Measuring the travel behaviour impact of free-floating car-sharing

Measuring the Travel Behaviour Impact of Free-Floating Car-Sharing

Date of submission: 2016-07-24

Henrik Becker, *Corresponding Author*
IVT, ETH Zürich,
CH-8093 Zürich
phone: +41-44-633 32 79
fax: +41-44-633 10 57
henrik.becker@ivt.baug.ethz.ch

Francesco Ciari
IVT, ETH Zürich,
CH-8093 Zürich
phone: +41-44-633 71 65
fax: +41-44-633 10 57
ciari@ivt.baug.ethz.ch

Kay W. Axhausen
IVT, ETH Zürich,
CH-8093 Zürich
phone: +41-44-633 39 43
fax: +41-44-633 10 57
axhausen@ivt.baug.ethz.ch

Words: 5544 words + 1 figure + 5 tables = 7044 word equivalents

ABSTRACT

Free-floating car-sharing schemes operate without fixed car-sharing stations, ahead reservations or return-trip requirements. Providing fast and convenient motorization, they attract both public transport users and (former) car-owners. Thus, its impact on individual travel behavior depends on the user type. Estimating the travel behavior impact of these novel systems therefore requires quantitative data. Using a two-wave survey approach including travel diaries, this research shows, that free-floating car-sharing substantially reduces private vehicle ownership. The results further indicate, that free-floating car-sharing lets its members use cars less leading to lower energy consumption and CO_2 emissions. Moreover, the results suggest, that free-floating car-sharing both complements and competes with station-based car-sharing.

INTRODUCTION

Since its first implementation in Ulm, Germany, in 2009, free-floating car-sharing has seen a rapid expansion around the globe. Instead of relying on fixed car-sharing stations, free-floating car-sharing schemes usually make use of public parking spaces within a designated, citywide service area. Customers can locate and book the closest available vehicle using a smartphone app. At the end of their trip, they can leave the vehicle on any eligible public parking space. This way, free-floating car-sharing offers flexible one-way trips and therefore overcomes key limitations of classical, station-based car-sharing schemes.

Because free-floating car-sharing schemes need access to public parking space, they are more dependent on the support of local authorities. However, bound by energy efficiency commitments or concerns about a deteriorating traffic situation, most authorities limit the number of parking permissions for free-floating vehicles. Before relaxing those restrictions, they ask for more detailed knowledge about the travel behavior impact of free-floating car-sharing.

Addressing this issue requires new research, because given their structural differences, insights from previous studies on station-based car-sharing may not be easily transferable to free-floating car-sharing. Moreover, first attempts to determine the net effect on travel behavior have failed due to a lack of quantitative data *(1)*.

This paper reports on a new approach, which allows to quantify the travel behavior impact of free-floating car-sharing. The method is applied to a new free-floating car-sharing scheme launched in Basel, Switzerland, in August 2014.

BACKGROUND

The research presented in this paper studies a novel phenomenon using a modern survey technique. In the following, both the subject of this research as well as the methodology are presented.

Free-Floating Car-Sharing

Modern car-sharing dates back to the early 1990s and has seen an exponential growth in both customers and system size since then *(2)*. The schemes offer their customers access to cars on an as-needed-basis. By doing so, they represent a cheap alternative to a private vehicle - especially for households with a relatively low annual mileage *(3)*.

Earlier car-sharing schemes usually operate as station-based schemes: The cars are available at predefined parking spaces (stations) and need to be returned to one of those stations at the end of the trip. Whilst most schemes require the vehicles to be brought back to the start station (round-trip requirement), some of the schemes also permit one-way trips. Le Vine et al. *(4)* suggest, that due to its higher flexibility, one-way car-sharing is both more attractive to customers and less environmentally favorable than round-trip car-sharing.

By lifting the restriction of fixed car-sharing stations and generically allowing one-way trips, free-floating car-sharing is an even more flexible form of car-sharing. First launched in 2009, the number of customers and schemes have skyrocketed in the recent years *(5)*.

