Does Free-Floating Carsharing Reduce Private Vehicle Ownership? The Case of SHARE NOW in European Cities

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Abstract

During the last decade, the use of free-floating carsharing systems has grown rapidly in urban areas. However, little is known on the effects free-floating carsharing offerings have on car ownership in general. Also the main drivers why free-floating users sell their cars are still rarely analysed.

To shed some light on these issues, we carried out an online survey among free-floating carsharing users in 11 European cities and based our analysis on a sample of more than 10,000 survey participants. Our results show that one carsharing car replaces several private cars – in optimistic scenarios up to 20 cars. In Copenhagen (followed by Rome, Hamburg, and London) one carsharing car replaces about two times more private cars than in Madrid, the city with the lowest number. The main influencing factor of shedding a private car due to the availability of the free-floating carsharing services seems to be the usage frequency of the service. The more kilometres users drive with these cars, the more likely it becomes that they sell a private car (or they sell their car and, therefore, use this service more often). Further memberships of bikesharing and other carsharing services, users that live in larger buildings as well as users that own several cars are more likely to reduce their number of cars, too. Finally, our findings are highly valuable for carsharing operators and (transport) policy makers when introducing free-floating carsharing systems in further cities. According to our results, all 11 cities show a reduced private car fleet due to members' access to free-floating carsharing.

Highlights

- Survey of free-floating carsharing users carried out in 11 European cities.
- Each SHARE NOW car replaces up to 20 private cars.
- The probability of selling private cars increases with kilometres by this service.
- City-specific characteristics affect private car sales.
- The car fleet was reduced due to free-floating carsharing in all cities.

Keywords

Free-Floating Carsharing; Survey; Europe; Cities; Car Ownership

1 Motivation

Carsharing is an important segment of the sharing economy. The sharing economy strives for a more efficient use of resources with positive economic, social, and environmental impacts (Martin 2016). In a new culture of non-ownership, people increasingly prefer temporary access to resources over permanent ownership of resources – which makes the system more efficient in terms of economics and the environment. In urban passenger transportation, carsharing is already widely used and convinces more and more customers in terms of car-flexibility (i.e. selecting the right car for each purpose), lower costs, and less maintenance effort (Shaheen et al. 1998). Hence, a car sharing operator providing an adequate fleet size, fair distribution of cars, as well as sufficient available parking lots for its cars combined with a space shortage for other parkings, make carsharing systems highly attractive for many citizens (Li et al. 2018).

Today, carsharing appears in different types: (1) station-based car sharing, (2) peer-to-peer (P2P) carsharing, and (3) free-floating carsharing (FFCS). The origin of carsharing has been provided by (1), the station-based carsharing, which has a successful history of more than 20 years and is usually operated within a single city. However, the station based carsharing retains one main disadvantage of private cars: the usage is limited to complete round trips and the car cannot be used by someone else during the time at destination. This makes trips with longer duration at destination, such as commuting, rather unattractive. Returning the car is only possible at the same location as the rental has been started. This makes it similar to conventional car rental, but with a facilitated access to the car without personal contact. Hence, this type of carsharing is well suited if a carsharing station is located nearby and the user either drives rather seldom (so the car can be used by others in-between) or duration at the destination is short. Another, more recent carsharing type is (2), the P2P carsharing, where private owners of cars offer the temporary usage of their own private car to others, typically facilitated by an internet platform (cf. Shaheen et al. 2019).

In the following, we focus on (3) the FFCS, i.e. a commercial fleet of cars, which is made available to users by a service provider within a dedicated area. While the users can use the cars also outside of this area, they have to return the car to an arbitrary official parking place within the dedicated area. The usage is charged on an hourly (or distance-based) tariff. Rental, accessing the car, and payment is facilitated by a smartphone application. FFCS is more dynamic and spontaneous, as one does not know in advance where to find a car. It allows one-way usages and is, consequently, more similar to the use of taxi services. FFCS has been on the market for almost 10 years and is mainly provided by automotive companies and rental car companies.

Carsharing, in general, has seen double-digit growth over the last few years (Deloitte 2017). In Europe, the number of carsharing users has grown from 200,000 in 2006 to 6.76 million in 2018 (Shaheen and Cohen 2020). FFCS showed a fast development. Car2go, part of Daimler, launched the first FFCS service in Ulm, Germany, not before 2008 (car2go 2017; Shaheen et al. 2009). A few years later, in 2011, BMW started its FFCS service DriveNow in Munich and in Berlin (Kopp et al. 2015). Since then, the use of FFCS systems has grown rapidly in urban areas in the past years and both companies increased their number of users considerably. In January 2018, car2go was offered in 26 cities (8 different countries) all over the world and passed the number of 3 million users (car2go 2018). In 2018 DriveNow and car2go merged to SHARE NOW, the largest FFCS service provider worldwide. Following the merger, SHARE NOW announced it planned to withdraw its fleet from all North American and several European cities. This leads to a condensed fleet in 16 cities and 8 countries in Europe, serving over 3 million users (SHARE NOW 2020). In the literature FFCS has been already analysed from different perspectives and for different locations and by different methods (cf. Section 2). However, there has been no paper examining the impact on the car fleet across different European cities at one point in time. Consequently, the objective of this paper is to analyse (differences in) FFCS services impacts on private car registrations in European cities and to characterise car sales[1] by FFCS users. The following research questions (RQ) are analysed:

> RQ1: How do FFCS services affect the number of private cars in cities and are there differences between European cities?
>
> RQ2: What are the main reasons for FFCS users reducing the number of private cars?

Consequently our research is focused on the change in fleet-sizes of FFCS users. These users – due to the new mobility option – may (a) reduce the number of their cars, (b) avoid or postpone purchasing a new car, or – less likely – (c) increase the number of cars. The latter case (c) might happen if a person who did not own a car previously became convinced of the convenience of owning a car after using the FFCS service. As a basis for our research SHARE NOW provided us exclusive access to their about 278,600 active FFCS users in the 11 European cities analysed. Further details on the survey and some first insights of our analysis are also given in Fromm et al. (2019).

The paper is structured as follows: Section 2 gives an overview of the literature and Section 3 describes the methods applied and the data processing. In Section 4 results are presented before Section 5 discusses the results and corresponding methods applied. Section 6 concludes our contribution.

2 Related Work

Different methodological approaches have been applied to analyse FFCS services. Most literature presents descriptive analysis from surveys with FFCS users and corresponding analyses of stated preferences (Martin and Shaheen 2016; Martin et al. 2010; Le Vine and Polak 2019; Giesel and Nobis 2016; Becker et al. 2017; Firnkorn 2012; Baptista et al. 2014; BMUB 2016; Riegler et al. 2016). Furthermore, logistic regression is used to characterise FFCS users (Giesel and Nobis 2016; Yoon et al. 2017; Namazu et al. 2018). Besides these survey based (i.e. user focused) studies, FFCS usage is also analysed based on operational usage data of carsharing operators (Schmöller et al. 2015; Kopp et al. 2015; Kortum et al. 2016; Ampudia-Renuncio et al. 2019). Münzel et al. (2019) explain carsharing supply across Western European cities based on data with city characteristics from international or national statistical databases for different carsharing systems. Sprei et al. (2019) analyse FFCS usage based on booking data from 12 cities finding that FFCS services are mainly used for shorter trips with a median rental time of 27 minutes and actual driving time closer to 15 minutes. A third source of data is coming from traffic simulation as shown by Balac et al. (2019), who conducted a multi-agent transport simulation (MATSim) in Zurich, Switzerland, to investigate how FFCS providers affect each other in a competitive market.

Firnkorn and Müller (2011) were the first who analysed the potential impact of FFCS on the number of cars. Their study focused on the first FFCS fleet in Ulm, Germany. Other studies focused on London (Le Vine and Polak 2017), Basel (Becker et al. 2017 and 2018), Munich (BMUB 2016), Berlin (Giesel and Nobis 2016), Stuttgart, Cologne, and Frankfurt (Hülsmann et al. 2018) as well as different cities in the US and Canada (Martin and Shaheen 2016). Becker et al. (2018) did a comprehensive analysis by using a panel survey and GPS tracking. The analysis of the impact on the car fleet is derived from a statistical regression analysis.

One of the challenges carsharing providers are facing is to ensure high availability of their vehicles while keeping the number of vehicles low in order to increase profitability. To investigate the attractiveness of two different fleet management mechanisms, Wu et al. (2019) did a stated choice

[1] In this study we use the word sold as a synonym for getting rid of (e.g. selling a car, scrapping a car, …)

survey with carsharing users in London, UK. The results show that in particular users who are in their 30s and can be characterised as "conscientiousness" are willing to pay more for the guaranteed advanced reservation option than paying less for the virtual queuing alternative. They do not want to take the risk of having a longer waiting and walking time in order to get a car. They also found out that users find it more burdensome to wait for the FFCS-vehicle than for buses or app-based taxis since they are more accustomed to wait for the latter.

