Personal car, public transport and other alternatives?
Predicting potential modal shifts from multinomial logit models and bootstrap confidence intervals

Amandine CHEVALIER
Frédéric LANTZ

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amandine_chevalier@hotmail.fr
frederic.lantz@ifpen.fr

Personal car, public transport and other alternatives? Predicting potential modal shifts from multinomial logit models and bootstrap confidence intervals

Amandine Chevalier[a,b,c,1], Frédéric Lantz[b]

[a]BIPE, Issy-les-Moulineaux, France
[b]IFPEN, Rueil-Malmaison, France
[c]CERNA, Mines ParisTech, Paris, France

Abstract

Households' daily mobility in France is characterized by the preponderance of the automobile. Passenger cars, mainly used by households but not only, are thus responsible for more than a half of fuel consumptions in road transport (CGDD/SOeS, July 2013) and more than a half of CO_2 emissions in the transport sector (SOeS/CDC, December 2012). The main objective of this paper is thus to explain the modal choice of French households for their daily trips, particularly the importance of the car, and to predict potential shifts from personal car to public transport and other alternatives, especially shared car. An independent multinomial logit model is estimated and reveals the particular importance of car equipment on modal choices and specifically on car use. Predictions by 2020 are conducted according to three cases for the household's motorization (no car, one car, two cars or more) and per different mobility profiles. Personal car should remain the main mode of transportation by 2020 except if households have no car. In that case, modal shares would be more balanced, public transport would become the main transport mode and the shift to shared car would be at a maximum. Modal share of shared car could thus reach 16% for "exclusive motorists". A conditional logit model is also estimated and shows no particular importance of the means of transportation's costs in the modal choices. These results show that the increase in distances between 2010 and 2020 makes motorized modes more necessary. Thus, personal car and public transport should remain the main modes of transportation by 2020. Moreover, expected changes in costs and travel time by 2020 does not seem to have any effect on the deployment of shared car, its modal share being constant (in an average) between 2010 and 2020.

Keywords: Modal choice; personal car; public transport; shared car; multinomial logit model; conditional logit model; bootstrap confidence intervals.

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[1] *E-mail address*: amandine.chevalier@ifpen.fr

Introduction

Households' daily mobility in France is characterized by the preponderance of the automobile. Passenger cars, mainly used by households but not only, are thus responsible for more than a half of fuel consumptions in road transport (CGDD/SOeS, July 2013) and more than a half of CO_2 emissions in the transport sector (SOeS/CDC, December 2012). But in recent years, we observe a decrease in fuel consumptions by private cars and an increase of fuel consumptions by motorcycles and buses and coaches (CPDP, 2012), suggesting a modal shift from private car to motorcycles and public transport. In the same time indeed, inflections in car use are observed. Thus, young people use less private car and are less often motorized than their elders. Moreover, households try to adapt to the high cost of car by travelling less kilometers by car each year, by pooling its use thanks to new mobility services such as carpooling and carsharing and by using more public transport in urban area.

The new mobility services, especially carsharing, can be considered as empirical applications of the business model of the functional service economy. According to some researchers, the new business model consisting of the substitution of the sale of the product's function to the sale of its property, which is the concept behind the new individual mobility services we mentioned, allows for a decrease in production, lower consumption of natural resources, in addition to encouraging companies to design products that consume fewer resources in their production, use, maintenance, recycling and reuse (Bourg and Buclet, 2005; Du Tertre, 2007). Fourcroy and Chevalier (2012) show that great energy savings can be achieved by these services only if they replace car ownership and do not add a new need of car.

Moreover, compared to the use of private car by only one person, the use of public transport allows for a decrease in energy consumptions and CO_2 emissions per capita.

These are the reasons why the main objective of this paper is to explain the modal choice of French households for their daily trips, particularly the importance of the car, to predict potential shifts from personal car to alternatives such as public transport, motorcycle or shared car.

From survey data (Mobility Observatory, BIPE, October 2010), we base on households' activities, ie their need for mobility, their car equipment, and socio-economic variables that could impact their modal choices. We estimate an independent multinomial logit model from these variables and a conditional logit model from characteristics of each mean of transportation (cost and travel time). From these estimations, we simulate modal choices by 2020 and apply a pairs bootstrap method to predict modal shares with confidence intervals.

In a first part of the paper, we present a brief review of the literature. Then we describe the method and the data we use in this paper. Our results are then presented. The fourth section is devoted to the predictions of modal shares by 2020 and the last section to the discussion of our results.

1. Literature review

The decision of an individual among several unordered alternatives is generally modelled through multinomial logit models. As an example of such a decision, the choice between means of transport is modelled in this way. Modal choice models such as those estimated by Train (1977), Carson et al. (1994) and more recently Hensher (2008) are mainly built from quantitative data describing the characteristics of the various modes (costs, transfer or transport time, etc.). They can then be used to test the effects of a transport policy (construction of a new road, creation of a new line of transport, etc.). Thus, from a sample interviewed before the introduction of the Bay Area Rapid Transit (BART) in San Francisco in 1973, Train (1977) developed a model to measure the effect of the service in terms of modal split. From the same type of model, Carson et al. (1994) wanted to know how can change the modal share of the car if its cost increases. More generally, research on modal choices show that they are influenced by the level of service (travel time and cost differentials), but also by the characteristics of individuals and households, such as the level of income, car equipment, area of residence and place of work (Stopher and Meyberg 1975, Koppelman and Pas, 1980 Kanafani, 1983, Ben-Akiva and Lerman, 1985; Wachs, 1991).

Moreover, the choice of a mode of transportation can be studied for a particular type of trip, most often commuting. This is particularly what study Train (1977) in San Francisco, Hensher (2008) in six Australian cities, Liu (2007) in Shanghai, Khattak and Palma in Brussels (1997).

Some are also interested in the impact of unexpected events on the modal choice. Thus, Khattak and Le Colletter (1994), and Khattak et al. (1995) show that longer travel time on road may encourage motorists to use public transport. Moreover, Khattak and Palma (1997) show that adverse weather conditions encourage half of motorists in Brussels to change their departure time or their itinerary.

It can also be question of interdependence between the choice of transport mode and trip purpose, more precisely the organization of trips depending on the schedule of the day. Thus one part of the literature focuses on modal choices on the basis of household's activities (activity-based demand model). Damm (1983), Golob and Golob (1983), Kitamura (1988) and Etterna (1996) conduct literature reviews on this subject. We mainly retain that Pas

(1984) shows that demographic factors such as employment status, gender, or the presence of children in the household have a significant impact on the activities and trips. In addition, Kitamura (1984) identifies the interdependence between the choice of destinations in travel chains and the choice of the mode of transportation. Moreover, Bhat and Koppelman (1993) propose an analytical model based on the organization of activities. More specifically and always on the basis of households' activities, the first models of travel chains were mainly developed in the 70's and 80's in the Netherlands (Daly et al, 1983; Gunn et al, 1987; Hague Consulting Group, 1992; Gunn, 1994). They were then used to model the movements in different cities and countries: Stockholm (Algers et al, 1995), Salerno, Italy (Cascetta et al, 1993), Boise, Idaho (Shiftan, 1995), New Hampshire (Rossi and Shiftan, 1997) or Boston (Bowman and Ben-Akiva, 2000). A key finding highlighted by Krygsman et al. (2007) is that there are variations in the order of choice of travel mode and trip purpose. But in most cases, the travel pattern is done before the modal choice. This therefore indicates that it rather depends on the choice of the pattern and the travel chain considered. It is precisely on this need for mobility we base to try to explain the modal choice, as well as on variables describing individuals and households and variables that are characteristics of the different modal choices (travel costs and time).

2. Methodology and data

As described in the introduction, the decrease in fuel consumptions by private cars and the increase of fuel consumptions by motorcycles and buses and coaches observed in recent years (figure 1), suggest a modal shift from private cars to motorcycles and public transport. Moreover, we observe a shared use of the car especially through carpooling and carsharing. Thus we decide to explain the modal choice of French households to predict potential shifts from personal cars to alternatives such as public transport, motorcycles or shared cars by 2020. The transport mode's choice is based on several factors corresponding to the travel mode's (distance, time, etc.) and to the household's characteristics. As mentioned in the previous section, there is a large literature on this topic. Each study point out that the choices are related to the characteristics of a country at a given period. A classical way to assess these choices is to use a multinomial logit model which aims to explain the modal choices by a set of explanatory factors. In the next two paragraphs, we develop the econometric approach that we use for the models' estimations and forecasts. Then, we present the data which are considered for the statistical estimation.

