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WHY CHANGE BEHAVIORS ?

COST-BENEFIT ANALYSIS OF DIFFERENT STRATEGIC SCENARIOS WITH RESPECT TO EQUITY AND SUSTAINABILITY

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1. INTRODUCTION

During the second half of the twentieth century, travel behaviors have profoundly changed in relation with increasing levels of car ownership and driving license diffusion. According to the French population census, the rate of motorized households increased from 53 to 80.6 % between 1968 and 2011, and the proportion of multi-motorized households from 9.9 to 33.8 % during the same period, leading to an increasing car modal share, and car traffic. According to national traffic accounts, the overall car traffic related to personal vehicles has increased from 328 to 433 billion vehicle*km from 1994 to 2014 in France, i.e + 32 % (CGDD, 2015). Along with the increasing car traffic, its environmental impacts have also risen up, notably those related to pollution and climate change. According to French national transport accounts, the transport sector contributed to 28.9 % of the total amount of greenhouse gas emissions in 2015, of which 92.8 % originated only from road transport. In addition, personal cars contributed to 55.8 % of the emissions of the road sector, followed by light-duty vehicles with 20.2 %. In order to reduce greenhouse gas emissions, national and local authorities have implemented measures to mitigate the dominant position of the car and encourage travel behaviors to shift towards other modes. These policies are briefly displayed in section 2 with their limits, especially the need to account for equity issues in the design of sustainable travel policies, in relation with increasing car dependency and higher fuel costs. To be more specific, cost-benefit analysis of different scenarios has to be performed in relation with alternative travel policies in both terms of sustainability and equity. For this purpose, an *ad hoc* model of car traffic generation is implemented to forecast average car use per adult, individual greenhouse gas emissions and the budget coefficient for fuel expenditures in 2060. This date was chosen for the availability of demographic projections from the French National Institute of Statistics and Economic Studies. In section 3, the modelling approach is exposed along with model specification, while the datasets that were used for model estimation are described in section 4. The methodology and results of model estimation are presented in section 5. The forecasting methodology and results are described in section 6, with a synthesis of the costs and benefits associated with different scenarios in terms of equity and sustainability. Finally, we deal with policy implications in section 7.

2. POLICIES TO MITIGATE CAR TRAVEL AND THEIR LIMITS

Confronted with the increasing environmental damages generated by car traffic, in particular pollution and climate change impacts, decision-makers have designed and implemented a series of policies and measures in order to mitigate car use and reduce its environmental footprint. Following the Rio and Kyoto protocols (1997), France has adopted the so-called law LAURE on the air and the rational use of energy, and French metropolitan areas with more than 100 000 inhabitants were endowed with Urban Travel Schemes (PDU in French) in order to develop alternatives to the car. More recently, the law on energetic transition from 2015 is also implementing incentives to change travel behaviors. In 2014, a carbon component was introduced in the national tax on the consumption of energetic products (TICPE), depending on greenhouse gas (GHG) emissions from the production and consumption of fuel products, with a planned increase from 14.5 € per ton of CO₂ to 56 € in 2020 and 100 € in 2030. In addition to national measures, very active policies were also designed locally from the 1990's to improve transit supply by means of important investments from local authorities. At the same time, these policies have implemented a series of measures to downgrade the relative efficiency of the car, through speed limitations, dedicated bus or car-sharing lanes, or parking restrictions and pricing.

At first sight, one may conclude that these policies were efficient in reducing the preference for car use and promoting alternative transport means, especially transit. For instance, the attendance of urban transit has increased from + 30 % in terms of number of trips per inhabitant in metropolitan areas with more than 250 000 inhabitants (De Solère, 2012a,b), while the average daily car travel has decreased from 3.4 trips per habitant during the period 1995-2004 to 2,8 during the period 2005-09. In addition, the average car traffic per capita has leveled off for the first time from 2003 (CGDD, 2012). However, the contribution of travel policies to this shift in travel behaviors is unclear, as a decreasing car use might also be a consequence of higher fuel prices from the late 1990's, at the same time fostering the use of cheaper modes such as transit (Beauvais, 2012). By the way, the so-called « peak car » phenomenon is not French-specific but is a common trend to most countries of the OECD zone (Millard-Ball and Schipper, 2010). In addition, far from being restricted to the largest metropolitan areas, the stagnation of car traffic has even extended to low-density areas, including outer suburbs and the countryside (Grimal et al., 2013), which did not benefit from similar improvements in transit supply. Given the likely contribution of rising fuel prices to the recent shift in travel behaviors, this one might not be long-lasting (IAURIF, 2013). Incidentally, this statement is reinforced by the recent recovery of car traffic growth (CGDD, 2015), which is economically consistent with the downturn in fuel prices that happened from 2012.

