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30th June 2022

Preferred citation: this document may be cited directly referring to the above mentioned final published version:

Chicco, A., Diana, M., Loose, W., & Nehrke, G. (2022) Comparing car ownership reduction patterns among members of different car sharing schemes operating in three German inner-city areas. *Transportation Research Part A: Policy and Practice*, 163, 370-385.

Comparing car ownership reduction patterns among members of different car sharing schemes operating in three German inner-city areas

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Abstract

This paper explores the relationship between car sharing services membership and private car ownership levels. Compared to previous studies, we focus on differences among members registered in roundtrip station-based, free-floating, and combined services, by analysing the results of a survey addressed to members living in three German inner-city areas. Two logistic regression models were estimated to understand car ownership reduction patterns between different time points. In addition to car sharing membership and related patterns of use, sociodemographic characteristics of respondents, opinions about other transport means, attitudes towards private car, and environmental concerns were considered in the models' specification. Both regression models showed that car sharing membership is one of the strongest predictors of car shedding. Albeit all car sharing users reported significantly lower levels of car ownership than before registering to the service, roundtrip station-based members are about 15 times more likely to reduce car ownership than free-floating unique members. Respondents with membership in both schemes (either in combined or parallel offers) also showed higher propensity than free-floating members.

Keywords: *car sharing variants, car ownership changes, factor analysis, logistic regression*

1 Introduction

Car sharing is an alternative transport service where customers pay to use a shared vehicle, which is provided and maintained by a company or private individual. Through this service, members can benefit from the flexibility and privacy of a private car without bearing the costs and constraints of vehicle ownership (Kim et al., 2017; Shaheen et al., 2010). In part because of these advantages, car sharing rapidly spread in many urban areas throughout the world over the last decades. More recently, the exponential growth has been attributed to the introduction of free-floating car sharing services besides the traditional roundtrip station-based scheme (Rodenbach et al., 2018). Free-floating car sharing allows the users to end the rent in whatever parking space within an operational area, instead of a dedicated parking lot as for the station-based schemes. However, to be effective and potentially profitable, free-floating services need a high number of vehicles to serve an operational area that usually covers the central area of medium-large cities (Ferrero et al., 2018; Kortum et al., 2016). A mixed strategy of some operators is to offer combined services, where some cars are shared through fixed stations while others can be used within an operational area.

Many existing studies evaluated how car sharing impacts change according to the service typology (Becker et al., 2017; Martin and Shaheen, 2016). There is a general view that the single most important expected benefit of these schemes is the reduction of car ownership level, thus achieving a substitution effect between one shared car versus several privately owned and used cars. However, to the authors' best knowledge, very few studies analysed car sharing impacts on car ownership jointly considering users who subscribed to different car sharing schemes. Giesel et al. compared DriveNow (free-floating) and Flinkster (station-based) users in Berlin and Munich (Giesel and Nobis, 2016), but the information of the two users' groups comes from surveys administered in different time points (2014 and 2015). Namazu et al. compared car ownership levels of car2go (free-floating) and Modo (station-based) users in Vancouver (Namazu and Dowlatabadi, 2018). However, car sharing impacts may differ according to the location-specific variation (Lane, 2005; Shaheen and Cohen, 2007). Becker et al. compared station-based and free-floating users' groups in Basel (Switzerland) (Becker et al., 2018). Here, the free-floating service started its operation about one year before the data collection, thus results might be influenced by early adopters (Firnkorn, 2012; Firnkorn and Shaheen, 2016) and therefore they could not have a more general validity.

Based on the above sketched state of the art, in this study we evaluate the differences among car sharing members enrolled in different car sharing schemes, with an emphasis on car ownership changes. To achieve this goal, we analyse the data collected through a car sharing survey conducted by Bundesverband CarSharing e.V. in 2018, as part of the European H2020 STARS project (Bergstad et al., 2018), targeting car sharing members living in the central areas of Frankfurt, Cologne, and Stuttgart (Germany). These study areas were selected because all car sharing schemes were already operating since many years. The survey included users of roundtrip station-based, free-floating, peer-to-peer, and combined car sharing services.

The remainder of this paper is structured as follows. Section 2 presents a literature review on car sharing impacts with a focus on car ownership. Section 3 describes the data and methods used in this study. Statistical results and discussion are presented in Section 4. Section 5 concludes the paper.

2 Background

Despite the first implementation of car sharing took place in Switzerland at the end of 1940s (Becker et al., 2017), only in recent years car sharing has become a more commonplace urban mobility option in cities throughout the world (Clewlow, 2016; Ferrero et al., 2018; Namazu and Dowlatabadi, 2018; Shaheen and Cohen, 2007).

According to their operational characteristics, car sharing services can be classified in three main schemes: roundtrip station-based, one-way station-based and one-way free-floating (Shaheen et al., 2019). Roundtrip station-based schemes, which were the first being introduced, allow members to

pick up and return a shared car at the same dedicated location and typically pay for use by the hour, kilometre, or both. In Germany roundtrip car sharing started in 1988 with initiatives in several cities, one year after the beginning of modern car sharing services in Switzerland (bcs 2016). More recently, several big companies, typically car-makers and other corporations belonging to the automotive sector, entered in the car sharing market by introducing free-floating schemes (Ferrero et al., 2018). This scheme allows members to start and end a trip in different points belonging to an operational area (one-way trips) and pay for the use by minute. Other services have also been implemented, such as peer-to-peer car sharing and car among neighbours, or fractional car sharing. In the former, the operator runs a platform that allows members to share their own vehicles, and the users pay for the use by hour or even by day, whereas in the latter users co-own a car and share its costs and use (Martin and Shaheen, 2016; Rodenbach et al., 2018). Despite these services present different business models, they generally follow the roundtrip scheme from the operational point of view.

Car sharing is supposed to change the paradigm from car ownership to service use (Cervero et al., 2002a; Prettenthaler and Steininger, 1999). This produces a shift in the cost structure of driving, moving from fixed to variable cost (Cohen and Shaheen, 2016). Being more aware of the real costs of transport alternatives, users might choose their travel mode more rationally (Cervero et al., 2007; Cervero and Tsai, 2004). Thus, car sharing might influence mobility behaviour, travel habits, and have positive impacts on the environment (Ceccato and Diana, 2021; Chicco and Diana, 2021; Lane, 2005; Shaheen and Cohen, 2012). On the other hand, car sharing could induce motorised travel by increasing access to cars, especially in car-less members used to walking, cycling, and riding public transport (Cervero et al., 2002a; Diana and Ceccato, 2019; Martin et al., 2010). For these reasons, car sharing impacts on car ownership have been extensively investigated.

Different methodologies have however been used, and it is important to keep into consideration their different advantages and drawbacks when reviewing the literature in this sector. Many studies are based on cross-sectional surveys, where respondents are asked to self-evaluate the impact of car sharing on their car ownership levels (Becker et al., 2017; Giesel and Nobis, 2016; Kim et al., 2019; Ko et al., 2017; Le Vine and Polak, 2019; Martin and Shaheen, 2016). This methodology however, is expected to produce overestimated results as respondents are prone to conformity bias. Thus, other studies, which are still based on cross-sectional surveys, evaluate the impact on car ownership by looking at the respondents' observed behaviours in different periods. The number of cars owned by respondents is usually asked at the time of the first registration to car sharing (or 12 months earlier) and at the time of the survey (Namazu and Dowlatabadi, 2018; Nijland and van Meerkerk, 2017). Results, in this case, might be affected by recall bias, although buying or selling a car is an event that should stick to the memory of respondents. Finally, a limited number of studies is based on observed behaviours directly measured in multiple waves surveys, which are expected to produce less biased results (Becker et al., 2018; Cervero et al., 2007).

