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Substitution and complementarity patterns between traditional transport means and car sharing: a person and trip level analysis

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Abstract

Car sharing is a new transport mode which combines characteristics of private and collective traditional transport means. Understanding the relationship of this mode with existing ones is very important for policy makers to create an efficient transport system and to properly address public resources. This paper aims to analyze the interaction of car sharing with the existing offer of competing modes, using data from a specific travel survey administered in the city of Turin, where both free-floating and one-way station based car sharing services are offered. All transport modes operating in the study area were considered. Bivariate models were estimated to study the propensity to have a car sharing subscription and the substitution patterns between different travel means for a representative random sample of trips taken by the Turin population. Results show that the current car sharing system is perceived as efficient and useful; car sharing members are young males, living in high-income and low-size household with, in particular, a high number of workers and low number of available cars; moreover, the presence of private parking near home has a strong negative impact. There is evidence that car sharing can substitute car driving trips, while the evidence that the same can happen with biking and walking trips is not supported by models but only marginally seen from descriptive statistics. There is also some complementarity between car sharing and public transport and a strong complementarity between car sharing and bike sharing, so that policy makers should jointly promote those modes.

Keywords Car sharing · Sustainability · Public transport · Multimodality · Car ownership

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Introduction

In recent years car sharing was introduced as a new transport mode in a contest where private car, public transport and bike were the most widespread means (Becker et al. 2017c). In a society where car is perceived as a status-symbol (Steg 2005) and where existing infrastructures were designed mainly for vehicles, this new mobility service can be seen as a mix of different aspects of private and public modes (Morency et al. 2007). Car sharing is a new alternative which is flexible, like private car, and affordable, like a public transport service (Zhou and Kockelman 2011); in particular, car sharing members can enjoy the privacy (Efthymiou and Antoniou 2016) and the flexibility (Habib et al. 2012) of a car without bearing fixed costs of ownership (purchase, insurance, maintenance and fuel) (Efthymiou et al. 2013; Martin and Shaheen 2011a; Morency et al. 2007).

In Italy, car sharing was introduced and regulated by a national rule in 1998 (Ministero dell'Ambiente 1998), while from 2001 some Italian municipalities started implementing car sharing services (*Iniziativa Carsharing—ICS*). However the great diffusion of this mode took place in 2013 when, in Milan, two "big players" introduced a free-floating system (Osservatorio Nazionale della Sharing Mobility 2016). Nowadays car sharing operators are present in 29 cities (Osservatorio Nazionale della Sharing Mobility 2016). In Turin, in particular, car sharing started in 2002 and nowadays there are three operators: two operating a free-floating system since 2015, and a third one proposing a station-based system with electric vehicles since the end of 2016. In recent times, although the overall fleet size in the city decreased by 8%, the number of trips grew by 54% from September 2016 to February 2017 (Urbi 2017). The growing demand of the service, along with the contextual presence of operators with different schemes, makes the city of Turin an interesting study field for car sharing systems.

Transport policies are generally quite supportive to car sharing, since it is believed that it is beneficial to reduce private traffic. Although car sharing operators are mainly private companies, they often obtain direct or indirect incentives and concessions for their members (e.g. dedicated car sharing stations on public street space, free access to paid parking zones, access to limited traffic zones and to public transport lanes or high occupancy vehicles lanes, incentives to scrap cars). It is therefore important to provide a sound basis to such policies by scrutinizing the impacts of car sharing on urban communities, beyond car sharing users, in order to help local authorities and policy makers to properly address public resources.

This paper aims at contributing to this effort by focusing on the interaction of this new transport mode with the existing offer of competing means. While existing works mainly refer to private car drivers, and to some extent to public transport, we try to give a more global picture through an assessment of all public (metro, train, urban and sub-urban bus) and private (car as driver and as passenger, taxi, bike) transport modes which are available in the study area.

More in details, after having presented key descriptive statistics related to car sharing subscribers as opposed to the general population in the Turin metropolitan area and to the population residing in the operational area of at least one service, we present a bivariate statistical analysis to understand substitution patterns between different travel means for a representative random sample of trips taken by the Turin population.

Both person-level and trip level analyses are then reiterated through some modeling effort. A car sharing subscription model is first presented that considers household beyond individual characteristics. This is followed by a mode switching model to car sharing that analyses one trip that was made by the subject the day before the interview and assesses both past multimodality behaviours in relation with such trip and future intentions to use any of the above listed travel means. Jointly considering past behaviours, future intentions, individual characteristics and attributes of a real trip can improve our understanding on the extent to which car sharing can be complementary to environmental benign travel means (public transport but also bikes), while substituting the use of private vehicles or taxis.

Previous work and still open issues

Car sharing systems have been extensively analysed, evaluating both their impacts in a transport system and their determinants, i.e. which factors affect the choice to become a member and to use this service to complete a trip.

Concerning impacts, several authors concluded that they are in general positive not only for the users, but also for the society and the environment. The reduction of the number of cars owned by a household is the most frequently cited benefit (Martin and Shaheen 2016); this is generally estimated by comparing car ownership figures before and after joining a car sharing program (Martin et al. 2010) and between members and non-members (Clewlow 2016). Previous works in this area are notably focused only on personal vehicle ownership, without considering the relationship with car sharing at a trip level. In related works, car sharing was reported inducing members to decrease vehicle miles traveled (Cervero et al. 2007; Martin and Shaheen 2016) and the number of trips per week (Zhou and Kockelman 2011) while increasing their attitudes to combine different transport modes such as bikes and walking (Clewlow 2016; Kopp et al. 2015). To sum up, car sharing is generally considered a sustainable transport means (Clewlow 2016; Martin and Shaheen 2011a).