Besides, these policies are now seemingly attaining their limits, the main one being that until now they were focused on improving transit supply in dense urban areas, where car dependency was less of a problem, while outer

suburbs and rural areas have become even more dependent on the car due to the lack of efficient alternatives (Hubert, 2009). Yet, the issue of car dependency has become more critical ever since along with higher energy costs, making households more vulnerable (Nicolas et alii., 2012), and forcing them either to increase their budget share for travel or to reduce their mobility. Besides, generally speaking, environmental goals are hardly ever balanced with other fundamental issues at stake when it comes to sustainable travel policies, especially concerns about social equity, economic efficiency and quality of life, within the scope of a comprehensive cost-benefit analysis. Talking about equity concerns, two major issues may at least be identified: on the first hand, the ability of sustainable travel policies to ensure an inclusive mobility for all; on the other hand, their capacity to account for situations of vulnerability resulting from car dependency associated with long-run increasing travel costs. A better integration of equity issues would represent a significant progress in designing strategies and measures maximizing environmental benefits without generating excessive social costs. In particular, these issues become critical when it comes to the carbon tax, establishing a non-reversible growth path for the carbon component of energetic taxation, which will ultimately impact household budgets, especially in the absence of compensatory measures or if these measures are not sufficiently well-designed. Yet, if the current drop of oil prices provides a favorable context for increasing environmental taxation, conversely new increases in taxation will become hardly acceptable if oil prices were to rise again. In the following analysis, an *ad hoc* model is used to simulate the raw outcomes of several scenarios, in order to introduce a discussion on the respective costs and benefits of different policy sets. Three indicators are considered: the average traffic per adult, individual CO₂ emissions and the average household budget coefficient for fuel expenditures.

3. MODELLING FRAMEWORK: A SEQUENTIAL, INDIVIDUAL AND SEGMENTED APPROACH

The modeling framework that was chosen to forecast these indicators is based on a sequential approach enabling to generate, for every individual, the average car traffic generated by the vehicles of which he is the main driver, by associating two discrete choice models and a log-linear model.

In practice, model specification is as follows:

$$z_{it}^* = \nu Z_i^2 + \gamma X_{it}^2 + \alpha_i + u_{it}, z_{it} = 1 \text{ if } z_{it}^* > 0, \text{ otherwise } z_{it} = 0 \quad (1)$$

$$y_{it}^* = \delta Z_i^1 + \beta X_{it}^1 + \eta_i + \varepsilon_{it}, \text{ if } z_{it} = 1; y_{it} = 1 \text{ if } y_{it}^* > 0, \text{ otherwise } y_{it} = 0; \\ y_{it} = 0 \text{ if } z_{it} = 0 \quad (2)$$

$$w_{it} = \mu Z_i^3 + \theta X_{it}^3 + \xi_i + r_{it}, \text{ if } y_{it} = 1, \text{ otherwise } w_{it} = 0 \quad (3)$$

For a given individual, one is modeling successively its likelihood of holding a driving license, of being the main driver of a vehicle, given that he holds a driving license, and the average car traffic generated by the vehicles

distributed per main driver. As the model is estimated on panel data (cf. section 4), observations are organized according to both an individual and a temporal dimension, respectively represented by indexes i and t . The panel structure implies a particular specification of error terms, divided between a permanent individual-specific effect, and an idiosyncratic shock, relative to individual i and period t . For instance, the error term for the driving license model can be divided between the individual effect α_i , of variance σ_α^2 , and the local shock u_{it} , of variance normalized to 1. The sub-model for driving license likelihood is described by equation (1), while equation (2) stands for the model for being the main driver of a vehicle if the individual is licensed, and equation (3) for the expectation for car traffic – in vehicle*km- if the individual is the main driver of a vehicle. In this model, two filterings express the necessary conditions for an individual to be considered as a traffic generator. First, he has to be a driving license holder; second, he has to be the main driver of a vehicle, as car mileages are always attributed to the vehicle main driver. Models (1) and (2) are *probit* error component models, where dependent variables z_{it}^* and y_{it}^* stand for latent utilities of being licensed and being the main driver of a vehicle if licensed. Model (3) is a generalized linear regression model. In every equation, variables Z_i stand for permanent individual characteristics of generation and gender, while variables X_{it} stand for time-varying attributes, such as income per consumption unit, average local density and vehicle mileage cost. ν , γ , δ , β , μ , and θ stand for variable parameters. The model was also segmented to account for heterogeneity in car-related behaviors according to a number of criteria, namely gender, household type (by separating singles and couples), job status and the type of residential area (by separating conurbations and low-density areas, including outer suburbs and rural areas).

4. DATASET

Model estimation was realized with the French car fleet surveys, a panel dataset consisting of households living in France and surveyed every year on their vehicle fleet and driven mileage. 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). Around six to seven thousand households are questioned every year, the sample being renewed by a third every year. The dataset consists of three levels, containing information respectively on the household, the individuals within the household, and finally on the vehicles and their characteristics, which are described up to three vehicles per household, including personal cars but also light-duty vehicles. For every vehicle, the main driver can be identified. Given that adulthood is required to drive a vehicle, only individuals aged more than 18 are used for model estimation. There are also missing values for some variables, in particular for income and annual mileage. In order to prevent the loss of information that would lead to less precise and possibly biased estimates, the “hot-deck” method is used to complete missing values ¹. Age and generation effects are estimated by dividing the population into equal five-year brackets ². The income per consumption unit is used to compare

households from different size and composition ³. A fuel price index, expressed in €/l, is obtained by weighting the price of every fuel type by the vehicle fleet structure (fuel/diesel/GPL). A mileage cost indicator is also calculated by accounting for vehicle consumption (in l/100 km), expressed in €/km. Besides, all monetary values – income and fuel prices – are corrected from inflation, using the consuming price index (IPC) of the French National Institute of Statistics and Economic Studies, and expressed in constant €'s.