2.1. Multinomial logit model

The objective of the model is to explain that each individual i (i,=1,…n) has a choice between a set of unordered alternatives j (j=0,…m). Here, we consider m+1=6 alternative transportation's modes. As this dependent variable is a qualitative one with a limited number of unordered terms, we use a discrete choice model: the multinomial logit model (MLN).
More specifically, we use two types of logit models: single or independent multinomial and conditional. The distinction between these two types of models is primarily based on the nature of the selected explanatory variables. The first includes variables that are characteristics of individuals, while the second includes variables that are characteristics of the different means of transportation and differ according to the dependent variables and individuals as well. In the case of modal choice, individual i compares the different levels of utility associated with different choices and chooses the one that maximizes his utility from the j choices.
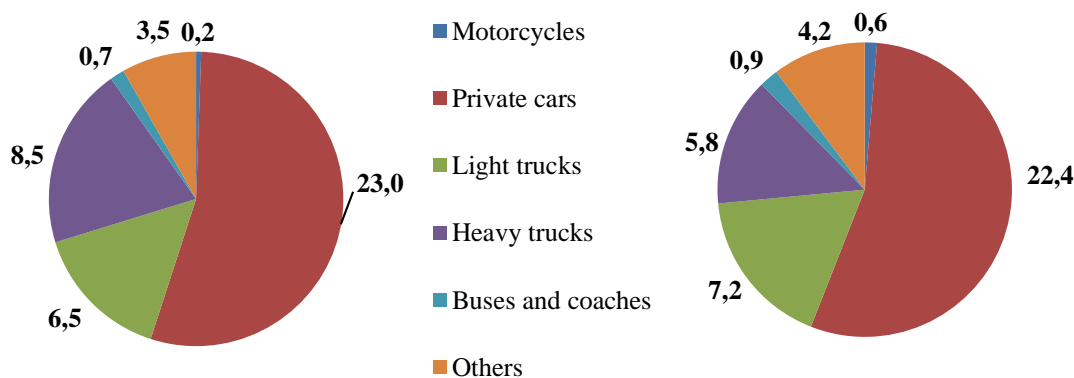

Figure 1 – Fuel consumption in France (a) in 2000 and (b) 2011, from CPDP (2012)

For individual i, the utility of the choice j is:

$$U_{ij} = f(\beta X_{ij}) + \varepsilon_{ij} \qquad (1)$$

Where β is a vector of unknown parameters, X_{ij} is a vector of the individuals' or households' characteristics and ε_{ij} a random error term.

As MLN are probabilistic models, their results reflect the utility maximization. Thus the probability that the individual i chooses the alternative j is the probability that the value of j is greater than that associated with all other modes. For instance, for j=0:

$$Prob(yi=0) = Prob(U_{i0} > U_{i1}, \ U_{i0} > U_{i2}, \dots U_{i0} > U_{im}) \qquad (2)$$

We denote $U_{ij} = V_{ij} + \varepsilon_{ij}$ where V_{ij} is a deterministic function and ε_{ij} a random variable.

Thus, the probability that the individual i chooses the alternative 0 is:

$$Prob(yi=0) = \frac{e^{vij}}{\sum_{k=1}^{m} e^{vik}} \qquad (3)$$

As $V_{ij} = x_i\beta_j$, in the case of an independent logit model, then the probability that the individual i chooses the alternative j is:

$$Prob(yi=0) = \frac{e^{xi\beta j}}{1 + \sum_{k=1}^{m} e^{xi\beta k}} \qquad (4)$$

As $V_{ij} = x_{ij}\beta$, in the case of a conditional logit model, then the probability that the individual i chooses the alternative j is:

$$Prob(yi=0) = \frac{e^{\beta z*ij}}{1 + \sum_{k=1}^{m} e^{\beta z*ik}} \qquad (5)$$

Where $z*_{i,j} = x_{i,k} - x_{i,0}$

The parameters' estimations are obtained by the method of maximizing the log likelihood of the model with constants using the SAS software version 9.4 through Logistic and Mdc procedures.

2.2. Bootstrap prediction intervals

The estimated multinomial logit models are then used for predictions. For this purpose, we consider a set of expected future values of the explanatory variables X_f from which we predict the probability of each transportation's mode Prob(y_f=j).

From logit model, it is only possible to perform predictions for ''case study'' i.e. for a new individual representative of the population in 2020. Thus, we set the main explanatory variables according to their most probable evolution by 2020 in an average. However, the probability distribution being not linear, the average probabilities predicted by the models are not equal to the probability at the average of the variables as shown in figure 2. It is therefore imperative to provide predictions with confidence intervals. To do this, we use the method of bootstrap prediction intervals.

The principle of the bootstrap is to approximate the theoretical distribution of a statistic of interest from the empirical distribution obtained from B random samples of size N in the sample of the original data. In our case, we repeat B=1,000 times a random drawing with replacement of 1,413 individuals of the original population with their characteristics (pairs bootstrap) to get 1,000 bootstrap samples. We then estimate the models on each of the 1,000 samples to obtain an empirical distribution of the probabilities predicted by the models.

From these distributions we construct confidence intervals with 95% degree of confidence.

The bootstrap method is realized using the SAS software version 9.4 through the surveyselect procedure.
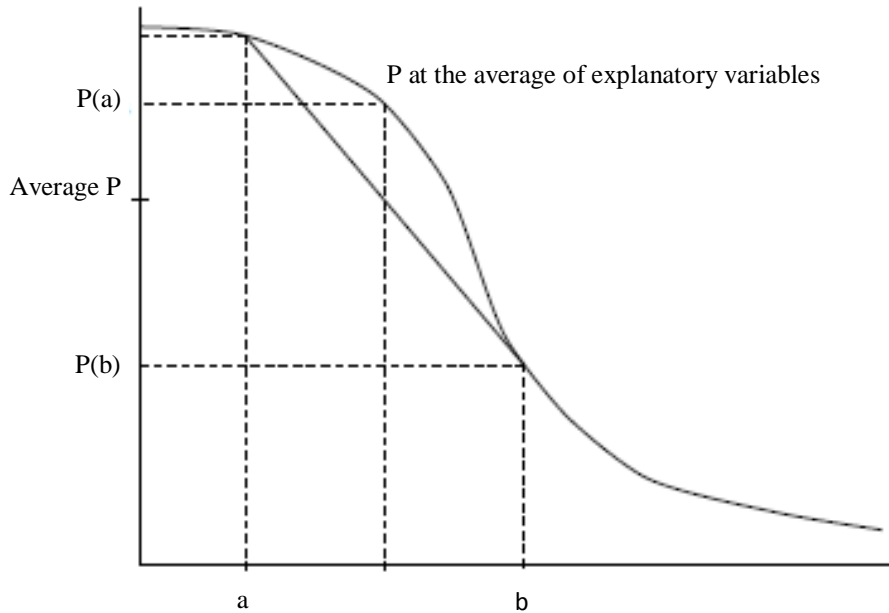
Figure 2 – Theoretical probability distribution of predicted probabilities

2.3. Data and economic analysis

As described in the literature review, modal choices are associated with travel needs corresponding to the distance to travel for different purposes, individuals' characteristics, and travel cost and time. The assessment of these choices depends therefore on individual data based on surveys. In our case, we base on a sample of 1,413 people (representative of the French population) involved in the Mobility Observatory (BIPE, October 2010). This survey is conducted every six months to describe mobility practices of French households. The questionnaire is passed face to face during 45 minutes to one hour. For this work, we take into account three main questions concerning the travel modes used for a "normal week day", the transportation mode used for the different mobility patterns and the distance travelled with each of the different travel mode. Thus we define travel needs as the distance to travel for each of the mobility purpose.

The variable to explain is the modal choice on a normal week day. We take into account the primary mode of transportation that is the one with which individual travel the highest distance each day. It has six categories: personal car (including company car), shared car (carpooling and carsharing), motorcycle, bike, walking and public transport. The modal distribution of the sample is described in figure 3. 59% of individuals use personal car which is the main mode of transportation to travel each day. Thus 84% of daily kilometres are travelled by personal car. The second mode is public transport used by 20% of the sample to travel 12% of the travel needs each day, followed by walking for 15%. Shared car is used by only 1% (homogeneous groups of people for carpooling and carsharing) to travel less than 1% of the daily travel needs.

