include some subjectivity which can be related either to travel experience or mental habits, for instance. Given the role of transport experience, there is also induced traffic resulting from the increasing availability and diversity of transport supply. In particular, the widespread diffusion of the car has considerably widened the horizon of choice in terms of potential destinations over time.

establish a saturation threshold at the household level, apart from very distant theoretical limitations that would be based on the amount of time spent travelling, for instance. However, because of decreasing marginal returns of additional car travel, one can assume car travel growth to slow down with the level of car mileage already reached – or with increasing income – in such a way that from a certain stage, growth would become inappreciable, a notion which can be designed as « pseudo-saturation ».

Constraints explaining the gap between realized and potential demand may be diverse in nature, either technical, economical, regulatory or related to the physical environment, for instance. Technical constraints are notably related to travel speeds of available transport modes. With the broader availability of a personal car, bounds to mobility are lowering, while the average travel speed is approaching to its potential limit which is related to car equipment rates at saturation. Car travel speed growth is also related to road infrastructure improvements which might have ceased. In addition to technical factors, economical constraints also contribute to explain the gap between realized and potential demand. For instance, limitations to the diffusion of personal car availability are weakening with an increasing average income, while decreasing fuel prices may contribute to a higher car mileage. However, upper limits to car use are also determined within the scope of trade-off mechanisms between different expenditures (food, housing, energy, etc.). Apart from financial limitations, regulatory measures may also hinder car use (authorized speed limits, parking restrictions, road pricing, alternate driving schemes, traffic restrictions for pollutant vehicles in some areas…). Finally, additional constraints may come from the physical environment. For instance, traffic-calming oriented urbanism might result in greater traffic and parking difficulties, thus providing an incentive to reduce car use, especially in dense metropolitan areas well-provided with transit, dedicated bike lanes and bike-sharing schemes. However, in this study, we will essentially focus on the role of economic constraints by estimating saturation thresholds and modelling growth paths of car ownership and car mileage towards saturation with an increasing average income, assuming other constraints to be stable.

3. Data analysis and modelling framework

3.1. The French Car Fleet Surveys

Analysis relies on the French car fleet survey waves from 1993 to 2010, based on a panel sample containing six to seven thousand households living in France surveyed on their vehicle fleet and driven mileage, being renewed by a third every year. Realized by the polling institute TNS-SOFRES from 1976, the survey is financed by a bunch of public and private stakeholders and analyzed by the French Institute of Sciences and Technologies for Transports, Planning and Networks (IFSTTAR). The dataset contains information on the household vehicles and their characteristics, up to three vehicles per household, including personal cars but also light-duty vehicles. This information can be used to design models of car availability and car mileage by vehicle rank, by dissociating the first, second and third household vehicle. Given the existence of missing values for some variables, in particular for income and annual mileage, the “hot-deck” method[2] was used to complete missing values and prevent the loss of information that would lead to less precise and possibly biased estimates. The income per consumption unit is used rather than the total income, in order to compare households from different size and composition[3].

3.2. Data analysis

Following the arguments exposed in section 2, the analysis is performed by vehicle rank, and for every vehicle rank we disentangle car ownership rates from the annual car mileage per vehicle among equipped households. In addition, the analysis is split by household category in order to account for heterogeneous choice sets, corresponding to different classes of needs. In particular, the choice set for the number of vehicles per household is strongly related

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2 After having identified the determinants of the dependent variable with missing values, observations are then classified according to the values of these determinants. An observation with missing value is finally given the value of the observation immediately preceding or following.
3 The number of consumption units per household is calculated using the OECD scale of equivalence, where the household head is weighted for 1, other household adult members for 0.5, and children aged less than 14 for 0.3.

to the number of adult members. For instance, for households containing a single adult member, the choice set is usually restricted to being non-motorized or owning one single vehicle, while the case for owning two vehicles or more is extremely marginal, as additional vehicles would be superfluous. In the same way, households containing two adult members will tend to choose between holding zero, one or two vehicles, while the case for three or more vehicles will be very scarce, given the lack of necessity. A consequence is that in the vast majority of cases, the number of adults represents an upper limit for the number of household vehicles.

Table 1. Segment names and descriptions

Segment name	Description
PSISE	Non-working adult without children
PSASE	Working adult without children
PSAAE	Working adult with children
1A1ISE	One working adult, one non-working adult, without children
2ASE	Two working adults without children
2ISE	Two non-working adults without children
1A1IAE	One working adult, one non-working adult, with children
2AAE	Two working adults with children
3A+SE	Three and more working adults without children
3A+AE	Three and more working adults with children
2A1I+SE	Two working adults, one non-working adult, without children
2A1I+AE	Two working adults, one non-working adult, with children
1A2I+SE	One working adult, two non-working adults, without children
1A2I+AE	One working adult, two non-working adults, with children
3I+SE	Three and more non-working adults without children
IAE	Only non-working adults with children

Using a unified model without separating different household types would therefore inaccurately describe choice sets, leading to overestimate some marginal choices by ignoring the notion of superfluous equipment. In addition to the number of adults, we also include segmentation variables for professional activity and the presence of children, as indicators of additional travel needs notably related to commuting and accompanying trips. Distinguishing different classes of needs or household categories also allows accounting for different levels of potential demand and income sensitivities. Sixteen segments were used for data analysis and model estimation. The last segment IAE was made up of three initial categories, some of which were statistically too small for data analysis and model estimation, including either one, two or three and more non-working adults with children.

The calculation of equipment rates confirms the heterogeneity of choice sets between household types depending on the number of adults. For single-adult households, alternatives are usually restricted to being de-motorized or owning one single vehicle, the alternative of owning two vehicles or more remaining marginal. In the same way, households with two adults are confirmed to choose between owning zero, one or two vehicles, while the alternative of holding a third vehicle is in minority. The alternative of holding three vehicles or more becomes substantial only for households containing at least three adults. This is why households with three vehicles remain in strong minority as few of them contain more than two adults, apart from the temporary situation of adult children still living at home during their college studies. In addition, in most household categories, equipment growth is found to slow down from a certain level of income and converge towards an equilibrium, which may also be considered as a saturation threshold.

It is also confirmed that saturation thresholds differ much according to the number of adults and by vehicle rank : in particular, they testify that the diffusion process of a given equipment may remain incomplete. For instance, the maximal equipment rate for the first vehicle reaches roughly 80 % among single working adults without children in the highest income groups, while it is close to 99 % among dual workers with children. Within the same group, the maximal equipment rate for the second vehicle reaches roughly 75 %, while it remains marginal among single working adults. In addition, in every household category, saturation thresholds also differ much by vehicle rank : for instance, the status of the first vehicle as an equipment shifts from an essential to something vital between single-adult households and households with two adults, with equipment rates at almost completion in the second case ; between the same groups, the status of the second vehicle comes from a superfluous equipment to an essential. On the contrary, the maximal equipment rate doesn’t depend much on the activity status of adult household members. For instance, the maximal diffusion rate for the first vehicle is similar for working and non-working adults without children. In the same way, the maximum diffusion rate of the second vehicle is roughly 60 % among households with two adults and no children, no matter how much is the proportion of adults working. Finally, the existence of children is also a case for higher levels of potential demand, though less influential than the number of adults. For instance, the maximum equipment rate goes from 90 % to 80 % between single working adults with or without children.