5. MODEL ESTIMATION

Considering model (3) which is linear, parameters are estimated through the quasi-generalized least squares estimator, which was chosen in order to minimize the variance of estimates. For models (1) and (2), the maximum likelihood estimator is preferred, maximizing the likelihood of the realized sequence of events. In addition, income and fuel cost elasticities are also estimated for the different steps of the sequential process of car traffic generation. Estimation results are displayed in table 1 for a partial segmentation of the model based on gender. Generation effects are slightly different between men and women: *ceteris paribus*, the likelihood of being licensed is increasing until generations born in the 60's for men, and until generations born in the 70's for women. Conversely, it is decreasing in generations born in the 80's, which are sometimes called the "millenials" or "generation Y" ⁴. The likelihood of being licensed is also dependent on income, given the training costs of driving license exams which can be deterrent for low-income groups. Finally, the variance of individual effects is higher for women, which can be explained by a larger proportion of housewives and opportunities of sharing the main household vehicle, explaining why some women did not require to hold a driving license and pass driving license exams, especially in the oldest generations.

Everything else equal, the likelihood of being the main driver of a vehicle among driving license holders is constantly increasing from a generation to another, either for men or for women. However, age effects differ according to gender. Among men, the likelihood of being the main driver of a vehicle is increasing continuously until the age of seventy-five, before decreasing. Among women, a peak for car ownership is reached by forty-five to fifty, corresponding to a period of maximum professional and family duties for women along with the need to escort children to school in many cases. It is also a period where households often live in outer suburbs, where they rely more tightly on the car to fulfill their travel needs.

As generation effects are not significant for vehicle travelled distances per main driver of a vehicle, they were excluded from model (3). Everything else equal, vehicle mileage is increasing until 25-35 before decreasing all life long, either for men or for women. The effect of mileage cost on travelled distances per main driver is almost independent from gender, with elasticities estimated respectively at – 0.53 for men and – 0,58 for women. In the same manner, income elasticities of car use are estimated respectively at + 0.11 for men and + 0,07 for women.