Earlier studies compared the vehicle ownership of station-based car sharing members with non-members. In general they found that car sharing facilitates a reduction in household vehicle holdings (Cervero et al., 2007; Martin et al., 2010) albeit members already owned less cars before registering to car sharing compared to the generic population (Cervero et al., 2007; Ko et al., 2017; Martin et al., 2010). In some cases the reduction occurred in single-car households that became car-free (Martin et al., 2010), while in other car sharing replaced the second or third car (Nijland and van Meerkerk, 2017). Car sharing effects on car ownership are usually evaluated through cross-sectional studies where members and non-members are compared. However, in such cases it is difficult to assess a causal link between car sharing membership and car ownership, since self-selection and simultaneity biases might arise. These issues were addressed by Mishra et al. in two studies based on the dataset of the California Household Travel Survey (Mishra et al., 2019, 2015). In the first study, in which only the self-selection bias was addressed, the authors found that car sharing members significantly owned less vehicles rather than non-members with similar individual and household demographics, residential and job location characteristics (Mishra et al., 2015). In

the second work, in which both self-selection and simultaneity bias were jointly addressed, they found that only 20% of the observed difference in the average vehicle holding between members and non-members reflects the estimated effect of car sharing. Therefore, car sharing was found to reduce one vehicle every six households with at least one car sharing member.

On the other hand, free-floating members usually report a smaller reduction in the number of household cars since participating in car sharing compared to station-based users (Belter et al., 2015; Jochem et al., 2020; Martin and Shaheen, 2016; Steer Davies Gleave, 2017; Wittwer and Hubrich, 2018). This might be related to the fact that different schemes are used by different customers, in different ways (Becker et al., 2017) and with different motivations (Lempert et al., 2019). Many other subjective variables and attitudinal factors of car sharing members may influence the decision to get rid of the private car, such as the satisfaction with the service, environmental concerns, attitudes including habit, symbolic and affective factors related to car driving, which are however considered in a handful number of car sharing studies. For example, car sharing members are more likely to reduce the number of cars owned as they become more satisfied with the service, in particular for the elements associated with the accessibility to shared cars (availability at the desired time, the proximity of the vehicle/station) and the rental system (Kim et al., 2019; Ko et al., 2017; Schreier et al., 2018). In another study, car sharing members who give up all vehicle ownership showed a high environmental awareness (Namazu and Dowlatabadi, 2018).

Apart from the considered business model, different results might be influenced by the characteristics of the specific area under study (Lane, 2005). For instance, (Clewlow, 2016) found that car sharing members living in dense urban neighbourhoods own fewer cars compared to non-members while suburban households did not, thus showing that the potential for reducing vehicle ownership is also tied to the built environment. Indeed, private cars can more easily be substituted by other means in denser areas, where trip lengths are more likely to lie within the range of active means (walk, bikes) and valid alternatives such as high quality public transport and shared mobility services are more frequently encountered.

Another element influencing the impact of car sharing on car ownership is the point in time when the outcome is measured (Firnkorn and Shaheen, 2016). Studies carried out after just one year after the launch of a car sharing service are more likely to produce outcomes that are biased by early adopters, compared to studies where the service is mature (Firnkorn, 2012; Le Vine and Polak, 2019). The longitudinal study on City CarShare operating in the San Francisco Bay area (California) confirmed this thesis (Cervero et al., 2007, 2002a, 2002b; Cervero and Tsai, 2004). They administered a travel survey a few weeks before the official starting of the City CarShare program, after the first year, after the second year, and after the fourth year. The authors found that four years after the inauguration of the service, 29% of the members had sold one or more cars. However, they observed that car ownership reduction mainly occurred during the first 2 years of the program, while during the third-fourth year the degree of car shedding levelled off (Cervero, Golub, and Nee 2007). Indeed, such changes could also be related to other factors, such as changes in the household structure.

Few studies however, evaluated the impacts of different car sharing schemes operating in the same city and period of time. Le Vine et al. evaluated the potential impact of introducing a free-floating service (point-to-point) in London, where a roundtrip station-based service already exists (Le Vine et al., 2014). The authors estimated that the subscription to a roundtrip service produced a 3.5% reduction in the number of cars owned by Londoners. In contrast, only a little additional reduction of 0.5% would be produced by the introduction of a free-floating scheme afterward, since most of the reduction in vehicle ownership has already occurred due to the former subscription (Le Vine et al., 2014). Similarly, Giesel et al. studied the impacts of roundtrip station-based and free-floating systems in Berlin and Munich (Germany) (Giesel and Nobis, 2016). Members of both services reported a reduction in the number of cars owned mentioning that car sharing had an important role, but this was rarely the main reason. In particular, the authors found that about 15% of the roundtrip members gave up a car due to the car sharing subscription, while only 6.5% of free-floating

members did the same. In addition, modelling the car ownership reduction they observed that the subscription to both services positively influences the probability of shedding a car (Giesel and Nobis, 2016). Another study compared station-based and free-floating members in Basel (Switzerland) (Becker et al., 2017). The authors found that both kinds of car sharing contribute to lower private vehicle holdings. In particular, they found out that 8% of free-floating car sharing members and 19% of station-based members would buy an extra car if the car sharing service were not be available anymore.
Lastly, Namazu et al. analysed effects on car ownership of both roundtrip station-based and free-floating schemes by administering a questionnaire to members in Vancouver (Canada) (Namazu and Dowlatabadi, 2018). The authors found that both user groups reduced vehicle ownership after joining a car sharing service, however members who either only use a roundtrip service or both roundtrip and free-floating services were more likely to dispose of personal cars than those who only use a free-floating service. In particular, 35% of respondents belonging to the first two user groups reduced ownerships, whereas only 12% of members of the latter group reported the same behaviour. Furthermore, the car ownership rate of members of the free-floating service shifted from 1.08 cars per household before joining to 0.98 afterward, whereas, for members of the roundtrip system, the rate switched from 0.68 to 0.36, showing that free-floating members already owned more cars than station-based ones before subscribing the service, thus pointing to different lifestyles between the two groups independently on car sharing usage.
Unlike these previous works, this paper compares car ownership differences among car sharing members enrolled in different car sharing schemes, namely roundtrip station-based, free-floating, peer-to-peer, and, for the first time, the combined scheme. Differently from the study carried out by Giesel et al.(Giesel and Nobis, 2016), who compared users of two services through surveys carried out in two different time points (2014 and 2015), in this paper the same time baseline is kept for all services to reduce the influence of changes in travel demand or other contextual elements, which might have occurred in that time lapse, on the results. In addition, the collected data from the present study come from three German cities where all car sharing schemes were already operating for many years at the time of the survey, thus related results are not simply referring to a sample of early adopters but hopefully more representative of the behaviours of the larger population. Moreover, the selected cities for the comparison are ranging between 500k and 1M inhabitants, which is a size more frequently encountered in European metropolitan areas and where the car sharing market is more quickly growing in recent years, after having been developed in larger metropoles. Furthermore, since car sharing variants are not equally available everywhere, we conducted a comparative analysis by considering inner-city areas only. In this way, we evaluate impacts of car sharing on respondents that have comparable access to all car sharing schemes, reducing the influence of built environment features on the outcomes. Finally, a broader range of explanatory variables is considered compared to previous studies, especially to better investigate the influence of subjective and attitudinal factors, as illustrated in the following sections.

3 Data, preliminary analyses, and model development

3.1 Study area

Germany is one of the leading markets for car sharing worldwide, with 226 car sharing providers operating in 840 German cities and municipalities, giving access to 25400 shared vehicles to more than 2 million customers (Bundesverband Carsharing, 2020). In 2012, a combined car sharing offer was introduced in Hannover, where in addition to the station-based fleet, free-floating vehicles were made available for the first time from the same provider (Bundesverband Carsharing, 2018). Nowadays, this kind of service is operated by various providers in several German cities; Frankfurt is one of the largest cities where all car sharing variants coexists, thus it has been considered in this work. The other two cities part of the study are Stuttgart and Cologne, which were ranked among the top five cities for car sharing offer in terms of number of shared cars per 1000 inhabitants in

2017 (1.47 and 1.27 respectively)[1]. Table 1 summarises the car sharing offers in the three cities at the time of the study here reported.