One basic objection that can be made to such studies is that results might be affected by self-selection and simultaneity biases (Clewlow and Mishra 2017). Self-selection in particular is related to the fact that impacts of car sharing might be due to individual differences between users and not users, rather than to the adoption of car sharing. Mishra et al. (2017) reported for example that "80% of the observed difference of 0.9 units in average vehicle holdings between carsharing nonmembers and members may be explained by the biases listed above". To avoid such shortcoming, an alternative is to take a stated preferences (SP) approach involving both users and not users. However, this method is characterised by a level of abstraction that might blur the difference between attitudes, intentions and behaviours. With the notable exception of Ciari and Axhausen (2012), many researches on car sharing involving SP experiments are in fact based on a hypothetical trip with given attributes that was not really experienced by the respondent (Efthymiou et al. 2013; Efthymiou and Antoniou 2016; De Luca and Di Pace 2015). This can be particularly problematic when respondents are not familiar with one or more of the alternatives (Diana 2010), as it is generally the case of car sharing.

One of the main focuses of the literature is to contrast the profiles of car sharing subscribers with those of the general population. Consistently with marketing studies, these researches could be used to support decision makers to promote the development of car sharing (Zhou and Kockelman 2011), although they are also incidentally reinforcing the idea that the above mentioned sample selection biases might affect global impact estimates. Authors showed in fact that car sharing users are younger (Martin et al. 2010; Martin and Shaheen 2011a), with higher employment rate (Dias et al. 2017), more educated (Becker et al. 2017c; Clewlow 2016; Kopp et al. 2015), with higher income (Clewlow 2016;

Efthymiou and Antoniou 2016) but fewer owned cars (Becker et al. 2017c; Martin et al. 2010), than the average, and also living in denser urban areas (Clewlow and Mishra 2017; Kopp et al. 2015).

Different sociodemographic variables related to car sharing subscription and use are found statistically significant, possibly depending on the analysis technique (Efthymiou and Antoniou 2016), and even the signs of the coefficients are occasionally changing. Despite such limitations, results seem to agree in depicting a profile of “early technology and social innovation adopter” for car sharing subscribers, in line with findings related to the diffusion of other forms of innovation both within and outside the transport sector. This prompted many researchers to focus their study of attitudes and behaviours related to car sharing on a convenience sample that is more or less matching some of the above mentioned characteristics, such as university students, or even directly considering car sharing subscribers only. In such case, it is clearly difficult to generalize the findings of those surveys to assess impacts on the whole population. To the best of our knowledge, only a handful of studies use data from a sample which is representative of a general population (Rodier and Shaheen 2004; Clewlow and Mishra 2017; Becker et al. 2017a, b, c). In the latter case, the difficulty is given by the fact that the adoption of car sharing is still relatively uncommon in a general population and therefore it is not easy to observe it in a sufficiently high number of individuals to draw some statistical inference. This induces the need of either solely relying on existing datasets such as large-scale household travel surveys, which might on the other hand not provide all the sought information to study car sharing-related behaviours, or to implement travel surveys with larger than usual sample sizes (Becker et al. 2017a, b, c).

Another interesting distinction can be made between the majority of studies that considers individuals as the unit of analysis and the few ones that take a more disaggregated approach, referring to single trips (Ciari and Axhausen 2012; Huwer 2004; Kopp et al. 2015; de Luca and Di Pace 2015; Morency et al. 2007; Schmöller et al. 2015). Trip-level analysis including the characteristics of travellers is clearly needed for a more detailed and realistic understanding of travel choices.

After the adoption of car sharing, changes in the use of other travel modes are always reported (Clewlow 2016; Lane 2005) since, becoming aware of the costs of driving cars, users appear to act more rationally concerning their daily mobility decisions (Barth and Shaheen 2002; Cervero et al. 2007; Coll et al. 2014; Huwer 2004; Nobis 2006; Zheng et al. 2009). This effect of car sharing on travel behaviour leads to a reduction in transportation energy consumption (Chen and Kockelman 2016; Martin and Shaheen 2016; Martin and Shaheen 2011b). Considering this important aspect and in order to understand and predict related changes in travel demand, several authors analysed the relationship between car sharing and other transport means, in particular public transport.

Comparing modal choices before and after the introduction of a car sharing operator, some authors reported that car sharing members increased the use of public transit, but others found the opposite. For example, Cooper et al. (2000) showed that the use of public transport increased of 14% in Portland, Oregon, while Martin and Shaheen (2011a) argued that car sharing may reduce public transport usage, because of the greater access to a car which it offers. With a more disaggregated analysis, the latter authors reported in fact an overall similar number of users either increasing or decreasing trips on public transport. However, when restricting the analysis to members of some selected providers, a slight reduction in public transit usage was observed (Martin and Shaheen 2011a). Moreover, when analysing the impacts of a one-way car sharing operator in five north American cities, the same authors found that there are members who either increase or decrease public transport usage, even if in most cases users decreasing the use of public transport are the majority (Martin and Shaheen 2016). According to Lane (2005), these different findings might depend on the different profiles of car sharing users, particularly related to car ownership levels. Looking at data from Philadelphia, this author observed that, considering only car sharing members that reduced their car ownership, 37% of them used more public transport after subscribing to the service; however, 12% of members that gained access to a car through car sharing reduced their public transport usage. Analysing differences between member and non-member, some other authors reported that car sharing members are used to take trips by public transport (Becker et al. 2017a; Clewlow 2016; Kopp et al. 2013; Mishra et al. 2015; Murphy 2016).