Table 1 : Model parameter estimates

Driving license										
	Men					Women				
	Estimate	Error	Pr > t	95% C.I.		Estimate	Error	Pr > t	95% C.I.	
G ₀₋₁ (< 1920)	0.72	0.076	<.0001	0.57	0.87	-1.37	0.137	<.0001	-1.64	-1.10
G ₂₋₃ (1920-30)	1.22	0.042	<.0001	1.14	1.30	0.91	0.047	<.0001	0.82	1.00
G ₄₋₅ (1930-40)	1.68	0.045	<.0001	1.59	1.77	1.36	0.039	<.0001	1.28	1.43
G ₆₋₇ (1940-50)	2.17	0.086	<.0001	2.01	2.34	1.66	0.043	<.0001	1.57	1.74
G ₈₋₉ (1950-60)	1.97	0.054	<.0001	1.86	2.07	1.97	0.051	<.0001	1.87	2.07
G ₁₀₋₁₁ (1960-70)	2.40	0.071	<.0001	2.26	2.54	2.20	0.085	<.0001	2.03	2.36
G ₁₂₋₁₃ (1970-80)	2.17	0.061	<.0001	2.06	2.30	2.40	0.062	<.0001	2.28	2.53
G ₁₄₋₁₆ (> 1980)	1.18	0.071	<.0001	1.04	1.32	1.56	0.075	<.0001	1.41	1.70
18 - 20 years	-2.35	0.072	<.0001	-2.49	-2.21	-2.60	0.076	<.0001	-2.75	-2.45
20 - 25 years	-0.94	0.066	<.0001	-1.07	-0.81	-1.19	0.070	<.0001	-1.33	-1.06
Income	4.0 ^{e-5}	1.6e-6	<.0001	3.6 ^{e-5}	4.3 ^{e-5}	2.7 ^{e-5}	1.6 ^{e-6}	<.0001	2.4 ^{e-5}	3.0 ^{e-5}
σ_{η}^2	2.90	0.068	<.0001	2.77	3.04	4.96	0.084	<.0001	4.80	5.12
Main user of a vehicle among driving license holders										
	Men					Women				
	Estimate	Error	Pr > t	95% C.I.		Estimate	Error	Pr > t	95% C.I.	
G ₀₋₁ (< 1920)	-2.22	0.192	<.0001	-2.59	-1.84	-1.96	0.232	<.0001	-2.41	-1.51
G ₂₋₃ (1920-30)	-1.83	0.135	<.0001	-2.09	-1.57	-1.71	0.139	<.0001	-1.99	-1.44
G ₄₋₅ (1930-40)	-1.51	0.123	<.0001	-1.75	-1.27	-1.55	0.115	<.0001	-1.77	-1.32
G ₆₋₇ (1940-50)	-1.06	0.111	<.0001	-1.27	-0.84	-1.33	0.107	<.0001	-1.54	-1.12
G ₈₋₉ (1950-60)	-0.81	0.095	<.0001	-0.99	-0.62	-0.50	0.095	<.0001	-0.69	-0.32
G ₁₀₋₁₁ (1960-70)	-0.47	0.078	<.0001	-0.63	-0.32	-0.24	0.079	0.0024	-0.39	-0.08
G ₁₂₋₁₃ (1970-80)	-0.33	0.069	<.0001	-0.46	-0.19	-0.14	0.070	0.0490	-0.27	-0.00
18-20 years	-0.53	0.094	<.0001	-0.71	-0.34	-0.93	0.104	<.0001	-1.14	-0.73
20-25 years	0.43	0.064	<.0001	0.31	0.56	0.16	0.066	0.0190	0.03	0.28
25-30 years	1.38	0.071	<.0001	1.24	1.52	0.84	0.069	<.0001	0.70	0.98
30-35 years	1.86	0.079	<.0001	1.71	2.02	1.22	0.077	<.0001	1.07	1.37
35-40 years	2.11	0.084	<.0001	1.95	2.28	1.36	0.082	<.0001	1.20	1.52
40-45 years	2.30	0.092	<.0001	2.12	2.48	1.38	0.089	<.0001	1.20	1.55
45-50 years	2.55	0.099	<.0001	2.36	2.74	1.43	0.096	<.0001	1.25	1.62
50-55 years	2.74	0.107	<.0001	2.53	2.94	1.36	0.103	<.0001	1.16	1.57
55-60 years	3.08	0.115	<.0001	2.86	3.31	1.14	0.108	<.0001	0.93	1.35
60-65 years	3.52	0.122	<.0001	3.28	3.75	0.98	0.112	<.0001	0.76	1.20
65-70 years	3.65	0.127	<.0001	3.40	3.90	0.89	0.116	<.0001	0.67	1.12
70-75 years	3.76	0.133	<.0001	3.50	4.02	0.78	0.122	<.0001	0.54	1.02
75-80 years	3.58	0.139	<.0001	3.31	3.85	0.66	0.132	<.0001	0.40	0.92
80-85 years	3.12	0.152	<.0001	2.82	3.42	0.19 (NS)	0.155	0.2200	-0.11	0.49
85-90 years	2.18	0.192	<.0001	1.80	2.56	-0.65	0.222	0.0036	-1.08	-0.21
90-95 years	1.84	0.322	<.0001	1.21	2.47	-2.19	0.611	0.0003	-3.38	-0.99
> 95 years	0.54 (NS)	0.593	0.360	-0.62	1.71	-0.46 (NS)	1.153	0.6911	-2.72	1.80
Income	1.2 ^{e-5}	1.2 ^{e-6}	<.0001	9.7 ^{e-6}	1.4 ^{e-5}	1.1 ^{e-5}	1.2 ^{e-6}	<.0001	8.5 ^{e-6}	1.3 ^{e-6}
σ_{η}^2	3.21	0.086	<.0001	3.04	3.37	4.47	0.111	<.0001	4.25	4.69
Average distance travelled per vehicles by main user										
	Men					Women				
	Estimate	Error	Pr > t	95% C.I.		Estimate	Error	Pr > t	95% C.I.	
18-20 years	5.56	0.208	<.0001	5.16	5.97	5.92	0.279	<.0001	5.37	6.47
20-25 years	6.03	0.191	<.0001	5.65	6.40	6.44	0.265	<.0001	5.92	6.96
25-30 years	6.25	0.189	<.0001	5.88	6.62	6.64	0.264	<.0001	6.13	7.16
30-35 years	6.24	0.188	<.0001	5.88	6.61	6.60	0.263	<.0001	6.08	7.11
35-40 years	6.16	0.187	<.0001	5.79	6.53	6.56	0.263	<.0001	6.05	7.08
40-45 years	6.19	0.187	<.0001	5.82	6.55	6.52	0.263	<.0001	6.01	7.04
45-50 years	6.19	0.187	<.0001	5.83	6.56	6.52	0.263	<.0001	6.00	7.03
50-55 years	6.12	0.188	<.0001	5.75	6.48	6.43	0.264	<.0001	5.91	6.95
55-60 years	6.09	0.188	<.0001	5.72	6.46	6.27	0.264	<.0001	5.75	6.79
60-65 years	6.06	0.188	<.0001	5.69	6.43	6.14	0.264	<.0001	5.62	6.66
65-70 years	5.98	0.188	<.0001	5.61	6.35	5.98	0.264	<.0001	5.47	6.50
70-75 years	5.82	0.187	<.0001	5.45	6.18	5.77	0.264	<.0001	5.25	6.29
75-80 years	5.58	0.187	<.0001	5.22	5.95	5.50	0.265	<.0001	4.98	6.02
80-85 years	5.22	0.188	<.0001	4.85	5.58	5.15	0.271	<.0001	4.62	5.68
85-90 years	4.81	0.198	<.0001	4.43	5.20	4.94	0.301	<.0001	4.35	5.53
90-95 years	4.09	0.267	<.0001	3.56	4.61	5.33	0.528	<.0001	4.29	6.36
Income	0.11	0.011	<.0001	0.09	0.14	0.068	0.013	<.0001	0.043	0.093
Mileage cost	-0.53	0.065	<.0001	-0.65	-0.40	-0.58	0.090	<.0001	-0.76	-0.40