In a preliminary work on the same data set we performed a multiple correspondence analysis from the main individuals' socio-economic and travel characteristics (see table 1 in appendix). It shows that the most discriminating variables distinguishing mobility profiles are: the travel need, i.e. the distance to travel (in km / pattern), the type of the municipality of residence (density), the marital status, the household's motorization, the age, the employment status and the income. Thus we use these variables to estimate multinomial logit models to explain modal choice. Moreover, this work led to the construction of mobility profiles described in figure 4.
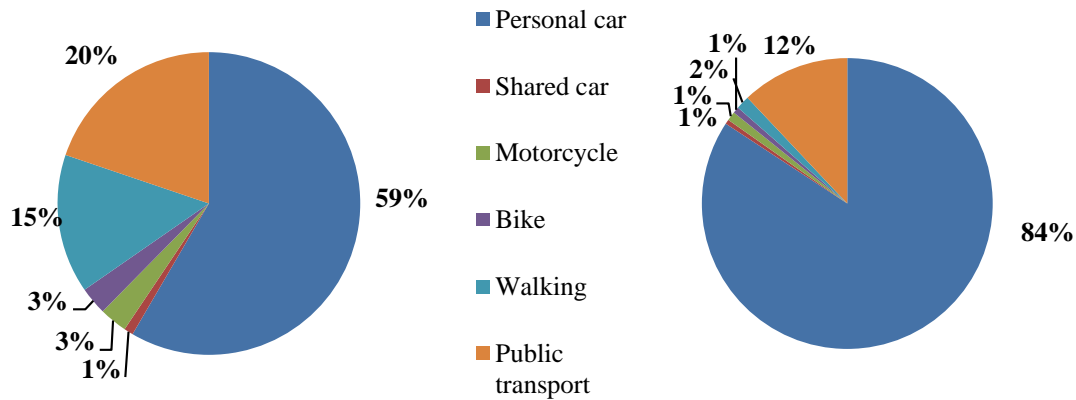
Personal car
Shared car
Motorcycle
Bike
Walking
Public transport

20% 1% 12%
59% 2%
15% 1%
3% 1%
3% 84%
1%

Figure 3 – Modal distribution of the sample (a) among individuals and (b) passenger-kilometers (Mobility Observatory, BIPE, October, 2010)

Multimodal   Motorists

Single   Family

Pensioners walking and using public transport 12%
Young alternative to car 20%
Working and motorist couples 23%
Students alternative to car 4%
Travel on low distances 15%
Travel on medium distances 16%
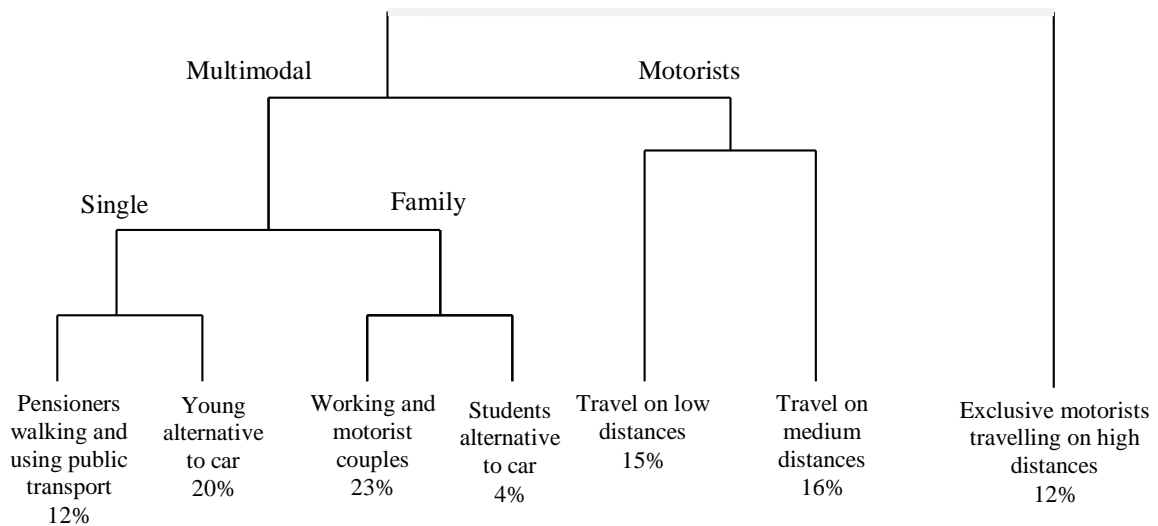Exclusive motorists travelling on high distances 12%

Figure 4 – Mobility profiles

The first level of partition distinguishes "exclusive motorists" from others. These individuals have the highest travel needs for all patterns and move exclusively by car. They are from 30 to 60, are working, live in couple and have children. They live in low density areas and are motorized. The rest of the population is then cut in two classes: people using their car (exclusively or in combination with one or more other modes) and people being "multimodal". The third level of partition occurs between individuals using the car (the "motorists"), some travelling on low distances, others having higher travel needs and living in lower density areas. Within the group of "multimodal" we then distinguish people living alone (rather non-working or workers, under 30 or over 60, without children, with modest incomes, living in large city-center, non-motorized and travelling mainly by motorcycle, walking and public transport), from people living in family (with two working persons, under 60, with children, living in Paris area and large city-center, motorized and travelling mainly by car, motorcycle, walking or public transport). Within the "singles" we distinguish "pensioners" of more than 60, living alone and walking or using public transport, from "young" inactive or low-skilled labour, living alone or with roommates, and travelling mainly by motorcycle, walking or public transport. Finally, within the "families" we distinguish "working couples" of more than 30 and travelling mainly by car, from "students" of less than 30 travelling mainly by motorcycle, walking or public transport.

Finally we select the following explanatory variables to explain modal choices for daily trips: the travel need which corresponds to the distance to travel for different purposes and is linked to the density of the municipality of residence (from 1=Paris to 7=rural area), the household's motorization (0 car, 1 car, 2 cars or more) which is linked to the household's income, the marital status (single, couples, cohabitation / roommate) and the age linked to the employment status (0=not working, 1= working).

In addition, it is possible to model modal choices from their own characteristics: their costs and travel time. The expenditure incurred by the travellers to the use of public transport in France was calculated by the National Federation of Transport Users (FNAUT, 2012) and corresponds to the price paid by users for public transport thus taking into account state aids. The costs of personal car and motorcycle correspond to the mileage rates set by the French tax administration. The cost of shared car is a half of that of the private car.

The travel time with each mode of transport is also taken into account to explain modal choice. It is calculated from the distance to travel and the average speed associated with each of the transportation mode (the average speed is that observed in the Mobility Observatory in October 2010).

3. Results

From the different characteristics we thus estimate two types of logit models: an independent model from individuals' characteristics and a conditional model from the travel modes' characteristics.

3.1. Independent logit model

3.1.1. Estimated parameters

We estimate an independent multinomial logit model explaining the modal choice between six different modes (personal car, shared car, motorcycle, bike, walking and public transport) by the explanatory variables distance to travel, density of the municipality of residence, household's motorization, age, marital status, employment status and income. The distance is the log of the kilometers travelled each day with the primary transportation mode, the density of the municipality of residence is a density index going from 1 for Paris to 7 for the rural area, the household's motorization corresponds to three cases: the household has no car, one car, or two cars or more, the marital status as well: single, in couple, or in cohabitation, and the employment status is a binary variable: 0 if the person is not working and 1 if the person is working.

Quality indicators of the model are good enough (ρ^2 McFadden: 0.58 and Estrella indicator: 0.95), but the estimators associated with activity status and income are not significant so we cannot say that they have an effect on the modal split in the sample we study. This conclusion cannot be generalized to the total population in that the significance of the parameters depends on the sample size. We decide anyway to remove the employment status and income variables, which does not deteriorate the quality of the model in so far as the employment status is clearly correlated to the age and the income to the household's motorization. This one is therefore an indicator of standard of living. The model is estimated with the personal car as the reference.

Table 1 shows that the distance has a negative effect on the use of alternatives to the personal car: the longer the distance to travel, the greater the probability to choose the personal car. Similarly, the lower the density of the residence area, the higher the household is motorized, the older the person and the more there are people in the household, and the more the alternatives to the car are used.

Table 1 – Estimated parameters

Variable	Shared car	Motorcycle	Bike	Walking	Public transport
Constant	-3.8070**	3.6326***	6.1623***	5.8934***	4.5689***
	(1.9152)	(1.0709)	(0.9501)	(0.6520)	(0.5291)
Distance	-0.2625	-0.6165***	-1.8559***	-2.3348***	-0.7297***
	(0.2946)	(0.2174)	(0.2151)	(0.1451)	(0.0920)
Density index	0.3062	-0.2449**	-0.2455**	-0.2080***	-0.4802***
	(0.1879)	(0.1145)	(0.1059)	(0.0655)	(0.0544)
Motorization	-2.6028***	-3.8533***	-3.0637***	-1.6787***	-2.0262***
	(0.5760)	(0.4233)	(0.3527)	(0.2157)	(0.1811)
Age	-0.0107	-0.0722***	-0.0519***	-0.0121*	-0.0233***
	(0.0170)	(0.0140)	(0.0102)	(0.006302)	(0.005149)
Marital status	1.1477**	1.1749***	0.8464***	0.6427***	0.8741***
	(0.5057)	(0.2767)	(0.2909)	(0.2084)	(0.1534)
Number of obs.			1413		
Log-likelihood			-1079		

Standard deviation in parenthesis
***: significant at 1% ; **: significant at 5% ; *: significant at 10%

Only variables of motorization and marital status appear to have an effect on the choice between personal and shared car. Obviously, non-motorized people have no choice than using shared car. Contrary to intuition, age does not seem to have any effect on the choice between personal car and shared car. In addition, motorization seems to be crucial. However, it is important to remain vigilant with these findings in that, on the observed sample, we have very few individuals using shared car.