The observed relative changes in the intensity of use of car sharing and public transport could be explained by the existence of either a substitution or a complementarity effect between these two modes. Several different explanations have been put forward to support the latter view. It has for example been advocated that car sharing is used to connect public transport stations to final destination of travellers (Barth and Shaheen 2002; Shaheen and Chan 2016), thus increasing transit accessibility (Coll et al. 2014). Car sharing also addresses discretionary trips not really suit to public transport, providing the necessary convenience and accessibility typical of car (Cooper et al. 2000), and it is used in time periods in which public transport is less frequent (Costain et al. 2012; de Luca and Di Pace 2015); in more general terms, it is adopted in regions where public transit accessibility is low (Kopp et al. 2013). On the other hand, some authors argued that car sharing appears as a substitute of public transit also for systematic (work and school) and medical trips (Cervero et al. 2007).

It is also interesting to note that impacts on public transport are probably different according to the car sharing operational service model. Separately considering free-floating and station-based car sharing systems, Becker et al. (2017c) reported that station-based car sharing, not being used for daily trips, can complement public transit. On the other hand, free-floating is considered the most suitable alternative to public transport due to its flexibility (Becker et al. 2017b). In particular it complements public transport (Becker et al. 2017a; Wagner et al. 2015, 2016) during the night, in bad weather conditions and for discretionary trips (Becker et al. 2017b). Becker et al. (2017a) therefore conclude that free-floating increases the use of public transport and non-motorized trips. On the contrary, Ciari et al. (2014) reported that free-floating can substitute public transport since it was reported being used for commuting trips.

The second distinction considers one-way and round-trip car sharing service models. Le Vine et al. (2014) showed that the one-way system is more used for commuting trips, and the round-trip for shopping purposes; therefore the former can substitute public transport and the latter rather complements it. Shaheen and Chan (2016) argued that one-way service model provides the flexibility for first- and last-mile connections to public transit.

To sum up, the relationship between car sharing and public transport is controversial both for its effect (increasing/reduction in public transport usage) (Clewlow 2016; Stillwater et al. 2009) and for its role (complementary/substitution). Differences might be due to site-specific variables and to the fact that different public transport services are not distinguished (e.g. urban vs. suburban or rail vs. road).

On a methodological viewpoint, the present work tries to overcome some of the above mentioned research gaps of car sharing studies. In fact, it involves a representative sample of the general population of more than 4000 individuals and, among other things, asks about the intention of using different transport modes in the future, but referring to a trip that was completed the day before the interview rather than to an abstract choice task. Both person-level and trip-level analyses will be carried out, while a fuller set of household characteristics will be considered beyond those of the individuals.

Field activities

A survey was implemented in the Turin metropolitan area, made by the Turin municipality, with about 800,000 inhabitants and 23 traffic analysis zones, and the municipalities surrounding the city, with about 544,000 inhabitants and 31 traffic analysis zones. Nowadays, in Turin there are three car sharing operators. Two of them adopt a one-way (free-floating) system, i.e. vehicles are picked up and returned on public parking places everywhere within an operational area, which covers the majority of the city; the number of cars available is about 750. The third operator provides 130 electric vehicles in a one-way (free-floating) system with 54 pool stations, i.e. shared cars are picked up from a charging station and can be returned to another station. The fleets of all three operators are composed of economy cars (city cars), and the number of members in 2015 was about 51,500 (Osservatorio Nazionale della Sharing Mobility 2016). A representative sample of the population aged 18 and more was stratified according to gender, age, occupational status and traffic analysis zone where the individual lives.

The survey consisted of six sections:

A. Brief introduction and preliminary screening questions (gender, age, occupation and zone) to understand which stratum the interviewee belongs to.
B. Travel diary and related activity patterns spanning over the 24 h before the interview; all activity locations were geocoded by embedding Google Maps APIs in the questionnaire to better estimate travel times and covered distances.
C. Focus on a randomly selected trip among those listed in the travel diary. In order to increase the degree of realism for the respondent related to car sharing services, trips longer that 50 km and/or carried out outside the study area were excluded from the draw. Additionally, if the selected trip was preceded or followed by an activity lasting less than 1 h, a trip chain containing shorter activity durations was automatically selected for further analysis rather than the individual trip. Previous research (Diana 2008, 2010), has shown that this helps in better matching the common understanding of a trip beyond the technical definition which is used in transport planning (i.e. a movement between any two activities) and it is again intended to help respondents in focusing on a trip chain that makes sense to them. Detailed questions were posed about this chained trip (e.g. travel times with all means, walk and wait times, travel contingencies, info on vehicles, on-trip activities), also considering modes used (e.g. cost, duration, presence of parking, number of persons, use of different modes in the past to complete the same trip).
D. Attitudinal questions on the chained trip [e.g. intention to use different modes in the future to complete the same trip, possible accidents, satisfaction levels through a valence and activation scale (Ettema et al. 2010, 2011)].
E. Stated-preference experiments to investigate mode switching attitudes for the chained trip, which is not relevant to the present research.
F. Socio-economic questions at both household (e.g. number of members, cars, income) and individual (e.g. education, driving license) level.