6. PROJECTIONS OF AVERAGE CAR MILEAGE, CO₂ EMISSIONS AND FUEL BUDGET SHARE IN 2060

6.1 Forecasting methodology

In order to forecast the indicators of interest in 2060, one has to distribute first the population between model segments in order to account for structural effects that are likely to affect projection results. Starting with demographic projections from the model OMPHALE designed by the French National Institute of Statistics and Economic Studies, providing forecasts of the population distributed by sex and age group in 2060, we define a methodology to distribute these groups according to additional criteria, i.e household type, job status and type of residential area, leaning on the lifecycle profiles of these variables which can be calculated from the *French Car fleet Surveys*. Indeed, either the proportion of individuals living in a family, activity rates or the proportion of residents of low-density areas were found to follow bell-shaped curves with a peak in the middle of individuals lifecycle before decline. These curves were supposed to remain essentially unchanged, resulting in stable rates by sex and age group between 2010 and 2060, or said otherwise, we assumed a stable way of life, except for the spatial distribution of the population, which was modified in consistency with the assumptions retained in section 6.2.

Once the population distributed between segments, model parameters were used to forecast the indicators. However, as generation parameters are known only for generations born before 1975, assumptions have to be made for later generations. Given the exhaustion of generation effects, behaviors of generations born after 1975 were assumed identical to those of generation 1970-75, the last to be known with certainty, an assumption which is consistent with what we currently know about the behaviors of generation Y (cf. note 4). For vehicle mileages reported to their main drivers, we have already noticed that age effects did not differ significantly from a generation to another, while generation effects were negligible. Consequently, to forecast vehicle mileages per main driver, we simply applied to the sample values by sex and age group, income and mileage cost elasticities estimated from the model, according to the following formula, where R and C respectively represent income and mileage cost, and θ_R and θ_C elasticities with respect to the same variables :

$$w_{it} = w_{i2010} \left(\frac{R_{it}}{R_{i2010}} \right)^{\theta_R} \left(\frac{C_{it}}{C_{i2010}} \right)^{\theta_C} \quad (4)$$

Then, the average car use per adult can be deduced for every segment and age group, by applying the following formula:

$$E(U_{it}) = E(w_{it}) P(y_{it} = 1 | z_{it} = 1) P(z_{it} = 1) \quad (5)$$

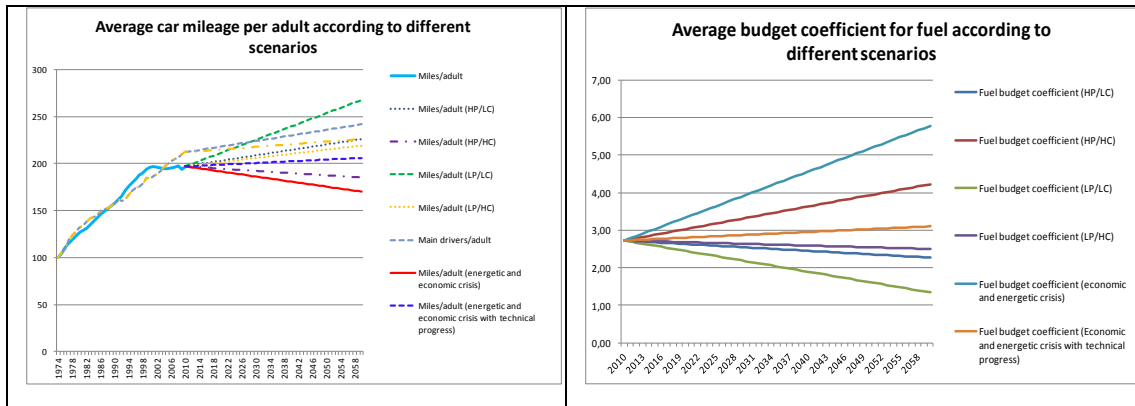
In words, the average car mileage per adult is the product of the average car use per main user of a vehicle, by the likelihood of being licensed and by the

likelihood of being the main driver of a vehicle, if licensed. By multiplying the average traffic per adult by vehicle cost – itself calculated from fuel price and vehicle consumption – and by dividing by household income, we then obtain an estimation of the average fuel budget share. Finally, CO₂ emissions per adult are estimated by multiplying the average traffic per adult by unit emissions.