3.1.2. Odds ratio

The interpretation of estimated parameters can be specified by measuring the magnitude of a change in explanatory variables on the probability to use each mode of transportation through odds ratio presented in table 2. Odds ratios are calculated as follows:

$$Odds\ ratio\ _{kj} = exp\ [\beta_{kj}]\qquad\qquad(6)$$

Table 2 – Odds ratio

Variable	Shared car	Motorcycle	Bike	Walking	Public transport
Distance	0.769	0.540	0.156	0.097	0.482
Density index	1.358	0.783	0.782	0.812	0.619
Motorization	0.074	0.021	0.047	0.187	0.132
Age	0.989	0.930	0.949	0.988	0.977
Marital status	3.151	3.238	2.331	1.902	2.397

Increasing the distance to travel of one unit decreases the probability of using alternative modes to personal car of 0.23 points (1-0.769) for shared car, 0.46 points for motorcycle, 0.84 points for bike, 0.90 points for walking and 0.52 points for public transport. Concerning shared car, this result shows that for a given level of distance to travel, it is better to own a private car than sharing a car when needed so that individuals are quite rational.

Similarly, the decrease in the density of the residential area decreases the same probability from 0.38 points for public transport to 0.19 for walking, but increases the probability to use shared car, which means that it should rather develop in low density areas. But we must be careful with this conclusion which is mainly explained by the fact that shared car is mainly used in the less dense area in our sample.

To be older of one year also decreases this probability: from 0.07 points for motorcycle to 0.01 points for shared car.

An extra car owned by the household also decreases this probability: from 0.98 points for motorcycle to 0.81 points for walking. The motorization is crucial: its effect on the probability of choosing the different modes of transportation is the largest. Once purchased, the car is thus used almost exclusively. This conclusion has been already widely demonstrated in the literature.

Finally, with an additional person in the household, it is 1.9 times more likely to choose walking than personal car or 3.24 times more likely to choose motorcycle. Thus, the more in the household (even if it is motorized), the less likely to use the personal car.

3.1.3. Independence of Irrelevant Alternatives (IIA) assumption test

To test the independence of irrelevant alternatives assumption necessary to validate the multinomial logit model, we realize the test proposed by Hausman and McFadden (1984). Thus, we calculate the test statistic S for five different sub-groups in which we removed each time a modality (except personal car which is the reference category). Thus we consider A_1 the sub-group excluding shared car, A_2 excluding motorcycle, A_3 excluding bike, A_4 excluding walking and A_5 excluding public transport.

As shown by Hausman and McFadden (1984), the test statistic can be negative, especially in the case of small samples. This does not then challenge the IIA property. As shown in table 3, in the case of subgroups excluding motorcycle, walking and public transport, the test statistic S follows a χ^2 distribution with 24 degrees of freedom. In the subgroup excluding motorcycle, the test statistic is less than the critical value (at 99.5%) so we do not reject H_0. P-value = 1 also tells us that there are 100% chance of being wrong in rejecting the null hypothesis of independence. The IIA assumption is indeed satisfied in this case. Similarly, in the subgroup excluding walking, the test statistic is less than the critical value (at 99.5%) so we do not reject H_0, p-value = 0.99 also indicates that there are 99% chance of being wrong in rejecting the null hypothesis of independence. Finally, in the subgroup excluding public transport, p-value = 0.87 indicates that there are 87% chance of being wrong in rejecting the null

hypothesis. Thus we do not reject the null hypothesis at 87% and have 13% chance that our model does not respect this property.

Table 3 – Results of the IIA assumption test

	S	p-value
A_1 : shared car excluded	Negative	
A_2 : motorcycle excluded	2.6645332	1.00
A_3 : bike excluded	Negative	
A_4 : walking excluded	6.0857236	0.99
A_5 : public transport excluded	16.570484	0.87

3.2. Conditional logit model

To take into account the economic rationality of individuals in their modal choices, we estimate a conditional logit model, taking into account variables that are characteristics of choices: the cost and travel time. In addition, we also introduce specific constants for each mode of transport to take into account their own characteristics hardly captured elsewhere (including comfort for example).

Table 4 shows that parameters associated with the constants are all negative which confirms the preference for personal car compared to all other means of transportation for its comfort, flexibility… In addition, the parameters associated with the cost and travel time are negative which means that a high cost and a long travel time do not encourage the use of alternative modes to the personal car. This result shows that mobility is an arbitrable need on the basis of its cost. Thus, odds ratios show that an increase in the cost of a transport mode (of a cent per kilometer) decreases by 0.02 points the probability of its use (1-0998). Similarly, an increase in the travel time of one minute of a mode of transport decreases by 0.06 points the probability of its use.

The model is estimated with the personal car as the reference.

Table 4 – Conditional logit model: estimated parameters and odds ratio

Variable	Estimated parameters	Odds ratio
Cs_shared car	-4.2787*** (0.2931)	0.014
Cs_motorcycle	-3.1629*** (0.1711)	0.042
Cs_bike	-2.6704*** (0.1585)	0.069
Cs_walking	-0.4331*** (0.1155)	0.649
Cs-public transport	-0.9830*** (0.0710)	0.374
Cost	-0.0016** (0.0008)	0.998
Travel time	-0.0055*** (0.0007)	0.994
Number of observations	1414	
Log-likelihood	-1573	
ρ^2 McFadden	37.89	
Estrella indicator	81.57	

Standard deviation in parenthesis
***: significant at 1% ; **: significant at 5% ; *: significant at 10%

4. Predictions by 2020 and bootstrap prediction intervals

The objective of the predictions is to predict the modal choices in 2020 from the estimated models. Thus we set the main explanatory variables according to their most probable evolution, in an average, by 2020 to try to approach the closest to reality.

4.1. Independent logit model

4.1.1. Hypothesis
The independent logit model explaining modal choices is estimated using the following variables: the distance, the category of the municipality of residence (density), age, motorization and marital status.

About the distance to travel, we base on figures from the National Transportation Survey (INSEE, 1982; INSEE, 1994; SOeS, 2008) to realize a projection to 2020 based on a logarithmic adjustment on previous data and continuing the observed trend. Indeed, according to a recent report to the French Minister of Transport by the Commission "Mobilité 21" (2013), travel need should grow by 2020 but its growth should be weaker than in the past. These evolutions are applied to the data in our sample. Therefore, the log of the distance to travel in 2010 was 3.029 and will be 3.102 in 2020. This result is that applying on an average of the sample, but the trend between 2010 and 2020 is applied to the average distances observed in each subgroup used to perform predictions (different mobility profiles) and that is the case for all other explanatory variables.

In our sample, the mean age is 47.2 years in 2010. According to population's projections made by the BIPE (Residential Migration, 2010), the average age is expected to increase in 2020 and should be 48.7 years.

In our sample, people living in a couple are the majority. According to the BIPE's projections (Residential Migration, 2010), this mode of cohabitation should remain dominant in 2020 but the number of households of one person is expected to grow: singles will be 45% of the households in 2020 (42% in 2010) and couples will be 52% (55% in 2010).

Concerning the evolution of the distribution of households between urban and rural areas, projections of the BIPE (Residential Migration, 2010) show no significant changes by 2020. Therefore, we do not change the structure depending on the category of municipality of residence.

Finally, as motorization is a key explanatory variable of modal choice, we perform predictions in three cases: the household has no car, the household has one car (current situation on average and therefore central scenario) and the household has two cars or more.