Given the novelty of the system, there is not a large corpus of scientific literature dealing with the environmental impact of free-floating car-sharing yet. Whilst early studies expected a significant reduction in car ownership and CO_2 emissions *(6)* due to free-floating car-sharing, the actual impact seems to be more complex as non-car-owners reduce bike, walk and public transit trips, but start to use a (shared) car instead *(7)*. First reports from municipalities having introduced free-floating car-sharing are also ambivalent due to a lack of quantitative data *(1)*. Moreover, the relatively small system size when compared to the number of private vehicles in a city makes it hard to observe impacts on the level of the transport system *(8)*.

Measuring Car-Sharing Impact

The environmental and travel behavior impact of (station-based) car-sharing has been subject to various studies around the globe. Despite different methodological setups, previous studies have consistently found, that whilst a small group of car-sharing members increase their car use, their additional vehicle mileage is more than offset by previous car-owners, who have substantially reduced their car ownership and travel in the course of their car-sharing membership *(9)*. Moreover, it has been pointed out, that the environmental impact exceeds the savings in vehicle miles, because on average, car-sharing vehicles consume significantly less energy than the private vehicles they replace *(9)*.

One of the first comprehensive explorations of the travel behavior impacts of car-sharing was conducted in Switzerland *(10)*. In a survey, respondents were asked to report their travel behavior both at present and retrospectively for the time prior to their car-sharing membership. Lacking any observational data, the study purely relied on respondents' estimates for their current and past vehicle miles travelled with no information about the magnitude of the respective error. Moreover, neglecting any unobserved heterogeneity, all changes in car-ownership and vehicle miles travelled were attributed to the respondents' car-sharing membership likely inflating the actual effect *(11)*. Furthermore, it has to be assumed, that a retrospective survey approach like this prompts recall bias *(12)* particularly affecting estimates of vehicle miles travelled. Despite such severe limitations, similar methodologies have been adopted by most of the later studies *(9, 13–15)*.

Cervero et al. *(16, 17)* were the first to address those limitations. In a longitudinal setting, they administered their survey to a panel in multiple waves to overcome recall bias. Moreover, the survey was complemented by a two-day travel diary increasing the validity of the travel behavior data. Eventually, a control group was supposed to allow isolating the actual impact of car-sharing membership from external effects. However, the control group suffered from self-selection issues probably biasing the results.

Some of the very first data on the impact of free-floating car-sharing have been published by the Seattle Department of Transportation *(1)* citing results of a Car2go member survey. The results indicate a rather small reduction in household vehicle holdings. The impact on mode choice remains unclear given that 40% of the customers claim to use a private car less often, but also 50% of the respondents state to use public transportation less frequently. Lacking any quantitative data on travel behavior, the net impact of free-floating car-sharing is yet to be determined.

Travel Diary Methods

Given that free-floating car-sharing members reduce their use of private cars but also use public transportation less often, a determination of the net impact requires quantitative travel behavior data. As individual travel behavior varies over the course of the week, the travel diary should span multiple days to account for such variation. However, collecting manual trip diaries may lead to imprecise and missing data *(18, 19)*. GPS-loggers would allow to improve data quality, but they come with high administrative cost for the researcher *(20)*. A most recent alternative promising to reduce both the response burden as well as the administrative effort whilst achieving a high data quality is smartphone-based GPS-tracking *(21–24)*. However, due to their novelty, only few surveys have already applied such smartphone-based systems.

METHODOLOGY AND DATA

The methodology used for this research builds upon the approach used by Cervero et al. *(16, 17)* and enhances it by using a more representative control group and a smartphone-based GPS tracking system to collect travel diaries. It uses a panel of two cohorts who were surveyed first directly after the launch of the free-floating car-sharing scheme and again one year after. Part of each survey wave was a week-long travel diary. Whilst one cohort has been drawn from members of free-floating car-sharing scheme, a second cohort was randomly drawn from the local population with driver's license (control group).