Table 2. Equipment rates by household category, income group and vehicle rank
Source : French Car Fleet Surveys, 1993-2010

	PSISE			PSASE			PSAAE			1A1ISE		
	V1	V2	V3	V1	V2	V3	V1	V2	V3	V1	V2	V3
< 500 €	38,4	2,0	0,2	52,9	3,0	0,4	62,8	1,0	0,0	76,2	19,7	2,2
500-1000 €	47,1	1,7	0,2	63,7	2,1	0,4	82,5	2,7	0,3	86,4	24,9	2,1
1000-1500 €	61,2	3,1	0,3	77,4	3,8	0,2	87,5	4,2	0,2	92,6	38,5	2,6
1500-2000 €	72,8	4,1	0,2	79,9	4,4	0,3	88,8	7,0	0,0	95,6	45,1	2,9
2000-2500 €	78,9	4,0	0,3	79,1	4,5	0,4	90,7	7,0	0,0	97,2	51,3	4,3
2500-3000 €	80,5	6,6	0,4	74,9	3,0	0,3	92,9	14,3	0,0	96,9	64,3	5,1
> 3000 €	82,7	8,0	0,9	74,3	5,3	0,2	83,3	5,6	0,0	97,1	63,4	8,5
	2ASE			2ISE			1A1IAE			2AAE		
	V1	V2	V3	V1	V2	V3	V1	V2	V3	V1	V2	V3
< 500 €	81,5	36,4	3,1	77,6	13,4	0,7	84,2	25,6	1,5	91,9	47,9	2,7
500-1000 €	89,7	36,7	2,4	90,5	14,0	1,2	96,2	41,4	1,9	98,4	58,4	3,0
1000-1500 €	95,2	52,2	3,7	95,3	20,3	1,2	98,2	55,0	3,0	98,9	72,3	4,8
1500-2000 €	96,5	58,5	4,8	96,9	30,0	2,1	98,0	61,7	4,9	98,5	72,9	4,7
2000-2500 €	96,3	60,2	5,3	98,2	40,4	3,4	97,0	66,4	1,5	97,8	74,7	5,0
2500-3000 €	92,3	59,2	5,5	97,6	51,5	6,1	96,5	77,2	3,5	97,5	70,1	4,9
> 3000 €	93,5	60,9	5,0	97,3	54,5	5,4	100,0	64,2	4,5	96,3	64,6	4,9
	3A+SE			3A+AE			2A1I+SE			2A1I+AE		
	V1	V2	V3	V1	V2	V3	V1	V2	V3	V1	V2	V3
< 500 €	87,1	64,5	45,6	86,7	58,1	25,7	89,4	49,3	16,5	91,6	47,6	10,8
500-1000 €	95,5	77,2	43,0	95,9	70,7	31,4	97,1	64,3	22,7	99,1	65,3	12,8
1000-1500 €	97,0	81,5	48,8	97,2	80,0	30,6	98,8	75,4	24,2	99,1	74,4	12,5
1500-2000 €	97,6	86,9	53,9	98,7	81,8	28,6	99,1	81,1	26,3	100,0	80,9	16,1
2000-2500 €	97,0	87,8	56,1	100,0	87,9	30,3	100,0	85,0	33,1	100,0	83,7	24,8
2500-3000 €	100,0	90,9	56,4	94,7	57,9	0,0	98,6	84,1	31,2	95,7	85,5	27,5
> 3000 €	93,7	76,2	41,3	93,3	80,0	0,0	97,6	84,6	34,2	100,0	68,4	10,5
	1A2I+SE			1A2I+AE			3I+SE			IAE		
	V1	V2	V3	V1	V2	V3	V1	V2	V3	V1	V2	V3
< 500 €	86,2	33,5	5,0	84,2	27,0	4,2	82,2	33,5	8,9	35,8	3,3	0,0
500-1000 €	95,6	48,9	11,9	97,1	47,9	6,7	96,1	50,0	16,4	65,5	16,1	0,0
1000-1500 €	98,0	64,0	18,4	99,3	70,8	13,4	99,3	70,8	26,6	89,5	36,8	2,6
1500-2000 €	98,8	73,9	20,5	98,8	79,8	21,4	97,8	72,3	22,8	100,0	28,6	28,6
2000-2500 €	98,9	73,9	24,4	100,0	78,3	17,4	100,0	73,8	29,5	100,0	50,0	16,7
2500-3000 €	95,8	70,4	16,9	94,7	57,9	5,3	97,6	64,3	21,4	0,0	0,0	0,0
> 3000 €	98,2	65,5	34,6	100,0	75,0	0,0	90,5	52,4	19,1	100,0	100,0	0,0

The distribution of vehicle rates by income group also highlights the existence of minimum diffusion rates in lower income groups, which may be interpreted as non-negotiable equipment needs. By differentiation between maximum and minimal equipment rates, one can estimate the amount of negotiable equipment needs, which can be abandoned in case of insufficient financial resources. For the first vehicle for instance, this amount is quite negligible for dual workers with children, for which the equipment rate reaches nearly 100 % even in lower income groups, indicating that the first vehicle is considered vital and merely non-negotiable. On the other hand, the equipment rate shifts from 50 to 80 % between lower and higher income groups for single working adults without children, while the equipment rate for the second vehicle increases from 50 to 75 % with an increasing income among dual workers with children. The amount of negotiable needs, altogether with minimum and maximum equipment rates, are therefore similar to those observed for the first vehicle among single working adults. Professional activity and the existence of children also strongly influence the minimal equipment rate and therefore the amount of negotiable needs. While the minimum equipment rate for the first vehicle approaches 40 % for single non-working adults without children, it reaches 52 % for working adults without children, and 66 % for working adults with children.

Finally, the level of potential demand by vehicle rank can be empirically estimated for every household type from the observation of equipment rates by income groups, giving an indication of saturation thresholds to be reached with the complete relaxation of financial constraints. Potential demand consists of both non-negotiable and negotiable needs, to be removed in case of insufficient resources. For the main vehicle, the saturation threshold is usually very close to completion in most household groups, indicating that it is considered a first necessity good. The influence of household characteristics (the number of adults, activity status, the existence of children…) on the level of potential demand exists but is rather limited. Contrary to the main household vehicle, the potential demand for the second vehicle is much differentiated by household type : the status of the second vehicle varies from a medium-range to a first necessity good with travel needs increasing. However, the market is made both of negotiable and non-negotiable needs. While the potential market size for the first vehicle is roughly independent from household travel needs, household characteristics are more influent on the amount of negotiable needs. For instance, the first vehicle is partly negotiable among singles while it is essentially non-negotiable among couples. The amount of negotiable needs according to the household resources also varies in relation with travel needs for the second vehicle. This is *a fortiori* the case for the third vehicle, which can be considered an up-range good until now, with limited diffusion.