The same survey was administered through both CAWI (Computer Assisted Web Interviewing) and CATI (Computer Assisted Telephone Interviewing) protocols 7 days a week in three different 4-weeks periods, to control for seasonal effects, to the following samples:

- September–October 2016 (1526 respondents);
- February 2017 (1460 respondents);
- June 2017 (1480 respondents).

Data obtained from the three waves were aggregated (4466 interviews). Those interviewees that did not travel the day before the interview or had only trips longer than 50 km or travelled outside the study area were not considered, therefore 3280 interviews (73.4%) were retained.

Car sharing subscribers and prospective users versus the general population

Table 1 shows the main characteristics of the sample of the general population both at household and individual level (columns 3 and 4), of the fraction of the sample living within the operational area of at least one car sharing operator (columns 5 and 6), of the fraction of the sample having subscribed a car sharing service (columns 7 and 8) and of the fraction of the sample that declared a propensity to use car sharing for the previously introduced chained trip (last two columns). At the whole sample level, about 73% of interviews were collected through CATI; the number of males and females is the same. The majority of households have two members with two licensed drivers; the percentage of 1 and 2 cars owned is similar. About 1 out of 5 persons interviewed have a public transport subscription and 4.2% of individuals are car sharing members; the latter result is similar to Milan (3.1%) (Osservatorio Nazionale della Sharing Mobility 2016). Individuals living in the operational area, which is to say nearer the city centre in broad terms, have similar socioeconomic characteristics compared with the general sample but with slightly lower car ownership rates and higher ownership of a public transport pass.

Concerning the characteristics of car sharing subscribers in Turin, the mean age is between 35 and 44 years, like in studies on other systems; the majority of car sharing members has a high level of education (50.7% have a Master's degree or Ph.D.), as reported in available studies from Italy (Osservatorio Nazionale della Sharing Mobility 2016) and other countries (Clewlow 2016; Clewlow and Mishra 2017; Dias et al. 2017; Kopp et al. 2013). Households of car sharing members have more dispersed income levels and a number of cars between 1 and 2; about 35% of individuals have a public transport subscription, more than the average in the whole population, and most of them (62.3%) use this mode frequently. The majority of car sharing users became a member from 6 months up to 2 years, since several car sharing firms operated in Turin from 2015 to 2016. People reporting a positive propensity to use car sharing for the chained trip have similar characteristics to the car sharing members, both at individual and household level; however, the majority of them live outside the operational area (63.1%) and are not members of the service (63.1%).

Modal substitution patterns among travel modes for the randomly selected chained trip

Considering the randomly selected chained trip under investigation, interviewees were asked to list all transport means they had used in the past to complete it in different

Table 1 Key demographic characteristics

	Entire sample		Sample living in OA[a]		Car sharing members		Would use car sharing for their chained trip	
	N	(%)	N	(%)	N	(%)	N	(%)
Totals	3280		1429		138		203	
Household characteristics								
Household members								
1	431	13.1	219	15.3	23	16.7	27	13.3
2	1195	36.4	517	36.2	52	37.7	71	35.0
3	955	29.1	420	29.4	29	21.0	51	25.1
4	602	18.4	224	15.7	32	23.2	45	22.2
5	84	2.6	45	3.1	1	0.7	7	3.4
More than 5	13	0.4	4	0.3	1	0.7	2	1.0
Licensed drivers								
0	185	5.6	110	7.7	0	0.0	2	1.0
1	700	21.3	316	22.1	29	21.0	36	17.7
2	1570	47.9	671	47.0	76	55.1	118	58.1
More than 2	825	25.2	332	23.2	33	23.9	47	23.2
Household cars								
0	277	8.4	159	11.1	19	13.8	16	7.9
1	1388	42.3	660	46.2	55	39.9	82	40.4
2	1472	44.9	563	39.4	54	39.1	91	44.8
More than 2	143	4.4	47	3.3	10	7.2	14	6.9
Household income [€/month]								
Less than 1000	159	4.9	78	5.5	9	6.6	11	5.4
1000–1500	461	14.2	204	14.3	19	13.8	34	16.7
1500–2000	840	25.6	376	26.3	18	13.0	43	21.2
2000–2500	513	15.6	215	15.0	26	18.8	35	17.2
2500–3000	516	15.7	218	15.3	19	13.8	30	14.8
3000–4000	544	16.6	249	17.4	27	19.6	28	13.8
4000–6000	221	6.7	81	5.7	16	11.6	18	8.9
6000–10,000	18	0.5	6	0.4	2	1.4	2	1.0
More than 10,000	8	0.2	2	0.1	2	1.4	2	1.0
Individual characteristics								
Type of interview								
CATIF	2551	77.8	1088	76.1	16	11.6	23	11.3
CAWIC	729	22.2	341	23.9	122	88.4	180	88.7
Gender								
Male	1622	49.5	722	50.5	83	60.1	118	58.1
Female	1658	50.5	707	49.5	55	39.9	85	41.9
Age								
18–20	142	4.3	71	4.9	1	0.7	3	1.5
21–24	172	5.2	76	5.3	9	6.5	9	4.5
25–29	226	6.9	87	6.1	29	21.0	36	17.7
30–34	270	8.2	110	7.7	27	19.6	34	16.7

