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Carpooling and carsharing for commuting in the Paris region: a comprehensive exploration of the individual and contextual correlates of their uses

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Abstract: The transport sector and the use of individual cars in particular are sources of negative externalities. Shared mobility could form a solution to this issue. This study contributes to a better understanding of the implementability of such a shared mobility by exploring the potential determinants of the use of carpooling and carsharing for commuting among a comprehensive set of socio-demographic, socio-economic, interpersonal and contextual variables. The analyses are based on a representative sample of 2002 workers living in the Paris region. Fisher's exact and Wilcoxon tests and multivariate logistic models were used to characterize the differences between carpoolers and carsharing users and to identify the correlates of mode use in our sample. We outline that the correlates differ between the two shared modes. Our models first highlight the importance of contextual variables: the use of carpooling mainly concerns people who live in rather deprived neighborhoods, while carsharing is overrepresented in well-to-do and denser neighborhoods. We identify the importance of mobility management policies within the workplace and the positive role of information. Having a carpooling service within the company is positively associated with carpooling for commuting. Regarding carsharing, the awareness of existing services (free-floating and peer-to-peer) is positively associated with carsharing use. Finally, the main originality of this study is the identification of the key role of the entourage (colleagues and/or family members) in both carpooling and carsharing. Public policies should therefore consider these results to exploit several levers to favor the use of shared modes in the Paris region.

1. Introduction

Transport represents almost a quarter of Europe's greenhouse gas (GHG) emissions and is the main cause of air pollution in cities. Within this sector, road transport is by far the biggest emitter accounting for more than 70% of all GHG emissions from transport in 2014 (European Commission, https://ec.europa.eu/clima/policies/transport_en). In 2014 in France, the transportation sector (fossil fuel combustion) was the main source of GHGs (29.2%) and was responsible for almost 40% of CO₂ emissions (French Government, 2017, <http://www.statistiques.developpement-durable.gouv.fr/indicateurs-indices/f/2082/0/emissions-gaz-effet-serre-secteur-1.html>). In 2016, levels of nitrogen dioxide (NO₂) and particulate matter (PM₁₀) concentrations in Île-de-France (Paris region) remained problematic, significantly exceeding the limit values. In total, in 2016, more than 200,000 inhabitants were living in the agglomeration in the vicinity of major traffic arteries and were potentially affected by exceeding the daily limit value for PM₁₀ particles (35 days greater than 50 µg/m³ allowed) (Airparif, 2017).

The collaborative economy is booming and tending to change the current socio-economic model (Botsman and Rogers, 2010; Frenken and Schor, 2017). This relative reconsideration of individual property by the collaborative economy is seen as a model that meets the criteria of sustainability. Shared mobility is an illustration. It corresponds to a form of sustainable mobility insofar as it reconciles (i) environmental benefits (e.g. decreasing negative externalities, congestion, GHG emissions and noise); (ii) economic benefits (e.g. sharing the costs of ownership, maintenance costs) and (iii) socio-ethics (better accessibility, increased well-being and quality of life, social inclusion) compared to traditional mobility and transport.

According to a European Commission report (2014), carsharing and carpools are part of the solutions to be implemented by cities and local authorities to reduce congestion and pollution. Therefore, a better understanding of the determinants of people's adherence to these shared mobility systems is needed in order to promote them and achieve sustainable mobility.

Research on the benefits of and barriers to carpools has developed considerably, first as a result of the oil crisis in the 1970s and 1980s (Margolin et al., 1978; Stefen and Dueker, 1974) and in recent years with the awareness of developing sustainable cities and therefore sustainable mobility (Abrahamse and Keall, 2012; Delhomme and Gheorghiu, 2016; Shaheen et al., 2016). There is a significant literature on carpools and congestion pricing as a tool (or transport policy) to promote the reduction of congestion and pollution. This type of policy is very common in North America with high occupancy vehicle (HOV) lanes and high occupancy vehicle and toll (HOT) lanes. It has been studied extensively from the point of view of congestion management (Burris et al., 2014; Konishi and Mun, 2010; Li et al., 2007; Small, 1997; Small et al., 2006). Recently, there have been studies on the environmental effects of these management tools for congestion and pollution (Javid et al., 2017). While studies on carpools have been common since the 1970s, there are fewer on carsharing systems, despite an increase over the last decade (Namazu et al., 2018; Shaheen and Cohen, 2007). There is still very little research on carsharing in France and particularly in the Paris region.

Hildermeier and Villareal (2014) compared carsharing systems in Paris and Berlin. There are recent studies on carsharing abroad, for example in Lisbon, where Baptista et al. (2014) analyzed the energy, environmental and mobility impacts of carsharing systems. In Toronto, Costain et al. (2012) investigated the behavior of carsharing members. The environmental benefits of carsharing have also been studied in Rome (Musso et al., 2012) while the propensity to join a carsharing service has been explored in Greece (Efthymiou et al., 2013; Efthymiou and Antoniou, 2016).

Most of the literature has aimed at identifying patterns of shared mobility users (carpoolers and carsharing users). However, these works have usually focused on one of these systems independently of the other (except Carroll et al., 2017) and analyzed very specific issues (for example, Wilhelms et al. (2017) analyzed peer-to-peer carsharing). Compared to the existing literature, the originality of our study, focusing on a sample of 2002 individuals living in the Paris region, is threefold: (i) it compares the determinants of carpoolers and non-carpoolers with those of the users/non-users of carsharing; (ii) it considers the spatial effect in addition to the usual factors determining the demand for transport, i.e. those relating to the price effect, the income effect, and the quantity/quality effect of transport. This spatial effect is considered by including spatial variables, which are rarely taken into account in existing studies. iii) it investigates the perception of the entourage (family members and colleagues) as potential determinants of the use of shared mobility, which is, to the best of our knowledge, unprecedented in this field.

The first section presents a review of the literature focusing on the two systems (carpooling and carsharing) in order to have an overview of the characteristics of the users worldwide. The second section focuses on our empirical research: Fisher's exact tests and Wilcoxon tests were used for qualitative and quantitative variables, respectively, and multivariate logistic models were used to characterize the differences between carpoolers and carsharing users and to identify the correlates of mode adoption in our sample. The third section discusses the findings and their implications for policy makers in Île-de-France in particular.

2. Literature review

Although carpools and carsharing are the two major shared mobility modes, their purpose – and therefore their determinants – are assumed to be different. In the literature review below, the

determinants of carpooling and carsharing are listed, based initially on the usual transport demand determinants defined in the transportation economics literature.