Several studies have already analysed the effects of station-based carsharing service offerings on private car ownership. E.g. an analysis of City CarShare operating in the San Francisco Bay area show that two years after introduction nearly 30% of the members have gotten rid of one or more cars (Cervero and Tsai 2003). Millard-Ball et al. (2005) provide an overview on studies with empirical evidence of the effects of carsharing on car ownership. On average, 21% of members give up a car after joining a carsharing program (North America 21%, Europe 22%). Some studies also count stated avoided car purchases, which usually overstates the overall impacts. On average, 34% of members state that they have avoided buying a car due to the carsharing service. According to Schreier et al. (2018) each station-based carsharing car in Bremen replaces or avoids 16 private cars. Similarly, 20% of the Dutch population indicated that they may forego a planned purchase or sell a current car, if a nearby carsharing becomes available (Liao et al. 2018). Martin et al. (2010) observe a reduction of car ownership by carsharing members in North America. The average number of cars per household drops from 0.47 to 0.24, i.e. between nine and 13 cars are taken off the road for each carsharing car. Most of these shifts are constituted by one-car households becoming car-free.

For North America, Martin and Shaheen (2016) analyse impacts of car2go on car ownership of car2go users actively using the service (at least once per month) in five different North American cities in which car2go had been operating for at least 3 years (Calgary, San Diego, Seattle, Washington D.C., Vancouver). They show that 2% to 5% of the car2go users sold their car due to the availability of car2go's FFCS service. They show that 7% to 10% of respondents did not acquire a new car because of car2go. Even if these percentages seem to be small, the impact becomes evident when relating the overall number of private cars reduced to the number of car2go cars operating in the cities under consideration: each car2go car replaces one to three private cars, and four to nine stated car purchases were avoided for each car operating. This accumulates to an overall number of 28,000 cars in the five cities. Le Vine and Polak (2019) investigate a FFCS service in London three months after the service had been launched. This study shows that 11% of the users indicated that they sold their private car as a response to the FFCS service while 6% indicated that they plan to sell their car within the next three months. Notably, 30% of the users indicated that during the three months prior to the survey, they did not purchase a car that they otherwise would have purchased.

Recently, there are more studies aiming to find out the potential of electric vehicles in carsharing systems. By creating two alternative scenarios in the city of Lisbon, Baptista et al. (2014) found out that a change of the drive technology to hybrid/fully electric vehicles would lead to a reduction of the energy consumption by up to 47% and a corresponding reduction of CO_2 emissions by up to 65%. Ferrari Luna et al. (2019) conducted a simulation-based approach in the city of Fortaleza, Brazil, in order to investigate the impact of an e-carsharing scheme in carbon emissions and electric vehicle adoption. By reducing the number of conventional cars and increasing the number of electric vehicles in the carsharing fleet, awareness of people regarding electric vehicles can be raised, boosting the diffusion process in society and taking an important role in the reduction of CO_2 emissions and the improvement of urban mobility. On the contrary, Hülsmann et al. (2018) show that in Stuttgart, Cologne, and Frankfurt that each car2go car replaces only between 0.3 to 0.8 private cars – which leads consequently in an increasing urban vehicle stock.

Empirical findings on the characteristics of people who sell cars due to FFCS are scarce. FFCS users might be willing to sell their cars if they want to reduce the fixed costs associated with car ownership. First analyses show that the typical users of FFCS have similar characteristics like the users of station-based carsharing (Cervero and Tsai 2003). It attracts young people, people who have a high educational level (Münzel et al. 2019), high incomes (Loose and Nehrke 2018; Hülsmann et al. 2018) and people that live in small households (Giesel and Nobis 2016; Schmöller et al. 2015). In contrast to station-based carsharing (cf. Carroll et al. 2017), the users of FFCS use the system also for commuting and the trips are on average shorter than trips made with station-based carsharing (Ciari et al. 2014). According to Becker et al. (2017) the users of FFCS have on average a higher income and use the carsharing service more frequently compared to station-based carsharing users. According to Hülsmann et al. (2018) there is an above-average number of customers without cars among FFCS users and the personal endowment with bicycles and commutation tickets is above-average.

When it comes to main influences for these sales due to FFCS, a convincing service quality, overall mobility cost reductions, environmental aspects, limited parking space and the change of working/living location as well as a high usage frequency are already identified by the German Federal Minister for the Environment, Nature Conservation, and Nuclear Safety (BMUB 2016). Furthermore, the availability of convenient alternative transport modes have an impact (Ampudia-Renuncio et al. 2019) as well as the membership of other carsharing services increases the probability to decrease the car fleet of an household (Loose and Nehrke 2018). According to Le Vine and Polak (2019), highly educated people with high incomes tend to neither selling nor disposing vehicles. Similarly, rather young carsharing users might postpone or even avoid car ownership (Liao et al. 2018).

Overall, the results of the previous studies show that successfully introducing FFCS services effects car ownership substantially. As European cities have not yet been analysed to the same extent and simultaneously, we expect that users will replace even more cars than in the United States (cf. Martin and Shaheen 2016) due to the well-developed public transportation systems and the higher population density. Moreover, at the time when the study was carried out, the FFCS service analysed has been operating longer in the European cities this study is focusing on.

3 Survey and data analysis

In the following, we give an outline of applied methods. Section 3.1 outlines the specifications of the survey in the European cities while Section 3.2 gives insights in the data analysis, i.e. descriptive statistics and the logistic regression.

3.1 Survey design and data collection

In order to provide an answer to the research questions, a survey was developed and conducted with FFCS users in 11 European cities. The questionnaire of Martin and Shaheen (2016) was slightly adjusted according to the European context (i.e. mainly adjustments of wording, metric system, company names etc.) in order to assure comparability of results. The first survey responses were collected in cooperation with car2go during March and April 2018 for the six European cities Amsterdam, Berlin, Hamburg, Madrid, Rome, and Vienna. The survey was online for 14 days in each city. After the two providers car2go and DriveNow merged into SHARE NOW, a second survey was conducted in summer 2019 in the five European cities Brussels, Copenhagen, Helsinki, Lisbon, and London.

In both cases, a link to the questionnaire was sent out by e-mail to all active (between 5000 and 40,000) members in the selected cities. Members were considered active if they had made at least one trip with a SHARE NOW car within the last 91 days before the survey started[2]. Inactive or less active members are ignored in the analysis, since carsharing membership is not expected to influence their overall mobility behaviour (Martin et al. 2010). Furthermore, only members were included in the survey who had previously opted-in (or agreed) to receive advertising emails. As an incentive to participate, vouchers with SHARE NOW free minutes and Amazon vouchers were raffled off in every city (cf. Appendix A1).

The survey was divided into five thematic areas (cf. the questionnaire in Appendix A9): General questions, use of SHARE NOW, mobility behaviour, hypothetical questions and demographic data. The participants were asked about their usage behaviour of SHARE NOW, their use of other traffic modes, the cars registered in their households, and about their demographics.

After the survey, the number of completed questionnaires (about 13% of all contacted customers) was reduced by the following criteria. First, uncompleted questionnaires were deleted which reduced our sample by between 10 to 33% depending on the city. For the sake of data quality, a minimum response time of 5 minutes per answer is set. Furthermore, completed questionnaires with incorrect answers to control questions (e.g. Questions 20, 21, 39, and 40, cf. Appendix A9) and with implausible responses were excluded. This content-related implausibility and the consideration of response times ("plausibility check" hereafter) lead to a further reduction of the sample size of between 2 and 9% across the cities. Finally, we removed participants who stated they were living in another city or had relocated their home or work recently and stated that their relocation had a significant impact on their change in mobility behaviour. For our logistic regression, we deleted participants without cars before becoming a FFCS user as these users cannot reduce their number of cars. These two steps reduced our sample again between 7 and 17% across the cities. Hence, the final sample size represents between 1.6 and 14.3% of the regular FFCS users (cf. Table 1 and Appendix A2).

3.2 Data analysis

Before introducing the logistic regression (cf. RQ2) we shortly give an outline of our approach for estimating the number of replaced cars by FFCS (cf. RQ1) in the following.

3.2.1 Impact of FFCS services on car ownership

For determining the change in numbers of registered cars due to FFCS in the cities considered the following approach was chosen (cf. Figure 1). As already noted, three main effects by FFCS users were measured: whether they (a) reduced the number of their cars, (b) increased the number of their cars, or (c) avoided or postponed purchasing a new car ("*Number of car purchase suppressed*"). All three actions are only considered if the survey participants indicated that their main reason for doing so was because of the FFCS service and if the indicated number of cars in the survey shows the same direction (cf. Appendix A4). While (a) and (b) are real changes in the fleet (the respondents gave numbers of their fleet before and after becoming a member of the FFCS service) these two numbers are seen more reliable than the answers to the question (c) on avoided or postponed purchases. As the latter question is hypothetical the numbers should be interpreted with caution because customers may overestimate their intensions (cf. Jamieson and Bass 1989, Manski 2004, and Loomis 2011). Consequently, we handled these two numbersseparately in the following calculation.

[2] This limit varies depending on the size of the customer population and the potential of the respondents in the respective city. In Berlin, Hamburg, Madrid and Vienna the limit was set to three trips in the last 91 days. In Brussels, Copenhagen, Helsinki, Lisbon, London and Rome it was one trip in the last 91 days. And in Amsterdam the participants had to do at least one trip within the last 182 days.