6.2 Scenarios

However, the formulation of scenarios is required to highlight the likely consequences of different plausible evolutions in the main determinants of demand in a context of high uncertainty. For instance, income growth, vehicle consumption and fuel prices are not known for sure at the forecasting horizon. Therefore, we built up a family of six scenarios, among which four share the assumption of moderate economic growth, resulting in an average income growth of about + 1 % a year until 2060. However, these four scenarios differ among them by their assumptions relative to the evolution of fuel prices (in €/l) and vehicle consumption (in l/100 km). In the first one, which is noted HP/HC for “High Price – High Consumption”, fuel price is multiplied per two while vehicle consumption remains stable, given the lack of technical progress and a low penetration rate of new hybrid and electric vehicles. In the second scenario, which is noted HP/LC for “High Price – Low consumption”, fuel price is also multiplied by two but this time, vehicle consumption is turned downwards. We assume that unit emissions keep on decreasing from – 1 % a year, in line with what was observed from 1990, along with the replacement of old pollutant vehicles by newer and cleaner technologies, and therefore decrease from 172 to 75,7 gCO₂/km between 2010 and 2060 ⁵. In this scenario, technical progress enables the stabilization of fuel mileage cost by counterbalancing increases in fuel prices. In the third scenario, called LP/HC for “Low Price – High Consumption”, corresponding to the *statu quo*, fuel prices remain at their current level as much as vehicle consumption. Finally, in the fourth scenario, represented as LP/LC for “Low Price – Low Consumption”, fuel prices remain at their current level but in addition, vehicle consumption is decreasing like in scenario 2, so that the mileage cost is divided by more than two. A second group of two additional scenarios corresponds to a situation of long-lasting recession, yielding to the stagnation of household average income. Moreover, we assume fuel prices to be multiplied by two, like in scenario 1. However, the two scenarios differ by their assumptions relative to technical progress, the first one being characterized by stable fuel efficiency while in the second, unit emissions are decreasing like in scenarios 2 and 4. Assumptions are also necessary about the evolution of local densities. Indeed, if the average density can be calculated from total demographic growth, one also has to make assumptions about the distribution of the population between conurbations and low-density areas. For now, we assume the business-as-usual assumption of an increasing disequilibrium to the benefit of outer suburbs (Floch et Lévy, 2011) ⁶.

6.3 Projection results and cost/benefit analysis of different scenarios with respect to equity and sustainability



Figures 1 and 2: Average car traffic per adult and household average budget coefficient for fuel in 2060 according to different scenarios, index basis 100 in 1974

Sources: Household consumption surveys (ECAM), French car fleet surveys (ParcAuto), model forecasts in 2060

Projection results are then analyzed, starting by the average car traffic per adult which is moderately increasing on average, for instance from + 11,3 % in the scenario of *statu quo* where fuel prices and fuel efficiency remain at their current level, in a context of moderate income growth, and from + 14,8 % in the scenario where the impact of higher fuel prices is offset by greater fuel efficiency. The future growth of average car traffic per adult is therefore expected to be far less intense than what it has been before, between the 1970's and the 2000's, where it was multiplied per two. This slowdown can be attributed to progressive saturation in the diffusion of personal car availability, given the exhaustion of generation effects which were related to differences between generations in the diffusion of driving license and personal car availability, especially among women. Based on long-term observation of car traffic generation at the household level, our modeling framework also implicitly assumes that traffic growth is based on the number of main drivers, rather than the number of cars per adult, i.e that additional cars beyond the access to personal autonomy will not generate additional traffic but rather a different distribution of household car use among vehicles. Consequently, it results in the average car traffic per capita slowing down towards saturation from a certain threshold in the diffusion of personal car availability.

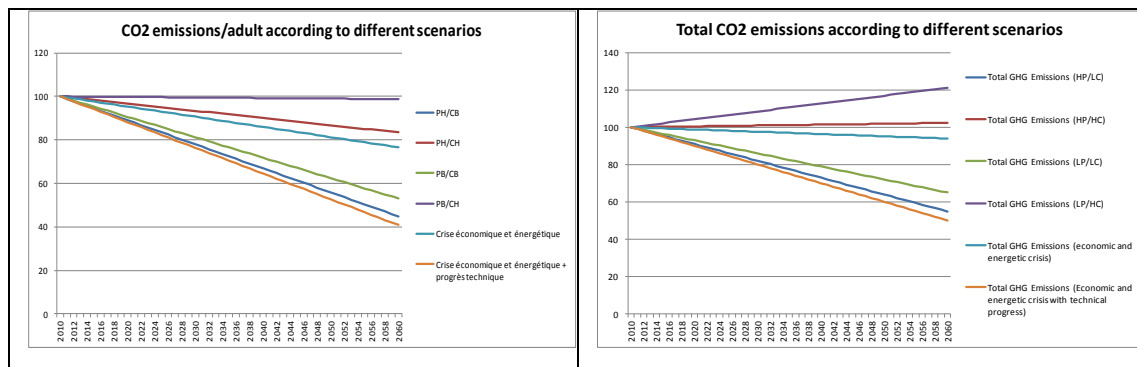
Given the assumption of stable behaviors of generations to come, which is consistent with the stagnation of car ownership in France from the mid-2000's which was noticed from the French continuous population census, the growth of car traffic per capita can be attributed to the increasing average income. However, the main effect of higher incomes is on the proportion of vehicle main drivers, which is increasing from 55,2 to 63 % in scenarios with income growth, i.e + 14,2 %, while the average annual car mileage per main driver is rather slightly decreasing, from 13 892 to 13 535 km. In fact, the effect of an increasing income on the proportion of main drivers and the average annual

mileage per main driver is partly offset by population ageing, which contributes to decreasing levels of car ownership and car mileage, everything else being equal.

Only two scenarios result in a decline of average car traffic per adult. The first one, the most pessimistic, consists of fuel prices being multiplied by two in a context of recession and in the absence of technical progress. In such conditions, the average car traffic per adult declines from – 13.7 %. The other scenario is almost identical, except that a moderate income growth is expected. In this case, the average car use per adult is decreasing only from – 6 %. Both scenarios are characterized by an increasing mileage cost. Conversely, the three scenarios where the mileage cost remains stable result in average car traffic per adult leveling off or increasing, depending on income growth. Apart from the two first scenarios already mentioned, the scenario of doubled fuel prices with increasing fuel efficiency and a long-lasting recession results in only a slight increase of average car traffic per adult, from + 4,6 %. Finally, the last scenario yielding a higher level of car traffic per adult is where fuel prices remain at their current level while fuel efficiency is increasing, in a context of income growth. In this case, the average car traffic per adult is increasing from + 35,9 %. The main cause of variation in future levels of car traffic between scenarios is therefore the energetic purchasing power or the relationship between income growth and fuel mileage cost.