2.1. Carpooling and demand determinants

Transport demand determinants can be categorized in many ways. The traditional classification used in transportation economics is based on price, income, quantity and, sometimes, spatial effects (Small and Verhoef, 2007). The demand for carpooling and carsharing can follow this traditional classification, although it is now common to include supplementary effects (e.g. attitudinal variables) (Neoh et al., 2018, 2017).

The first factor affecting transportation demand is the price (McFadden, 1974). In the case of the private car, the demand increases when the cost of the car use is reduced. One of the benefits promoted by carpooling is the reduction in the car use cost (e.g. cost sharing). According to Abrahamse and Keall (2012), when the costs of driving alone are relatively high, carpooling is more likely to be considered as an alternative, and in their study they noted that saving money was one of the most liked aspects of carpooling. According to Tischer and Dobson (1979), the cost is an important factor associated with the intention to start carpooling. The results of the study of van der Waerden et al. (2015) and Shaheen et al. (2016) for casual carpooling followed the same direction. The fuel price elasticity of demand can deepen this price effect. Indeed, rising fuel prices limit the mobility by car (Goodwin, 1992). In the same vein, Bento et al. (2013) highlighted the impact of the price changes of gasoline on the carpooling demand in Los Angeles (United States).

In transportation economics, the second determinant of transportation demand is income. Dargay and Hanly (2002) and Bresson et al. (2004) showed a positive relationship between income and car use and highlighted a negative relationship between the number of bus trips and the level of income. Carpooling is more common among commuters with lower incomes (e.g. Baldassare et al., 1998; Teal, 1987). More generally, concerning the socio-demographic variables, some studies have found that women and younger people are more likely to switch to carpooling (e.g. Baldassare et al., 1998; Koppelman et al., 1993).

The third determinant of transport demand is the quantity of goods or services available (Mogridge, 1989, 1967) that can be related to a quality analysis (e.g. frequency for public transport). The quantity factor influencing carpooling demand can be measured by the motorization level, i.e. the number of vehicles per household, as well as whether the employer offers a carpooling service to employees. The quality and quantity of public transport can also be a determining factor in not carpooling (Vanoutrive et al., 2012).

The fourth determinant of demand considered in transport studies is the spatial effect. According to Small and Verhoef (2007), the type and density of buildings and the type of activity are factors that influence travel decisions. A number of studies have analyzed the relationship between the built environment and transport-related behaviors (Cao et al., 2006; Ewing and Cervero, 2001; Feuillet et al., 2015; Limanond and Niemeier, 2003; Van Acker et al., 2014; Van Acker and Witlox, 2011). For instance, a study conducted near Amsterdam found evidence that solo-driver attitudes about carpooling were negatively influenced by the construction of a new carpool lane (Van Vugt et al., 1996). However, to our knowledge, in relation to the carpooler's decision, these spatial effects are very rarely taken into account except in the papers of Vanoutrive et al. (2012) and Wang and Chen (2012).

In carpooling studies, another determinant arises: attitudinal effects (personal effects) such as "time flexibility" or environmental awareness. To commute by carpooling, individuals need to communicate, coordinate and in most cases they need to adapt their schedule to enable cooperation (Hussain et al., 2016). In this study, the authors showed that when the flexibility time is larger, the chances for carpooling are greater than when using the smaller time window. For environmental awareness, Delhomme and Gheorghiu (2016) found that compared to non-carpoolers, carpoolers are more environmentally aware. The results of Shaheen et al. (2016) indicated that the environmental motivations for casual carpooling participation are ranked low (compared to convenience, time

saving, and monetary saving). According to Canning et al. (2010), intentions to reduce carbon footprints are important to carpooling drivers.

A last determinant related to the interpersonal and societal effects can be taken into account. It includes the influence of the media, the entourage or nudges on the decision about the travel mode. Picard et al. (2018) notably illustrate how spouses' preferences and bargaining power within couples influence intra-household carpooling. However, these effects are rarely considered in the literature.

2.2. Carsharing and demand determinants

The growth in the costs of owning and using a car (vehicle purchase, gasoline, insurance and parking) is a reason for the development of carsharing in big cities (Clewlow, 2016; Costain et al., 2012; Efthymiou et al., 2013). Depending on the carsharing system, fuel, maintenance, insurance, parking and sometimes congestion charges (e.g. in the case of London's Zipcar) are included in the price. According to Morency et al. (2008), Shaheen and Cohen (2007) and Shaheen et al. (2009), car users usually underestimate car costs. Therefore, increasing the cost of car ownership and use would encourage carsharing.

Concerning the income and socio-demographic effects, Burkhardt and Millard-Ball (2006) found that in North America, only 50% of the members of carsharing services have a relatively high income (>60,000\$). Similarly, Efthymiou and Antoniou (2016) highlighted that people with a medium to low income are more willing to join a hypothetical carsharing scheme. Zhou and Kockelman (2011) showed that car owners with a high income are not interested in a carsharing service. However, in the work of Kopp et al. (2015), the members of free-floating carsharing have a significantly higher educational and income level compared to non-members. Le Vine and Polak (2017) showed that the average income and education level of users of free-floating carsharing in London are both higher than for the general population. Douma and Guag (2009) found that carsharing is popular among middle-income population groups. Cervero et al. (2007) also found that income is inversely proportional to carsharing activities, meaning that carsharing is popular among middle- and lower-income groups.

The quantity factor influencing carsharing demand can be measured by the motorization level, i.e. the number of vehicles per household, as well as the number of carsharing services available around the home. The latter is also a spatial variable. In the literature, Le Vine and Polak (2017) focused on the impact of free-floating carsharing on car ownership in London. Other results relating carsharing to car ownership are interesting. For example, Clewlow (2016) showed that the average number of vehicles is significantly lower among carsharing member households than among non-member households while several studies have found that households tend to maintain or reduce their vehicle holdings after becoming carshare members (Cervero et al., 2007; Martin et al., 2010).

Regarding spatial effects (i.e. built and social environment variables), Costain et al. (2012) found that the majority of the members live in dense neighborhoods near downtown Toronto. Similar findings have been reported elsewhere (Burkhardt and Millard-Ball, 2006; Cervero, 2003; Shaheen and Rodier, 2005; Stillwater et al., 2009). Costain et al. (2012) used the median income of neighborhoods where carsharing members live and found that those living in lower-income neighborhoods are high-frequency carsharing users. Finally, spatial effects in carsharing studies are rarely taken into account, except for the population density.

Attitudinal effects (personal effects), such as lifestyle or environmental awareness, are often taken into account in carsharing studies. For example, Costain et al. (2012) pointed out that carsharing members are, in general, environmentally-conscious people who are willing to pay for carbon offsetting if given the option. Burkhardt and Millard-Ball (2006) highlighted that carsharing appeals to individuals who can be considered social activists and environmental protectors. Schaefers (2013) found that environmental awareness appears to be an important psychosocial consequence for

carsharing users. The results of Efthymiou et al. (2013) and Efthymiou and Antoniou (2016) are similar.