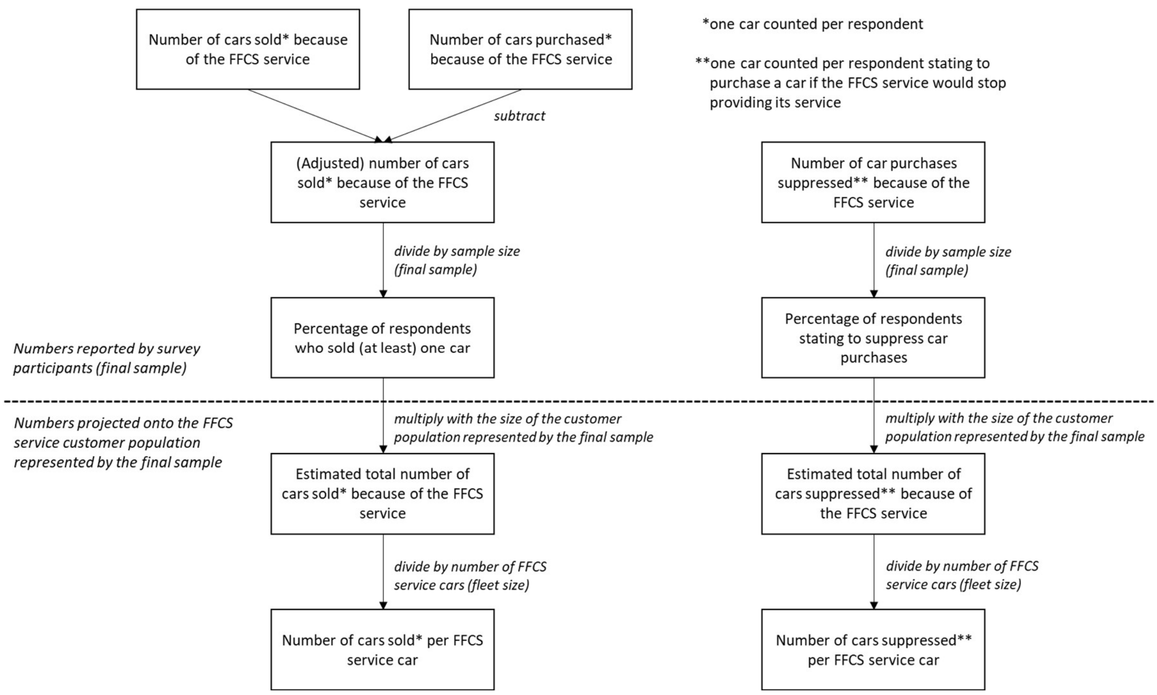

Figure 1: Calculation of the impact on car holdings due to the FFCS service

As a result, we get the share of respondents who stated to have reduced the number of cars and the share of respondents who stated to have suppressed car purchases because of the FFCS service. Now, these percentages are applied to the overall population of FFCS users. In doing so, we multiplied our share with the number of users in the corresponding city which led us to the estimated total number of cars sold (or suppressed) because of the FFCS service. In a final step, these numbers are divided by the number of offered cars by the FFCS provider. Consequently, the number of cars sold (or suppressed) per FFCS car since the start of the service is derived.

3.2.2 Characterisation of persons selling cars due to the FFCS service

The reasons behind FFCS induced vehicle sales are interesting because this is the main leverage for lowering the environmental impact from FFCS (Cohen and Shaheen 2018). For this end, a logistic regression approach is used which determines the probability p of reducing the number of private cars dependent on different user specific (i) characteristics (cf. Equation 1).

$$p_i = \frac{e^{z_i}}{1 + e^{z_i}} = \frac{1}{1 + e^{-z_i}} \tag{1}$$

with

$$\begin{aligned} z_i = \ & \beta_0 + \beta_1 \cdot Children_i + \beta_2 \cdot DurationOfMembership_i + \beta_3 \cdot Bikesharing_i \\ & + \beta_4 \cdot OtherCarsharing_i + \beta_5 \cdot Age_i + \beta_6 \cdot NoOfVehicles_i \\ & + \beta_7 \cdot HouseholdSize_i + \beta_8 \cdot Mileage_i + \beta_8 \cdot Frequency_i + \beta_9 \cdot City_i + \varepsilon \end{aligned} \tag{2}$$

Several variables are taken from the questionnaire. In order to reduce the number of variables and identify the most relevant ones, a forward/backward selection algorithm is applied, which leads to omitting the two variables gender and education (cf. Equation 2). An additional application of the backward and forward selection algorithm alone leads to the same model with an AIC value of 4746.9.(cf. Figure 2). This model includes the following variables: Age group of Children in the household (*Children*), time being a SHARE NOW customer (*DurationOfMembership*), use of bikesharing (*Bikesharing*), use of other carsharing (*OtherCarsharing*), age group (*Age*), number of cars before using SHARE NOW (*NoOfVehicles*), number of members of the household (*HouseholdSize*), use of SHARE NOW per month in km (*Mileage*), use frequency of SHARE NOW

(*Frequency*), and city (*City*) (cf. Appendix A6). Of the ten variables in the final model, one is cardinal, five are ordinal and four are nominal.

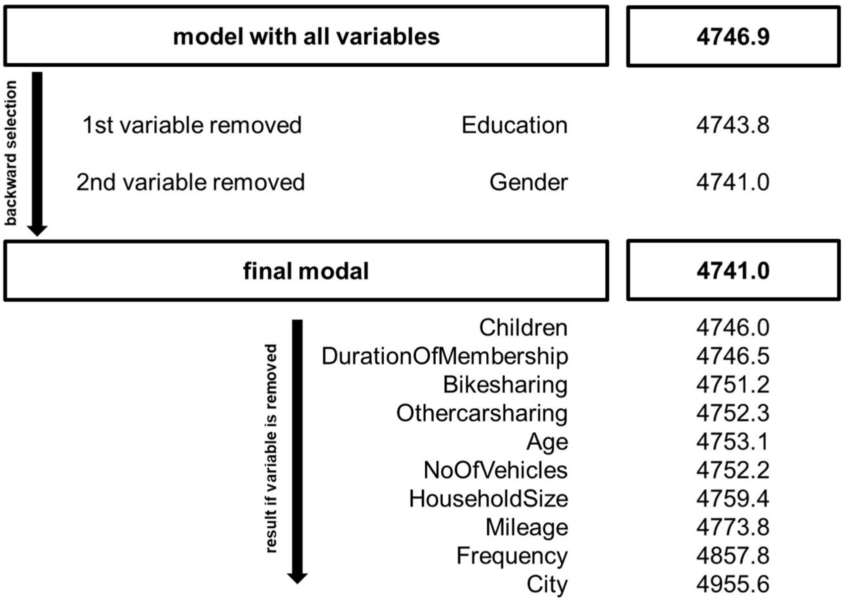

Figure 2: Models of the Backward and Forward/Backward Selection algorithms with their corresponding AIC values

Before starting the regression, we tested all included variables for multicollinearity (cf. Appendix A5 and A7). In order to detect collinearity in the data, two approaches are used. The first one is the utilisation of the generalised variance inflation factor (GVIF). Here, the variables *Children* (1.59) and *HouseholdSize* (1.51) had the highest values. The second approach is the use of correlation coefficients. The correlation coefficients which are used are Spearman's rank correlation coefficient and Kendall's tau. The highest correlation was found between the variables *Mileage* and *Frequency* with values of 0.375 (Kendall) and 0.44 (Spearman). Accordingly, the logistic regression was executed as intended.

4 Results

First, a descriptive analysis of the sample is given before the results of the logistic regression are presented.

4.1 Sample description

Overall, there are 12,790 completed questionnaires in our sample. Due to our plausibility (too short response times and implausible answers to our control questions) and residential check this number reduced to a final sample of 10,596 questionnaires, i.e. from 258 questionnaires for Amsterdam up to 1691 for Madrid (cf. Table 1). The number of regular users (N) represents the reference population in the different markets.

Table 1: Number of observations in the city specific samples

	City	Number of regular users (N)	Question-naires completed	Reduced sample (after plausibility check)	Final sample (after residential check) (n)	Share of regular users (n/N)
car2go	**Amsterdam**	16,486	341	311	258	1.6%
	Berlin	53,714	1339	1280	1127	2.1%
	Hamburg	42,995	1193	1151	1001	2.3%
	Madrid	31,550	2065	1985	1691	5.4%
	Rome	35,912	1505	1444	1224	3.4%
	Vienna	26,286	867	800	699	2.7%
	Total	**209,943**	**7310**	**6971**	**6000**	**2.9%**
DriveNow	**Brussels**	10,665	1090	1044	922	8.6%
	Copenhagen	30,136	1025	970	893	3.0%
	Helsinki	5696	912	860	738	13.0%
	Lisbon	9557	1680	1641	1369	14.3%
	London	12,622	773	727	674	5.3%
	Total	**68,676**	**5480**	**5242**	**4596**	**6.7%**

Concerning the representativeness of the study, the sample shows typical characteristics of carsharing users. In accordance with the data from the FFCS provider, the majority of the participants of our survey is male (range between 61% in Madrid and 84.9% in Lisbon), young, and has a high level of education. However, the age group of 20-29 is somewhat underrepresented in all of the city-specific samples and older participants are slightly overrepresented. While these characteristics show very similar distributions for all cities, other characteristics differ significantly. While the percentage of bike sharing members is high in Helsinki (51.8%), Hamburg (46%), Lisbon (39.1%), and Brussels (38.7%), it is rather low in Amsterdam (9%) and Copenhagen (10.8%). Also the usage frequency of other carsharing services differs significantly, i.e. from Madrid (83%) to Helsinki (24.1%). Not surprisingly, we measured a difference in household sizes: In the Southern European cities of Lisbon (45.7%) and Madrid (46.5%), more participants are living in households with two or more people than in the other cities where this share is only 30.8% in average. Also for the usage frequencies and mileage differences between our sample and the population of FFCS users can be observed. In Amsterdam, Brussels, Copenhagen, Helsinki, Lisbon, and London users extensively using SHARE NOW are underrepresented. In Rome and Madrid, however, these users are overrepresented (cf. Appendix A3). In Berlin, Hamburg and Vienna no such differences is identified. Nevertheless, we assume that our samples are roughly representative of the populations regularly using FFCS services in these cities.