Table 3 : Average car mileage (in km) by household category, income group and vehicle rank
Source : French Car Fleet Surveys, 1993-2010

	PSISE			PSASE			PSAAE			1A1ISE		
	V1	V2	V3	V1	V2	V3	V1	V2	V3	V1	V2	V3
< 500 €	8516	3810	0	10953	6632	4470	12637	9300	4000	12892	10532	3756
500-1000 €	8064	3934	1440	12403	7718	125	13944	8987	5000	13894	8413	4665
1000-1500 €	8262	5317	2454	13259	7077	714	14036	8522	-	14048	8999	6361
1500-2000 €	8770	4014	7345	14009	7782	2524	13835	12105	-	14823	8906	5360
2000-2500 €	9223	5106	6575	13881	11857	2229	16918	5333	-	15164	10031	5231
2500-3000 €	10452	4872	8750	14719	12760	6159	16945	5000	-	15574	9501	8527
> 3000 €	11088	5348	5400	14094	8018	0	11072	5000	-	16198	9408	5505
	2ASE			2ISE			1A1IAE			2AAE		
	V1	V2	V3	V1	V2	V3	V1	V2	V3	V1	V2	V3
< 500 €	14284	10043	6490	10198	6746	5790	14998	10896	6488	15232	11099	6404
500-1000 €	14522	9742	8371	9897	5790	3089	15661	10523	8434	16116	10532	6940
1000-1500 €	16148	11723	9005	11136	6189	4087	16696	11460	9859	16884	11388	8532
1500-2000 €	16913	11949	7489	11881	6531	5214	16764	11965	9947	16980	11692	8148
2000-2500 €	17224	11832	8372	12725	6346	4122	17617	10302	4000	17181	11436	5800
2500-3000 €	17267	12347	8918	12625	6681	5908	18184	12291	10500	17792	12965	3575
> 3000 €	16463	11743	8543	13004	7017	3400	21144	11909	5033	17954	12391	9985
	3A+SE			3A+AE			2A1I+SE			2A1I+AE		
	V1	V2	V3	V1	V2	V3	V1	V2	V3	V1	V2	V3
< 500 €	13875	12941	12003	16005	9755	8174	14248	10865	10518	14847	10886	10560
500-1000 €	14964	12455	11980	16780	11950	12597	15287	11521	11308	15872	10490	8227
1000-1500 €	15618	11915	13421	14082	11096	12758	16054	11370	11592	17274	11531	10187
1500-2000 €	16062	12177	11687	15697	12453	13432	16602	11941	11168	17268	10698	10175
2000-2500 €	15972	11818	13027	19154	9267	9680	16497	11271	12049	19074	13433	12254
2500-3000 €	16953	12560	12677	17883	10401	-	17593	11423	9120	19259	11732	6681
> 3000 €	17479	11374	10362	20714	9017	-	16790	12574	10986	14850	11897	14500
	1A2I+SE			1A2I+AE			3I+SE			IAE		
	V1	V2	V3	V1	V2	V3	V1	V2	V3	V1	V2	V3
< 500 €	12508	10141	9324	13704	9403	10657	10856	10500	10000	12945	6243	0
500-1000 €	13333	10330	10077	15686	10237	7868	11584	8841	6863	12299	10501	0
1000-1500 €	14766	10874	9917	17435	12843	8966	13045	8372	7588	14753	8143	0
1500-2000 €	14809	10975	10031	18502	10347	8944	16185	8425	5254	13293	10000	10000
2000-2500 €	15683	10415	8439	16576	10504	5750	12348	5673	10500	19833	7400	2500
2500-3000 €	17118	12834	14858	20097	10227	16000	11350	3454	6000	19833	7000	0
> 3000 €	15244	9465	10137	7575	6167	-	12676	8378	750	15000	7000	0

Then we consider the average car mileage per vehicle[4], depending on vehicle rank, in relation with household

4 Some mileage values are missing as the corresponding groups were empty, essentially for the third vehicle.

income group. The average car mileage for the first vehicle is found to be sensitive to income, but ever-less with income increasing, which is a consistent result with the prior assumption of pseudo-saturation. In addition, the average car mileage tends to level off from a certain income group for many household types, or is even decreasing in the highest income groups. However, the dependence of car mileage on income is usually weak, the minimum mileage, corresponding to non-negotiable needs, being close to the maximum mileage. For instance, among single working adults without children, the average car mileage is increasing from 11 000 to 14 000 km between lower and higher income groups. The mileage is more dependent on household type, varying from 15 200 to 18 000 km depending on income for households with two working adults and children, vs. 8 500 to 11 000 km for single non-working adults without children. The number of adults, the existence of professional activity and children are all factors of increasing car mileage in relation with higher travel needs. However, the relation between these factors and the amount of negotiable needs in relation to income is less obvious than for equipment rates. A reason might be the existence of a selection bias resulting from vehicle ownership decisions already endogenizing travel plans, which would also explain the low income sensitivity of vehicle mileage for equipped households. Car mileage for the second vehicle appears to be almost independent from income. The difference with the main vehicle can be interpreted in terms of their respective functions. Given its multipurpose usage, the main vehicle is also used for discretionary motives such as leisure and holiday trips, which are more sensitive to income as they can more easily be removed in case of insufficient resources, while the second vehicle is rather dedicated to daily trips, by nature less sensitive to income. The average car mileage is also very stable dependent on household type and approximately equates 10 000 km in every group, apart from single adults holding a second vehicle and households containing no working adult. Again, this apparent homogeneity can be interpreted assuming the proportion of negotiable needs to become negligible among equipped households as car ownership decisions are already endogenizing travel plans. Finally, car mileage for the third vehicle is negatively correlated to income. This apparently paradoxical result might express some endogenous bias, third vehicle ownership being even less correlated to travel needs as income is increasing or in other words, the mileage threshold triggering purchasing decisions would be decreasing with income.

3.3. Modelling framework

In order to estimate saturation thresholds for car ownership rates and average car mileage per person, and later on to calculate their growth path towards saturation - or pseudo-saturation - over time, we design the following model :

$$\tau_{ijk} = \frac{\alpha_{jk}}{1+\exp(-\beta_{jk}R_{ik}-\gamma_{jk})} + \varepsilon_{ijk} \tag{1}$$

τ_{ijk}	Diffusion rate of vehicle rank *j*, for household *i* belonging to category *k*
R_{ik}	Income per consumption unit of household *i*, belonging to category *k*
$\alpha_{jk}, \beta_{jk}, \gamma_{jk}$	Parameters ($\alpha_{jk} < 1, \beta_{jk} > 0$)
ε_{ijk}	Disturbance term

In this formula :

α_{jk} stands for the saturation threshold - or alternatively, the potential demand - for vehicle *j* in household category *k*, which is also an indicator of market size. This is the equipment rate that would be reached with the complete relaxation of financial constraints, i.e, when the income becomes infinite. As already mentioned, $\alpha_{jk} < 1$ shall express the lack of need for vehicle *j* for some households or the persistence of other constraints at equilibrium - for instance the existence of a handicap, or the lack of parking supply - resulting in an incomplete diffusion process.

β_{jk} is an income parameter that should be positive, as the diffusion rate of equipment *j* is assumed to increase with the relaxation of financial constraints. A greater value of β_{jk} is an indicator of the concavity of the diffusion curb, also meaning that the equipment rate of vehicle *j* is converging more rapidly towards saturation. With greater values of β_{jk} , an increasing proportion of households are closer to saturation, only the lower income groups being underequipped. A greater value of β_{jk} can therefore also be considered an indicator of lower inequalities.