Finally, we have found no study concerning the relationship between interpersonal effects (e.g. an entourage effect) and carsharing.

In our study, we decided to consider carpoolers and carsharing users separately, since we hypothesized that the demand determinants could differ in each system. One objective was therefore to explore the differences between the correlates of the two modes.

3. Data and Methods

3.1. Study design and sampling

In order to understand carpools and carsharing practices better and to identify the obstacles to using these shared modes for commuting, a specific questionnaire was designed within the VEDECOM Institute and the University of Paris-Saclay. It was distributed by the BVA survey institute to a sample of 2002 workers in the Paris region in September 2016. The sample was selected to be representative of the workers who travel within the Paris region, in terms of gender, age, socio-occupational category and department of residence. In order to correct possible bias, the respondents were given weights (using a calibration technique on margins) that indicated their representativeness in the population.

In our questionnaire, carpools and carsharing definitions were clarified in order to avoid any confusion between the two systems. The carpool definition given was: "Carpooling is the joint and organized use of a car by several individuals to travel", whereas the carsharing definition was: "Carsharing is the use of a car provided by an individual, a community or a specialized company". Although they are both shared modes, their purposes and uses are different so their determinants are assumed to be different too.

3.2. Individual, socio-demographic and transport-related variables

The questionnaire was divided into three parts. The first part included questions about general and socio-demographic characteristics (home address, work address, gender, age, income, educational level, household size) and participants' current commuting travel, such as the modes they use to commute, travel time, monthly transport budget, having a car driving license, inquiring about traffic status and mode availability. The second part concerned their interest in carpools for commuting. This section began by a definition of carpools and questions about their carpools practices, such as whether their employer has a carpools service, whether they use a carpool to commute, the frequency of carpools, the conditions of carpools (with whom, payed or not, etc.). Then, there were some questions about their reasons for carpools or not to commute, their knowledge about carpools services (companies) and whether their entourage (family and colleagues) practices carpools in order to measure interpersonal effects. The third part related to their interest in carsharing for commuting. Like the second section, this began by a description of carsharing and questions about their carsharing practices such as if they use a peer-to-peer (**defined as a system where a facilitating company connects car owners to car renters, i.e. between private individuals**) or a free-floating (**defined as system allowing users to start and end vehicle-rentals at any point in a city**) carsharing service and how frequently. Then there were some questions about their reasons for carsharing or not to commute, their awareness of both peer-to-peer and free-floating carsharing services, and whether their entourage (family and colleagues) uses a carsharing service in order to measure interpersonal effects.

3.3. Contextual variables

Contextual variables potentially associated with shared mobility behaviors were assessed at the IRIS Census unit scale (data from 2014) or through individual buffers around the home address. The IRIS areas (acronym for “Aggregated Units for Statistical Information”) are provided by the French National Institute of Statistics and Economic Studies (INSEE, www.insee.fr); they represent the smallest unit for dissemination of French infra-municipal data. Five variables related to the socio-economic and built environments were specifically targeted:

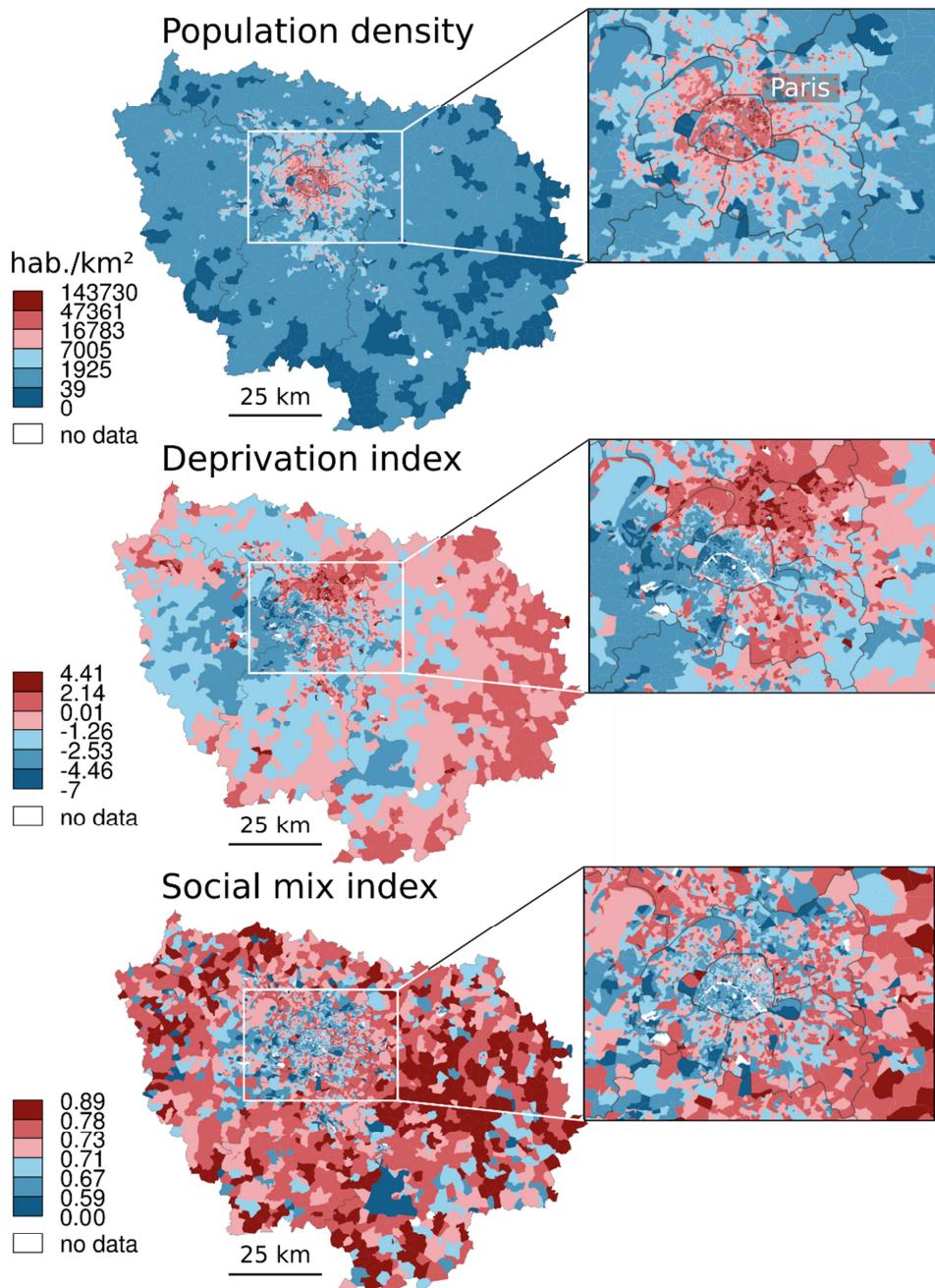
- (i) the population density (inhabitants/km², see figure 1);
- (ii) a social **mix** index. This is a measure of the evenness of distribution of the percentages of six main INSEE-based socio-professional classes (farmers, artisans, managers and higher intellectual professions, intermediate occupations, low-grade white collars, blue collars) in each IRIS. It therefore quantifies the social heterogeneity in each unit. It is inspired by the Shannon's diversity index and was computed as follows:

$$\text{Social mix index} = - \sum_{i=1}^6 p_i \ln p_i / \ln(6)$$

Where i corresponds to socio-professional classes ($n = 6$) and p_i is the proportion of a specific socio-professional class. The index ranges from 0 to 1. A value of 1 indicates an equal distribution of the six classes in the IRIS (see figure 1), that is a perfect social mix. A value of 0 indicates the occurrence of a single social class in the unit;

- (iii) a deprivation index. This French deprivation index was calculated following the protocol described elsewhere (Rey et al., 2009). Theoretically, deprivation has been initially defined by Townsend as a "state of observable and demonstrable disadvantage relative to the local community or the wider society to which an individual, family or group belongs" (Townsend, 1987, in Rey et al., 2009). Empirically, it has been here quantified as the first component of a principal component analysis including four socio-economic variables (the median household income, the percentage of high-school graduates in the population aged 15 years and older, the percentage of blue-collar workers in the active population, and the unemployment rate) (see figure 1);
- (iv) the **number** of Autolib' stations in a 500-m radius buffer (i.e. approximately 10 minutes' walk) around each home address. Autolib' was the main **carsharing** company in the Paris area in 2016 (at the time of the questionnaire), although it has since been removed.
- (v) the train/RER (acronym for regional express network) station accessibility, assessed as a dummy variable (1 if there was a station in the 500-m radius individual buffer, 0 otherwise).

*Figure 1. Maps of the three contextual variables included in the final models: population density, deprivation index and social **mix** index.*



3.4. Statistical analyses

3.4.1. Bivariate statistics

First, descriptive statistics were carried out to characterize the subsamples of (i) carpoolers and non-carpoolers and (ii) carsharers and non-carsharers, according to individual and contextual variables. Based on the literature and the data available from the questionnaire, we retained as individual variables: the monthly transport budget in €, the household income and socio-demographic variables such as gender, age, educational level and the number of people in the household. The quantity and quality effects were captured by including the number of cars in the household, the travel time to commute and the mode of transport used to commute. The awareness of carpooling between

carpoolers and non-carpoolers and the awareness of both peer-to-peer and free-floating carsharing services for carsharing users and non-users were analyzed.

Then, bivariate statistics were computed to explore the relationships between the use/non-use of the two modes and each of the putative explanatory variables (both individual and contextual). Relations with the categorical explanatory variables has been explored through Fisher's exact tests (independence as null hypothesis), rather than chi² tests, because of some low frequencies in the contingency table. Relations with quantitative explanatory variables have been explored through Wilcoxon tests (independence as null hypothesis).

3.4.2. Multivariate econometric investigation

The variables that appeared significant in one of the two samples (carpoolers and carsharing users) in the bivariate analyses (Tables 1 and 2) were kept as regressors in the subsequent multivariate econometric models. To model the first outcome (the use of carpooling), two models – logit and Poisson – were performed, according to the way we quantified it. First, the use of carpooling can be viewed as a binary decision; in this case, a logit model was used. Second, its use may be modeled as a frequency (here four frequencies: no use, once a week, twice a week, three or more times a week). In this case, a Poisson regression was used, as a suitable method for modeling count data. The results of the two models were then compared to capture any nuances that would only be due to the regress and quantification choice (i.e. a methodological artefact). To model the second outcome (the use of carsharing), a logit model only was used, since the frequency of use of this mode was too weak to envisage something other than a dichotomous discretization.

In the logit model, the underlying assumption is that an individual gains a certain level of utility in making a decision. The utility is composed of two components: deterministic and random. The deterministic utility (V) is considered linear in the parameter function of variables (X) and corresponding parameters (β). Considering that the random utility component follows a logistic distribution, then the probability of choosing the binary decision can be written as:

$$\text{Pr}(\text{binary decision}) = \frac{e^V}{1+e^V} = \frac{e^{(\sum_i \beta_i X_i)}}{1+e^{(\sum_i \beta_i X_i)}}$$

The parameters (β) of the model can be estimated using the maximum likelihood estimation process. The Hosmer-Lemeshow test was conducted as a goodness-of-fit test (p-values were not significant (>0.05), so the model appears well adapted to the data).

Poisson regression is typically used for the modeling of count data. The Poisson probability distribution of the number h of occurrences of an event (here the four different frequencies of carpooling) is expressed as follows (Winkelmann, 2008):

$$\text{Pr}(Y = h|\lambda) = \frac{e^{-\lambda} \lambda^h}{h!} \text{ for } h = 0,1,2,3 \text{ and } \lambda > 0$$

where λ is the only Poisson parameter, as the distribution is equidispersed (i.e. the mean and the variance of Poisson distribution are both equal to λ). In the Poisson regression model, the expected value λ is the result of the exponential function of the linear combination of the explanatory variables and must be positive. Regression parameters are then estimated by maximizing the log-likelihood in an iterative manner. The deviance test was conducted as a goodness-of-fit test (p-values were not significant (>0.05), so the model is well adapted to the data).

Finally, the multicollinearity between the regressors in the three models was checked through the variance inflation factor (VIF). Values higher than 2 (implying a multiple coefficient of determination > 0.5) were removed.

All the statistical operations were run in R Studio (R Core Team, 2015).

4. Results and Discussion

In the three subsections below, the results are directly discussed in each subsection rather than in a separate discussion section, in order to ensure a clearer demonstration.

4.1. Overall characteristics of carpoolers and carsharers

The sample was composed of 2002 workers (56.4% women) living in the Paris area and with an average age of 41.8 years. The sample included 320 carpoolers (16%) and 185 carsharers (9%), which is in line with the existing literature (for example, carpoolers represent 12.2% of the sample in Abrahamse and Keall (2012), 9.3% in Habib et al. (2011)). Tables 1 and 2 present the descriptive and bivariate statistics of users and non-users of carpooling and carsharing, according to their individual and contextual characteristics, respectively.