4.1.2. Predictions and bootstrap confidence intervals
To obtain results close from reality, we realize our forecasts according to the different mobility profiles presented in section 2.3 (figure 3). From the logit model we obtain the choice probability of the average individual representative of each profile. Moreover, we consider three sets of values for explanatory variables according to the households' motorization (no car, one car, two cars or more).
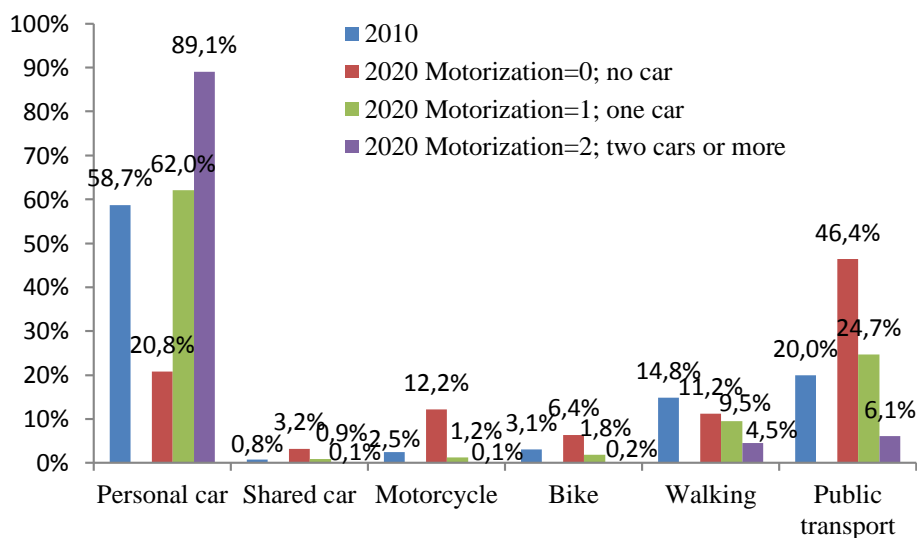

Figure 5 – Modal shares in France in 2010 and 2020 according to three cases of motorization

The aggregated results correspond to the weighted sum of the average individual forecasts for each mobility profile as recommended by Ben-Akiva & Lerman (1985). They provide the modal split described in the figure 5.

In the original sample, 18% of households are not motorized, 62% have one car and 20% have two cars or more. The results show a wide variation depending on the motorization scenario. Personal car should remain the main mode of transportation by 2020 except if households have no car. In that case, public transport would become the main mode of transportation, the modal distribution would be more balanced and shared car would deploy. More specifically, these general conclusions should be specified by discussing the results per mobility profile.

We choose to provide the detailed results of two extreme profiles, the others being just discussed.
The "pensioners walking and using public transport" mainly includes people with no car. That is why we study only one alternative: the equipment (one car), as shown in table 5. In this case, the probability of using the private car increases while that of all other modes decreases. Being by nature not very motorists "pensioners walking and public transport" do not constitute an important target for car-sharing: 2.37% at a maximum as shown by bootstrap confidence intervals.

Table 5 – Modal shares of "pensioners walking and using public transport" in 2010 and 2020

Year	Personal car	Shared car	Motorcycle	Bike	Walking	Public transport
2010 observed	26.38%	1.84%	0%	3.07%	35.58%	33.13%
2020 No car	16.43%	1.12%	1.49%	7.3%	42.9%	30.76%
Bootstrap confidence intervals 95%	[12.53 ; 20.94]	[0.19 ; 2.37]	[0.53 ; 2.8]	[3.75 ; 10.7]	[35.82 ; 50.1]	[24.89 ; 37.66]

Similarly "young alternative to car" use less car (personal and shared) than the average population and more motorcycle, bike and public transport. They are mainly motorized (one car). The shared car could only grow in the case of a household with no car to 3.93% at a maximum.
"Working and motorist couples" however use more personal car than the average population and are an attractive target for car-sharing, especially in the case of a household without a car. In that scenario the use of public transport could also develop significantly, especially since they mainly live in urban areas (Paris and its region and city centers of more than 100,000 inhabitants).
"Students alternative to car" mainly use public transport and motorcycle. They are also the second shared car users. But their low car use (personal as shared) does not make them a prime target for shared car. Thus, a decrease in the use of personal car is accompanied by an increase of motorcycle, bike and walking.
"Motorists" on the contrary use more personal car than the average population. The more their travel needs are important, the more they use it. They are preferred targets for car-sharing, but also for motorcycle and public transport, primarily in a scenario of a household not motorized.

Table 6 – Modal shares of "exclusive motorists travelling on high distances" in 2010 and 2020

Year	Personal car	Shared car	Motorcycle	Bike	Walking	Public transport
2010	80.37%	2.45%	0.61%	0.00%	9.20%	7.36%
2020 No car	41.35%	8.36%	12.71%	1.48%	0.87%	35.22%
Bootstrap confidence intervals 95%	[32.99 ; 49.89]	[1.84 ; 16.33]	[5.64 ; 21.92]	[0.39 ; 3.16]	[0.33 ; 1.61]	[25.86 ; 43.74]
2020 One car	87.93%	1.24%	0.55%	0.14%	0.34%	9.79%
Bootstrap confidence intervals 95%	[85.02 ; 90.80]	[0.33 ; 2.16]	[0.26 ; 0.94]	[0.04 ; 0.30]	[0.14 ; 0.62]	[7.20 ; 12.43]

"Exclusive motorists travelling on high distances" (table 6) are the first users of shared cars and the main target for developing its use for daily trips. This share could even reach 16% of the modal share of this mobility profile. But even in that case, shared car would not become the main mode of transportation, which would remain personal

car (obviously company car) and public transport would represent a third of modal shares. Motorcycle would also develop substantially.

4.1.3. Substitutions between travel modes

From bootstrap replications, we obtain statistical distributions of probabilities predicted by the independent model. In the case where the household has no car, we study potential modal shifts from personal car to public transport, motorcycle and shared car by distinguishing the probabilities to use them depending on whether we are above or below the median of the probability of using private car.

As shown by figures 6, 7 and 8, the people using the less personal car (the 50% using personal car the less) are more among those using public transport, motorcycle and shared car the most. Thus we observe a potential modal shift from personal car to public transport, motorcycle or shared car.
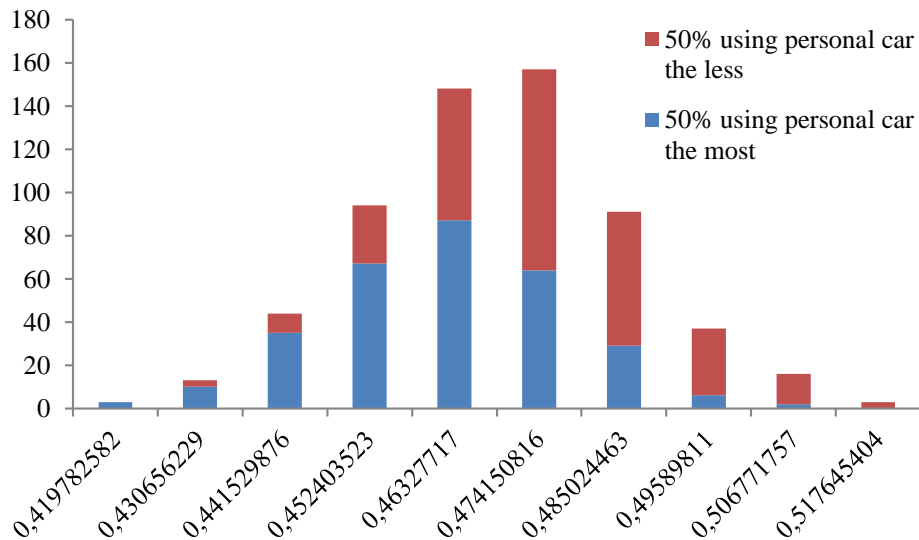

Figure 6 – Statistical distribution of predicted probabilities for public transport by 2020
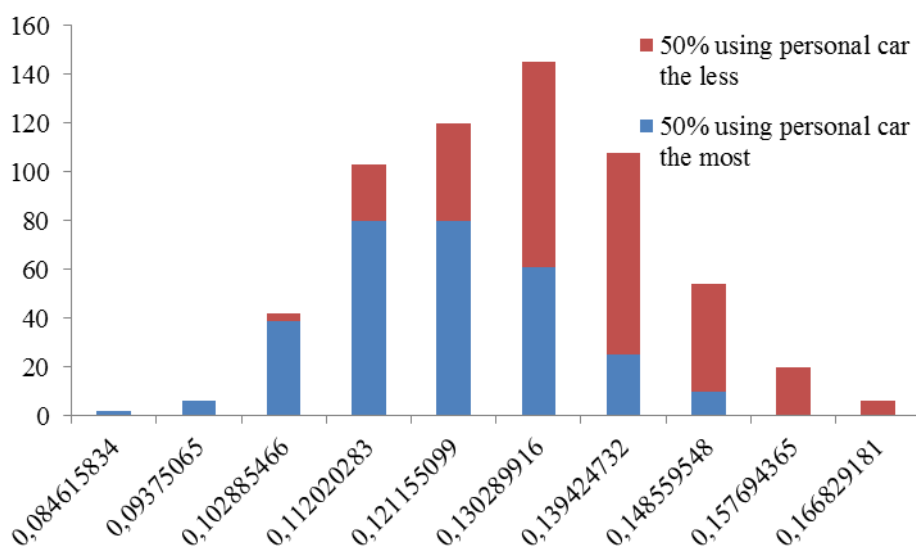