γ_{jk} is an intercept, which can be positive or negative, of which depends the minimum level of diffusion corresponding to a zero income. As we assume the diffusion rate to be described by a logistic curve, $\gamma_{jk} > 0$ implies that $\tau_{ijk}(0) > \alpha_{jk}/2$ or said otherwise, that the diffusion process always stands in its second phase of convergence towards saturation. It also means that the majority of equipment needs are non-negotiable due to low financial resources and therefore gives an indication that equipment *j* is considered an essential. On the contrary, $\gamma_{jk} < 0$ means that $\tau_{ijk}(0) < \alpha_{jk}/2$, implying that a majority of equipment needs are negotiable due to lower income, and therefore that equipment *j* is rather a mid-range or even luxury good.

α_{jk} therefore defines market size or the amount of potential demand for equipment *j*, γ_{jk} – modulo the *logit* c.d.f function – the proportion of non-negotiable needs, while the difference $\alpha_{jk} - \Lambda(\gamma_{jk})$ stands for the amount of negotiable needs due to insufficient resources, and β_{jk} increases the concavity and therefore the velocity of the convergence path towards saturation.

The following model is then implemented for the annual car mileage expectation of vehicle *j* for individual *i* in household category *k*, conditional on vehicle *j* ownership.

$$(U_{ijk}|V_{ijk} = 1) = \eta_{jk} + \delta_{jk} log(R_{ik} + 1) + \nu_{ijk} \quad (2)$$

U_{ijk} Annual mileage of vehicle rank *j* for household *i* in category *k*, for households holding vehicle *j*
V_{ijk} Indicator for vehicle *j* ownership
R_{ik} Income per consumption unit of household *i* in category *k*
$\delta_{jk,}\eta_{jk}$ Parameters
ν_{ijk} Disturbance term

According to this formula, the car mileage for a given vehicle rank, conditional on vehicle holding, is increasing with income – provided $\delta_{jk} > 0$ - however ever-more slowly, traducing the notion of pseudo-saturation. Though R_{ik} is theoretically non-limited, an empirical threshold could be estimated that would fulfil the needs of 99 % households. Here again, a minimum car mileage η_{jk} is estimated for households with zero income, corresponding to non-negotiable needs. As in ParcAuto, up to three vehicles are described for every household, the expectation for the total car mileage of a given household can then be expressed as :

$$E(U_{ik}) = \sum_{j=1}^{3} E\left(U_{ijk}|V_{ijk} = 1\right) P(V_{ijk} = 1) \quad (3)$$

4. Model estimation

Car equipment models by household category and vehicle rank are then estimated by maximum-likelihood. Initial values are deducted from empirical thresholds being emphasized by data analysis. Then, the algorithm is proceeding through successive iterations to perform maximum likelihood estimation. Log-linear models for car mileage are estimated through regular regression procedures. Estimation results are synthetized in tables 4 and 5, respectively for car ownership and car mileage models.

In most cases, saturation thresholds are consistent with empirical observations. They confirm the diffusion process of the first vehicle to be often almost complete, with a level of potential demand varying between 80 and 100 % depending on household type. Potential demand is slightly lower for singles, where it establishes between 80 and 90 % according to household type, while it reaches 95 to 99 % among households containing two adults. Results are clearly different for the second vehicle, for which the diffusion process is always incomplete. As expected, the potential demand for a second vehicle is very limited among singles for which it can be assimilated to a superfluous equipment, reaching only 5 to 10 %. For households containing two adults, its status can be considered as intermediary with potential diffusion rates ranging from 60 to 75 %, essentially depending on the existence of children, representing an additional case for a second vehicle. Finally, potential demand for a second vehicle ranges from 75 to 90 % of households containing three adults or more, making of it an essential in these groups, especially for households where at least two adults are working. Coming to the third vehicle, potential demand is almost non-significant for singles, still remains marginal among households containing only two adults, with a potential market size ranging from 5 to 10 %, but becomes more substantial in households with three or more adults. However, apart from households with two working adults and no children, the third vehicle still remains an up-range equipment, with a level of potential demand comprised between 20 and 35 %.

Table 4 : Estimated saturation thresholds of diffusion rates by household category and vehicle rank
Source : French Car Fleet Surveys, 1993-2010

	α			β			γ		
	V1	V2	V3	V1	V2	V3	V1	V2	V3
PSISE	0,863	0,095	0,010	1,12e-4	7,2e-5	2,7e-5	-0,767	-1,902	-6,367
PSASE	0,795	0,056	0,003	1,9e-4	6,6e-5	3.5e-3	-0,028	-0,454	0,558
PSAAE	0,899	0,099	-	2,58e-4	1,4e-4	-	0,039	-2,332	-
1A1ISE	0,976	0,660	0,213	1,55e-4	1,07e-4	4,5e-5	0,671	-1,372	-2,637
2ASE	0,958	0,624	0,058	2,3e-4	1,46e-4	9,9e-5	0,876	-0,664	-0,802
2ISE	0,978	0,623	0,082	2,13e-4	1,04e-4	9,1e-5	0,522	-2,227	-2,891
1A1IAE	0,985	0,706	0,046	3,54e-4	1,76e-4	1,4e-4	0,548	-1,246	-1,465
2AAE	0,986	0,747	0,052	3,78e-4	2e-4	1,91e-4	1,710	-0,338	-1,173
3A+SE	0,976	0,876	0,564	2,6e-4	1,48e-4	7,8e-5	1,330	0,563	0,721
3A+AE	0,974	0,806	0,287	4,74e-4	2,32e-4	3,2e-3	0,555	0,098	-2,748
2A1I+SE	0,991	0,860	0,329	3,39e-4	1,54e-4	1,05e-4	1,049	-0,319	-0,373
2A1I+AE	0,994	0,851	0,280	4,46e-4	1,54e-4	2,7e-5	1,075	-0,266	-2,214
1A2I+SE	0,985	0,764	0,241	3,23e-4	1,74e-4	2,06e-4	0,745	-0,947	-1,923
1A2I+AE	0,993	0,808	0,204	4,43e-4	2,41e-4	1,57e-4	0,180	-1,644	-1,935
3I+SE	0,982	0,647	0,134	4,03e-4	2,49e-4	2,75e-4	-0,730	-2,305	-3,733
IAE	0,942	0,437	-	2,63e-4	3,11e-4	-	-1,335	-3,312	-

Values of γ_1 are almost always positive, suggesting that the majority of potential demand for the first vehicle is non-negotiable. Only for singles and households with no working adult is potential demand for the first vehicle mostly negotiable. The highest amounts of non-negotiable needs are found for households with two working adults or even more. On the contrary, values of γ_2 are in majority negative, indicating a higher amount of negotiable needs due to insufficient resources for the second vehicle. This is obviously the case for singles, for which a second vehicle is generally superfluous, but also for households including only one working adult, and even more for households with no working adult at all. The number of professionals therefore increases the degree of necessity of a second vehicle among households with two adults or more. The proportion of negotiable needs is even higher for the third vehicle, which has been shown to represent an up-range equipment, even for households with three adults or more.