Table 1. Characteristics of users/non-users of carpooling and carsharing among a sample of 2002 French workers (Paris region) and bivariate relationships with individual variables. p-values < 0.05 (in bold) indicate whether the relationships are significant.

Variables	Carpoolers (%)	Non-carpoolers (%)	Fishers's exact test (p-value)	Carsharers (%)	Non-carsharers (%)	Fishers's exact test (p-value)
Gender						
Women	53.61	57.01	0.27	43.96	56.87	<0.01
Men	46.39	42.99		56.04	43.13	
Age group						
16-24	5.33	3.23	0.23	7.14	2.54	<0.01
25-39	36.99	36.53		51.65	34.76	
40-49	36.68	40.30		29.67	41.22	
50-65	21.00	19.94		11.54	21.48	
Educational level						
< Bac	15.05	13.29	0.39	8.24	13.80	<0.05
Bac	15.67	14.85		12.09	14.95	
Bac+2	19.75	24.25		23.08	23.38	
Bac+3/4	20.06	21.20		21.43	21.36	
Bac+5	16.30	15.99		17.58	16.28	
> Bac+5	13.17	10.42		17.58	10.22	
Household income per month in euros						
< 1000€	3.76	1.38	<0.05	3.30	1.44	<0.01
1001 to 2500€	26.96	20.90		27.47	20.79	
2501 to 4000€	28.53	34.01		29.12	33.60	
4001 to 6000€	21.63	23.23		22.53	23.27	
6001 to 9000€	8.15	7.19		12.64	7.10	
> 9000€	1.57	2.34		2.75	2.25	
Decline to answer- I'd rather not say	9.40	10.96		2.20	11.55	
Household size						
1	17.87	17.84	0.22	17.58	17.61	0.27
2	23.82	27.19		26.92	26.39	

3	23.82	21.08		21.43	21.59	
4	22.57	25.15		20.88	25.75	
≥ 5	11.91	8.74		13.19	8.66	
Number of cars in household						
0	5.70	6.52	0.78	8.94	4.53	<0.01
1	41.14	42.37		58.10	50.90	
≥ 2	53.16	51.12		32.96	44.57	
Main mode of transport for commuting						
Car, as driver	66.46	55.93	<0.01	37.36	62.24	<0.01
Car, as passenger	7.21	1.50		5.49	1.73	
Public transport (regional train, subway, bus, tram)	19.44	32.75		40.11	27.83	
Motorized two-wheeled vehicle	2.51	2.16		4.40	1.96	
Walking (≥ 10 minutes)	1.88	5.75		7.69	4.50	
Cycling	2.51	1.92		4.95	1.73	
Transport budget per month in euros						
< 65	33.33	27.59	<0.01	24.16	29.24	0.12
65-75	14.74	24.35		28.09	20.63	
75-120	24.04	24.03		22.47	24.91	
> 120	27.88	24.03		25.28	25.21	
Travel time to commute						
< 15 min	17.24	17.66	<0.01	17.03	17.84	0.35
16 to 30 min	41.07	29.34		30.77	30.95	
31 to 45 min	22.26	21.92		27.47	21.42	
46 to 60 min	11.91	18.32		15.93	17.67	
> 61 min	7.52	12.75		8.79	12.12	
Carpooling service at work (firm)						
Yes	19.12	7.72	<0.01	-	-	
No	71.79	83.05		-	-	
IDK	9.09	9.22		-	-	
Awareness of carpooling						
0	10.44	13.82	<0.01	-	-	
1	60.13	67.23		-	-	
2	20.89	15.75		-	-	
≥ 3	8.54	3.20		-	-	
Awareness of carsharing free-floating services						
0	-	-		2.75	13.05	<0.01
1	-	-		51.10	70.32	
2	-	-		18.68	12.59	
≥ 3				27.47	4.04	
Awareness of carsharing peer-to-peer services						

0	-	-		14.29	41.34	<0.01
1	-	-		17.58	31.76	
2	-	-		28.57	17.90	
3	-	-		14.84	6.35	
≥ 4	-	-		24.73	2.66	
Entourage						
Carpoolers among family members/friends				Carsharers among family members/friends		
Yes	52.98	33.35	<0.01	60.99	12.24	<0.01
No	26.02	50.48		21.98	61.49	
IDK	21.00	16.17		17.03	26.27	
Carpoolers among colleagues				Carsharers among colleagues		
Yes	55.80	24.79	<0.01	52.20	6.35	<0.01
No	14.42	43.53		24.18	54.85	
IDK	29.78	31.68		23.63	38.80	

Table 2. Characteristics of users/non-users of carpooling and carsharing among a sample of 2002 French workers (Paris region) and bivariate relationships with contextual variables. p-values < 0.05 (in bold) indicate whether the relationships are significant.

Variables	Carpoolers		Non-carpoolers		Wilcoxon test (p-value)	Carsharers		Non-carsharers		Wilcoxon test (p-value)
	Mean	Sd	mean	Sd		Mean	Sd	Mean	Sd	
Population density (hab./km ²)	9574	9531	9428	10368	0.07	13761	12332	8737	9629	<0.01
Social mix index	-0.07	1.05	0.01	0.99	0.48	-0.14	1.01	0.02	1.00	<0.05
Deprivation index	0.11	1.07	-0.02	0.98	<0.05	-0.13	1.10	0.01	0.98	0.08
Density of Autolib' stations (500-m buffer)	-	-	-	-	-	1.86	2.61	0.93	1.92	<0.01
Train/RER station (500-m buffer)	%		%		Fishers's exact test (p-value)	%		%		Fishers's exact test (p-value)
No	79.94		83.17		0.17	80.22		83.08		0.35
Yes	20.06		16.83			19.78		16.92		

4.1.1. Individual characteristics

Overall, we noted that the correlates of carpooling and carsharing are not the same. In terms of socio-demographics, gender, age and educational level are associated with carsharing but not with carpooling. Carsharing is mostly used by men (56%) and younger people (51.6% of carsharers are between 25 and 39 years old). Household income is associated with using both modes, unlike household size, which is independent.

In terms of transport-related variables, the main mode of transport for commuting is related to carpooling and carsharing, but not in the same way. For instance, there is an underrepresentation of public transportation users among carpoolers (19.4%) compared to non-carpoolers (32.7%), but an overrepresentation among carsharers (40.1%) compared to non-carsharers (27.8%). Transport budget and travel time are only associated with carpooling.