Figure 7 – Statistical distribution of predicted probabilities for motorcycle by 2020
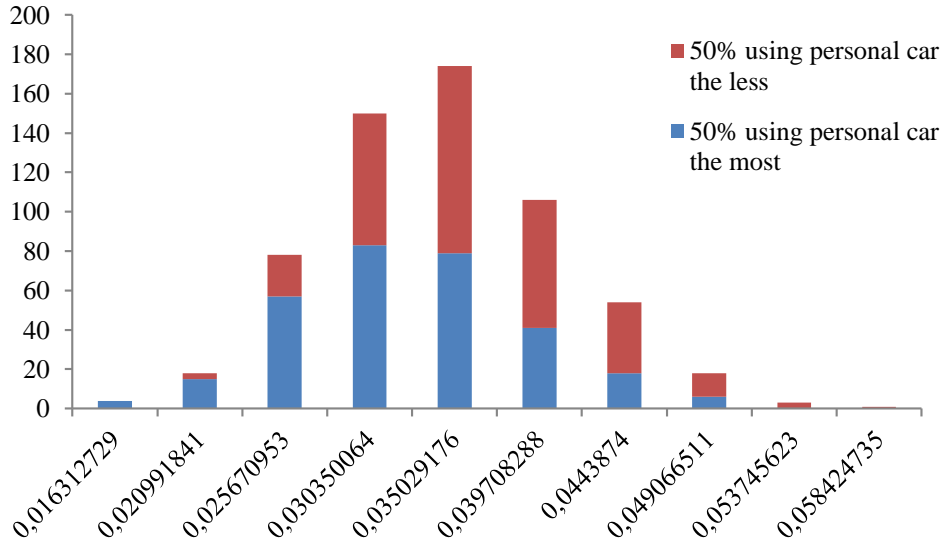
Figure 8 – Statistical distribution of predicted probabilities for shared car by 2020

4.2. Conditional logit model

4.2.1. Hypothesis
The conditional model is estimated from the variables of cost and travel time.
Concerning transportation costs, we base on the calculation of expenses incurred by the travellers by car and public transport between 1970 and 2010 conducted by the National Federation of Transport Users (2012). In 2020, these costs correspond to the projection of the linear fit of the observed costs between 1970 and 2010. This evolution is then applied to the cost of other modes of transportation (shared car and motorcycle). The transportation costs to 2020 will therefore continue to increase.

In addition, we propose a scenario in which we apply a carbon tax. Indeed, at the environmental conference on 20 and 21 September 2013, the entry into force of a Climate-Energy Contribution (CEC) in 2014 was announced (Le Figaro, September 20th, 2013). The price of a ton of carbon is 7 € in 2014 and then increases to 14.5€ in 2015 and 22 € in 2016. In 2020, we retain a CO_2 price at 22 € / ton. At this price, the impact of the tax on the user cost per kilometer of the car or motorcycle is almost zero (0.4 € cents / km). We also apply very high taxes but no inflection in use behaviour of different modes of transport is observed.
Finally, the transport time to 2020 depends on the evolution of distances whose assumptions were presented in section 4.1.1, the speed remaining constant. Therefore, the average transport time will increase by 6% by car and motorcycle, 6.7% by bike, 7.6% by walking and 8.1% by public transport.

4.2.2. Predictions and bootstrap confidence intervals
The predictions are performed at the average point of the sample and give the modal distribution shown in figure 9. These results show that the increase in distances between 2010 and 2020 makes motorized modes more necessary. Thus, personal car and public transport should remain the main modes of transportation by 2020. In addition, costs of the different means of transport increasing linearly, differentials of cost do not vary. Arbitrations are thus rather realised in terms of travel time than costs.
Concerning shard car more precisely, expected changes in costs and travel time by 2020 does not seem to have any effect on its deployment, its modal share being constant (in an average) between 2010 and 2020. It will be 1.21% at a maximum as shown in table 7.
Predictions have also been realized taking into account a carbon tax. At different prices of the carbon tax (from 22€/ton to very high taxes), costs do not really differ from the situation without a carbon tax and no modal shift is observed. Moreover, even if the car costs are doubled, we do not observe modal shifts or a significant increase in the use of shared car.
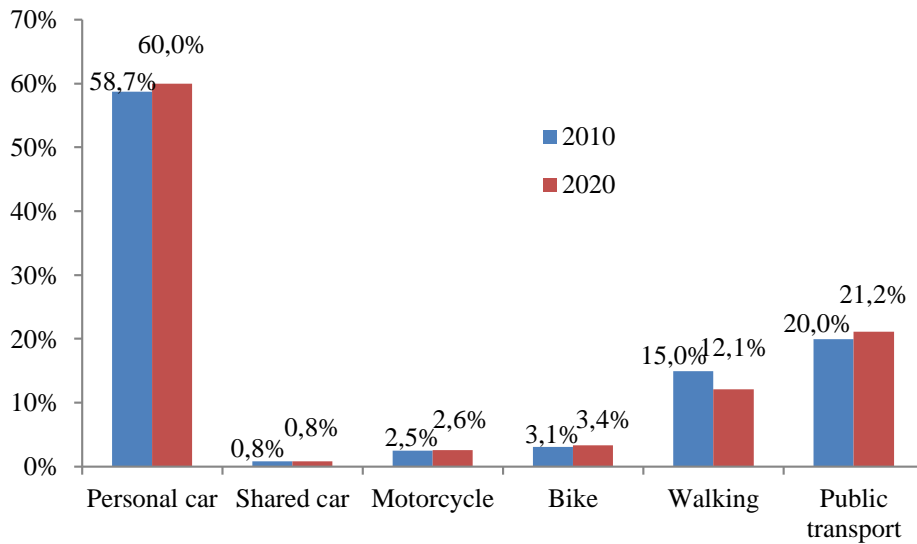
Figure 9 – Modal shares in France in 2010 and 2020

Table 7 – Modal shares in France and bootstrap confidence intervals in 2010 and 2020

Year	Personal car	Shared car	Motorcycle	Bike	Walking	Public transport
2010	58,7%	0,8%	2,5%	3,1%	15,0%	20,0%
2020	60,0%	0,8%	2,6%	3,4%	12,1%	21,2%
Bootstrap CI	[57,25 ; 67,25]	[0,45 ; 1,21]	[1,87 ; 3,34]	[2,57 ; 4,15]	[0,39 ; 15,39]	[19,00 ; 26,18]

4.2.3. Substitutions between travel modes

From bootstrap replications, we obtain statistical distributions of probabilities predicted by the conditional model. Thus we study potential modal shifts from personal car to public transport, motorcycle and shared car with the same method than in the section 4.1.3.
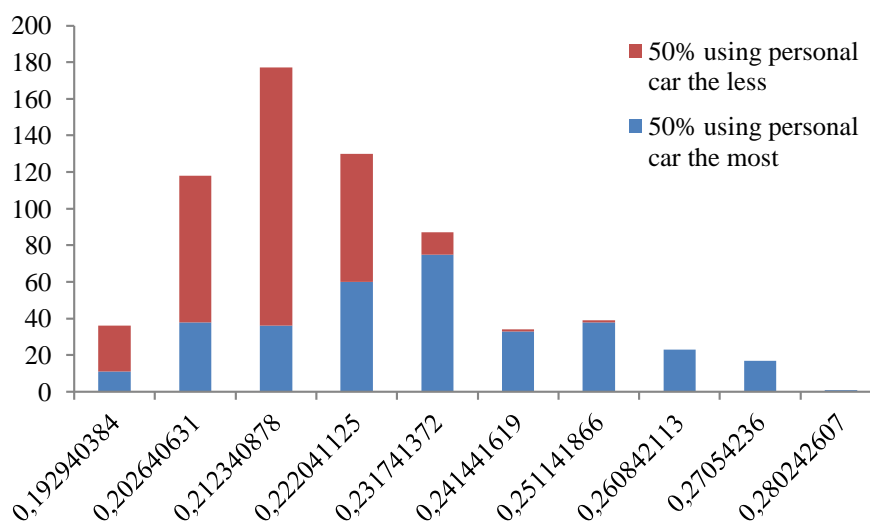