Table 1 (continued)

	Entire sample		Sample living in OA[a]		Car sharing members		Would use car sharing for their chained trip	
	N	(%)	N	(%)	N	(%)	N	(%)
35–44	630	19.2	268	18.8	35	25.4	57	28.1
45–54	616	18.8	253	17.7	18	13.0	36	17.7
55–64	471	14.4	213	14.9	15	10.9	23	11.3
65–74	452	13.8	198	13.9	4	2.9	4	2.0
More than 75	301	9.2	153	10.7	0	0.0	1	0.5
Education level								
Not high school graduate	643	19.6	279	19.5	8	5.8	16	7.9
High school graduate	1821	55.5	780	54.6	60	43.5	97	47.8
Master's degree or Ph.D.	816	24.9	370	25.9	70	50.7	90	44.3
Occupational status								
Work out of home	1725	52.6	726	50.8	105	76.1	164	80.8
Work at home	293	8.9	127	8.9	3	2.2	4	2.0
Student	285	8.7	139	9.7	15	10.9	19	9.4
Retired	773	23.6	353	24.7	6	4.3	9	4.4
Unemployed	204	6.2	84	5.9	9	6.5	7	3.4
PT subscription								
Yes	675	20.6	393	27.5	49	35.5	62	30.5
No	2605	79.4	1036	72.5	89	64.5	141	69.5
Use of public transport								
Never	979	29.8	302	21.1	16	11.6	33	16.3
Occasional	1333	40.6	604	42.3	36	26.1	46	22.7
Frequent	968	29.6	523	36.6	86	62.3	124	61.1
Car sharing time membership								
Less than 1 month	10	0.3	7	0.5	10	7.3	2	0.9
From 1 up to 6 months	26	0.8	18	1.3	26	18.8	12	5.9
From 6 months up to 1 year	30	0.9	20	1.4	30	21.7	17	8.4
From 1 up to 2 years	48	1.5	38	2.6	48	34.8	26	12.8
More than 2 years	24	0.7	21	1.5	24	17.4	18	8.9
Not member	3142	95.8	1325	92.7	0	0	128	63.1
Residence within OA[a]								
Yes	1429	43.6	1429	100.0	104	75.4	75	36.9
No	1851	56.4	0	0	34	24.6	128	63.1

[a]At least one operative area of a car sharing service

occasions, as well as all those means they are considering to use in the future. Table 2 presents the related crosstabulation of the answers to those two questions, where a selection of the most frequently used means is listed in rows and future means are in columns. Percentages reported in each cell of the table therefore indicate the fraction of individuals that might use the mode indicated in the column label, among all individuals having already used the mode indicated in the row label to complete at least part of the trip. Less

Table 2 Modal diversion patterns for the chained trip under consideration (respondents %)

	Walking	Bike	Bike sharing	Motorbike	Car as driver	Car sharing	Car as passenger	Taxi	Urban bus	Metro	Suburban bus	Train
Walking	**90.2**	32.4	8.2	9.1	34.7	8.2	27.6	5.3	29.3	13.7	4.7	2.4
Bike	55.9	**78.2**	12.2	14.7	52.4	9.6	41.3	6.1	31.1	17.5	5.6	4.3
Bike sharing	70.3	70.3	**81.1**	43.2	54.1	35.1	35.1	18.9	75.7	35.1	16.2	18.9
Motorbike	29.7	35.9	12.4	**84.8**	53.8	11.0	31.0	6.9	29.7	11.0	4.1	3.4
Car as driver	14.8	14.0	3.1	6.8	**91.2**	5.1	27.5	2.9	23.7	10.9	4.3	2.2
Car sharing	70.4	70.4	40.7	44.4	74.1	**81.5**	63.0	37.0	81.5	66.7	22.2	29.6
Car as passenger	20.1	15.5	2.7	8.0	60.4	4.6	**86.6**	4.6	38.3	15.3	5.4	2.5
Taxi	34.7	32.7	14.3	22.4	65.3	30.6	55.1	**77.6**	61.2	40.8	10.2	10.2
School/company bus	50.0	42.3	23.1	26.9	57.7	11.5	30.8	23.1	80.8	42.3	19.2	11.5
Urban bus	21.6	15.3	7.0	7.5	43.4	6.9	32.5	5.4	**86.6**	23.3	5.1	3.8
Metro	23.9	21.4	9.8	8.3	52.9	11.3	37.3	7.6	60.9	**83.8**	9.5	7.6
Suburban bus	26.1	19.6	15.2	12.0	71.7	15.2	48.9	7.6	43.5	37.0	**68.5**	19.6
Train	33.3	13.3	6.7	11.7	63.3	6.7	45.0	11.7	55.0	48.3	26.7	**46.7**

commonly selected modes to make the same chained trip in the future (such as boats crossing the Po river in Turin) were not included in columns, while also those modes used in the past in less than 20 cases were not included in rows. Since respondents could indicate more than one past or future transport mode, row and column sums are greater than 100%.