Finally, values of β_{jk} are found to increase with the number of adults, the proportion of working adults and the existence of children, the most important factors being the number of adults and the existence of children. It means that income gaps in vehicle rates are decreasing with the intensity of travel needs, being a factor of homogeneity in equipment behaviors. However for a given household category, values of β_{jk} are decreasing with vehicle rank j, showing the existence of increasing income differentiation with a higher vehicle rank, as the corresponding equipments are becoming less of a necessity. The degree of necessity for a given vehicle is therefore a function of household category k and vehicle rank j, which have an influence on both the market size or potential demand for this type of good, the amount of negotiable needs and the rapidity of convergence towards saturation or income-related inequalities in equipment rates. This result is important and should be kept in mind when interpreting income-differentiated behaviors which do not necessarily express pure inequalities, but result from an interaction between inequalities and necessity. Therefore, sharper income distributions may in some cases illustrate a higher degree of necessity rather than pure inequalities.

Car mileage models per household category and vehicle rank are then estimated. The η's are representing the estimated amount of non-negotiable travel among equipped households, while the β's stand for the income sensitivity of car mileage.

Table 5 : Parameter estimates of car mileage models by household category and vehicle rank
Source : French Car Fleet Surveys, 1993-2010

	η			δ		
	V1	V2	V3	V1	V2	V3
PSISE	3145	2739	1750	592,4	247,8	309,8
PSASE	3250	7970	5010	1064	119,9	-256,0
PSAAE	7588	5077	-	703,5	550,4	-
1A1ISE	4894	8648	69	1006,1	73,7	611,4
2ASE	5718	4454	7218	1113,1	745,9	231,5
2ISE	10210	3761	1912	131,7	279,0	286,9
1A1IAE	5314	5628	16000	1186,7	602,7	-585,9
2AAE	7375	4632	8610	997,5	713,6	50,6
3A+SE	3957	18313	8585	1242,7	-620,3	439,3
3A+AE	9971	11054	8691	679,2	48,4	475,0
2A1I+SE	6753	10371	13877	978,6	141,4	-217,0
2A1I+AE	1165	5869	6970	1667,0	568,8	333,4
1A2I+SE	3582	11712	12361	1135,9	-93,8	-201,4
1A2I+AE	18443	1125	28444	-275,7	1084,3	-2111,2
3I+SE	8713	17190	12437	422,4	-909,7	-586,0
IAE	724	8394	-	1464,6	65,4	-

For every vehicle rank, the η's are higher for households with at least two adults, and generally increase with children and the number of professionals, though some results may appear counter-intuitive possibly due to biased parameters for some segments which might not benefit from sufficient sample size. Estimates for the δ's confirm that the first vehicle mileage is in general more sensitive to income than for the second and third vehicle, which we explained by its type of usage, including some proportion of discretionary trips.

5. Equipment and traffic forecasts

5.1. Methodology

Starting from this model, we realize equipment and traffic projections up to 2050, also estimating levels of potential demand for car equipment, in the absence of financial constraints. All projections account for structural demographic change, which is notably related to population ageing and the evolution of family models. Indeed, as models are defined by household category, the results must be weighted by predictable household structure to obtain aggregate forecasts, which implies making projections of the household structure at the forecasting horizon[5]. The methodology to obtain projections of the household structure was the following. We started from official projections from the Department of Observation and Statistics of the French General Council of Sustainable Development (CGDD), distinguishing between single adults with or without children, couples and other household types[6]. Projections include intermediary points every five years from 2015 to 2050, allowing to figure convergence paths towards saturation or pseudo-saturation. However, to further distribute households between the different groups, one also has to make assumptions about activity rates of adults by cohabitation mode. In order to do this, we first estimated the weight of the age group 15-69 by aggregate household type - singles with or without children, couples - using projections of cohabitation patterns by age group (CGDD, 2012c)[7]. Then we used projections of activity rates for the age group 15-69 from the National Institute of Statistics and Economic Studies (Filatriau, 2011). These calculations already allow to estimate the distribution of adults living alone or within couples - either with or without children - between working and non-working adults, assuming that adults aged more than 69 are non-working. However, an additional assumption is required to determine the distribution of working adults living with a partner between bi-active and mono-active

[5] However, we implemented a simplified segmentation which was consistent with household categories used in official demographic projections, which also implied to re-estimate corresponding models.
6 These projections were realized to estimate the potential housing demand in France, relying on regular assumptions about fertility, net migration, mortality and cohabitation behaviors (CGDD, 2012b).
[7] As projections were available only up to 2030, trends were prolongated up to 2050, in particular the decreasing proportion of adults living with a partner and correlatively, the increasing proportion of singles.

households, depending on behaviors of social endogamy. The assumption was made that behaviors of social endogamy were essentially unchanged, i.e that the probability for one working adult to be associated with another working adult would be the same than in 2010.

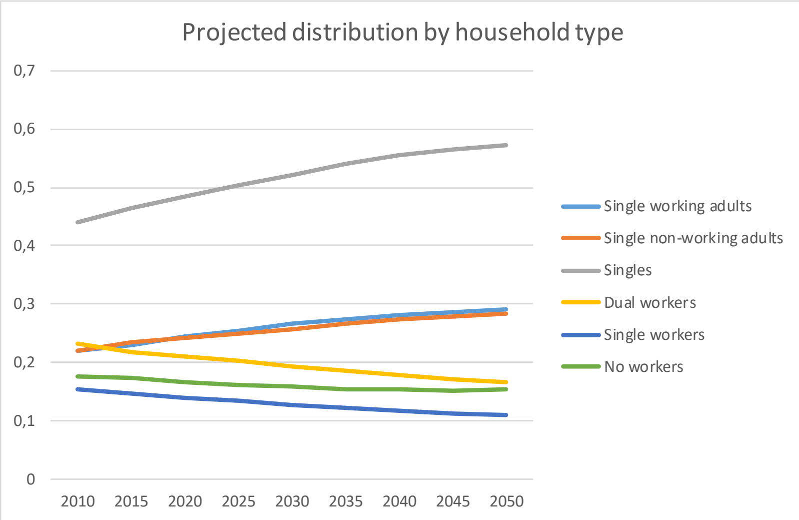

Figure 1 : Projected distribution by household type, 2010-2050

The household typology which we used to forecast future levels of car equipment and traffic finally distinguishes between single adults, either working or non-working, with or without children, and couples sorted by the number of working adults (dual working, single working and no working). Future household distribution is summarized in figure 1. Predictably, population ageing will result in decreasing activity rates and related commuting travel needs, while combined with changing family models, it will lead to a greater proportion of single adults. These structural changes must be kept in mind when analyzing projections of equipment and traffic growth. These calculations allow the estimation of levels of potential demand for car equipment by vehicle rank at different dates by weighting disaggregate saturation thresholds by projected household structure. However, in order to estimate real equipment rates – differing from potential equipment rates because of persistent financial constraints – and car mileages, one also has to make projections of the income distribution at intermediary points, relying on assumptions about income growth. The assumption retained here was of an homogeneous and constant income growth of 1 % on average.