Regarding the interpersonal variables, we noted a strong influence of the behaviors of both family/friends and colleagues. Having carpoolers/carsharers among family/friends and colleagues seems to be clearly associated with engaging in these modes. For instance, 61% of carsharers reported having family members or friends who share the use of a car, compared to only 12.2% among non-carsharers.

4.1.2. Contextual characteristics

There is a relationship between the population density of the home environment and carsharing, but not carpooling. The carsharer residential context is much denser than that of non-carsharers (13,761 hab./km² vs. 8,737 hab./km²). The social mix index is significantly lower in the carsharer residential context than in that of non-carsharers (difference not significant regarding carpooling). In turn, the deprivation index is significantly higher in the carpooler residential context than in that of non-carpoolers. Finally, having a train/RER station around home is not related to carpooling or sharing the use of a car.

4.2. Multivariate modeling

Beyond the bivariate analysis presented above, a multivariate modeling was needed to ensure a *ceteris paribus* rationale, because of the likely collinearity between explanatory variables. The variables that were not significant in the bivariate analysis were not considered therein.

4.2.1. Results and interpretation of the logit and Poisson models for carpooling

Figures 2 and 3 present the odds ratios derived from the logit and Poisson models, respectively. As expected, some significant bivariate associations disappeared in the multivariate analyses. First, at the individual level, we found that socio-demographic variables are not associated with the likelihood of carpooling, which is in line with most studies (e.g. Buliung et al., 2010; Canning et al., 2010; Ferguson, 1997; Teal, 1987). Regarding socio-economic variables, only one income bracket appeared significant: individuals earning between 2.5 and 4 k€ are 0.41 times less likely to adopt carpooling than those earning less than 1 k€. Therefore, carpooling is more popular among low-income commuters, as outlined by other studies (e.g. Baldassare et al., 1998; Teal, 1987; Vanoutrive et al., 2012). Most importantly, having family members/friends (OR = 1.69) or colleagues (OR = 4.65) who carpool is strongly associated with engaging in carpooling oneself. In the terminology of Manski (1993), this could result from a combination of “exogenous” peer-effects (the carpooling propensity varies with the exogenous characteristics of the entourage), “endogenous” effects (individuals carpool because the entourage carpools) and “correlated” effects (individuals carpool because they share similar characteristics with the carpooling entourage (e.g. they have the same sociodemographic profile).

In addition, individuals with a carpooling service at work are two times more likely to adopt carpooling than others. At the contextual level, only the deprivation index is significantly and positively associated with carpooling. The more deprived the neighborhood, the higher the likelihood of carpooling.

The results of the Poisson regression model exhibited the same associations, except that one travel bracket appeared significant: commuters with a travel time of between 16 and 30 minutes are 1.3 times more likely to engage in carpooling than those with a commuting time of less than 15 minutes.

4.2.2. Results and interpretation of the logit model for carsharing use

In the following model, the carsharing-based behaviors of colleagues were removed because of a too strong collinearity with family behaviors (VIF > 2). Regarding socio-demographic variables, two age groups were significant: aged between 40-49 (OR = 0.28) or 50-65 (OR = 0.24) years is associated

with a lower likelihood of engaging in carsharing compared to the 18-24 years group. In other words, young people are the most susceptible to adopting carsharing, a finding already outlined elsewhere (e.g. Shaheen and Cohen, 2007). In terms of income, only the group including those who did not want to answer the question is negatively associated with the likelihood of carsharing (OR = 0.13). One may hypothesize that this category includes mainly high incomes. In this case, this finding would be in line with the study of Zhou and Kockelman (2011), who highlighted that high-income individuals are not interested in the carsharing solution. We also found that knowing two or more free-floating (OR = 4.18) or peer-to-peer (OR = 3.36) services is positively associated with using carsharing. Since the causality can theoretically be bidirectional in this relationship, two interpretations are possible: either adopting carsharing leads to learning about the available services, or – more interestingly – knowledge of the existing services encourages engaging in carsharing.

Regarding the interpersonal variables, as for carpooling, the behaviors of the entourage were found to be of prime importance. Individuals with family members and/or friends who share the use of a car are 10 times more likely to adopt carsharing themselves.

Finally, the two contextual variables (population density and deprivation index) are also associated with the probability of carsharing. The denser the neighborhood, the higher the probability of carsharing. However, in contrast with carpooling, the more deprived the neighborhood, the lower the probability of carsharing. The effect of density can be explained by parking difficulties in very dense neighborhoods, which enhance carsharing by making car-ownership less relevant in those areas.

Figure 2. Carpooling correlates: graphical illustration of the odds ratios estimated through the logit model in a sample of 2002 French workers (Paris region). Statistical significance of odds ratios is indicated by asterisks (= $p < 0.05$; ** = $p < 0.01$; *** = $p < 0.001$).*