Table 1: Car sharing offer in the area under analysis in 2018. Source:(Bundesverband Carsharing, 2018)

City	Provider	First year of operation	Car sharing variant	Shared cars (2018)
Cologne	Cambio	1992**	Roundtrip station-based	513
	Flinkster	2009	Roundtrip station-based	52
	Ford carsharing	2013***	Roundtrip station-based	43
	car2go*	2012	Free-floating	650
	DriveNow*	2012	Free-floating	620
	Drivy	2015	Peer-to-peer	-
Frankfurt	book-n-drive	2015 (2000)	Combined (Roundtrip station-based)	468
	car2go	2014	Free-floating	260
	Stadtmobil Rhein-Main	2000	Roundtrip station-based	150
	Mobilee	2015	Roundtrip station-based	50
	Flinkster	2001	Roundtrip station-based	22
	Ford carsharing	2013***	Roundtrip station-based	17
	Drivy	2014***	Peer-to-peer	-
Stuttgart	car2go	2012	Free-floating	550
	Stadtmobil Stuttgart	1992	Roundtrip station-based	520
	Flinkster	2009	Roundtrip station-based	42
	Ford carsharing	2013***	Roundtrip station-based	4
	Drivy	2014***	Peer-to-peer	-

* Cologne and Düsseldorf business area
** as STATTAUTO CarSharing GmbH
*** in Germany

Inner-city areas were selected for this study (namely, postcodes 60385, 60316 and 60318 for Frankfurt; postcodes 50937 and 50539 for Cologne; postcodes 70176, 70193 and 70197 for Stuttgart) rather than the whole urban areas to limit the variability of some built environment parameters, such as public transport offer, presence of car sharing stations and operational areas, population density, and presence of mobility attractors, which seemed not controlled in a previous study in other bigger German cities (Giesel and Nobis, 2016). These elements strongly influence mobility choices and car sharing adoption and therefore its impacts (Stillwater et al., 2009).
The three inner-city areas have a population density above the average and a good land use mix (with housing, shopping, and workplaces all in the same quarter). The districts are characterized by several mobility options. Concerning the car sharing offer, all the above introduced car sharing variants have already existed here for many years. Besides car sharing, there are bus, tram, and subway stations that are accessible to residents at a short distance. The offer is partially complemented by bike and scooter-sharing. Figure 1 shows a map of car sharing stations and public transport stops in the Frankfurt study area.

[1] https://carsharing.de/sites/default/files/uploads/rangliste_carsharing-staedteranking_2017.pdf - Accessed June 4th, 2020

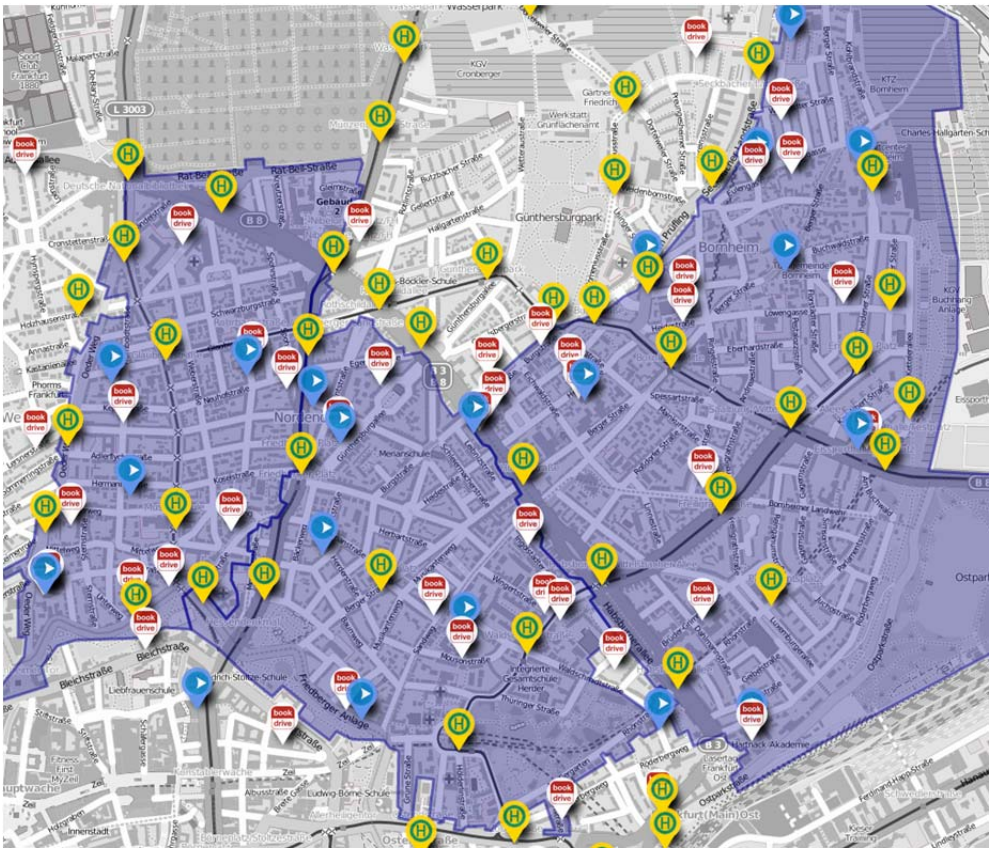

Figure 1: Car sharing stations and public transport stops in Frankfurt study area – Source:(Bergstad et al., 2018)

3.2 Survey contents and distribution

Data used in this study were collected in May 2018 through a web survey addressed to both car sharing members and non-members, although the latter are not considered here (Bergstad et al., 2018).

The questionnaire aimed to collect information about car sharing membership, motives to use car sharing, satisfaction about service costs and booking features, retrospective questions on car ownership levels in different periods (12 months before the first service registration, at the time of the registration, and at the time of the survey), along with sociodemographic information both at the individual (gender, age, and education level) and household level (composition, income, number of driving licences). Furthermore, a set of questions was addressed to collect travel habits information (frequency of use of different transport means), private car attitudes, and environmental concerns.

Irrespective on their frequency of use of the service, all car sharing members were invited to take part to the survey through an e-mail sent from the car sharing provider. The selection of those customers residing in the study areas was done by the car sharing providers. Six out of nine operators listed in Table 1 participated in the survey distribution: three of them provide roundtrip station-based services, one free-floating, one peer-to-peer, and one combined car sharing. Therefore, car sharing members of all different schemes were contacted.

These operators were asked not to include members who were identifiable as entirely commercial customers or company employees, since the aim was to focus exclusively on private households. As a result, some 14,858 customers of roundtrip, combined, free-floating, and peer-to-peer services were contacted out of 23,915 car sharing customers living in the areas of the study (Bergstad et al., 2018). No incentives were corresponded to the survey participants. In total, 904 responses were received, which correspond to a response rate of 6.1%; 292 questionnaires, which represent 32% of the collected ones, were furtherly discarded because not completely filled out. The final dataset consisted of 612 completed questionnaires. The complete dataset can be found on Zenodo (Ramos et al., 2019).

Due to the voluntary nature of the survey, some specific user groups might be oversampled (e.g. frequent car sharing users, younger users, users with higher education level); however, the sample could not be weighted since the sociodemographic characteristics of the car sharing users' population of each service operating in the study area in 2018 were not known.
Car sharing members have been grouped according to the car sharing variant (free-floating, station-based, combined), instead of the single car sharing provider's brand. Thus, for example, members enrolled in car2go and DriveNow service both are part of the free-floating user group. The complete breakdown of the respondents' membership is reported in Table 2. The first four rows of the table represent users' group of sufficient size to be separately considered in the following.