5.2. Projection results

For every household type and vehicle rank, we calculated growth paths of equipment rates towards saturation levels estimated in section 4, which allows to evaluate both market maturity and correlatively, reserves of potential growth. For the first vehicle, reserves of potential growth are weak for couples as diffusion is already very close to completion, while they appear to be greater for singles and especially for non-working singles. For instance for non-working singles with children, the equipment rate for the first vehicle will increase from 31, 2 to 53,2 % between 2010 and 2050 in relation with an increasing income. For non-working singles without children, it will raise from 60,6 to 70,4 %. By comparison, the diffusion rate for dual workers will stay almost stable - from 96,6 to 97,3 %.

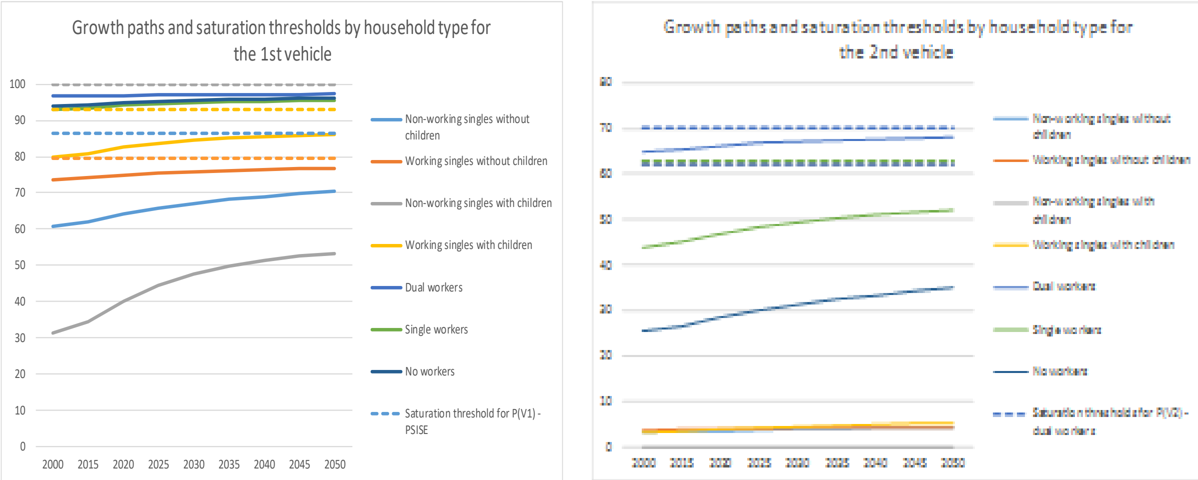

Figure 2a,b : Estimated growth paths and saturation thresholds by household type for the 1st and 2nd vehicles

For the second vehicle, the saturation threshold is almost already attained for dual workers, but reserves of potential growth still remain for couples with at least one unemployed adult. For instance, for single workers, the diffusion rate will increase from 43,9 to 52,1 %, and from 25,5 to 34,9 % for couples with no workers. Finally, the diffusion of the third vehicle will remain almost stationary among dual workers at roughly 11,4 %, while low reserves of potential growth still remain for couples with one or no working adult – with a corresponding equipment rate raising from 5,5 to 6,8 % in the first case, and from 2,0 to 3,0 % in the second. As a whole, reserves of potential growth for car equipment still remain among households with at least one non-working adult. However, potential equipment growth is globally limited and convergence towards saturation appears to be quite slow with equipment growth slowing down from 2025.

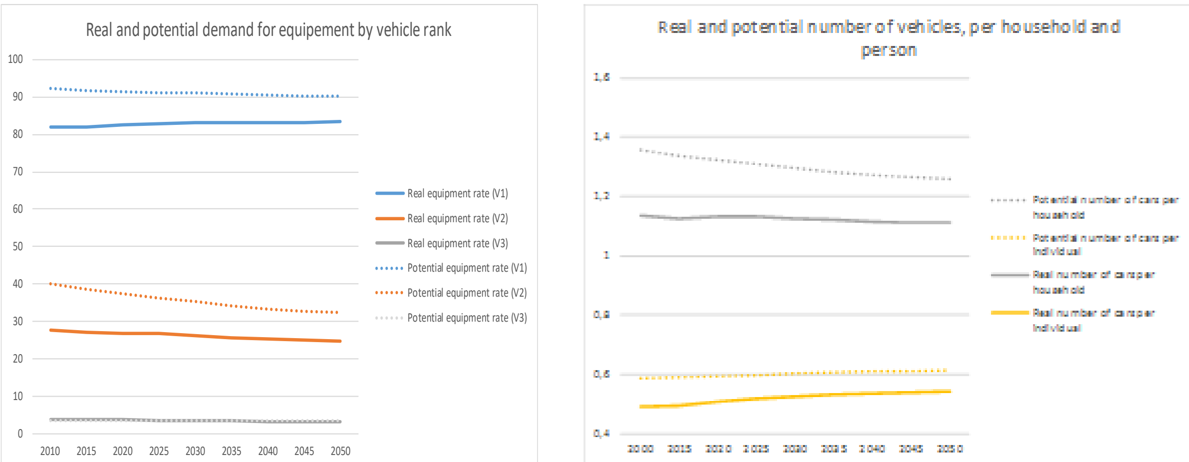

Figure 3a,b : Real and potential estimated car equipment levels 2010-2050

These results are then combined with household structure projections to calculate global indicators of real and potential demand by vehicle rank. In relation with the increasing proportion of singles and retired resulting from population ageing and changing cohabitation patterns, potential demand for the first and the third vehicle will sligthly decrease – respectively from 92,2 to 90,3 %, and from 3,4 to 3,3 %, while demand for the second vehicle will fall down more substantially from 40,0 to 32,2 %. In addition, real equipment rates will slowly approach levels of potential demand by increasing softly for the first vehicle and decreasing for the second vehicle, as real car equipment will decrease more gently than potential demand for the second vehicle due to an increasing income. The equipment rate for the first vehicle will increase from 81,9 to 83,4 %, while it will decrease from 27,6 to 24,6 % for the second vehicle.

Aggregating all vehicle ranks, the potential number of cars per household would decrease substantially along with the narrowing market for the second vehicle - from 1,36 to 1,26 vehicle per household - while the potential number of cars per individual would slightly increase, from 0,59 to 0,61. The real number of cars per household will slightly decrease while the average number of cars per individual would softly increase, approaching the estimated saturation threshold of 0,6 car per person.