4.2 Description of results

In the following, the impacts on the car fleet (cf. RQ1) and the results with the main reasons of selling a private car due to the FFCS service (RQ2) are presented.

4.2.1 Impacts on car ownership

Our approach for estimating the impact of FFCS services on the number of cars in the city (cf. Figure 1) leads to the following results (Table 2). Overall, it is indicated that the availability of FFCS services reduce the number of cars throughout all cities (a one-sided Mann-Whitney U test confirmed statistically significant differences). Not surprisingly, the reported number of sold cars due to FFCS service is much higher than the number of acquired cars. Throughout all cities, only 2.3% or less of the participants reported that they had acquired a car because of the FFCS service. Across almost all cities the share of survey participants selling a car ranges between 3.6% and 16.0%. While the lowest percentage of people selling a car is found in Madrid, the highest is shown in Brussels. On average between 2.1 and 5.3 users per FFCS car indicate having sold a car. Madrid and Lisbon have the lowest share, Brussels again the highest.

Table 2: Summary of impacts on car holdings from FFCS

	City	Percentage of participants who sold a car	Cars sold per FFCS car[1]	Percentage of participants who suppressed a car purchase	Cars suppressed per FFCS car[2]
car2go	**Amsterdam** (n = 258, N = 16,486)	8.1%	3.4	24.8%	10.3
car2go	**Berlin** (n = 1127, N = 53,714)	10.0%	4.6	24.8%	11.3
car2go	**Hamburg** (n = 1001, N = 42,995)	8.7%	4.0	29.4%	13.4
car2go	**Madrid** (n = 1691, N = 31,550)	3.6%	2.1	14.3%	8.4
car2go	**Rome** (n = 1224, N = 35,912)	7.8%	3.8	29.4%	14.4
car2go	**Vienna** (n = 699, N = 26,286)	10.0%	3.3	23.2%	7.7
DriveNow	**Brussels** (n = 922, N = 10,665)	16.1%	5.3	26.1%	8.6
DriveNow	**Copenhagen** (n = 893, N = 30,136)	4.9%	3.2	28.6%	18.6
DriveNow	**Helsinki** (n = 738, N = 5696)	8.7%	2.9	27.2%	9.0
DriveNow	**Lisbon** (n = 1369, N = 9557)	5.3%	2.1	26.1%	10.4
DriveNow	**London** (n = 674, N = 12,622)	7.4%	2.4	40.7%	13.3
	Average (weighted)	7.8%	3.3	25.8%	11.4

[1] real car sale [2] hypothetical car

Regarding the number of suppressed car purchases, Copenhagen has the highest rate with 18.6 suppressions per FFCS car. With a value of 7.7 the rate in Vienna is less than half as high as in Copenhagen. But also London shows a high value of 13.3 suppressed cars per FFCS car. Not surprisingly, these figures for suppressed cars show high rates and should be interpreted with caution as these are based on responses of hypothetical questions.

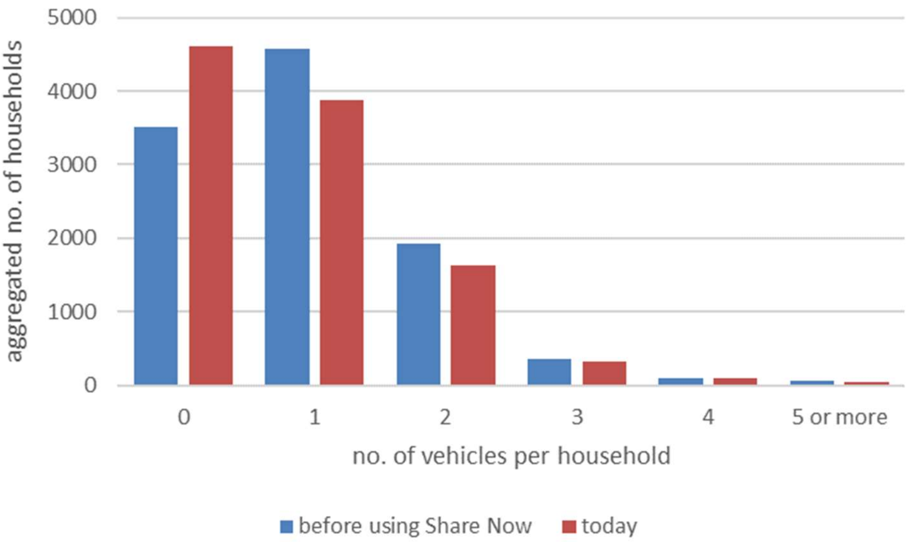

Figure 3: Number of cars per household before and after joining the FFCS service

When comparing the number of cars in each household before and after a household member subscribes to the FFCS service, it becomes obvious that there is a significant increase in the number of households without any car and all other segments are decreasing (cf. Figure 3), which indicates the overall decrease in all fleets for all segments. The share of households without cars in our sample is highest in Amsterdam (55%), London (52.1%), Copenhagen (51.8%), and Helsinki (49.6%), even before they have started using the FFCS service. These percentages are significantly lower in Southern European cities (Lisbon: 13.7%, Madrid: 30.2%, and Rome: 14.5%). The average number of cars per household after having introduced the FFCS service, ranges between 0.35 (London) and 0.72 (Brussels) cars per household in all cities not located in Southern Europe. The sharpest drop in the number of cars is observed in Brussels where the participants initially owned on average 1.0 car per household and reduced this number to 0.72 cars after joining the FFCS service. In contrast, the three Southern European cities show unchanged high levels (Madrid: 0.94; Rome: 1.32; Lisbon: 1.53 after joining the FFCS service).

4.2.2 Identifying main factors for car sales due to the availability of FFCS services

In the following, the results of the logistic model are presented. The final sample size consists of 7073 survey participants. 879 of them sold cars due to the FFCS service. Most of the estimates in the binary logistic regression analysis confirm the hypotheses from the literature (Table 3). The three pseudo R^2 measures represent comparatively low values of around 0.1. Nevertheless, we consider the model as acceptable.

As expected, the number of cars shows a significant positive impact, i.e. the more cars exist in a household, the higher the probability to reduce the number of cars due to the FFCS service is. The dummy variables of *HouseholdSize* are significant, too and indicate that households with fewer members are more likely to sell their car. In contrast, the results for the variable *Children* contradict our hypothesis that households with young children as the parameters for families with young children do not significantly differ from households without children. Only families with older children show a significant positive impact here. The likelihood of users selling their cars increases with their age. At least users aging between 40 and 69 are more likely to sell cars compared to young customers below 20. However, it should be noted that the significance levels of the variables are comparably low.

If users use bikesharing services or other carsharing services in addition to the FFCS service, it is more likely that they sell a car. The impacts of both variables to the predicted outcome are on a similar level, as their beta values as well as corresponding odds ratios show. However, the beta values are the lowest of the significant variables of the model. Also, the mileage driven with carsharing cars has a positive impact on the probability to sell a car. Especially the high (and significant) beta value for users travelling more than 40 km per month with carsharing cars shows that this variable has a high effect on the dependent variable.