Table 2: Car sharing user groups

Car sharing membership	Respondents	(%)
Station-based only	190	(31.0%)
Free-floating only	130	(21.2%)
Combined only	115	(18.8%)
Station-based+free-floating	91	(14.9%)
Combined+station-based	27	(4.4%)
Combined+free-floating	21	(3.4%)
Combined+station-based+free-floating	21	(3.4%)
Station-based+free-floating+peer-to-peer	7	(1.1 %)
Peer-to-peer only	4	(0.7 %)
Free-floating+peer-to-peer	4	(0.7 %)
Combined+peer-to-peer	2	(0.3%)
Total	612	(100.0%)

3.3 Preliminary analyses and development of the car ownership reduction model

Preliminary descriptive statistics of all car sharing members and of members grouped by car sharing variants informed the specification of two binary logistic regression models to ascertain the factors influencing the car shedding. Model 1 considers the reductions between 12 months before the car sharing participation and the time of the survey, whereas Model 2 refers to the changes occurred between the car sharing subscription and the time of the survey. The two modelling outcomes are not independent of each other, since the time period examined in the latter one is within the longer time span of the former model and thus the two are partly overlapping. In absence of a complete panel dataset with a complete survey replicated several times and considering that changes which occurred before subscribing to the service are less relevant for our research question, the joint consideration of both models is helpful in at least partially addressing sample selectivity issues, namely the fact that an observed correlation between car sharing membership and car ownership reduction might not imply causation between the former and the latter but rather vice-versa (Mishra et al., 2019, 2015). Indeed, if car sharing membership were a significant predictor of both models, then it would more likely be a real cause of the modelled outcome. We reinforce here that this analysis is not statistically showing the presence or absence of sample selectivity, nevertheless it aims at giving some insights on this issue that is seldom addressed in studies in this area. Finally, it should also be noted that the experimental design allows to at least partially control some of the most commonplace causes of self-selectivity, namely the effect of the built environment (since we focus on inner city areas with comparable characteristics, as mentioned above) and the role of attitudes and personality traits (that are considered as well in both models, unlike most of previous research in this area).
Concerning the latter, a maximum-likelihood factor analysis with a Varimax rotation was applied to 16 questions containing statements about private car attitude and environmental concerns through 5-

points Likert-scales. These items are listed in rows in Table 3 and they are sorted in two groups according to the original questionnaire layout. Such questions were selected based on the consideration of previous research findings and they were already adapted to the car sharing context in a previous study (Ramos et al., 2020). More specifically, the first six items of the Table 3 are taken from the self-reported index of habit strength (Verplanken and Orbell, 2003), while the following five were proposed by well-known researches dealing with instrumental, symbolic and affective motives for car use (Steg, 2005) and the primary versus derived nature of travel demand (Diana, 2008; Mokhtarian and Salomon, 2001). Concerning the five items related to the "environmental concerns" section of the questionnaire, the first two represent the "Awareness of need" construct proposed by (Klöckner and Friedrichsmeier, 2011), while the last three capture personal norms according to (Van Der Werff and Steg, 2015).
Using a scree plot of eigenvalues, which shows variance explained by that particular factor out of the total variance, three factors were extracted. The columns of Table 3 report the factor loadings (which represent the correlations between the factor and the original variable).

Table 3:Statements considered in the factor analysis and respective factor loadings (loadings under 0.3 are cut-off)

	Factor_1	Factor_2	Factor_3
The following statements relate to your attitude to different modes of transportation. To what extent do you agree with these statements? (1=totally disagree, 5=totally agree)			
I feel strange travelling without a car.	0.547		
I use the car without planning ahead.	0.599		
It would require an effort for me not to use a car.	0.663		
Using a car is part of my daily routine.	0.726		
Using a car is something that I do automatically.	0.595		
I have been using a car for a long time.	0.403		
Driving a car saves time.	0.540		
Driving a car makes life easier.	0.628		
Driving is fun.	0.422		
For me, a car is just a means to an end.	-0.448		
If I have a choice, I prefer to use a car rather than public transport.	0.654		
To what extent do you agree with the following statements about the impact of car traffic on the environment? (1=totally disagree, 5=totally agree)			
It is urgent to do something against the ecological destruction caused by using the car.			0.928
I believe that using the car causes many environmental problems.		0.339	0.622
I feel morally obliged to reduce the environmental impact due to my travel patterns.		0.787	
I would feel guilty if I did not reduce the environmental impact of my travel patterns.		0.783	
I would feel good if I could travel more sustainably.		0.545	
Eigenvalue	3.794	1.804	1.454
% of variance	0.237	0.113	0.091
% of cumulative variance	0.237	0.350	0.441

Factor analysis results show that the set of questions related attitudes towards driving can be explained by one factor (Factor_1), whereas environmental concerns can be expressed with two factors (Factor_2 and Factor_3), that are reproducing the two above mentioned constructs

"Awareness of need" and "Personal norms". Among Factor_1 loadings one item shows a negative value, which is correctly estimated since the statement direction is opposite to the others (the higher the score, the lower the private car attitude). Overall, the three factors explain about 44% of the cumulative variance of the original variables, which is a rather low figure but still making these factors worth being considered in the model.

The complete list of explanatory variables is presented in Table 4, while in the following we shortly present some justification for their inclusion, let aside the three factors that were previously introduced.

Since the regression models aim to understand the influence of different car sharing membership on car shedding, the categorical variable "CS variant", which describe the type of membership, was explicitly considered. The variable "City" was also considered to identify whether car ownership reductions were influenced by the city in which respondents live.

Besides, several variables describing both household and individual characteristics were included in the list of candidate explanatory variables according to similar studies in the literature. Concerning household characteristics, the household size is expected to negatively influence car ownership reduction (Becker et al., 2018; Jochem et al., 2020; Kim et al., 2019; Ko et al., 2017; Namazu and Dowlatabadi, 2018). Similarly, the number of household's members working out of home (Namazu and Dowlatabadi, 2018) and the income levels show a negative effect on car shedding (Becker et al., 2018; Ko et al., 2017). Additionally, the number of driving licence available at the household level was considered since it may involve a strong commitment to car ownership (Clark et al., 2016). On the contrary, the number of household cars is expected to have a positive effect on car shedding – households with more cars are more likely to get rid of one or more cars (Jochem et al., 2020; Namazu and Dowlatabadi, 2018). The presence of children within the household was also considered, since its effect on car ownership reduction can be either positive (Jochem et al., 2020; Namazu and Dowlatabadi, 2018) or negative (Cervero et al., 2007).

Regarding individual characteristics, men are more likely to reduce car ownership than women (Kim et al., 2019). Car shedding, in general, increase with age (Cervero et al., 2007; Jochem et al., 2020; Kim et al., 2019; Ko et al., 2017) and with a higher level of education (Becker et al., 2018).

The length of car sharing membership positively affects car ownership reduction (Jochem et al., 2020; Namazu and Dowlatabadi, 2018) as well as the frequency of use of car sharing, albeit very frequent users (many times per week) show a reverse trend (Namazu and Dowlatabadi, 2018). The ownership of transit passes was also considered (PTpass) since it positively affects car ownership reduction (Cervero et al., 2007).

According to previous discussions, we also consider subjective variables in our models. User satisfaction with the service costs, with the availability of cars, and with the booking procedure (here indicated with SatCost, SatConv, SatAvWhenNeed and SatAvBook) are supposed to positively affect car shedding (Kim et al., 2019; Ko et al., 2017).

Individual preferences towards more sustainable transport means (LikePT and LikeBike) and how members perceive car sharing in comparison with the private car (CSreplaceCar, CSadditionCar) were also investigated. Moreover, some binary variables describing the motives to use car sharing were considered, namely the availability near home (CSmotive_1) and the cost savings compared to own a car (CSmotive_2 and CSmotive_5), since they are also expected to have a positive effect (Ko et al., 2017; Namazu and Dowlatabadi, 2018).

Apart from those statements analysed through the above mentioned factor analysis, all 5-points Likert-scales were included in the model specification as metric variables (namely LikePT, LikeBike, CSreplaceCar, CSadditionCar, CScheaperCar, and satisfaction statements). We are aware that ordinal variables such as Likert-scales should not be treated like metric ones, however considering such variables as categorical ones through dummy coding did not significantly affect the later reported modeling results.

Finally, contrarily to a previous study carried out in other German cities (Giesel and Nobis, 2016) we decided to not include in the model specification the use frequency of other transport means

(such as private car and public transport) because this information is referred to the survey time, when car ownership changes already occurred. Clearly the high percentage of car-free respondents strongly affects the mobility choices and therefore may blur the real elements influencing the reduction (car driver use frequency is negatively correlated with car ownership reduction because only those respondents who still own a car can use it).
In both models the complete set of explanatory variables (Table 4) were reduced by using a stepwise selection (a combination of backward and forward selection) based on the Akaike Information Criteria (AIC). The reduced models were finally tested using a 10-fold cross-validation were randomly selected 80% of the survey data are used as train set and 20% are used as a test set.
All the analyses have been performed with R (R Core Team, 2013), in particular the *psych* package for the factor analysis and the *MASS* package for the logistic regression and the stepwise selection.