Future budget coefficients also depend simultaneously on income growth and future car travel costs. Two scenarios are leading to a higher budget coefficient for fuel expenditures. One of them is when fuel prices are multiplied by two, in the absence of substantial progress in fuel efficiency, which is aggravated by a context of recession. In such conditions, the household budget coefficient for fuel is increasing from 2.7 to 4 %. The other scenario is almost identical to the first one, except that this time we assume the existence of moderate income growth. Under these assumptions, the budget coefficient is increasing only from 2.7 to 2.9 %, as the impact of higher fuel prices on the fuel budget coefficient is partly offset by a higher average income. Together they represent the scenarios where fuel mileage cost is increasing. The increasing mileage cost of vehicle use results in higher budget coefficients because of compulsory activity programs and car dependency, as households are not capable of reducing car travel to fully compensate the increasing mileage cost. However, the increase of budget coefficients is far less important than what it would be in the absence of structural demographic effects, as it is partly offset by population ageing, resulting in a lesser level of car ownership and car travel. Given income growth and structural population ageing, all other scenarios result in a decreasing budget coefficient for fuel. One of them is the scenario of *statu quo*, where fuel prices and fuel efficiency remain at their current level. In this case, the budget coefficient for fuel is decreasing steeply, from 2.7 to 1.7 % in 2060. The amplitude of the fall is similar in the scenario “High Price – Low consumption”, where the influence of a higher fuel price is balanced by technical progress and an increasing income. In this case, the budget coefficient is decreasing to 1.6 % in 2060.

Finally, the scenario resulting in the strongest fall of the budget coefficient for fuel is when fuel prices remain at their current level, while fuel efficiency is increasing. In this case, the budget coefficient reaches only 0.9 % in 2060.



Figures 3 and 4 : Individual and total CO₂ emissions in 2060 according to different scenarios, index basis 100 in 1974

Sources : French car fleet surveys (ParcAuto), model forecasts in 2060

Finally, we consider the consequences of the various scenarios on the level of CO₂ emissions per capita. A clear distinction can be made between scenarios with technical progress, all resulting in a sharp decrease of CO₂ emissions per capita – from - 40 to - 55 % by comparison to 2010 – and scenarios without technical progress, where the fall of CO₂ emissions is much more limited. Everything else equal, improving fuel efficiency almost results in dividing by two the level of GHG emissions per capita. In one scenario, the level of CO₂ emissions is even slightly increasing. This is the case in the scenario “Low Price – High Consumption”, where the level of emissions per capita is increasing from + 11.3 %, while it falls down by – 40.3 % in the scenario “Low Price – Low Consumption”. Similarly, CO₂ emissions per capita decrease by only – 6.0 % in the scenario “High Price – High Consumption”, while it falls down by – 49,5 % in the scenario “High Price – Low Consumption”.

Comparatively, the influence of rising fuel prices on the level of GHG emissions per capita is rather limited. For instance, comparison between the scenarios “High Price – High Consumption” and “Low Price – High Consumption” highlights the fact that to double fuel prices only yields a – 17.3 points decrease in the level of CO₂ emissions, an effect which is even more limited in scenarios with technical progress. Indeed, the level of CO₂ emissions per capita in the scenario « High Price – Low Consumption » is only – 9.2 pts lower than in the scenario « Low Price – Low Consumption ». Therefore, it looks like the most efficient way to reduce the level of individual GHG emissions is to increase fuel efficiency, while the additional benefit of increasing fuel prices, for instance through the implementation of a “carbon tax”, appears to be more limited, especially in scenarios with technical progress.

Finally, we synthesize the relative costs and benefits of the different scenarios with respect to issues of equity and sustainability. From the last analysis, it

appears that scenarios where higher fuel prices are not offset by increasing fuel efficiency could generate social costs while presenting limited benefits in terms of reducing GHG emissions. Indeed, they may simultaneously result in a loss of motility and a higher financial burden for households. These social costs are especially important if the impact of higher fuel prices is aggravated by a long-lasting recession. The scenario of *statu quo* for fuel prices and fuel consumption with income growth will yield some social benefits as it allows both to increase personal motility and reduce the financial burden for households, but it has negative environmental counterparts, with an increasing level of total emissions, given demographic growth combined with the absence of progress in fuel efficiency. Only the three scenarios with increasing fuel efficiency allow the conciliation between equity and sustainability concerns, resulting simultaneously in decreasing levels of total emissions and household budget coefficients for fuel. Among these, the scenario where fuel prices remain at their current level offers the most important social benefits while sharply cutting off GHG emissions.