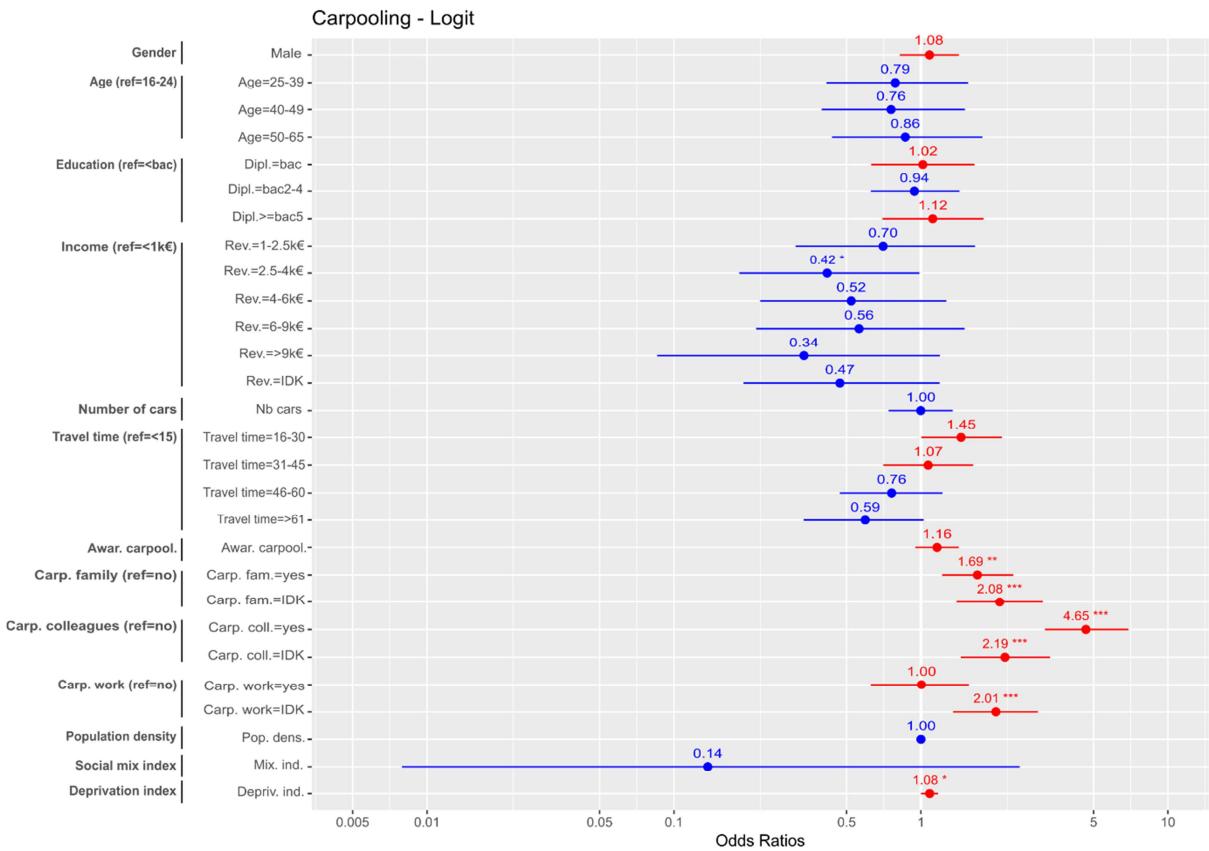


Figure 3. Carpooling correlates: graphical illustration of the incidence rate ratios estimated through the Poisson model in a sample of 2002 French workers (Paris region). Statistical significance of incidence rate ratios is indicated by asterisks (= $p < 0.05$; ** = $p < 0.01$; *** = $p < 0.001$).*

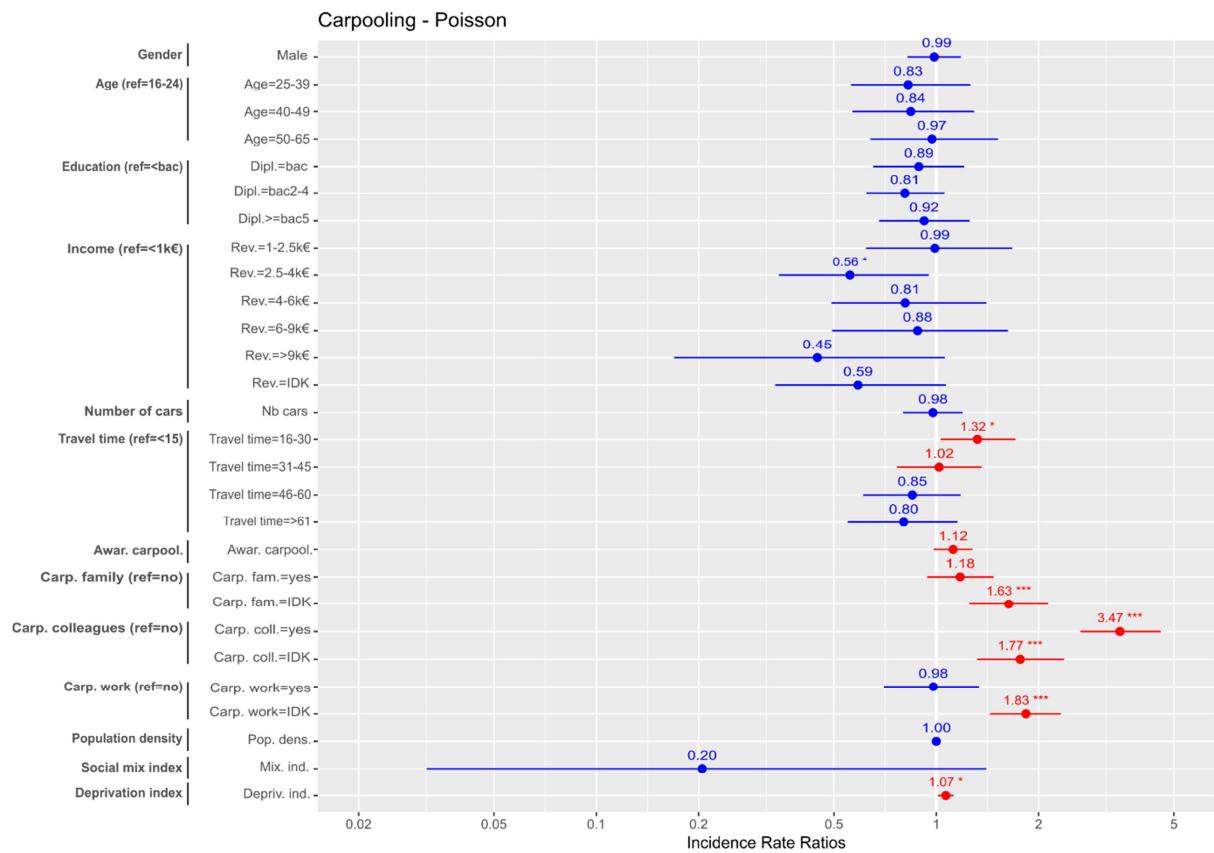
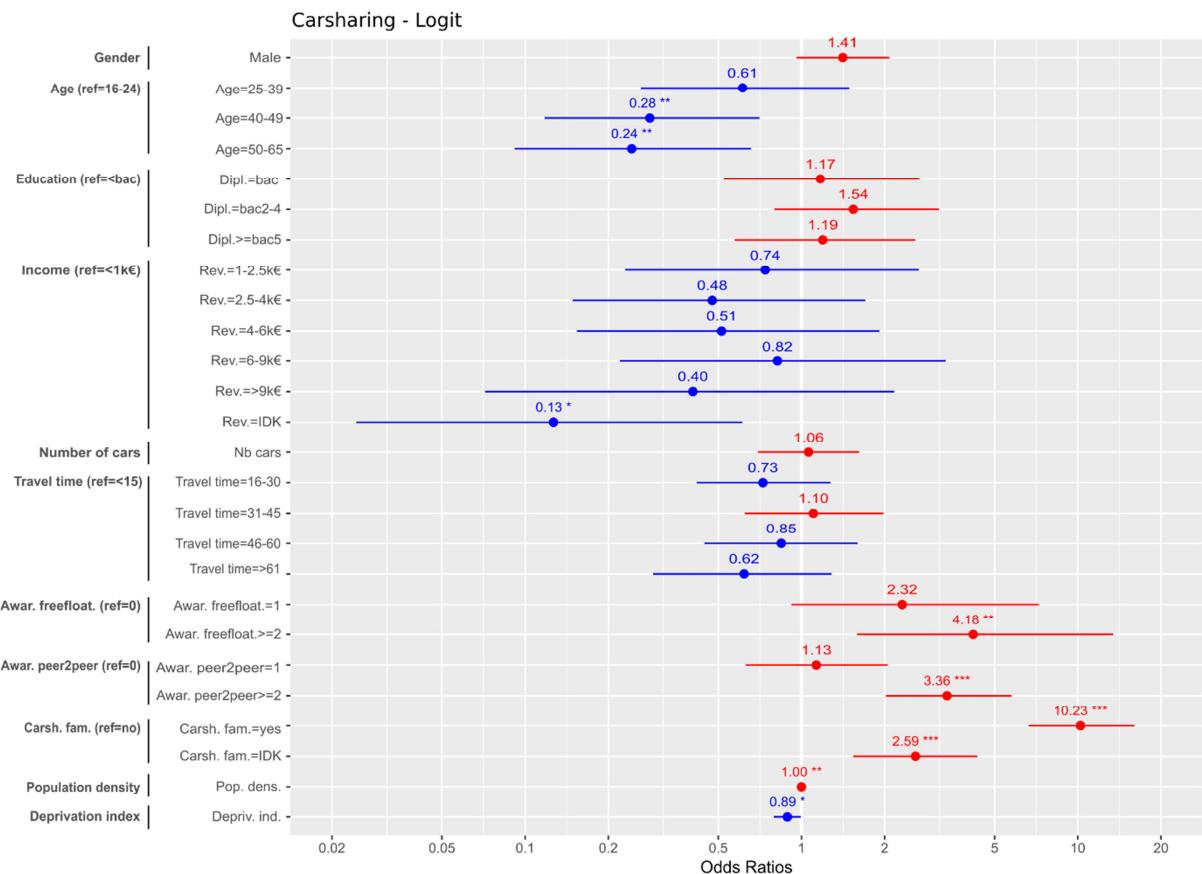