Table 3: Logistic regression analysis results

	beta	SE	Wald test (z)	odds ratio	p-value	
(Intercept)	-7.54	0.77	-9.83	0.00	0.0000	***
Children						
children younger than 6 years old	0.23	0.15	1.58	1.26	0.1143	
only children between 6 and 17 years old	0.38	0.13	2.95	1.47	0.0031	**
no children			reference value			
DurationOfMembership						
less than 3 months			reference value			
3 - 6 months	0.38	0.19	2.02	1.47	0.0437	*
7 - 12 months	0.19	0.19	1.03	1.21	0.3035	
1 - 2 years	0.34	0.17	1.99	1.41	0.0469	*
more than 2 years	0.53	0.17	3.09	1.71	0.0020	**
Bikesharing						
yes	0.31	0.09	3.49	1.36	0.0005	***
no			reference value			
OtherCarsharing						
yes	0.33	0.09	3.73	1.39	0.0002	***
no			reference value			
Age						
18 - 19			reference value			
20 - 29	0.55	0.44	1.25	1.74	0.2107	
30 - 39	0.75	0.44	1.69	2.11	0.0902	.
40 - 49	0.97	0.44	2.20	2.63	0.0279	*
50 - 59	0.98	0.44	2.20	2.65	0.0276	*
60 - 69	1.18	0.46	2.56	3.26	0.0105	*
older than 69	1.18	0.56	2.12	3.27	0.0340	*
NoOfVehicles						
no. vehicles	0.23	0.05	4.43	1.26	0.0000	***
HouseholdSize						
1 person	0.60	0.13	4.63	1.83	0.0000	***
2 persons	0.33	0.12	2.75	1.39	0.0059	**
more than 2 persons			reference value			
Mileage						
0 - 5 km			reference value			
6 - 15 km	0.03	0.16	0.21	1.03	0.8338	
16 - 25 km	0.40	0.16	2.42	1.49	0.0154	*
26 - 40 km	0.43	0.17	2.48	1.54	0.0132	*
more than 40 km	0.80	0.18	4.48	2.22	0.0000	***
Frequency						
more than once a day	2.03	0.65	3.14	7.64	0.0017	**
once a day	2.87	0.65	4.41	17.70	0.0000	***
4 - 6 days per week	2.69	0.61	4.39	14.78	0.0000	***
1 - 3 days per week	2.49	0.60	4.16	12.03	0.0000	***
every other week	1.85	0.60	3.10	6.38	0.0019	**
once per month	1.49	0.60	2.48	4.43	0.0132	*
once every 3 months	1.01	0.62	1.64	2.73	0.1019	
once every 6 months			reference value			
City						
Brussels	2.00	0.17	11.75	7.38	0.0000	***
Helsinki	2.01	0.21	9.68	7.49	0.0000	***
Copenhagen	1.38	0.21	6.49	3.97	0.0000	***
Lisbon	0.58	0.19	3.15	1.79	0.0016	**
London	1.41	0.21	6.71	4.08	0.0000	***
Amsterdam	1.64	0.27	6.13	5.15	0.0000	***
Berlin	1.45	0.17	8.53	4.28	0.0000	***
Hamburg	1.07	0.18	6.01	2.91	0.0000	***
Rome	0.43	0.18	2.47	1.54	0.0134	*
Madrid			reference value			
Vienna	1.08	0.19	5.68	2.94	0.0000	***
significance level	' *** ' 0.001 |	' ** ' 0.01	| ' * ' 0.05	| ' . ' 0.1		
goodness of fit	log-like	MacFadden	Cox&Snell	Nagelkerke	AIC	
	4660.9	0.122	0.088	0.166	4741.0	

A similar picture emerges for the frequency of use. The more often a customer uses the carsharing car the more likely he or she gets rid of the own car. Moreover, the regression coefficients and consequently the odds ratios are relatively high. The category "once a day" has the highest values of the whole model. If a customer uses the FFCS once a day, the odds ratio is 17.7%, which means that the probability of car disposal increases by this share compared to non-frequent users. The duration of membership does not show a clear picture but indicates that a longer membership also increases the probability to sell a car. The variable *City* turns out to be the most significant predictor of car disposals. The results thus confirm the high AIC value for this variable from Figure 2. As indicated above, the Southern European cities around Lisbon, Rome and Madrid have the lowest regression coefficients. Individual regressions of each city show that the variables have different degrees of influence on the probability of shedding a car. E.g. the additional bikesharing membership in Brussels and Helsinki has a greater impact on the decision to shed a car than in the other cities.

Concluding, frequency of use and mileage together with the city-specific characteristics have the most severe impact on the car shedding decision of FFCS users.

5 Discussion

As we made several compromises in our study, the results are not uncontroversial and are, therefore, discussed in the following. Furthermore, we give some limitations of the applied method.

5.1 Discussion of results

One surprising result from the regression is that households with small children do not have a significantly higher probability to sell their car even though literature gives strong indications that these families are more car dependent (Prillwitz et al. 2006; Oakil et al. 2014; Sauer 2019). It seems that public transportation also provides a similar convenient option for these families compared to households without children. Families with older children (between age 6 and 17) show in our regression a higher probability to sell their car. We may explain this development from a cohort perspective: families often buy a car because of their first child. Therefore, their car endowment is sufficient and the willingness to sell a car is similar to those without children (even though the car-endowment of the latter is lower). When children grow up, car dependency of the family decreases and the “over-dimensioned” endowment results in higher willingness to sell a car.

Obviously, all our regression coefficients say nothing about causalities. Especially the effects from user frequency and mileage with FFCS cars may rather have the opposite reasoning: If the user sells its car, she or he might use the FFCS service more often and at a higher mileage. Further analysis is required here for identifying individual reasons.

Furthermore, any interpretation of survey data and especially those of hypothetical questions needs to be treated carefully. Surveys asking questions on hypothetical actions tend to overestimate actual decisions (cf. Jamieson and Bass 1989, Manski 2004, and Loomis 2011). One striking singularity in our analysis of car sales is the identified difference between the individual cities. While city specific differences in the results can be partly explained by the city characteristics, the number of replaced cars per FFCS car is additionally dependent on the FFCS fleet size and is in our opinion sometimes veiling other impacts and the traceability. For example, while 41% of FFCS users in London suppressed a car purchase (which is by far the highest value) the replacement rate of 13.3 is only in the midfield due to a relatively large FFCS fleet. City specific characteristics might not only depend on good public transport systems or limited parking space, but also on the importance of the local societal attitude on vehicle ownership and further indirect effects which are hard to measure. When analysing our results some geographical differences can be observed between cities in Northern and Southern Europe. E.g. more participants from the southern cities (Lisbon and Madrid) live in households with more than two persons. This implies that also the number of cars per household is higher there. Nevertheless, the share of participants who have sold a car is lower in the southern cities (Lisbon, Madrid, and Rome). But for suppressed car purchases, no statistical difference is identified. One reason for this might be that in Lisbon and Madrid fewer participants state that the reason for shedding a car was because of "carsharing is sufficient" and in all three southern European cities (i.e. Lisbon, Madrid, and Rome) less participants claimed to do so because of the good public transportation (or cycling infrastructure). Overall, the main reason for shedding a car is cost saving (cf. Appendix A8). Due to larger sample sizes (cf. Table 1), the Southern European cities have a stronger influence on the model results. Comparing the number of replaced car by FFCS vehicle with the results of the sister-study by Martin and Shaheen (2016), it is striking that in the European cities both the number of sold cars and the number of suppressed cars are higher than in the North American cities. Explanations might be the higher population density in European cities (which results in shorter distances), the better public transportation systems as well as the lower motorisation rate in Europe (which indicates a higher experience with other modes). In further studies, a testing of single cities and their specific impact might be analysed. Possible impacts might be the quality of public transport services, the bicycle infrastructure, the general availability of parking space, the population density, regional attitudes, and the existence of driving bans and low emission zones in city centres. These impacts should be taken into account by (transport) policy makers, who intend to reduce the urban car fleet. They may increase the quality of public transport systems and other sharing services, reduce parking space and may focus more on older people and families with older children in order to archive high replacement rates. Furthermore, our results indicate that a high proportion of single-person households, an age above 40 as well as an already high rate of cars per inhabitant or household is a good prerequisite for abolition. It is also promising if many of the inhabitants already use bikesharing or another carsharing service.

5.2 Methodological discussion and limitations

This study is based on a comprehensive questionnaire translated into different languages. Despite careful translation, the different languages might have an influence on the results. The survey data collected is based on subjective, self-reported information. Using survey data from online questionnaires is economic and might hardly be avoidable for our research task, as the widely distributed FFCS service users are the only persons that know how the FFCS service affected their behaviour and especially whether or not the FFCS service was the reason for behavioural changes. Only face-to-face interviews at the customers' homes, or telephone interviews could have been provided additional insights concerning causalities and thus might have improved the quality of the study but at high costs. Personal mall or street intercept surveys seem to be inconvenient for our research questions.

The examination of representativeness showed that, particularly in Copenhagen, young users aged between 20 and 29 years are underrepresented in the samples (cf. Appendix A3). Furthermore, the regression showed that younger people are less likely to get rid of a car than older people. This could have had a positive effect on the figures for car disposals and should be taken into account when considering the results of the analysis. On the other hand, users who drive frequently are underrepresented in all cities. As these drivers tend to shed their private car more often, the number of car disposals might be underestimated. Due to a lack of information, it is not possible to quantify the two effects in the analysis presented here.

The most critical question in the questionnaire is Question 41. It is a hypothetical question on whether the FFCS service users would acquire a car if the FFCS service would stop providing its service. Therefore, the answers of participants in such questions may be subject to a hypothetical bias (cf. Jamieson and Bass 1989, Manski 2004, and Loomis 2011), which suspects that the reported suppressed car purchases are overestimated.

6 Conclusion and future work

Results show that FFCS has an impact on the car ownership of urban citizens living in the eleven European cities regularly using the FFCS service. However, the share of FFCS users having sold cars seems to be rather low. Nevertheless, the number of sold cars still exceeds the number of operating FFCS cars, significantly, hence, the overall number of cars decreased. Between the cities, we observe differences. The rates range from 2.1 sold cars per FFCS car in Madrid and Lisbon to 5.3 per FFCS car in Brussels. FFCS users might realize during the time they have been using the FFCS service that they can reduce their personal fleet because of FFCS. Consequently, the number of stated avoided purchases is considerably higher and shows values between 7.8 (Vienna) to 18.6 (Copenhagen) avoided purchases per FFCS car.