Values written in bold in Table 2 show which fraction of travellers would ideally use the same mode in the future. As expected, the majority of those having used a given travel mode would consider using it again in the future. However it is interesting to note some remarkable variations of this measure of behavioural inertia across different means. Travellers by train and suburban bus are those that are least considering using the same means, a likely measure of dissatisfaction with public transport for suburban trips. Bike sharing and car sharing score relatively lower compared to urban transit, car and walk.

Other values on the other hand show the substitution patterns across different modes for the random trip. Several comments would be possible on those data, but focusing on the goal of this research it can be noted that the "car as a driver" row has the lowest values beyond the bold one compared to other rows, thus indicating that drivers tend to stick more to their means than users of other means. Car sharing is in the opposite situation, with many customers willing to shift to other means (if they were available). Considering columns rather than rows, values under "car sharing" are on the other hand low if compared with those of traditional transport modes. This could be due to the fact that car sharing has been only recently introduced in Turin. Overall, car sharing seems to be a more appealing substitute of public transport and of active means than of car as a driver and car as a passenger. One general conclusion is that car sharing seems not likely to become a massively used travel means, at least in a business as usual scenario.

Models

Two binary logit models were applied on the dataset: the first was adopted to investigate which factors affect the choice to subscribe a car sharing system, while the second was used to identify factors affecting the propensity to use this transport means. For both models, independent variables were first selected according to literature review and personal considerations of authors; then, non-significant variables were removed both manually and using an automated stepwise procedure, obtaining different models which were compared; after that, best models were retained. The entire procedure was carried out using R (R Core Team 2017). Table 3 shows the exogenous variables used in both models (incidentally, the first variable AUCS_ABBON is endogenous to the first model and exogenous to the second). Correlations among exogenous variables were also calculated for each model, considering Pearson coefficients when both variables were metric, Phi coefficients for correlations between two dichotomous variables, and point-biserial correlations when one variable was metric and the other dichotomous.

Car sharing subscription model

The first binary logit predicts the probability to have a car sharing subscription; since only drivers are obviously allowed to use car sharing, only 2809 respondents owing a driving license were retained (Becker et al. 2017c). Table 4 shows estimation results. Consistently with previous works, age has a negative impact, however it is not so significant compared with other variables in the model (OR). On the contrary, gender is found to be very

Table 3 Exogenous variables used in the two models

	Description	Type	Level
AUCS_ABBON	Car sharing subscription	Dummy	Individual
ETA	Age	Metric	Individual
F_AUCS	Frequency of use of car sharing [times/week]	Metric	Individual
F_AZSB	Frequency of use of school bus [times/week]	Metric	Individual
F_BIBS	Frequency of use of bike sharing [times/week]	Metric	Individual
F_BUS	Frequency of use of urban bus [times/week]	Metric	Individual
FAM_AUTO	Number of cars	Metric	Household
FAM_LAVORO	Number of employees	Metric	Household
FAM_MOTO	Number of motorbike	Metric	Household
FAM_N	Number of members	Metric	Household
FERIALE	Working day	Dummy	Macro-trip
FUT_AUCO	Willing to use car as driver in the future for this trip	Dummy	Macro-trip
FUT_AUPA	Willing to use car as passenger in the future for this trip	Dummy	Macro-trip
FUT_AZSB	Willing to use school bus in the future for this trip	Dummy	Macro-trip
FUT_BIBS	Willing to use bike sharing in the future for this trip	Dummy	Macro-trip
FUT_EXTRA	Willing to use suburban bus in the future for this trip	Dummy	Macro-trip
FUT_MOTO	Willing to use motorbike in the future for this trip	Dummy	Macro-trip
FUT_TAXI	Willing to use taxi in the future for this trip	Dummy	Macro-trip
GOO_DAUkm	Distance [km]	Metric	Macro-trip
GOO_TAUmin	Time [min]	Metric	Macro-trip
INCOME	Income [1000€]	Metric	Household
ORIG_TO	Origin inside Turin	Dummy	Macro-trip
PARK_CASA	Presence of parking near home	Dummy	Household
PASS_AUCO	Used car as a driver in the past for this trip	Dummy	Macro-trip
PASS_AUCS	Used car sharing in the past for this trip	Dummy	Macro-trip
PASS_AZSB	Used bus in the past for this trip	Dummy	Macro-trip
PASS_METRO	Used subway in the past for this trip	Dummy	Macro-trip
PASS_TRENO	Used train in the past for this trip	Dummy	Macro-trip
SESSOM	Male	Dummy	Individual
TIPO_INTERVCAWIC	CAWI interview	Dummy	Individual
TP_ABBON	Public transit pass	Dummy	Individual

significant, males in particular are more likely to subscribe to car sharing than females (SESSOM), consistently with findings from previous works (Becker et al. 2017c). As obtained by other authors (Clewlow 2016; Dias et al. 2017), if household income increases, the probability to buy a subscription grows; this is related to the number of employees (it has the same sign of INCOME). However, the effect of the number of household members is negative (FAM_N), as found by other authors (Becker et al. 2017c); this suggests that car sharing is used by employed persons who live in low-size households. Like in previous studies, car availability plays a significant and negative role, both considering the number of vehicles owned (FAM_AUTO) and the presence of private parking near home (PARK_CASA). Car sharing members also tend to own a public transport pass (TP_ABBON), a relationship that was not studied in the above reviewed subscription models; this means that car sharing is considered and used as a complementary mode to public transport.