Table 4: Candidate explanatory variables

Variable	Description	Type	Level
CSvariant	Typology of car sharing subscription Free-floating (Ref), combined, station-based, station-based+free-floating	Categorical	Individual
City	City where respondent lives Frankfurt (Ref), Cologne, Stuttgart	Categorical	Individual
HHsize	Number of members	Categorical	Household
HHincome	Monthly net income	Metric	Household
HHdrivLic	Number of driving licences	Metric	Household
HHcarReg	Number of cars owned at the time of the first registration to CS	Metric	Household
HHcarBef	Number of cars owned 12 months before the first registration to CS	Metric	Household
HHchild	Presence of children (<18 years)	Binary (No=0, Yes=1)	Household
HHchildNum	Number of children (<18 years)	Metric	Household
Gender	Gender Male (Ref), Female	Categorical	Individual
Age	Age	Metric	Individual
Edu	Level of education Primary (Ref): primary school diploma, Secondary: secondary school diploma, UniAdmission: qualification for the university, UniDegree: university degree, master or Ph.D.	Categorical	Individual
Empl	Job status Employed (Ref), Not employed, Self-employed, Student, Training	Categorical	Individual
YearsMemb	Years of CS membership	Metric	Individual
FreqCS	CS monthly use frequency More seldom (Ref), 1-3 times/week, More frequently	Categorical	Individual
PTpass	Public transport season ticket ownership	Binary (No=0, Yes=1)	Individual
SatCost	Satisfaction with CS cost of use	Ordinal	Individual
SatConv	Satisfaction with CS convenience	Ordinal	Individual
SatAvWhenNeed	Satisfaction with availability of shared cars at the desired time	Ordinal	Individual
SatAvBook	Satisfaction with the availability of the booked vehicles	Ordinal	Individual

LikePT	I like to travel by public transport	Ordinal	Individual
LikeBike	I enjoy cycling	Ordinal	Individual
CSreplaceCar	CS is a full replacement of a private car	Ordinal	Individual
CSadditionCar	CS is more like an additional offer of your own car	Ordinal	Individual
CScheaperCar	CS is cheaper than maintaining your own car	Ordinal	Individual
CSmotive_1	Motive to use CS: Availability of shared cars near home/ workplace	Binary (No=0, Yes=1)	Individual
CSmotive_2	Motive to use CS: To reduce expenses	Binary (No=0, Yes=1)	Individual
CSmotive_3	Motive to use CS: To travel more sustainably	Binary (No=0, Yes=1)	Individual
CSmotive_4	Motive to use CS: The convenience of having a car only when I need it	Binary (No=0, Yes=1)	Individual
CSmotive_5	Motive to use CS: To avoid responsibilities with maintenance and repairs of my own car	Binary (No=0, Yes=1)	Individual
CSmotive_6	Motive to use CS: To avoid looking for parking spots	Binary (No=0, Yes=1)	Individual
CSmotive_7	Motive to use CS: For more comfort when traveling	Binary (No=0, Yes=1)	Individual
Factor_1	Private car attitude (attitude towards driving)	Metric	Individual
Factor_2	Awareness about the negative effect of private cars on environment	Metric	Individual
Factor_3	Personal norms related to the environmental impacts of travel patterns	Metric	Individual

4 Results and discussion

4.1 Demographic of respondents

Sociodemographic characteristics of all car sharing users who answered the survey, along with those of the four main user groups individuated in section 3.2 (which represents the 85.9% of the completed questionnaires), are summarised in Table 5. Those descriptive statistics might be not fully representative of all users of those services, due to the voluntary participation to the questionnaire, however some distinct patterns clearly emerge. The reader interested in the comparison among user groups here analysed and non-users living in the same study area is referred to (Bergstad et al., 2018).

Table 5: Sociodemographic structure of respondents

	All users (N=612)		Free-floating (N=130)		Station-based (N=190)		Combined (N=115)		Free-floating+ Station-based (N=91)	
Individual information										
Age	45.6	(12.7)	38.2	(11.2)	50.1	(11.2)	48	(13.1)	45.9	(13.8)
18-24	15	(2.5%)	10	(7.7%)	0	(0.0%)	3	(2.6%)	1	(1.1%)
25-34	127	(20.8%)	51	(39.2%)	17	(8.9%)	19	(16.5%)	21	(23.1%)
35-44	153	(25.0%)	35	(26.9%)	42	(22.1%)	24	(20.9%)	22	(24.2%)
45-54	170	(27.8%)	19	(14.6%)	69	(36.3%)	33	(28.7%)	24	(26.4%)
55-64	99	(16.2%)	12	(9.2%)	41	(21.6%)	21	(18.3%)	18	(19.8%)
>65	48	(7.8%)	3	(2.3%)	21	(11.1%)	15	(13.0%)	5	(5.5%)
Gender										
F	275	(44.9%)	57	(43.9%)	93	(48.9%)	64	(55.6%)	28	(30.8%)

M	337	(55.1%)	73	(56.1%)	97	(51.0%)	51	(44.4%)	63	(69.2%)
Education										
Primary	6	(1.0%)	1	(0.8%)	4	(2.1%)	1	(0.9%)	0	(0.0%)
Secondary	46	(7.5%)	8	(6.2%)	13	(6.8%)	10	(8.7%)	10	(11.0%)
Univ. admission	88	(14.4%)	27	(20.8%)	23	(12.1%)	17	(14.8%)	11	(12.1%)
Univ. degree	472	(77.1%)	94	(72.3%)	150	(79.0%)	87	(75.6%)	70	(76.9%)
Employment status										
Employed	456	(74.5%)	92	(70.8%)	142	(74.7%)	85	(73.9%)	73	(80.2%)
Not employed	47	(7.7%)	1	(0.8%)	21	(11.1%)	15	(13.0%)	6	(6.6%)
Self-employed	77	(12.6%)	19	(14.6%)	22	(11.6%)	12	(10.4%)	8	(8.8%)
Student	29	(4.7%)	16	(12.3%)	5	(2.6%)	3	(2.6%)	3	(3.3%)
Training	3	(0.5%)	2	(1.5%)	0	(0.0%)	0	(0.0%)	1	(1.1%)
Membership length	5.9	(5.6)	2.3	(2)	8.2	(5.9)	5.2	(6.1)	7.1	(5)
<1 year	120	(19.6%)	57	(43.9%)	19	(10%)	27	(23.5%)	9	(9.9%)
2-5 years	257	(42.0%)	63	(48.5%)	61	(32.1%)	57	(49.6%)	35	(38.5%)
>5 years	235	(38.4%)	10	(7.7%)	110	(57.9%)	31	(27.0%)	47	(51.6%)
CS monthly use frequency										
never	16	(2.6%)	5	(3.8%)	3	(1.6%)	6	(5.2%)		
more seldom	479	(78.3%)	89	(68.5%)	168	(88.4%)	89	(77.4%)	70	(76.9%)
1-3 days a week	107	(17.5%)	30	(23.1%)	19	(10.0%)	20	(17.4%)	20	(22.0%)
4-6 days a week	8	(1.3%)	5	(3.8%)						
daily	2	(0.3%)	1	(0.8%)					1	(1.1%)
Monthly use frequency of other modes										
Car as driver	4.5	(7.5)	10.6	(9.9)	2.1	(4.6)	3	(6.1)	4.4	(7.4)
Car as passenger	2.5	(3.4)	4.4	(4.6)	1.9	(2.3)	1.8	(2.3)	2.4	(3.2)
Bike	14.4	(11.2)	9.5	(9.7)	14.4	(11.5)	17.6	(11.4)	14.5	(11)
Public transport	15.1	(9.9)	14.1	(10.2)	16.3	(9.8)	14.1	(9.9)	16.2	(9.4)
Taxi	3.3	(2.9)	3.6	(3.4)	3	(2)	2.8	(2.1)	3.5	(3.2)
Walk	21.4	(9.1)	20.2	(9.2)	23.1	(8.1)	20.8	(9.4)	22.6	(8.6)
Household information										
Dimension	2.1	(1)	1.9	(0.9)	2.1	(1.1)	2	(1.1)	2.1	(1.1)
1	206	(33.7%)	43	(33.1%)	69	(36.3%)	43	(37.4%)	30	(33.0%)
2	253	(41.3%)	65	(50.0%)	68	(35.8%)	42	(36.5%)	37	(40.7%)
3	78	(12.8%)	14	(10.8%)	26	(13.7%)	13	(11.3%)	13	(14.3%)
4	60	(9.8%)	5	(3.8%)	22	(11.6%)	16	(13.9%)	8	(8.8%)
5 or more	15	(2.4%)	3	(2.3%)	5	(2.6%)	1	(0.9%)	3	(3.3%)
Presence of children										
No	465	(76.0%)	112	(86.2%)	137	(72.1%)	82	(71.3%)	73	(80.2%)
Yes	147	(24.0%)	18	(13.9%)	53	(27.9%)	33	(28.7%)	18	(19.8%)
Driving licences	1.6	(0.5)	1.6	(0.6)	1.5	(0.5)	1.5	(0.5)	1.7	(0.6)
1	270	(44.1%)	53	(40.8%)	96	(50.5%)	59	(51.3%)	35	(38.5%)
2	324	(52.9%)	72	(55.4%)	90	(47.4%)	54	(47.0%)	50	(54.9%)
3 or more	18	(2.9%)	5	(3.8%)	4	(2.1%)	2	(1.7%)	6	(6.6%)
Monthly income [€]	3998	(2141)	4038	(2465)	3742	(1933)	3726	(1987)	4126	(2168)
Cars available at the time of the survey	0.39	(0.6)	0.9	(0.8)	0.18	(0.4)	0.22	(0.4)	0.34	(0.6)
0	432	(70.6%)	46	(35.4%)	160	(84.2%)	91	(79.1%)	63	(69.2%)
1	147	(24.0%)	57	(43.9%)	27	(14.2%)	23	(20.0%)	26	(28.6%)