Figure 4. Carsharing correlates: graphical illustration of the odds ratios estimated through the logit model in a sample of 2002 French workers (Paris region). Statistical significance of odds ratios is indicated by asterisks (= $p < 0.05$; ** = $p < 0.01$; *** = $p < 0.001$).*



The table 3 summarizes the main results.

Table 3. Main findings and differences between carpooling and carsharing

Carpooling		Carsharing	
Socio-demographics and socio-economics variables			
< 0	-Individuals earning between 2.5 and 4 k€ are negatively associated than those earning less than 1 k€.	<0	-Age groups: 40-49 and 50-65 are negatively associated compared to the 18-24 years group. Young people are the most susceptible to adopting carsharing
Carpooling service at work		Awareness of services	
> 0	-A carpooling service at work is positively associated with carpooling	> 0	-Knowing two or more free-floating or peer-to-peer services is positively associated with carsharing
Interpersonal variables: entourage (colleagues and/or family members)			
> 0	-Having family members/friends or colleagues who carpool is strongly positively associated with carpooling	> 0	-Individuals with family members/friends who share the use of a car are positively associated with adopting carsharing themselves.
Contextual variables			
> 0	- Deprivation index is positively associated with carpooling. The more deprived the neighborhood, the higher the likelihood of carpooling.	< 0	- Deprivation index: the more deprived the neighborhood, the lower the probability of carsharing - Population density: the denser the

		> 0	neighborhood, the higher the probability of carsharing.
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4.2.3. Implications of the main findings

It is essential to realize that the determinants of carpools and carsharing differ. Although the two solutions are shared modes, levers to encourage them have to be targeted differently. Regarding carpools, the socio-demographic characteristics of individuals are mainly insignificant, whereas the availability of a carpooling service at work and social influences play an important role. These results imply that enhancing mobility management policies in the workplace would be effective. In France, since 1 January 2018, employer mobility plans are mandatory for companies with more than 100 employees. These plans propose a set of measures aimed at optimizing and increasing the efficiency of employees' journeys, as well as reducing the negative externalities of individual car use (pollutant emission and congestion). Our results suggest that offering a matchmaking service to favor the use of carpools among employees would be a potentially relevant measure to include in mobility plans in the Paris region. In addition, we have revealed that the influence of the entourage (colleagues, family members) is important for carpools. Once again, employers have a role to play in encouraging their employees to carpool for commuting.

Regarding carsharing, beyond the socio-demographic variables (age, income) that are positively associated with carsharing, our results highlight the importance of contextual variables. Densely populated and less deprived neighborhoods should be targeted as a priority for implementing carsharing services. Carsharing for commuting could be seen as an alternative to public transport for better-off households, for example at peak times in the Paris region. However, the use of a carsharing service is influenced by awareness of the service and by family members. Public policies regarding transport should consider this finding and reinforce information and communication about this service. Awareness and the entourage are thus relevant levers for tackling obstacles to using carsharing.

5. Conclusion

This study explored the potential determinants of the use of carpools and carsharing for commuting among a comprehensive set of socio-demographic, socio-economic, interpersonal and contextual variables. The analyses were based on a representative sample of 2002 workers living in the Paris region. Four main findings are highlighted and offer some ways forward to encourage the use of shared modes such as carpools and carsharing.

- (i) We show that the correlates differ between the two modes. For carpools, our results suggest that socio-demographic characteristics are almost insignificant, except for income (negative association). In fact, carpools are more popular among low-income commuters, while young people are the most prone to carsharing.
- (ii) Our models highlight the importance of contextual variables, which have been little studied in the scientific literature of shared modes. We show that the use of carpools mainly concerns people who live in rather deprived neighborhoods, while carsharing is overrepresented in well-to-do and denser neighborhoods. There is therefore a contextual rift between the use of these two shared modes.
- (iii) We identify the importance of mobility management policies within the workplace. Having a carpools service within the company is positively associated with carpools for commuting. Regarding carsharing, the awareness of existing services (free-floating

and peer-to-peer) is positively associated with carsharing use. Public policies should therefore consider these results in order to implement information campaigns among target populations and to provide relevant guidelines for employers' mobility plans.

- (iv) Finally, the main originality of this study is the identification of the key role of the entourage (colleagues and/or family members) in engaging in both carpools and carsharing. Having family members and colleagues who carpool is strongly and positively associated with carpools oneself for commuting. Regarding carsharing, only the influence of family member behaviors was studied, again showing a positive association. However, this result should be completed by further qualitative analyses.

In conclusion, this study suggests that a combination of individual, contextual and interpersonal (entourage) characteristics would probably be effective in favoring the use of carpools and carsharing.

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