Despite the political relevance, more detailed research with a comparable extent on impacts of FFCS on car ownership is limited. Therefore, besides our results, further research including additional information is necessary. Empirical insights from those cities, where SHARE NOW stopped its service recently might be an interesting option for further research on the replaced private cars by FFCS vehicles. Our findings focus mainly on the usage frequency and mileage of FFCS services, the age of children in the household, the duration of membership, the use of bikesharing and other carsharing services, the age group, the number of cars before becoming a member of FFCS, the size of the household and further city-specific characteristics. These latter may include the scarcity of parking spaces or the quality and accessibility of public transport and other socio-cultural aspects. Hence, these aspects as well as a convincing FFCS service should be considered before introducing this concept to further cities.

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Appendix

A1: Overview of incentives to participate

Incentive	Cities
40 Amazon vouchers with a value of 30€	Amsterdam, Berlin, Hamburg, Madrid, Rome, Vienna
20 vouchers with a total value of 1000 minutes of driving credit	Brussels, Helsinki and Lisbon
One voucher with a value of 50DKK driving credit	Copenhagen
5 vouchers of £30, 5 of £15 and 10 of £10 driving credit	London

A2: Overview on sample reduction

	Brussels	Copenhagen	Helsinki	Lisbon	London	Total DN	Amsterdam	Berlin	Hamburg	Madrid	Rome	Vienna	Total c2g
No. of customers	**10,665**	**30,136**	**5696**	**9557**	**12,622**	**68,676**	**16,486**	**53,714**	**42,995**	**31,550**	**35,912**	**26,286**	**209,943**
No. of people who opted out	1737	22047	668	472	2738	27618							
No. of people who received the survey link	**8928**	**8089**	**5028**	**9085**	**9884**	**41,058**							
Percentage of members opted-in for advertising e-mails	*83.71%*	*26.84%*	*88.27%*	*95.06%*	*78.31%*	*59.79%*							
No. of people who didn't respond	7583	6917	4020	6982	8889	34435							
No. of received questionnaires	**1345**	**1172**	**1008**	**2103**	**995**	**6623**	**476**	**1795**	**1568**	**2806**	**2254**	**1135**	**10,034**
No. of received questionnaires / no of customers	12.6%	3.9%	17.7%	22.0%	7.9%	9.6%	2.9%	3.3%	3.6%	8.9%	6.3%	4.3%	4.8%
Response rate	*15.06%*	*14.49%*	*20.05%*	*23.15%*	*10.07%*	*16.13%*							
No. of uncomplete questionnaires	255	147	96	423	222	1143							
Share of incomplete questionnaires	19.0%	12.5%	9.5%	20.1%	22.3%	17.3%	28.4%	25.4%	23.9%	26.4%	33.2%	23.6%	27.1%
Completed questionnaires	**1090**	**1025**	**912**	**1680**	**773**	**5480**	**341**	**1339**	**1193**	**2065**	**1505**	**867**	**7310**
No. of deleted questionnaires due to responsetime <5 mins	22	35	37	12	41	147							
No. of deleted questionnaires due to response time <5/7 sec for question 12/23	4	6	1	6	3	20							
No. of deleted questionnaires due to incorrect answers to control questions	30	14	14	21	2	81							
No. of questionnaires after plausibility check	**1044**	**970**	**860**	**1641**	**727**	**5242**	**311**	**1280**	**1151**	**1985**	**1444**	**800**	**6971**
Share of deleted questionnaires due to plausibility check	4.2%	5.4%	5.7%	2.3%	6.0%	4.3%	8.8%	4.4%	3.5%	3.9%	4.1%	7.7%	4.6%
No. of reduced questionnaires because customers don't live in the area or they relocated recently	122	77	122	272	53	646							
No. of responses eliminated from the analysis	178	132	174	311	99	894							
Share of deleted questionnaires due to "other area" and "car-less before entering FFCS"	11.7%	7.9%	14.2%	16.6%	7.3%	12.3%	17.0%	12.0%	13.0%	14.8%	15.2%	12.6%	13.9%
Final no. of questionnaires	**922**	**893**	**738**	**1369**	**674**	**4596**	**258**	**1127**	**1001**	**1691**	**1224**	**699**	**6000**

A3: City-specific deviations in the distribution of age class, user frequency, and mileage between the final sample and the population

	Age		Frequency		Mileage	
	Delta	Comment	Delta	Comment	Delta	Comment
Brussels	older	not much	none		less intensive users	people driving more than 25km per month (38.7 vs. 21)
Copenhagen	much older	Especially the people 20-29 are underrepresented (42.0 vs. 26.3)	none	people using it once per month overrepresented	less intensive users	people driving more than 25km per month (41.2 vs. 23.2)
Helsinki	older		none	people using it very often and very rarely are underrepresented	less intensive users	people driving more than 25km per month (38.6 vs. 25.1)
Lisbon	older	people 20-29 and people older than 69 underrepresented	none	people using it very often and very rarely are underrepresented	none	
London	older		none	people using it every other week are overrepresented	none	
Amsterdam	older	young people are underrepresented and especially people 50-59 highly overrepresented	less frequent users		none	people using it very often and very rarely are underrepresented
Berlin	somewhat older	Especially the people 30-39 are underrepresented (37.0 vs. 26.7) but young people <20 are overrepresented (3.5 vs. 1.4)	none	every other week and once per month slightly overrepresented	none	
Hamburg	older	Especially the people 30-39 are underrepresented (35.0 vs. 25.8)	none		none	
Madrid	older		none		more intensive users	especially users driving 16-26km per month (16 vs. 29)
Rome	older	people 20-29 are underrepresented (23.4 vs. 13.4)	none		more intensive users	
Vienna	older		none		none	

Detailed distributions can be requested.

A4: Measuring the impact of FFCS on the number of cars

Assessment of FFCS users selling and purchasing cars due to the availability of FFCS service

A car of a survey participant accounts only as a **sold car** when the following **two conditions** are met. The **first condition** is related to the stated number of cars. This means, the number of cars today must be lower than the number of cars prior being a user of SHARE NOW. Therefore, survey participants were asked in Question 4 to list the number of their current cars available. They were not only asked to list cars they own, but also cars they currently lease. To determine the change in car holdings they were asked to list all cars they possessed (or leased) before using SHARE NOW (Question 7). The two numbers stated by each participant are then compared. If a user reduced or increased the number of cars in that time it does not necessarily mean that the change in cars holdings happened due to the presence of SHARE NOW. The **second condition** for the car sales to count is that SHARE NOW was the reason for the sale. In Question 10 participants were asked whether they sold a car, because of the mobility provided by SHARE NOW. If they stated that SHARE NOW had an impact on car reduction, they were asked in Question 11 to state how important SHARE NOW was for their decision to reduce the number of cars in their household. Car sales are counted if participants then chose one of the first three answers. Car sales of participants that chose answer option 4 ("not important at all") are not counted because SHARE NOW cannot be identified as a reason for selling their cars.

For **acquired cars because of Share Now** the same **two conditions** as for cars sold are used. Cars are only counted as acquired if participants indicate that SHARE NOW was the reason for their purchase. Participants had to answer Question 18 positively ("yes, mainly because of Share Now" or "yes, partly because of Share Now") in combination with a higher number of available cars today than before using Share Now. A conservative approach is made by limiting the number of sold and acquired cars to one car per customer. This conservative approach was also made in other studies concerning the impacts of carsharing on the car feet (Martin and Shaheen 2016).

To determine the **impacts on car ownership**, the number of persons having acquired cars is subtracted from the number of persons having sold cars. With the obtained number the net share of persons having sold cars is calculated.

Assessment of FFCS users hypothetically purchasing cars if FFCS service would disappear

For the number of not purchased cars (avoided cars) the participants were asked the hypothetical question (Question 41) whether they would acquire a car if SHARE NOW stopped offering its service. If they stated on a 4-likert-scale that they would "definitely buy a car" or "probably buy a car" they are counted as participants for whom the presence of Share Now avoids to purchase a car. It is likely that households selling a car due to the presence of SHARE NOW, would need to acquire a car again if Share Now was not offering its service anymore. To avoid double counting in such a case the cars are only counted as sold and not as not purchased. Finally, for the not purchased cars another percentage for the final sample is determined.

With the percentages obtained a projection on the customer population is made. In order to make such a projection, the samples have to be representative for the customer population in the corresponding cities. For the projection the customer population is scaled down proportionally to the reduction from the reduced sample to the final sample. This is done due to the fact that users who do not live in the city or whose relocation is more important than the existence of SHARE NOW for their traveling behaviour, have to be excluded from the population. The projection results in a number of total cars sold and total cars not purchased in the cities because of Share Now. The figures for the respective customer populations were provided by SHARE NOW and collected in July 2019

(DriveNow) and April 2018 (car2go). The numbers regarding the fleet sizes were also provided by Share Now and represent an average value over the year 2018 (DriveNow) and 2017 (car2go).