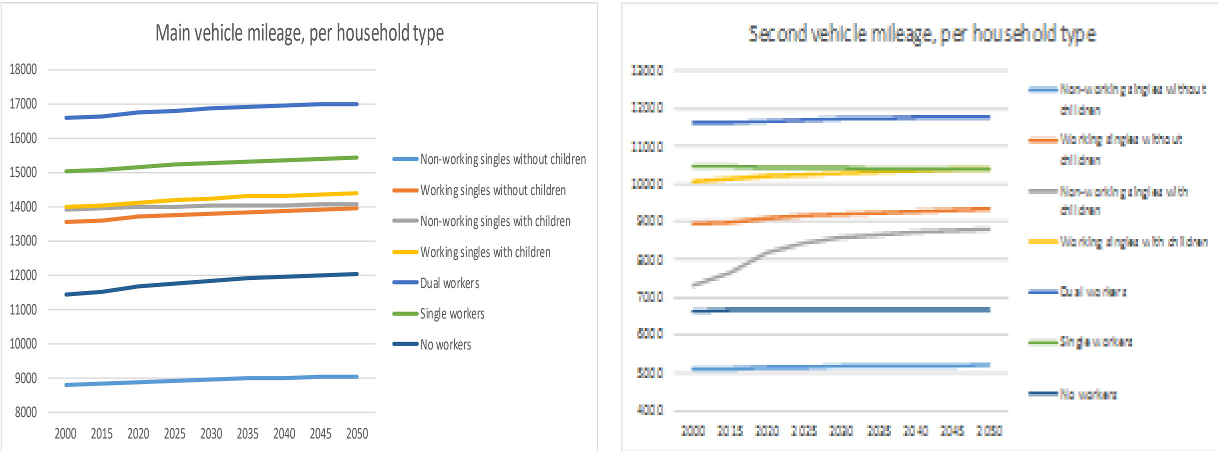

Figure 4a,b : Main and second vehicle mileage per household type

We finally estimate car mileages. In most categories - apart from single non-working adults with children - the main vehicle mileage is slightly increasing with income but at an ever-slower pace, seemingly attaining pseudo-saturation by 2040, apart from single working adults where growth would maintain afterwards. By contrast, the second vehicle mileage remains relatively stable on average, apart from single non-working adults with children.

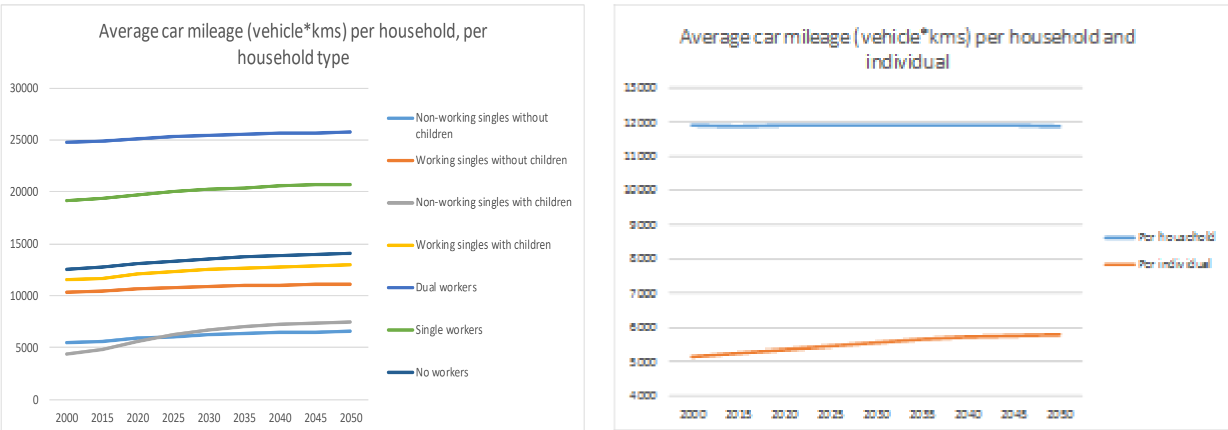

Figure 5a,b : Generated car traffic per household and individual, generally and by household type.

By aggregating all vehicle ranks, one obtains estimations of the average car mileage per household and individual. The average car mileage per household is softly increasing up to 2050 for every household type – for instance, for single workers, it is increasing from 19 100 to 20 750 km - but remains relatively stable on average because of household structural change already mentioned. By contrast, the average car mileage per individual keeps on increasing, from 5 140 to 5 780 km, but at a decreasing pace, especially from 2040, remaining almost stable afterwards.

6. Conclusion

After decades of continued increase, car traffic has temporarily levelled off during the 2000's, before coming back to growth once the economic crisis was passed, along with decreasing fuel prices. Though economic conditions may have decisively contributed to recent trends, there are strong reasons to believe, however, that traffic growth will not be infinite : among these, the diffusion process of car ownership as an equipment good will sooner or later be completed, daily travel time is rather stable on average and potentially limited by competing allocations of time budgets, real car travel speeds are getting stable or even decreasing, individuals benefit from decreasing marginal returns of additional car travel, and infrastructure supply is limited by credit cuts and re-orientation towards transport alternatives for motives of sustainability. In addition, car traffic levels are increasing proportionally to the number of vehicles, so that one may assume that the average car traffic per adult will come to saturation once every one who needs it will be equipped with a car. Also, empirical observation of car equipment rates by household type and vehicle rank provides evidence of convergence towards saturation from a given level of income. While it seems more arbitrary to assume the existence of an absolute limit to car use, car mileage growth is nonetheless decreasing with income, providing evidence for decreasing marginal returns of additional travel leading to pseudo-saturation. Assuming potential demand to be limited, one convenient way to describe realized demand is to model it as an equilibrium between potential demand and constraints, which may be of different natures, either technical, economical, regulatory or related to the physical environment. Assuming other constraints to be stable, one can study which effect has the relaxation of economic constraints on the level of demand. The estimation of an adapted *logit* model confirms the existence of saturation thresholds, which may sometimes express an incomplete diffusion process, also allowing to break down potential demand between negotiable and non-negotiable needs, in relation with insufficient financial resources, and to evaluate the rapidity of convergence towards saturation. Forecasting results obtained with these models confirm that while reserves of potential growth for car equipment still remain, they are nonetheless limited, and thwarted by population ageing and changing cohabitation patterns. In addition, mileage projections lead to anticipate a limited growth of average car traffic per adult until 2040, and quasi-stability afterwards. From this date, traffic growth would be essentially determined by demographic growth. In the light of these results, pollutant and GHG emissions abatement goals might be facilitated. Finally, we draw out some research tracks for the future. First on the side of model improvements : joint choices of car equipment and car mileage could be tested through *tobit* models, to account for possible internalization of travel plans into car ownership decisions, which would explain the low income sensitivity of car mileage, or even the counterintuitive relation between car mileage and income for the third vehicle. A theoretical basis for car mileage should also be defined, leading to offer alternative specifications and empirically decide which is the best. Another field of improvement consists in the formulation of alternate scenarios. For instance, traffic forecasts may also depend on energy prices and energy efficiency, which were not accounted for at this stage as our goal was to obtain a central scenario based on economic growth, assuming everything else to be equal. Yet, energy prices might keep on increasing in relation with heavier taxation – in particular with the implementation of a carbon tax – while this effect will be partially countered by technological progress resulting in increasing energy efficiency. In order to model their effect on traffic growth, income could be replaced by an indicator of energetic purchasing power, for instance. Purchasing prices for cars should also be introduced, in relation with different scenarios in terms of price dynamics – for instance, the development of low-cost vehicles, or quite the opposite, heavier vehicle taxation resulting in higher vehicle prices. Nonetheless, future levels of car use will also depend on regulatory constraints or related to the physical environment, which are likely to be reinforced in the future, along with the multiplication of restricted traffic areas, more severe regulations on pollutant vehicles, restrictive speed limits, etc. Finally, beyond the prospect of saturation, some factors could lead to a declining car use. Some of them might be economical, for instance the possible expansion of mass poverty, or the lack of efficiency gains combined with heavier environmental taxation - with the implementation of a carbon tax, for instance - while others might be technological and organisational, such as the autonomous vehicle, a wider deployment of telecommuting or car-based devices such as car-sharing and carpooling.