Figure 10 – Statistical distribution of predicted probabilities for public transport by 2020
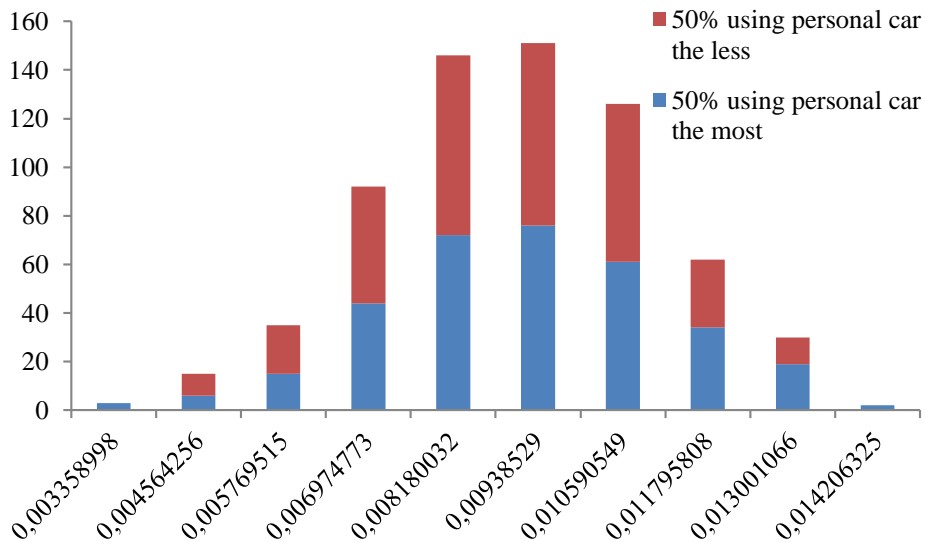
Figure 11 – Statistical distribution of predicted probabilities for motorcycle by 2020
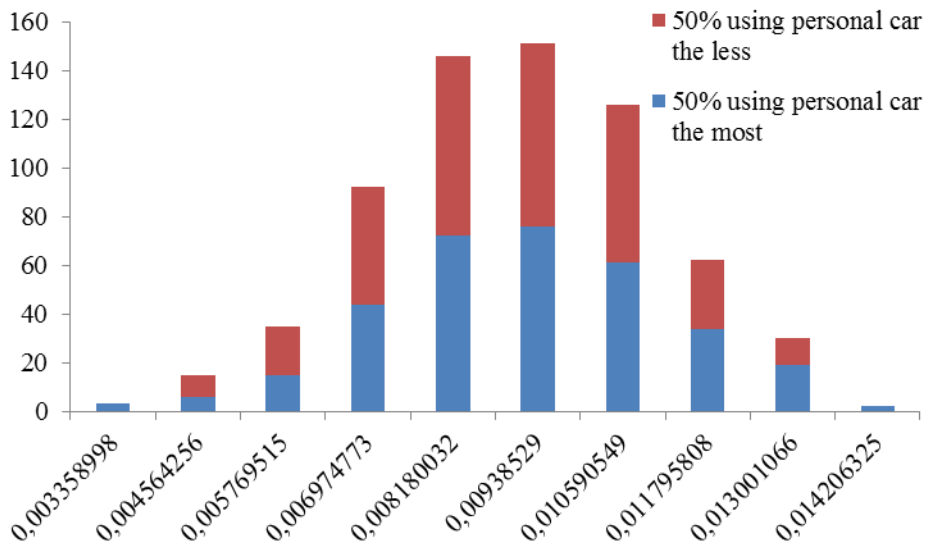
Figure 12 – Statistical distribution of predicted probabilities for shared car by 2020

As shown by figures 10, 11 and 12, the people using the less personal car use public transport and motorcycle the less too and shared car the most. From rational considerations, we observe less modal shifts from personal car to public transport or motorcycle but rather to shared car.

5. Discussion

Firstly, conclusions have to be taken with caution, especially for shared car, because we do not dispose of a large sample to analyze travel behavior and there are few observations concerning the use of shared car for daily trips. However, this is the only French survey representative of the French population and taking into account shared

car as a daily travel mode. The Household Travel Surveys only concern urban areas and the National Transportation Survey does not take into account shared car (carpooling and carsharing) as a daily travel mode.

From the independent logit model, predictions by 2020 have been conducted by mobility profiles to reflect the diversity of mobility habits. However, application of these mobility profiles to the conditional logit model does not allow assessing correctly the modal distribution observed in 2010. As a consequence, predictions from the conditional logit model have been performed at the average point. That means that, apart from purely rational considerations (cost and time of transport), modal choices are driven by other factors that are characteristics of households and their travel needs. Those two approaches are thus complementary and show that personal car should remain the main mean of transportation by 2020 with public transport.

Predictions by 2020 have been performed according to three cases of household's motorization from the independent logit model. We show that the use of personal car could decrease only if household's motorization decreases. In that case public transport would become the main mode of transportation and shared car would develop. But this situation of household's de-motorization is obviously not possible by 2020. However, changes in households' motorization are observed and it will be determinant to work on the future of households' motorization to know precisely its future level. Moreover, we notice that, even for a household with no car, modal share of personal car is not zero. This is explained by the fact that we introduce company car as a personal car in so far the household has it at its disposal as a private car owned by the household. In 2010, 2.6% of the sample use company car as a daily travel mode. The predictions results by 2020 show that personal car's share could reach 20% in the case of not motorized households. That means that there always will be a need of car available to households but that the mode of holding will change: the car will not necessarily owned by the household.

Thus personal car and public transport should remain the main modes of transportation by 2020, which implies that the supply of them should be available and sufficient everywhere.

In addition, forecasts from the conditional logit model could be achieved by income deciles to highlight the weight of the transport budget (as shown by Merceron and Theuliere, 2010) and the implications of a potential carbon tax on households more or less wealthy and dependent on their car that is hidden by the prediction from a midpoint. Finally, methods used in this paper to measure the potential development of shared cars in daily trips do not take into account diffusion phenomena or learning effects. Predictions realized in this paper are thus floor values for the use of shared car by 2020.

6. Conclusion

This paper shows that the main drivers of modal choices are the distance to travel, the density, the age, the marital status, the household's motorization, and travel cost and time. In an independent multinomial logit model, we confirm that motorization is the most determining factor of modal choices of French households in general and car use in particular. Thus the results of predictions by 2020 show a wide variation depending on the motorization scenario. In addition, the longer the distance to travel, the more we use motorized modes. However, an increase in the distance to travel results in a decrease of the probability to use shared car. This probably means that people with the highest needs to travel are motorized (what is then more profitable than carsharing) and suggests that shared car can hardly become a mean of transportation used exclusively. Thus the predictions show that personal car should remain the main mode of transportation by 2020, except if households have no car, which is the only case in which shared car could deploy, but in which public transport would become the main mode of transportation with personal car and motorcycle. Moreover, the study of statistical distributions of predicted probabilities for public transport, motorcycles and shared cars shows a substitution from personal car to these alternative travel modes. Furthermore, "motorists" are the main target for shared car, which means that we could observe shift from personal to shared car. But "motorists" are also those with the highest travel needs and the most motorized.

In addition, the estimation of a conditional logit model based on variables characteristics of the different modes of transportation (travel cost and time) shows that economic rationality explains modal choices as well and that the two approaches are complementary. Moreover, the increase in distances between 2010 and 2020 makes motorized modes more necessary. Thus, personal car and public transport should remain the main modes of transportation by 2020. Furthermore, only very high values of carbon tax could influence modal choices. However, expected changes in costs and travel time by 2020 does not seem to have any effect on the deployment of shared car, its modal share being constant (in an average) between 2010 and 2020. It could be 1.21% at a maximum. But from rational considerations, we observe less potential modal shifts from personal car to public transport and motorcycles but rather to shared cars. Therefore, the use of shared car seems to correspond to a specific profile and be essentially driven by the motorization of the households (as for all other travel modes). But the relationship between motorization and shared car use is not very simple and the de-motorization of households is not really possible by 2020, that is the reason why it will be determinant to work on the future of households' motorization and to connect the results with the predictions realized in this paper

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Table of variables used for multiple correspondence analysis