A5: Formulas of the VIF, Kendall's Tau and Spearman's Rho

Variance inflation factor:

$$VIF_j = \frac{1}{1 - R_j^2} \tag{A2.1}$$

The variance inflation factor measures the extent to which the variance of a regression coefficient increases through collinearity. Since the VIF is not applicable for categorical variables with more than one degree of freedom, it is recommended to use the generalised variance inflation factor (GVIF). It consists of the VIF corrected to the number of degrees of freedom (Fox and Weisberg 2011).

Kendall's Tau:

$$\tau = \frac{(No. of\ concordant\ pairs) - (No. of\ discordant\ pairs)}{n(n-1)/2} \tag{A2.2}$$

Each pair of observations (x_i, y_i) und (x_j, y_j) is concordant if the sorting order by x and by y is correct. This is the case if both $x_i > x_j$ and $y_i > y_j$ or if both $x_i < x_j$ and $y_i > y_j$. The pair of observations are disconcordant if $x_i > x_j$ and $y_i > y_j$ or if $x_i < x_j$ and $y_i > y_j$. A pair is neither concordant nor disconcordant if $x_i = x_j$ or $y_i = y_j$. For Kendall's Tau, a value of 0.8 is considered a high correlation (Backhaus 2018).

Spearman's Rho:

$$r_s = \frac{\sum_n (rg(x_n) - \overline{rg_x})\left(rg(y_n) - \overline{rg_y}\right)}{\sqrt{\sum_n (rg(x_n) - \overline{rg_x})^2}\sqrt{\sum_n \left(rg(y_n) - \overline{rg_y}\right)^2}} = \frac{cov(rg_x, rg_y)}{s_{rg_x} s_{rg_y}} \tag{A2.3}$$

In this equation $rg(x_n)$ describes the rank of x_n, $\overline{rg_x}$ is the mean value of the ranks of x, s_{rg_x} is the standard deviation of the ranks of x and $cov(rg_x, rg_y)$ is the covariance of $rg(x)$ and $rg(y)$.

A6: Overview of model variables

	Variable	Abbreviation	Level of Measurement	Reference Value
	Dependent Variable: no. of sold vehicles	Sold	Nominal (Binary)	-
1	Infant vs. older child in household	Children	Nominal	3: no children
2	time being a shareNOW customer	DurationOfMembership	Ordinal	1: less than 3 months
3	use of bikesharing	Bikesharing	Nominal (Binary)	0: no
4	use of other carsharing services	OtherCarsharing	Nominal (Binary)	0: no
5	age group	Age	Ordinal	1: 18 - 19
6	no. of vehicles before using shareNOW	NoOfVehicles	Cardinal	-
7	size of the household	HouseholdSize	Ordinal	3: more than two people
8	use of shareNOW per month (in km)	Mileage	Ordinal	1: 0 - 5 km
9	use frequency of shareNOW	Frequency	Ordinal	1: once every 6 months or less
10	city	City	Nominal	10: Madrid
11	educational level	Education	Ordinal	3: university degree
12	gender	Gender	Nominal	1: male

A7: Results of the multicollinearity tests

Table A.7.1: GVIF values

Variable	*df*	$GVIF^{(1/2*df)}$	${GVIF^{(1/2*df)}}^2$
Children	1	1.26	1.59
DurationOfMembership	5	1.04	1.08
Bikesharing	1	1.09	1.19
OtherCarsharing	1	1.12	1.25
Age	6	1.04	1.08
NoOfCars	1	1.10	1.22
HouseholdSize	2	1.23	1.51
Mileage	4	1.04	1.08
Frequency	6	1.03	1.07
City	10	1.05	1.11
Education	2	1.06	1.12
Gender	2	1.02	1.05

Table A.7.2: Kendall values

Kendall	DurationOf Membership	Age	NoOfCars	Household Size	Mileage	Frequency	Education
DurationOfMembership	1.000	0.219	0.024	-0.011	0.028	0.008	-0.040
Age	-	1.000	0.096	-0.060	0.071	-0.045	-0.047
NoOfCars	-	-	1.000	-0.234	-0.011	-0.065	-0.053
HouseholdSize	-	-	-	1.000	0.001	0.024	0.023
Mileage	-	-	-	-	1.000	0.375	0.050
Frequency	-	-	-	-	-	1.000	0.045
Education	-	-	-	-	-	-	1.000

Table A.7.3: Spearman values

Spearman	DurationOf Membership	Age	NoOfCars	Household Size	Mileage	Frequency	Education
DurationOfMembership	1.000	0.260	0.030	-0.010	0.030	0.010	-0.040
Age	-	1.000	0.110	-0.070	0.090	-0.050	-0.050
NoOfCars	-	-	1.000	-0.025	-0.010	-0.070	-0.060
HouseholdSize	-	-	-	1.000	0.000	0.030	0.020
Mileage	-	-	-	-	1.000	0.440	0.060
Frequency	-	-	-	-	-	1.000	0.050
Education	-	-	-	-	-	-	1.000

A8: City-specific main three reasons for shedding a car

	No. 1		**No. 2**		**No. 3**	
City	*Reason*	*Mentioned*	*Reason*	*Mentioned*	*Reason*	*Mentioned*
Brussels	CS is sufficient	63%	Costs	62%	Environment	52%
Copen-hagen	CS is sufficient	66%	Costs	50%	Environment	39%
Helsinki	Costs	73%	Good PT	63%	CS is sufficient	56%
Lisbon	Costs	65%	CS is sufficient	50%	Scarce parking	38%
London	Costs	71%	CS is sufficient	61%	Environment	52%
Amsterdam	Costs	70%	Scarce parking	45%	CS is sufficient	43%
Berlin	Costs	68%	CS is sufficient	67%	Good PT	64%
Hamburg	CS is sufficient	70%	Costs	68%	Good PT	59%
Madrid	Costs	72%	CS is sufficient	59%	Scarce parking	50%
Rome	Costs	65%	CS is sufficient	63%	Scarce parking	35%
Vienna	Costs	76%	CS is sufficient	67%	Good PT	62%
		#		#		#
	Costs	8	CS is sufficient	6	Good PT	3
	CS is sufficient	0	Costs	3	Scarce parking	3
					Environment	3

A9: Questions and answer options of the questionnaire

1	How long have you been customer of DriveNow?	less than 3 months 3-6 months 7-12 months 1-2 years 2-3 years longer than 3 years
2	Are you a customer of another car sharing provider* (besides car2go and DriveNow)? *e.g. Zipcar, Enterprise car club, Hiyacar	yes no
3	How often do you use other car sharing providers (besides car2go and DriveNow)?	more than once a day once a day 4-6 days a week 1-3 days a week every few weeks once a month once every 3 months once every 6 months once a year never
4	How many cars do you currently own / lease in your household?* *Please indicate the sum of the vehicles. Your household includes the people you live with and share your income.	0 1 2 3 4 5 or more
5	Please indicate the brand, model, year and fuel type of the vehicle you currently own / lease (e.g. BMW, 1 Series, 2012, P).	Vehicle 1 brand model year fuel type (D = diesel, P = petrol, E = electric, P = plug-in hybrid)
	Please indicate the brand, model, year and fuel type of the vehicle you currently own / lease (e.g. BMW, 1 Series, 2012, P).	Vehicle 2 brand model year fuel type (D = diesel, P = petrol, E = electric, P = plug-in hybrid)

	Please indicate the brand, model, year and fuel type of the vehicle you currently own / lease (e.g. BMW, 1 Series, 2012, P). Name the vehicle you use the most first.	Vehicle 1 (Vehicle 2) (Vehicle 3) (Vehicle 4) (Vehicle 5) brand model year fuel type (D = diesel, P = petrol, E = electric, P = plug-in hybrid)
6	Estimate how many miles you drive annually, on average, with this vehicle which you currently own / lease.	Vehicle 1
	Estimate how many miles you drive annually, on average, with these vehicles which you currently own / lease. Name the vehicle you use the most first.	Vehicle 1 Vehicle 2
	Estimate how many miles you drive annually, on average, with these vehicles which you currently own / lease. Name the vehicle you use the most first.	Vehicle 1 (Vehicle 2) (Vehicle 3) (Vehicle 4) (Vehicle 5)
7	In the year before you joined DriveNow, how many cars did you own / lease in your household?* *Your household includes the people you live with and share your income.	0 1 2 3 4 5 or more
8	Please indicate the brand, model, year and fuel type of the vehicle you owned / leased before you joined DriveNow (i.e. BMW, 1 Series, 2012, P). Name the vehicle you use the most first.	Vehicle 1 (Vehicle 2) (Vehicle 3) (Vehicle 4) (Vehicle 5) brand model year fuel type (D = diesel, P = petrol, E = electric, P = plug-in hybrid)