2	25	(4.1%)	21	(16.2%)	2	(1.0%)	1	(0.9%)	1	(1.1%)
3 or more	8	(1.3%)	6	(4.6%)	1	(0.5%)			1	(1.1%)
Cars available at the registration	0.4	(0.7)	0.92	(0.8)	0.21	(0.5)	0.24	(0.5)	0.51	(0.6)
Car-free	406	(66.3%)	46	(35.4%)	156	(82.1%)	92	(80.0%)	50	(54.9%)
Cars available 12 months prior the registration	0.7	(0.7)	1.13	(0.9)	0.61	(0.6)	0.61	(0.7)	0.76	(0.7)
Car-free	245	(40.0%)	32	(24.6%)	89	(46.8%)	53	(46.1%)	33	(36.3%)

Note: Numbers report mean values for metric variables and absolute frequencies for categorical ones. Numbers in parentheses report standard deviations for metric variables and relative frequencies (column percents) for categorical ones.

The average age of the interviewed car sharing members is 46 years. Considering the individual user groups, members of combined and of roundtrip car sharing are older than free-floating ones on average. This is clearly attributable to the higher shares of young members (18-34 years old) within the free-floating user group compared to the other variants. The proportion of men among car sharing members lies at 55%, rather low compared to other studies where the proportion of men lies between 70 and 80 percent (Becker et al., 2017; Belter et al., 2015; Giesel and Nobis, 2016; Kim et al., 2019). Respondents who either registered to free-floating schemes only, or jointly with station-based offers, are more likely to be men than station-based members only, although we can not determine whether the difference is caused by the sample size or the study area.

Like in other studies, independently from the type of membership, car sharing members report high levels of education and full-time employment (Becker et al., 2017; Giesel and Nobis, 2016; Kopp et al., 2015; Wittwer and Hubrich, 2018). In particular and in line with these three studies held in Germany, 77.1% of respondents has got a university degree, whereas another 14.4% holds the general certificate for entrance to a university. By comparison, only 30% of the population living in the three cities under study (entire city areas) holds a degree, whereas 40% has a certificate for entrance to university[2]. Concerning the employment status, free-floating user group shows the highest percentage of students, whereas station-based and combined the highest proportion of not employed people (which includes retired people).

Concerning car sharing membership length, respondents were asked to select the service they were members at the time of the survey and to indicate the first year of registration. In case of multiple registrations, both information was collected for each membership. Respondents who took part to the survey are mainly long-term users: individuals who registered less than one year before the survey represent only 19.6% of the whole sample, whereas the remaining 80.4% is almost half split in members registered for two to five years (42%) and longer (38.4%). Considering individual user groups, the free-floating group shows the highest percentage of short terms members (43.9%) followed by combined user group (23.5%). On the contrary, the majority of station-based and parallel (station-based and free-floating) members are registered for more than five years (57.9% and 51.6%, respectively). In the latter group, however, the membership length is measured considering the first registration in car sharing, which was a station-based service in 71% of the cases.

The service use frequency shows that car sharing plays a marginal role in everyday mobility; the service is usually used less frequently than once a week (78.3%), which is consistent with previous studies (Kim et al., 2019; Morency et al., 2011; Namazu and Dowlatabadi, 2018; Sioui et al., 2012). Free-floating, combined, and parallel members apparently use car sharing more frequently than station-based ones.

Some differences are also noticeable when comparing the monthly use frequency of travel means among members of different car sharing schemes. In particular, free-floating members use a private

[2] Data for the whole cities (Frankfurt, Cologne, Stuttgart) from population census 2011

car (both as a driver and as a passenger) more frequently than the other users, which is consistent with the private car holdings showed by each group. In addition, free-floating members show the lowest bike use frequency. Walk and public transport are the most frequent used modes among respondents, regardless the type of car sharing membership.
Regarding the household characteristics, car sharing members mainly live in single or two-members household (2.1 on average), without children (76%), and with a high income. Kids do significantly more often occur in households of roundtrip and combined users than in the households of free-floating users.

4.2 Car ownership changes during the car sharing membership

At the time of the survey, respondents reported a low number of cars (0.39 cars per household on average), which is strongly related to the fact that 70.6% of them live in car-free households and the remaining 29.4% are mainly one-car households. However, the comparison of the average number of cars shows that there are significant differences among individual user groups (Kruskal-Wallis chi-squared: 104.08, df: 3, p-value: < 0.001). We estimated that unique members of free-floating services own, on average, 0.9 cars per household, which is significantly higher compared to all the other user groups. The percentage of car-free households in this group lies to 35.4%. Respondents uniquely enrolled in station-based services show the lowest number of cars per household, 0.18 on average, significantly lower compared to free-floating users (p-value: <0.001). 84.2% of respondents uniquely enrolled in station-based services are car-free. The situation is different when free-floating members are also registered with station-based services. In this case, the average number of cars is 0.34, with 69.2% of respondents live in households without cars. Free-floating car sharing seems to enable or trigger a life without a private car only in combination with other car sharing variants. This can also be observed in members of combined services, who get both variants from one provider, where 79.1% of respondents are car-free.
Car ownership levels at the time of the first registration and 12 months before the registration are reported in Table 6 and they show that differences among user groups already existed before participating in car sharing. Interestingly, free-floating members showed the smallest car ownership reduction albeit it shares the highest number of early adopters, which generally are more likely to shed a car (Cervero et al., 2007).

Table 6: Car ownership changes in time (average cars per household)

	Free-floating (N=130)	Station-based (N=190)	Combined (N=115)	Station-based + Free-floating (N=91)
12 months before the first registration (a)	1.130	0.605	0.609	0.758
First CS registration (b)	0.915	0.205	0.235	0.505
Survey time (c)	0.900	0.179	0.217	0.341
Significance				
(a) vs. (b)	t = 1.988 df = 256.93 p-value <0.05	t = 6.9664 df = 351.66 p-value <0.001	t = 4.785 df = 216.17 p-value <0.001	t = 2.5665 df = 179 p-value <0.05
(b) vs. (c)	t = 0.14777 df = 257.96 p-value >0.05	t = 0.5544 df = 376.52 p-value >0.05	t = 0.27554 df = 221.29 p-value >0.05	t = 1.8476 df = 177.12 p-value >0.05
(a) vs. (c)	t = 2.1429 df = 256.46 p-value <0.05	t = 7.5893 df = 340.72 p-value <0.001	t = 5.3189 df = 197.61 p-value <0.001	t = 4.4811 df = 173.06 p-value <0.001

Observing car ownership changes in the three time period reported in Table 6, a noticeable reduction occurred before the registration, in line with the findings of Schreier et. al in the city of Bremen (Germany) (Schreier et al., 2018). The reductions occurred within the year before the first registration (time point a vs. time point b), and those from one year before and the time of the survey (time point a vs. time point c) were statistically significant for all the user groups considered. A little reduction is still observable between the time of the registration and the time of the survey, however it is not statistically significant. This result put additional uncertainty about the causal relationship between car sharing participation and vehicle ownership reduction.