Table 4 Car sharing subscription model

	Coefficient	SE	z value	OR	*p* value
(Intercept)	−0.933	0.456	−2.048	0.393	0.041*
FAM_N	−0.309	0.115	−2.693	0.735	0.007**
FAM_LAVORO	0.310	0.159	1.954	1.363	0.051†
FAM_AUTO	−0.385	0.176	−2.187	0.680	0.029*
FAM_MOTO	0.385	0.181	2.121	1.470	0.034*
INCOME	0.278	0.072	3.841	1.321	0.000***
SESSOM	0.349	0.189	1.846	1.417	0.065†
ETA	−0.029	0.007	−4.043	0.971	0.000***
PARK_CASA	−1.660	0.198	−8.386	0.190	0.000***
TP_ABBON	0.749	0.200	3.735	2.114	0.000***
Statistics					
N = 2809					
Null deviance					1100.79
Residual deviance					937.82
AIC (Akaike criterion)					957.82
Null log-likelihood					−550.39
Final log-likelihood					−468.91
Cragg and Uhler's pseudo R^2					0.17
McFadden's pseudo R^2					0.15
Maximum likelihood pseudo R^2					0.06

Significance codes: ***$p < 0.001$; **$p < 0.01$; *$p < 0.05$; †$p < 0.10$

The highest values of correlation in this model were obtained between the number of household members (FAM_N) and the numbers of employees in the household (FAM_LAVORO) (Pearson ρ = 0.55, *p* value < 0.001), and between FAM_LAVORO and household income (Pearson ρ = 0.50, *p* value < 0.001); however FAM_LAVORO was not retained in the final model specification, therefore these correlated values do not affect the model validity.

Car sharing modal switch model

In order to complement the results of the first model and, in particular, to understand how the characteristics of potential users of car sharing interact with both trip attributes and past and future multimodality behaviours, an additional binary logit was developed presenting a trip-level analysis. The model estimates the probability to use car sharing as a transport means for the selected chained trip, therefore results are related to a real situation. Estimation results are reported in Table 5. As regards socio-economic variables, consistently with the previous model and with other studies, the age of the respondent (ETA) and the number of cars owned (FAM_AUTO) have a negative effect; on the contrary, if the number of employees in the household (FAM_LAVORO) increases the probability to use car sharing grows.

People currently using car sharing seems satisfied with the service and are likely to use it in the future, since coefficients related to the car sharing subscription (AUCS_ABBON) and the frequency of past use in general (FREQ_AUCS) and for the specific trip (PASS_AUCS) use are all positive. The propensity increases as the frequency of trips on bus increases (FREQ_BUS), this seems to point more to a complementarity than to a substitution effect between the two means, since FREQ_BUS is related to all trips while the use of the bus for the trip under investigation was not found significant. Along the same

Table 5 Car sharing modal switch model

	Coefficient	SE	z value	OR	p value
(Intercept)	−5.0187	0.7082	−7.0870	0.0066	0.0000***
FAM_LAVORO	0.3728	0.1534	2.4310	1.4518	0.0151*
FAM_AUTO	−0.3565	0.1700	−2.0970	0.7002	0.0360*
ETA	−0.0156	0.0084	−1.8550	0.9845	0.0637†
FREQ_BIBS	−0.3657	0.1661	−2.2010	0.6937	0.0277*
FREQ_AUCS	0.7321	0.1725	4.2430	2.0795	0.0000***
FREQ_AZSB	−0.3739	0.1620	−2.3080	0.6880	0.0210*
FREQ_BUS	0.2027	0.0731	2.7740	1.2247	0.0055**
AUCS_ABBON	1.3850	0.3023	4.5820	3.9949	0.0000***
FERIALE	−0.9181	0.3721	−2.4670	0.3993	0.0136*
GOO_TAUmin	0.0450	0.0180	2.4980	1.0460	0.0125*
GOO_DAUkm	−0.0434	0.0249	−1.7440	0.9575	0.0812†
ORIG_TO	−0.6021	0.2497	−2.4110	0.5477	0.0159*
PASS_AUCO	0.5878	0.2923	2.0110	1.8001	0.0443*
PASS_AUCS	2.2568	0.5904	3.8220	9.5526	0.0001***
PASS_AZSB	−1.7713	0.8361	−2.1190	0.1701	0.0341*
PASS_METRO	0.5617	0.2615	2.1480	1.7536	0.0317*
PASS_TRENO	−1.8273	0.6559	−2.7860	0.1608	0.0053**
FUT_BIBS	1.2146	0.2794	4.3470	3.3690	0.0000***
FUT_MOTO	0.8107	0.2498	3.2450	2.2495	0.0012**
FUT_AUCO	0.7449	0.3205	2.3240	2.1063	0.0201*
FUT_AUPA	0.7312	0.2177	3.3580	2.0776	0.0008***
FUT_TAXI	1.2784	0.3177	4.0240	3.5909	0.0001***
FUT_AZSB	1.0812	0.4478	2.4150	2.9483	0.0157*
FUT_EXTRA	1.0293	0.3044	3.3820	2.7990	0.0007***
TIPO_INTERVCAWI	2.4283	0.2734	8.8830	11.3391	0.0000***
Statistics					
N = 3280					
Null deviance					1522.82
Residual deviance					729.26
AIC (Akaike criterion)					781.26
Null log-likelihood					−761.41
Final log-likelihood					−364.63
Cragg and Uhler's pseudo R^2					0.58
McFadden's pseudo R^2					0.52
Maximum likelihood pseudo R^2					0.21