	Please indicate the brand, model, year and fuel type of the vehicle you owned / leased before you joined DriveNow (i.e. BMW, 1 Series, 2012, P). Name the vehicle you use the most first.	Vehicle 1 (Vehicle 2) (Vehicle 3) (Vehicle 4) (Vehicle 5) brand model year fuel type (D = diesel, P = petrol, E = electric, P = plug-in hybrid)
	Please indicate the brand, model, year and fuel type of the vehicle you owned / leased before you joined DriveNow (i.e. BMW, 1 Series, 2012, P). Name the vehicle you use the most first.	Vehicle 1 (Vehicle 2) (Vehicle 3) (Vehicle 4) (Vehicle 5) brand model year fuel type (D = diesel, P = petrol, E = electric, P = plug-in hybrid)
9	Estimate how many miles you drove annually, on average, with the vehicle you owned / leased before you joined DriveNow.	Vehicle 1
	Estimate how many miles you drove annually, on average, with the vehicles you owned / leased before you joined DriveNow. Name the vehicle you use the most first.	Vehicle 1 Vehicle 2
	Estimate how many miles you drove annually, on average, with the vehicles you owned / leased before you joined DriveNow. Name the vehicle you use the most first.	Vehicle 1 (Vehicle 2) (Vehicle 3) (Vehicle 4) (Vehicle 5)
10	Did you get rid any vehicle/s due to the additional mobility provided by DriveNow?	No, I have not got rid of a vehicle Yes, definitely because of the availability of DriveNow Yes, partly because of the availability of DriveNow Yes, partly because of the availability of DriveNow and other car sharing services (Zipcar, Uber...) Yes, partly because of the availability of DriveNow and the availability of other sharing systems (bike sharing...) I got rid of a vehicle but NOT because of DriveNow
11	How important was DriveNow to the decision to reduce the number of vehicles in your household?	very important important not so important not important at all

12	Why did you reduce the number of vehicles in your household? (multiple answers possible)	environmental concerns car sharing is sufficient for my needs costs scarce parking space car was broken good public transport infrastructure good cycling infrastructure change of family situation job change change of residence
13	Are you planning to buy a new (or used) vehicle in the next 5 years?	yes no maybe
14	Will this vehicle be an additional vehicle or replace another vehicle in your household?	additional vehicle replacement vehicle
15	Since I've been a member of DriveNow, I drive (based on my total driving distance with cars) in total…	much more than before more than before the same as before less than before much less than before I changed my behaviour, but not because of DriveNow / SHARE NOW
16	To what extent has DriveNow contributed to the reduction of your total miles driven?	very strong strong little not at all
17	How important was DriveNow for the increase in your total miles driven?	very important important not so important not important at all
18	Did you buy a vehicle because of DriveNow? (Please choose the answer that works best)	no I did not buy a vehicle yes, and because of DriveNow yes, but not because of DriveNow
19	Why or how did DriveNow influence you when purchasing an additional vehicle?	I liked the DriveNow vehicle, so I wanted to own one I realised that I need my own car. DriveNow was not enough to fulfill my needs. other reason (please explain):

20	In the following paragraph, we ask you some questions about the way you are using DriveNow. How often do you use other car sharing providers (besides DriveNow)?	more than once a day once a day 4-6 days a week 1-3 days a week every few weeks once a month once every 3 months once every 6 months once a year never
21	How many miles do you drive on average per month with DriveNow vehicles?	1-3 miles 3-10 miles 10-15 miles 15-25 miles more than 25 miles
22	If you use DriveNow, how often do you take passengers with you?	every time sometimes seldom never
23	Why do you use DriveNow? (Multiple choices possible)	driving to a restaurant driving to the airport meeting visit friends / relatives going away for the weekend (outside London) commuting to work commuting to school / university In combination with public transport e.g. driving to the station business journeys shopping (food) shopping (other purchases) driving to medical facilities driving to the gym transporting large items other (please describe):
24	The following questions discuss how DriveNow has changed your mobility behaviour. Please select the most appropriate answer. Since I became a DriveNow customer, I use public transport	much more than before more than before the same as before (DriveNow has no influence) less than before much less than before I did not use public transport before and I do not use public transport now I changed my behaviour, but not because of DriveNow

25	Why do you use public transport less frequently? (Choose the reason that works best for your situation)	DriveNow is faster DriveNow is cheaper DriveNow is both faster and cheaper DriveNow makes it easier for me to transport items driving in a DriveNow vehicle feels safer traveling by public transport is often uncomfortable I need mobility at times when there is no public transport public transport is not regular enough the public transport routes do not fit my personal needs I can transport a child other (please explain):
26	Why do you use public transport more often? (Choose the reason that works best)	Public transport is faster Public transport is cheaper Public transport is both faster and cheaper Public transport feels safer DriveNow is not available enough DriveNow does not fit my personal needs other (please explain):
27	Since I have been a customer of DriveNow, I have been using the bus …	much more than before more than before the same as before (DriveNow has no influence) less than before much less than before I have not taken the bus before and I do not take the bus now I changed my behaviour, but not because of DriveNow
28	Since I have been a customer of DriveNow, I use the train on inner-city routes (tram, suburban train, underground) ...	much more than before more than before the same as before (DriveNow has no influence) less than before much less than before I have not taken the train before and I do not take the train now I changed my behaviour, but not because of DriveNow
29	Since I have been a customer of DriveNow, I have been using the train on national routes (National Rail, LNER, Virgin Trains) …	much more than before more than before the same as before (DriveNow has no influence) less than before much less than before I have not taken the train before and I do not take the train now I changed my behaviour, but not because of DriveNow
30	Since I have been a customer of DriveNow, I have been using taxis (black cabs) …	much more than before more than before the same as before (DriveNow has no influence) less than before much less than before I have not used a taxi before and I do not go by taxi now I changed my behaviour, but not because of DriveNow

31	Since I have been a customer of DriveNow, I have been walking…	much more than before more than before the same as before (DriveNow has no influence) less than before much less than before I changed my behaviour, but not because of DriveNow
32	Since I have been a customer of DriveNow, I have been cycling (own bike)…	much more than before more than before the same as before (DriveNow has no influence) less than before much less than before I have not cycled before and I do not cycle now I changed my behaviour, but not because of DriveNow
33	Since I have been a customer of DriveNow, I have been using motorcycles / scooters…	much more than before more than before the same as before (DriveNow has no influence) less than before much less than before I have not used a motorcycle / scooter before and I do not ride a motorcycle / scooter now I changed my behaviour, but not because of DriveNow
34	Since I have been a customer of DriveNow, I have been using other car clubs (e.g. Uber, Zipcar, Enterprise car club)...	much more than before more than before the same as before (DriveNow has no influence) less than before much less than before I have not used other car clubs before and I do not use them now I changed my behaviour, but not because of DriveNow
35	Since I´ve been a customer of DriveNow, I have been car pooling*... *(sharing cars/journeys with other people)	much more than before more than before the same as before (DriveNow has no influence) less than before much less than before I have not car pooled before and I do not do this now I changed my behaviour, but not because of DriveNow
36	Since I joined DriveNow, I am overall making ...	much more trips than before more trips than before about the same number of trips as before (DriveNow has no impact) less trips than before much less trips than before I have changed my behaviour but not because of DriveNow
37	Are you a customer of a bike sharing provider or are you planning to become one? (Mobike, Lime, Ofo etc.)	yes, I joined a bike sharing provider yes, I am planning to join a bike sharing provider have not decided yet/I am still undecided no, I am not a customer and not planning to be one

38	Since you started using DriveNow, have you taken trips with public transport and DriveNow (in combination), which you would have done with a car before?	yes no n/a
39	In the following, we will ask you some hypothetical questions. Please select the answer that is most likely to apply to your situation ... If car sharing providers (including DriveNow and all other operators) suddenly disappeared in London, I would within 12 months ...	definitely buy a car probably buy a car probably not buy a car definitely not buy a car
40	How many cars would you need to buy in your household?	0 1 2 3 4
41	If only DriveNow disappeared from London, in the next 12 months I would …	definitely buy a car probably buy a car probably not buy a car definitely not buy a car
42	Have you moved house or changed where you work since you joined DriveNow?	no yes, I´ve moved house yes, I´ve changed my work place yes, I´ve moved house and changed work place
43	What would you say has had the greatest impact on the change of your driving behaviour. The availability of DriveNow or the change of where you live/work?	Primarily DriveNow To a certain extent more because of DriveNow than my change of residence/workplace both equally Primarily because of moving house/changing where I work my driving behaviour hasn't changed
44	In the last part of the questionnaire, we have some questions that help us clasify the results of the study. Please specify your gender.	male female would prefer not to say
45	Please specify your year of birth	1928 - 2001

46	What is your highest level of education?	less than a high school diploma high school diploma or equivalent bachelor's degree (e.g. BA, BS) master's degree (e.g. MA, MS, MEd) doctorate (e.g. PhD, EdD) other (please specify)
47	Specify the number of members in your household (including yourself) who can be identified within the different age groups.	0-5 years 0 - 1 - 2 - 3 - 4 - more than 4 6-18 years 0 - 1 - 2 - 3 - 4 - more than 4 19-65 years 0 - 1 - 2 - 3 - 4 - more than 4 65 and older 0 - 1 - 2 - 3 - 4 -more than 4
48	What type of building do you currently live in?	detached house semi-detached house apartment building with less than 10 people apartment building with 10 – 100 people apartment building with more than 100 people other (please describe)
49	Which year did you start living in London?	I am not living in London 2019 2018 2017 2016 2015 2014 2013 2012 2011 2010 2009 prior to 2009
50	What is the approximate gross income of your household? Your household includes the people you live with and share your income.	less than £14,999 £15,000 - £24,999 £25,000 - £34,999 £35,000 - £49,999 £50,000 - £74,999 £75,000 - £99,999 £100,000 - £149,999 £150,000 - £199,999 more than £200,000
51	What is your post code?	