4.3 Car shedding models

Results coming out from the logistic regression models, which aimed at understanding the factors influencing car ownership reduction among car sharing members, are presented in this section. To better highlight the role of different car sharing variants we first studied car ownership models using only sociodemographic characteristics. The predictive power of such models was relatively low (Adjusted R^2 about 0.1), therefore we investigated car ownership reduction patterns through the complete set of variables presented in Table 4. Sociodemographic variables then increased their explanatory power when car sharing variants were also considered in the model specification. This preliminary result points at the importance of not considering car sharing as a general concept but rather to more precisely and concretely define the related operational variants while doing research on this topic.

Model 1 seeks to discover the characteristics of members who owned at least one car before their first registration with car sharing and that later reduced vehicle ownership levels. Respondents who did not own cars 12 months prior to the car sharing participation were then excluded from this analysis; 319 valid answers are then considered. On the other hand, Model 2 was conducted to understand the characteristics of members who owned a car at the time of registration with car sharing, and that later reduced the vehicle ownership. This time, respondents who did not own cars at the time of first registration with car sharing were excluded (n = 182).

Estimation results of Model 1 and of Model 2 are reported in Table 7.

Results of Model 1 show that membership to different car sharing forms has one of the strongest effects on predicting car ownership reduction. Respondents registered with station-based services are those who show the strongest tendency to reduce car ownership. In particular, they are 16 times more likely to shed a car compared to free-floating unique users (odds ratio: 16.488, p-value: <0.001) when other variables are unchanged. Members of combined services, as well as members registered with both free-floating and station-based services provided by different operators, are four times more likely to shed a car than members enrolled in free-floating service only (odds ratio: 3.805 and 3.749 respectively, p-value: <0.05).

The number of cars owned before the registration is, intuitively, another important factor that positively influences car ownership reduction: the more cars are available in the household the higher is the probability to reduce them, albeit the 78.8% of shed cars derives from single-car households becoming car-free. On the contrary, driving licences availability within car sharing members' households negatively influences the ownership reduction. In particular, the increase in the number of household's driving licences of one unit reduces the odds of shedding a car of one third.

The highest negative coefficient was estimated for the respondent's attitude towards driving (Factor 1); the coefficient of Factor 1 indicates that the higher is the respondent's attitude towards driving, the lower is the probability to shed private cars. On the other hand, the low explanatory power of Factor 3 (p-value: 0.102) suggests that the reduction of car ownership among car sharing members may be weakly tied to their environmental values.

How respondents perceive car sharing in respect to the private car, not surprisingly, influences the model outcome. The sign of the coefficient CSadditionCar shows that the more car sharing services

are perceived as an additional alternative to the private car, the lower is the probability of reducing ownership.

Table 7: Results for models 1 and 2

Name	Model 1 (N=319)				Model 2 (N=182)			
	Coeff.	p-value		Odds	Coeff.	p-value		Odds
(Intercept)	1.558	0.200		4.749	-2.823	0.135		0.059
CSvariant combined	1.336	0.031	*	3.805	1.129	0.170		3.093
CSvariant station-based	2.803	0.000	***	16.488	2.706	0.001	***	14.964
CSvariant station-based + free-floating	1.319	0.025	*	3.739	1.271	0.053	†	3.563
HHchildNum					-0.782	0.084	†	0.458
HHcarReg					3.502	0.000	***	33.187
HHcarBef	2.374	0.000	***	10.742				
HHdrivLic	-1.108	0.004	**	0.330	-1.386	0.010	**	0.250
HHincome	-0.134	0.127		0.875				
Age					-0.033	0.112		0.967
YearsMemb	-0.068	0.067	†	0.934				
FreqCS 1-3times/week	1.129	0.017	*	3.092				
FreqCS More frequently	0.580	0.698		1.786				
CSadditionCar	-0.835	0.000	***	0.434	-0.561	0.016	*	0.571
CSreplaceCar					0.700	0.004	**	2.014
SatCost	0.420	0.070	†	1.522				
SatAvWhenNeed	0.467	0.037	*	1.595				
LikePT					0.343	0.112		1.409
Factor1	-1.201	0.000	***	0.301	-1.622	0.000	***	0.197
Factor3	0.295	0.102		1.343				
*Significance codes: *** p< 0.001; ** p< 0.01; * p< 0.05; † p<0.10*								
Null deviance:	412.26				248.58			
Residual deviance:	210.15				120.02			
Adj. R^2 (McFadden):	0.49				0.52			
Akaike Information Criterion:	240.15				144.02			

Like in previous studies (Giesel and Nobis, 2016; Le Vine and Polak, 2019; Namazu and Dowlatabadi, 2018), the use frequency of car sharing services shows positive correlations with vehicle ownership reduction. However, in this case, members that frequently use car sharing (more than 3 times a week) are less likely to reduce car ownership than members who use the service 1-3 times a week; the former are almost twice more likely to shed a car (odds ratio: 1.786, p-value: 0.698), while the latter are three times more likely to reduce the number of owned cars (odds ratio: 3.092, p-value: <0.05) than members who use the service more rarely (less than once a week). This result is somewhat counterintuitive but may confirm the results obtained in Vancouver by Namazu et al., who found that people who shed cars after joining car sharing are infrequent drivers (Namazu and Dowlatabadi, 2018), and it is in line as well with the above mentioned effect of Factor 1 on the model outcome.

Furthermore, respondents' satisfaction with some car sharing service features, namely car sharing costs (p-value: <0.10) and availability of shared cars when need (p-value: <0.05), shows positive correlations with vehicle ownership reduction. These results reflect those of Kim et al. (Kim et al.,

2019, 2015), who also found that satisfaction with the service costs was a significant factor for car ownership reduction, especially in mature car sharing program. Rather intuitively, the more car sharing members are satisfied with the availability of shared cars in the location and at the time they need, in a certain way, the more they rely on the service, and the more they are likely to live without the need of a private car.
The negative coefficient of YearMemb shows that the longer is the car sharing membership, the lower is the probability of shedding a car, despite the low significance (p-value: <0.1). This finding is consistent with that of Cervero et al. in (Cervero et al., 2007), who observed that most declines occurred during the first two years of the program.
Model 2, in which the dependent variable reflects the reduction in car ownership occurring after car sharing registration, shows that only six variables significantly affect car shedding among those listed in Table 4.
In line with the estimates of Model 1, Model 2 shows that car sharing membership has one of the strongest effects in predicting car ownership reduction. Respondents registered with station-based services again show the strongest tendency to reduce car ownership: they are about 15 times more likely to shed a car compared to respondents registered in free-floating services (odds ratio: 14.964, p-value: <0.001), all else being equal. In this case, members registered with both free-floating and station-based services are three times more likely to shed a car than free-floating unique members (odds ratio: 3.563, p-value: <0.10), whereas combined users are not significantly different.
Intuitively, the number of cars owned at the time of the registration positively influences car ownership reduction (p-value: <0.001). On the contrary, the driving licences availability within car sharing members' households negatively influences the ownership reduction. Compared to Model 1, the increase in the number of household's driving licences of one unit reduces the probability of shedding a car of one fourth.
Attitudes towards driving measured through Factor 1 have the highest negative coefficient, indicating that the higher is the respondent's attitude towards driving, the lower is the probability to shed private cars.
As for Model 1, how respondents perceive car sharing in respect to private car influences the need for ownership. The sign of the coefficient CSadditionCar shows that the more car sharing services are perceived as an additional alternative to the private car, the lower is the probability of reducing ownership. Accordingly, the estimated coefficient for CSreplaceCar is positive, therefore the more car sharing is perceived as a full replacement of the private car, the higher is the probability of reducing ownership.
Finally, it is worth noting that in both car shedding models many of the subjective variables listed in Table 4 play an ancillary role. More specifically, variables reflecting motives to use car sharing and the two factors describing the environmental concerns of car sharing members (Factor2 and Factor3) seem not to significantly affect car ownership reduction. As previously mentioned, these two factors are respectively related to awareness of needs and personal norms and they probably represent only some fairly specific facets related to individual environmental concerns. A broader range of both attitudes and actual knowledge about the green could have been worth of investigation to draw stronger conclusions on the lack of influence of environmental concerns, which it was not possible to achieve due to the need to limit the questionnaire length that was administered through the car sharing providers.