Significance codes: $***p < 0.001$; $**p < 0.01$; $*p < 0.05$; $^{\dagger}p < 0.10$

lines of interpretation, since both FREQ_AZSB and PASS_AZSB are both negative, we can conclude that school and company buses serve trips that are not well suit to car sharing. Similarly, potential users are going to use car sharing less in a working day (FERIALE is negative). Jointly considered, these two aspects show that car sharing is not likely used for systematic trips, like school and work.

The frequency of use of bike sharing has a negative effect (FREQ_BIBS) while the intended future use of this means for the specific trip (FUT_BIBS) is positively correlated: there is thus a clear complementarity between the two modes. The same can be said in particular for taxis (FUT_TAXI coefficient is positive while the actual use of this means was not found significant, possibly due to its low level of use). Finally, car sharing seems to be attractive for long-duration (GOO_TAUmin is positive) and short-distance (GOO_DAUkm is negative) trips, which are characteristics of urban trips in congested streets.

In order to clarify the relationship of car sharing with other transport means, the effect of variables "PASS_*" on the outcome can be analysed. In particular, negative signs of PASS_AZSB and PASS_TRENO suggest that car sharing cannot substitute these modes; the first one is used for systematic trips (as described above), while, the latter is used for long distance (in fact GOO_DAUkm has a negative sign). On the contrary, PASS_AUCO and PASS_METRO have both a positive effect, suggesting that car sharing can substitute these two modes, which are characteristic of urban trips; both past use of car as driver and metro have an impact greater than school/company bus and train, since their odd ratios are higher, indicating that car sharing will be a real future alternative of these means.

On a more general note, variables related to the future use of other transport modes are all positive; this shows that, like previous works, multimodality positively affect the propensity to use car sharing (Diana 2010). Concerning the spatial characteristics of the trip, only ORIG_TO is significant, independently on the trip destination, possibly pointing to a not completely rational behaviour where the availability of car sharing near the trip departure point is more affecting travel choices than the possibility of dropping the car within the service operational area. Lastly, respondents interviewed with CAWI are more likely to use car sharing in the future, since car sharing users are usually familiar with smartphone and web applications.

Analysing correlations among exogenous variables of the second model, a high value was obtained between the distance and the duration of the macro-trip (Pearson $\rho = 0.83$, p value < 0.001), however even if the correlation is positive, the two parameters have opposite effects on the dependent variables of the model. A negative correlation (Pearson $\rho = 0.61$, p value < 0.001) was obtained between the age of the respondents and the number of employees in the household, indicating that old people might live in household with retired people. Positive correlation (Index $\varphi = 0.79$, p value < 0.001) was found between past and future use of car as driver, indicating that who adopted a car for the macro-trip is likely to use it in the future.

Conclusions

In order to clarify the relation between car sharing and other transport modes, this paper presented results obtained from both descriptive statistics and binary logit models at the person and trip level, based on a survey implemented and realized in the municipality of Turin. Since data used to estimate models are referred to representative sample of individuals and trips, results are reliable and can be generalized.

The first model in particular predicts the probability of a driver to buy a car sharing subscription; results suggest that car sharing members are young males, living in high-income and low-size household with, in particular, a high number of workers and low number of available cars; moreover, the presence of private parking near home has a strong negative impact.

The second model aims to identify factors affecting the propensity to use car sharing for the macro-trip, considering, in particular, interactions with all current transport modes in the study area (car as driver, car as passenger/car pooling, car sharing, bike, bike sharing, walk, motorbike, taxi, school/company bus, urban bus, suburban bus, metro and train). It was found that car sharing is likely to be adopted by people already using it, indicating that this current system is considered efficient and useful. Furthermore, potential members use this service not for systematic trips in working days, even if car sharing is suitable for urban trips in congested roads (high-duration and short-distance trips).

Interesting substitution and complementarity patterns between car sharing and other modes emerged from the analyses. In particular, there is evidence that car sharing can substitute car driving trips, while the evidence that the same can happen with biking and walking trips is not supported by models but only marginally seen in descriptive statistics. On the contrary, there is some complementarity between car sharing and public transport and a strong complementarity between car sharing and bike sharing, so that policy makers should jointly promote those modes. Taxi services seems complementary as well with car sharing, although empirical evidence is somewhat hampered by the fact that this mode is seldom used. Beyond such patterns that have been clarified through the presented models, descriptive statistics related to the consideration of car sharing as a means to complete a randomly selected trip seem to indicate that the market share of such services is likely to stay low in the near future, compared to that of private cars, transit and walking, even if there is still a large growth potential.

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Author contributions Riccardo Ceccato analysed the data, performed the literature review and wrote the manuscript. Marco Diana designed the survey and the analysis method, interpreted the results and contributed in writing the manuscript.

Compliance with ethical standards

Conflict of interest Both authors declare that they have no conflict of interest.

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