These results can be explained by the low price elasticity of car travel, which results from the combination of several phenomena. For a part, due to the compulsory nature of some activity programs, individuals are not always capable of reducing their trips in order to fully compensate the increase of their travel costs. In addition, households are sometimes car-dependent, depending on their place of residence, given limited availability and/or efficiency of alternative transport means, whether it is in terms of pure availability, travel time or flexibility. Car dependency is a well-documented fact in the literature (Dupuy, 1999), especially among residents of low-density areas, given higher trip distances and the scattering of activities. Yet, in the absence of technical progress, the evolution of GHG emissions is more or less indexed on car traffic, so that scenarios with higher fuel prices without technical progress only induce a limited fall in GHG emissions, corresponding to the low fuel price sensitivity of car travel. Besides, as individuals cannot reduce their travel by car so as to fully compensate higher fuel prices, their financial burden will also be increasing, especially the absence of income growth. Conversely, the progress in fuel efficiency is fully transmitted to the level of emissions as they are proportional to fuel consumption. Admittedly, it is partly offset by the rebound effect, leading individuals to use the decreasing travel cost resulting from a higher fuel efficiency to travel more (Greene et alii., 1999), but for the same reason than before, i.e the low price elasticity of car travel, the rebound effect remains of a far lesser amplitude than the gross fall in GHG emissions per capita. But in addition, the increasing fuel efficiency also has significant positive outputs on household budget coefficients and travel potential.

7. POLICY IMPLICATIONS

We are now considering some policy implications of these results. In order to cut off the total amount of GHG emissions, several great options can be considered by policy makers. One of them is to focus on trying to change behaviors by persuading individuals to reduce car use through transfer to

alternative modes. With this in mind, one critical strategy which is often advocated both by economists and environmentalists is based on increasing the cost of car travel through the incremental increase of environmental taxation, the carbon tax being one of the main tools of this policy. Another great option would be to rely mostly on technical progress, in relation with solutions of virtual travel (telecommuting, e-shopping, videoconferencing...) enabling to cut off travel needs at the root, and planning policies aiming for reducing the level of car dependency, given the established relationship between travel and urban patterns (Ewing et Cervero, 2001). What our results are suggesting is that, given the price elasticity of car travel, technical progress appears as the most efficient way in order to cut off GHG emissions from the transport sector, while measures based on taxation should be rather considered as additional tools that can be mobilized to improve the general result, as their efficiency is limited by urban and travel patterns, the organization of transport supply and the rigidity of activity programs. Besides, in looking for an optimal strategy, more attention should be paid to equity issues, in a background of long-run increasing fuel prices associated with car dependency. The study that we have just presented is suggesting that the first type of strategies doesn't enable to fully conciliate environmental and equity concerns. In addition, the potential negative social outputs of environmental fiscality, including a long-term planned and irreversible increase of the carbon tax, would be aggravated if oil prices were to increase again. Conversely, a strategy based on incentives to promote technical progress, by encouraging research and innovation among car-builders and subsidizing the purchase of more efficient clean-tech vehicles so as to accelerate the renewal of the vehicle fleet, would best conciliate environmental targets with equity issues and help making higher energy costs socially acceptable. Considering environmental fiscality as a complementary tool, one can however imagine different levels of taxation depending on governmental priorities. For instance, a government eager for equity could consider adapting the level of taxation to technical progress and income growth so as to stabilize household budget coefficients. An alternative method is to compensate *a posteriori* the potential welfare impacts of environmental fiscality and especially of a carbon tax, for instance through cut-offs in other taxes, or through an indirect return by recycling tax revenues in developing alternative travel devices for low-density areas.

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Notes

¹ Dependent variables with missing values to be estimated are first identified, along with their determinants. Then, observations are classified according to the values of their determinants. Finally, an observation is given the value of the observation immediately preceding or following.

² Except for generations born before 1915 and generations born after 1990, who were gathered each time in only one group, because of small samples.

³ The number of consumption units per household is calculated using the OECD scale of equivalence (Houriez et Olier, 1997), where the household head is weighted for 1, other household adult members for 0.5, and children aged less than 14 for 0.3.

⁴ However, we don't know for sure at this stage whether this generation is definitely renouncing to pass their driving license exams and have a car, or is simply delaying these life stages, in relation with changing life conditions of the youth. There is some evidence from the literature on « *peak car* » that there is a decline of car use in new generations, especially among men (Kuhnimof et alii., 2012). However, according to other studies, the access to car ownership would simply have been delayed, in relation with later and more uncertain life stages (longer studies, later family foundation, delayed access to the job market, and so on), metropolization making young people less dependent on the car, low financial resources (Kim, 2014 ; Garikapati et alii., 2016).

⁵ This assumption is quite « conservative » in comparison to the scenarios published by the French Environment and Energy Management Agency (ADEME, 2013), forecasting a drop in unit emissions from 167 to 100 gCO₂/km between 2010 and 2030, i.e more than a yearly – 3 % , and an average level of emissions from new electric and hybrid vehicles of 49 gCO₂/km in 2030. Therefore, it doesn't require a major technological break-up, but rather the continuation of the long-run progress in the efficiency of conventional engines and a wider diffusion of cleaner technologies, through the natural renewal of the fleet (Kolli, 2012).

⁶ To be more specific, we assume the ratio between demographic growth in low-density areas and in conurbations to remain constant, the overall demographic growth being estimated according to the forecasts from the model OMPHALE.