4.4 Potential car ownership change without car sharing

The interpretation of the above modelling results can be completed in light of additional information that is available through the survey, with specific reference to the causality link between car sharing and car ownership reduction. Respondents were asked to report how many cars they would have in their household if the car sharing scheme to which they subscribe did not exist. According to the results reported in Table 8, 55.9% of members would maintain the today's level of car ownership, whereas 33.2% declared they would have more cars.

Table 8: Potential car ownership change in case of no car sharing

	All users (N=612)	Free-floating (N=130)	Station-based (N=190)	Combined (N=115)	Station-based + Free-floating (N=91)
Less cars	0.7%	0.8%	1.1%	0%	0%
Same	55.9%	73.8%	56.3%	47%	48.4%
More cars	33.2%	16.2%	30.5%	40%	45.1%
I cannot say	10.2%	9.2%	12.1%	13%	6.6%

Differences are observable when comparing members of different car sharing schemes: free-floating members, who already own more cars compared to the other members, reported the lowest hypothetical car ownership increase related to car sharing absence (only 16.2% of free-floating members would have more cars – albeit this is still a remarkable result). The other user groups, which showed higher percentages of car-free households, would increase the number of cars in their possession to a larger extent (30.5% in case of station-based unique members, 40% and 45.1% in case of combined and parallel users respectively). Table 9 reports the comparison between the average number of cars owned by car sharing members at the time of the survey with the potential number of cars in case of no car sharing offers.

Table 9: Comparison of car ownership levels at the time of the survey and hypothetical car ownership levels by car sharing membership

	Free-floating (N=118)	Station-based (N=167)	Combined (N=100)	Station-based + Free-floating (N=85)
Survey time (real)	0.949	0.191	0.210	0.352
Survey time, no CS (hypothetical)	1.130	0.527	0.690	0.847
Significance (real) vs. (hypothetical)	t = -1.7029 df = 233.78 p-value =0.089	t = -5.8369 df = 317.2 p-value <0.001	t = -6.6243 df = 183.15 p-value <0.001	t = -5.3713 df = 166.57 p-value <0.001

In case of absence of car sharing services, the average number of cars owned by free-floating members would not significantly increase (p-value: 0.089), by moving from 0.949 to 1.13, thus returning almost at the same level observed before the car sharing subscription.
On the other hand, station-based members would significantly increase the average number of cars owned, rising from 0.191 to 0.52 (p-value: <0.001) cars per household, albeit maintaining a lower car ownership level than the one reported before the registration. A possible explanation for this might be that station-based members, who showed long-term membership, have already changed their mobility habits, completely abandoning the need for a private car.
Interestingly, respondents registered in combined or in both free-floating and station-based schemes would significantly increase the number of cars owned (p-value: <0.001), even exceeding the level reported 12 months before the subscription.
To sum up, although the hypothetical nature of this question is not giving a definitive answer on the car sharing causality on car ownership reduction, these findings suggest that car sharing membership allows members who live in inner-city areas to effectively lower private car holdings and, for some of them, not to own any more cars.

5 Conclusions

This paper explores the relationship between membership in car sharing services and private car ownership. In particular, we studied the difference between members registered in roundtrip station-based, free-floating, and combined services, by analysing the results of a survey addressed to members living in three German inner-city areas.

We found that all car sharing users reported significantly lower levels of car ownership compared to the period before the registration, irrespective of the car sharing scheme. However, the comparison of the average number of cars showed significant differences among different user groups. Respondents with only free-floating membership showed the highest number of cars per household during all the analysed time period, whereas roundtrip station-based members reported the lowest. It is remarkable, however, that users of free-floating car sharing who are registered in parallel with other station-based services are more likely to reduce their car stock than users who exclusively rely on free-floating car sharing. Possibly free-floating becomes a strong alternative to a private car only in combination with other variants.

In all user groups the most significant reduction occurred within the year before the registration. Car ownership reduction was still reported after the car sharing registration, although it was not significant.

To better understand the role of car sharing membership on car shedding, two logistic regression models were estimated. In addition to the car sharing membership and related characteristics, sociodemographic characteristics of respondents and other subjective variables such as opinions about other transport means, attitudes towards private car, and environmental concerns were considered in the model specification. The first model evaluated the reduction occurred during the whole period (from one year before registration until the time of the survey) whereas an additional one focused on the reductions occurred after the car sharing registration. Both regression models showed that car sharing membership is one of the strongest predictors of car shedding. In particular, roundtrip station-based members are about 15 times more likely to reduce car ownership than free-floating unique members. Respondents with a membership in both schemes (either in combined or parallel offers) also showed higher propensity than free-floating members, indicating that the registration to both services may positively influence the car ownership reduction. Other important factors emerging from the models were related to the respondents' attitude towards both cars and driving and how car sharing is perceived compared to the private car. Users who perceived the service merely as a complement to the private car are less likely to reduce their vehicle ownership. On the contrary, variables reflecting motives to use car sharing and two factors describing the environmental concerns of car sharing members seem not to significantly affect car ownership reduction.

This study is however not exempted from limitations; the main limitation is related to the survey distribution, which was only partially under our control since car sharing users at the time of the survey were contacted via the car sharing providers for data privacy reasons. Only 904 questionnaires were collected and 612 were completely fulfilled out of all car sharing members living in the study areas. Therefore, we cannot determine to which extent the survey respondents are representative of all car sharing members (e.g. more frequent car sharing users or those with higher education level might be more willing to answer). However, the observed differences in car ownership reduction patterns among different car sharing variants are remarkable and therefore likely to be valid for all users.

Future research developments should be targeted at further exploring the causality link between different forms of car sharing membership and private car shedding behaviours. Concerning this point, one third of the survey respondents stated they would have more cars if the service they subscribed stopped its operation. Additional factors affecting car ownership levels of car sharing members might be considered as well, in line with the state of the art on car ownership models, including the effect of life-cycle events (e.g. job relocation, marriage, and changes in the household structure) (Clark et al., 2014).

It should also be noted that car sharing is a relatively new service that is still spreading in many urban areas (Firnkorn and Shaheen, 2016), so its impacts strongly change over time, since for example, early and late adopters might behave in a different way. Spatial comparability of research results across different cities, and even temporal comparability within the same area, is therefore affected. Concerning the latter point, all the services have been operating since many years in the study area of this research, so that results should be rather "stable" by now.

CRediT authorship contribution statement

Andrea Chicco: Conceptualization, Methodology, Software, Formal analysis, Writing - Original draft preparation, Writing - Reviewing and Editing, Visualisation. **Marco Diana:** Conceptualization, Methodology, Writing - Reviewing and Editing, Supervision, Funding acquisition. **Willi Loose:** Conceptualization, Methodology, Investigation, Writing - Reviewing and Editing. **Gunnar Nehrke:** Conceptualization, Methodology, Investigation, Writing- Reviewing and Editing.

Declaration of Competing Interest

The third and fourth author of this paper worked or are presently working for the German car sharing association "Bundesverband CarSharing e.V." (bcs). Some of the car sharing operators mentioned in this paper joined bcs, whose purpose is to do political advocacy for its members on a national and regional level. However, there are no financial relationships between these car sharing operators and bcs, apart from the payment of the association membership fees. Therefore, the authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This study was partly sponsored by the European project "Shared mobility opporTunities And challenges foR European citieS" (STARS), which has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement no. 769513.

Availability of data and materials

The dataset used and analysed in the current study is available at http://doi.org/10.5281/zenodo.3661118 (Ramos et al., 2019).

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