Variable	Label	Description	N
	Mod1	Car only	840 (55.4%)
	Mod2	Motorcycle	34 (2.2%)
	Mod3	Bike	43 (2.8%)
Travel mode	Mod4	Walking	141 (9.3%)
	Mod5	Public transport	64 (4.2%)
	Mod6	Walking+public transport	162 (10.7%)
	Mod7	Car+walking	127 (8.4%)
	Mod8	Car+others	104 (6.9%)
Sex	homm	Male	719 (47.4%)
	femm	Female	797 (52.6%)
	age1	< 30	278 (18.3%)
	age2	30-39	277 (18.3%)
Age	age3	40-49	283 (18.7%)
	age4	50-59	249 (16.4%)
	age5	60-69	276 (18.2%)
	age6	>69	50 (3.3%)
	Celi	Single	668 (44%)
Marital status	Coup	Couple	763 (50.3%)
	Colo	Cohabitation	86 (5.7%)
	Enf0	0	977 (64.4%)
Number of children	Enf1	1	241 (15.9%)
	Enf2	2	213 (14%)
	Enf3	3 or more	86 (5.7%)
Number of working person	Act0	0	399 (26.3%)
	Act1	1	613 (40.4%)
	Act2	2 or more	501 (33%)
	Sa_1	Working	877 (57.8%)
	Sa_2	Unemployed	67 (4.4%)
Employment status	Sa_3	Pensioner	395 (26%)
	Sa_4	Student	66 (4.4%)
	Sa_5	Housewife	79 (5.2%)
	Sa_6	Other not working	33 (2.2%)
	CSP1	Farmer	33 (2.2%)
	CSP2	Artisans, tradesmen, business leader	99 (6.5%)
	CSP3	Senior manager, liberal professional	161 (10.6%)
Socio-professional category	CSP4	Middle manager, intermediate professional	292 (19.3%)
	CSP5	Employee	438 (28.9%)
	CSP6	Worker	316 (20.8%)
	Bac1	Before the baccalaureate	730 (48.1%)
Study level	Bac2	Baccalaureate	308 (20.3%)
	Sup1	Baccalaureate +2	221 (14.6%)
	Sup2	>Baccalaureate +2	258 (17%)
	Rev1	< 15 000€	300 (19.8%)
	Rev2	15 000 to 25 000€	365 (24.1%)
	Rev3	25 001 to 35 000€	255 (16.8%)
Household annual income (before taxes)	Rev4	35 001 to 45 000€	137 (9%)
	Rev5	45 001 to 60 000€	85 (5.6%)
	Rev6	> 60 001€	41 (2.7%)
	Rev7	n.c.	334 (22%)
Motorization	Aut0	Non-motorized	276 (18.2%)
	Aut1	Motorized	1,241 (81.8%)

	Zon1	Paris	66 (4.4%)
	Zon2	Paris area	207 (13.7%)
Category of the municipality of residence	Zon3	Large city-center (> 100 000 inhabitants)	380 (25.1%)
	Zon4	Small city-center (< 100 000 inhabitants)	208 (13.7%)
	Zon5	Suburb	292 (19.6%)
	Zon6	Periurban area	183 (12.1%)
	Zon7	Rural area	181 (11.9%)
Transport infrastructure in less than 10 minutes walk from home	Inf0	No infrastructures	859 (56.6%)
	Inf1	Infrastructures	658 (43.4%)
Motorcycle equipment	mot0	Not equipped	1,406 (92.7%)
	mot1	Equipped	111 (7.3%)
Bike equipment	Vel0	Not equipped	1,158 (76.3%)
	Vel1	Equipped	359 (23.7%)
Duration of commuting	Tdo1	Less than 20 minutes	921 (60.7%)
	Tdo2	20 to 40 minutes	153 (10.1%)
	Tdo3	40 to 60 minutes	168 (11.1%)
	Tdo4	More than 60 minutes	275 (18.1%)
Duration of business trips	Ttp1	Less than 30 minutes	1,351 (89.1%)
	Ttp2	30 to 50 minutes	59 (3.9%)
	Ttp3	50 to 90 minutes	49 (3.2%)
	Ttp4	More than 90 minutes	58 (3.8%)
Travel time to go with or pick up someone	Tac1	Less than 18 minutes	1,210 (79.8%)
	Tac2	18 to 30 minutes	70 (4.6%)
	Tac3	30 to 52 minutes	131 (8.6%)
	Tac4	More than 52 minutes	106 (7%)
Travel time for shopping	Tlv1	Less than 18 minutes	887 (58.5%)
	Tlv2	18 to 30 minutes	127 (8.4%)
	Tlv3	30 to 50 minutes	289 (19.1%)
	Tlv4	More than 50 minutes	214 (14.1%)
Travel time for leisure	Tso1	Less than 20 minutes	971 (64%)
	Tso2	20 to 30 minutes	19 (1.3%)
	Tso3	30 to 55 minutes	296 (19.5%)
	Tso4	More than 55 minutes	231 (15.2%)
Travel time for other patterns	Tau1	Less than 15 minutes	1,170 (77.1%)
	Tau2	15 to 30 minutes	104 (6.9%)
	Tau3	30 to 55 minutes	139 (9.2%)
	Tau4	More than 55 minutes	104 (6.9%)
Distance for commuting	kdo1	Less than 15 km	884 (58.3%)
	kdo2	15 to 30 km	205 (13.5%)
	kdo3	30 to 50 km	189 (12.5%)
	kdo4	More than 50 km	239 (15.6%)
Distance for business trips	Ktp1	Less than 20 km	1,358 (89.5%)
	Ktp2	20 to 43 km	55 (3.6%)
	Ktp3	43 to 80 km	45 (3%)
	Ktp4	More than 80 km	59 (3.9%)
Distance travelled to go with or pick up someone	kac1	Less than 10 km	1,191 (78.5%)
	kac2	10 to 20 km	94 (6.2%)
	kac3	20 to 40 km	118 (7.8%)
	kac4	More than 40 km	114 (7.5%)
Distance travelled for shopping	Klv1	Less than 6 km	892 (58.8%)
	Klv2	6 to 16 km	212 (14%)
	Klv3	16 to 33 km	206 (13.6%)
	Klv4	More than 33 km	207 (13.7%)
Distance travelled for leisure	kso1	Less than 7 km	886 (58.4%)
	kso2	7 to 20 km	201 (13.3%)

	kso3	20 to 39 km	220 (14.5%)
	kso4	More than 39 km	210 (13.8%)
Distance travelled for other pattens	kau1	Less than 5 km	1,195 (78.8%)
	kau2	5 to 15 km	110 (7.3%)
	kau3	15 to 30 km	107 (7.1%)
	kau4	More than 30 km	105 (6.9%)

Projection on the two first axes
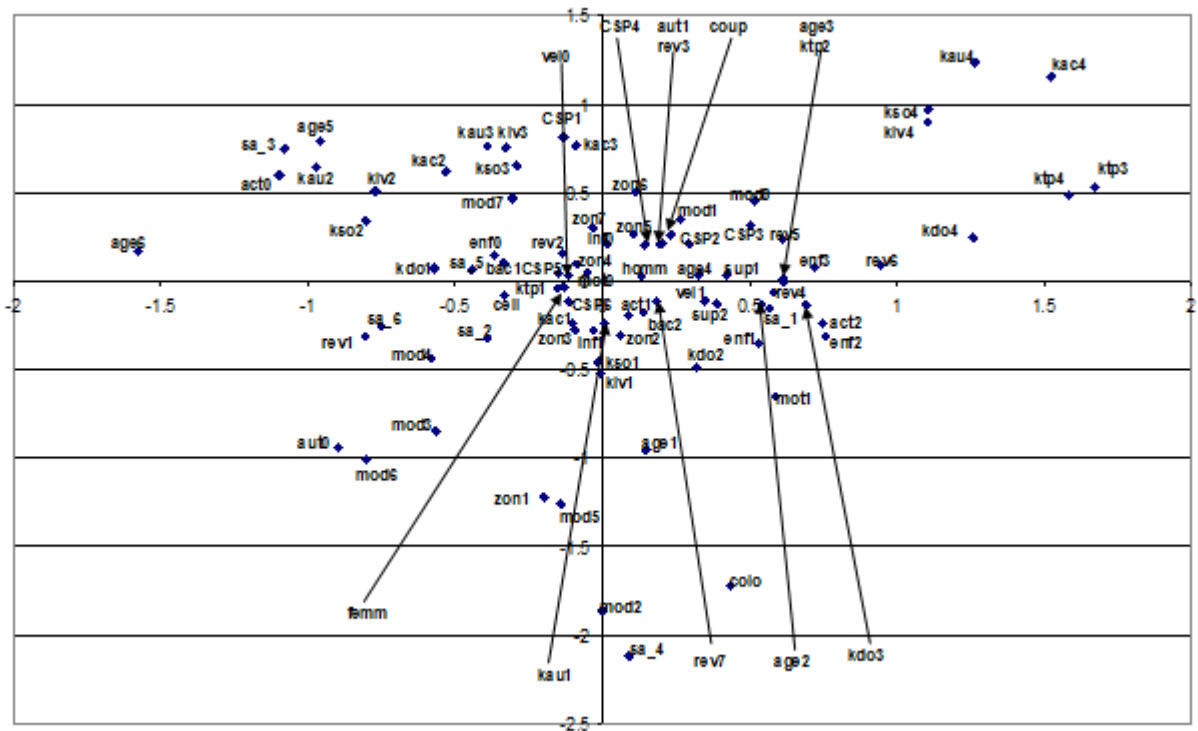
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