7. References

Bastian, A., Börjesson, M., Eliasson, J., 2016. Explaining 'peak car' with economic variables. Transportation Research Part A 88, 236-250.
BITRE - Bureau of Infrastructure, Transport and Regional Economics. 2012. Traffic growth : modelling a global phenomenon. Report 128, Canberra ACT.

Bussière, Y., Madre, J-L., Armoogum, J. 1996. Vers la saturation ? Une approche démographique de l'équipement des ménages en automobile dans trois régions urbaines. Population 4/5, 955-977.

Cairns, S., Hass Klau, C. Goodwin, Ph. 1998. Traffic impact of highway capacity reductions : assessment of the evidence. Landor Publishing, London.

Collet, R., Madre, J-L., Hivert, L. 2013. Vers quels plafonds pour la motorisation et l'usage de la voiture ? Economie et Statistiques 457-458, 123-139.

Commissariat Général au Développement Durable (CGDD). 2012a. La circulation routière augmente à un rythme ralenti depuis 2003. Le Point Sur, 118.

CGDD. 2012b. La demande potentielle de logements à l'horizon 2030 : une estimation par la croissance attendue du nombre de ménages. Le Point Sur, 135.

CGDD. 2012c. Projection du nombre de ménages et calcul de la demande potentielle de logements : méthode et résultats. Document de travail n°7, note logement-construction.

CGDD. 2017. Les comptes des transports en 2016, Tome 1, 54ème rapport de la Commission des comptes des transports de la nation, Juillet 2017.
Cornut, B., Madre, J-L., Boucq, E., Hivert, L. 2014. Diffusion of car ownership and use in Paris metropolitan area since the mid 70's", PANAM - XVIII Congreso Panamericano de Ingeniería de Tránsito Transporte y Logística, June 2014, Spain. 16 p, 2014.
Coulangeon, P., Petev, I.D. 2013. L'équipement automobile entre contrainte et distinction sociale. Economie et Statistiques 457-458, 97-122.
Filatriau, O. 2011. Projections à l'horizon 2060 : des actifs plus nombreux et plus âgés. INSEE Première 1345.
Fraser, A. 2014. Peak travel in a Megacity : Exploring the role of Infrastructure saturation on the suppression of automobile use », A thesis presented in partial fulfillment of the requirements for the degree Master of Science.
Goodwin, Ph., Dargay, J., Hanly. 2004. Elasticities of Road Traffic and Fuel Consumption with respect to price and income: a review. Transport Reviews 24.3, 275-292.
Goodwin, Ph. 2010-2011. "Peak Car", series of five articles in Local Transport Today. Local Transport Today, London.
Goodwin, Ph. 2013. Peak travel, peak car and the future of mobility - Evidence, unresolved issues, policy implications and a research agenda. Discussion paper n°2012-13, prepared for the roundtable n°152 on Long-run trends in travel demand.
Grimal, R., Collet, R., Madre, J-L. (2013). Is the stagnation of individual car travel a general phenomenon in France ? An analysis by zone of residence and standard of living. Transport Reviews, 33.3, 291-309.

Grimal, R. 2017. Modelling auto-mobility: combining cohort analysis with panel data econometrics. Asian Transport Studies 4, 741-763.

IAURIF. 2013. Peak car : La baisse de la mobilité automobile est-elle durable ? Note rapide Mobilité 620.

Ingram, G.K., Liu, Z. 1999. Determinants of motorization and road provision. Policy Research Working Paper, World Bank, Washington D.C.

Jarrige, J-M., Raynard, C. 2003. Politiques de stationnement et mobilité locale : approche empirique. Notes de synthèse du SES.

Le Breton, E. 2008. Domicile-travail : les salariés à bout de souffle. Les Carnets de l'Info.

Madre, J-L. Berri, A., Papon, F. 2002. Can a decoupling of Traffic and Economic growth be envisaged ?, in Social Change and Sustainable Transport, chapter 26.

Madre, J-L., Collet, R., Villareal, I.T, Bussière, Y. 2013. Are we heading towards a reversal for the trend towards ever-greater mobility ?, Discussion Paper 2012 (16), OECD/ITF Roundtable on Long-run Trends in Travel Demand.

Marchetti. C. 1994. Anthropological Invariants in Travel Behavior. Technological Forecasting and Social Change 47.1, 75-88.

Maurin, L. 2017. L'usage de la voiture de nouveau en progression. Futuribles, https://www.futuribles.com/fr/article/lusage-de-la-voiture-de-nouveau-en-progression.
Metz, D. 2010. Saturation of demand for daily travel. Transport Reviews 659.
Metz, D. 2013. Peak car and beyond: the Fourth Era of Travel. Transport Reviews 33.3, 255-270.
Millard-Ball, A., Schipper, L. 2011. Are we reaching peak travel ? Trends in Passenger Transport in Eight Industrialized Countries. Transport Reviews 31, 357-378.

Newman, P. et Kenworthy, J. 2011. Peak car use : understanding the demise of automobile dependence. World Transport Policy and Practice 17.2.

National Surface Transportation Policy and Revenue Study Commission. 2008. Transportation for Tomorrow.

OECD/ITF. 2011. Peak car travel in advanced economies ?, in "Transport Outlook: Meeting the Needs of 9 Billion People, International Transport Forum, Paris.

Papon, F., Madre, J-L. 2003. Existe-t-il des seuils de saturation de la mobilité des personnes ? Réalités Industrielles, une série des Annales des Mines, éditions ESKA.

Papon, F., Hivert, L. 2008. Adulterous behavior within the car-owner couple: some analyses from French panel data on car rental and car sharing within households. IATSS Research 32.2, 6–15.

Papon, F., Armoogum, J., Diana M. 2008. Specific experimental trials versus large-scale mobility surveys insets to investigate transport-related behavioural issues : the case of the primary utility of travel. ISCTSC Conference, Annecy.

Pendyala, R., Kostyniuk, L., Goulias, K. 1995. A repeated cross-sectional evaluation of car ownership. Transportation 22. 2, 165-184.

Rogers, E. 2003. Diffusion of innovations. 5th edition, Simon and Schuster.

Rougerie, C., Friggit, J. 2010. Prix des logements anciens – Dans les années 2000, ils ont augmenté beaucoup plus vite que les loyers et les revenus. INSEE Première 1297.

Schafer, A., Victor, D. (2000). The future mobility of the world's population. Transportation Research A 34, 171-205.

Tulpule, A.H. 1973. Forecasts of vehicles and traffic in Great Britain 1972 revision. Report LR543, Transport and Road Research Laboratory, Crowthorne.

Vanco, F. 2012. L'accès à la ville : vers une contrainte financière de plus en plus forte ? in La mobilité urbaine des années 2000, éditions CERTU.

Vignal, C. 2005. Logiques professionnelles et logiques familiales : une articulation contrainte par la délocalisation de l'emploi. Sociologie du Travail 47.

Vincent, S., Viry, G., Kaufmann, V. 2010. Carrières académiques : comment concilier mobilités spatiales et vie de famille ? Synergies Pays Riverains de la Baltique 7, 77-94.

Zahavi, Y. 1974. Traveltime Budgets and Mobility in Urban Areas. US Department of Transportation, Washington.