Given the expected advantages described above, *Studio Mobilità (25)*, a smartphone-based, passive GPS-tracking system has been used to collect the travel diaries. The system uses prompted recall for a manual imputation of trip mode and purpose by the respondents. In this setup, participants simply download an app on their smartphone, which automatically tracks their daily trips using the built-in GPS-sensor. Although this allows only smartphone-holders to take part in the study, selection-bias effects should be small with a smart-phone market share of 78% *(26)*. Moreover, the study is supposed to compare the travel behavior of free-floating car-sharing members with a control group, which would in principle also be able to use the service. As the free-floating car-sharing service can only be used by smartphone-owners, non-owners are excluded by design.

The chosen setting allows a before-and-after comparison of travel behavior. Moreover, the representative control group allows to isolate the actual impact of free-floating car-sharing.

Since no pre-registration to the free-floating car-sharing scheme was possible, it was impossible to identify members before the launch of the scheme. Therefore, the before-stage of the survey has been carried out shortly after the launch of the scheme. However, it is assumed, that in this short timeframe, no substantial changes in travel behavior have already taken place. This notion is supported by previous research indicating that the main effects of a car-sharing service occur about two years into the operation of that service *(17)*.

Recruitment

In total, 1 218 free-floating members and 6 000 members of the random sample were invited to take part in the study. Whilst address lists of car-sharing members were made available by the operator, surface-mail addresses for the random sample of the local population above legal age were provided by the Cantonal Statistical Office of Basel-Stadt.

Each survey wave consisted of two parts. The first was a questionnaire about socio-demographic attributes as well as the general mobility behavior, whereas the second part was a week-long travel diary using the system *Studio Mobilità*. Respondents were asked to complete in the questionnaire by the end of the week of receipt and to keep the diary the week after. Details and instructions concerning the travel diary were given at the end of the questionnaire.

Both cohorts were provided with a dedicated questionnaire. Whilst the car-sharing members were recruited via e-mail and were able to access the web-based survey using personalized web-links, members of the control group received the survey in pencil-and-paper-format via surface mail including a reply-paid envelope. Due to company policy reasons, car-sharing members were only invited to the questionnaire first. Upon completion of the questionnaire, they were automatically invited to take part in the travel diary and were promised a 15 CHF (equivalent to 10 USD at purchasing power parity) credit on their next car-sharing bill. In contrast, members of the control group have received all the necessary information along with the questionnaire. As incentive, they were offered 20 CHF in cash in return for their full participation.

Survey invitations were administered to the respondents in weekly waves between October and December 2014 and again between October and December 2015. In the last week, reminders were sent out to all those car-sharing members who had failed to complete the survey by then. Respondents, who were overdue in completing their mobility diary, were offered assistance. Moreover, free-floating car-sharing members having joined the service in early 2015 were invited to take the survey in April 2015.

Data acquisition

Respondents needed an average of 18 minutes in the first wave and 15 minutes in the second wave to complete the web-based survey. With this rather short survey time, fatigue effects causing response bias and reducing the likelihood of proceeding to the travel diary were minimized.

Compared to previous surveys *(27)*, the response rates shown in Table 1 were well within the expected range. The slightly higher response rate among free-floating car-sharers may be explained by the fact, that they were contacted on behalf of the service they have recently become member of and can therefore be regarded as pre-recruited.

In contrast, the response rate achieved for the diaries was much lower than expected. From earlier experiences, it was expected, that around 80% of the respondents would proceed to the travel diary after having completed the questionnaire. However, the response rate turned out to be substantially lower. Based on the respondents' feedback and the fact, that almost all dropouts occurred, when respondents had to confirm a data privacy declaration, the authors assume, that this drop in response rate can be attributed partly to data privacy concerns.

Data preparation

Response bias was addressed using three measures: Firstly, only completed questionnaires were considered for the analysis. Secondly, responses from car-sharing members who completed the survey in less than seven minutes (a third of the average time) were excluded. Thirdly, unreasonable answers were identified on a per-question basis (e.g. year of birth before 1900).

TABLE 1 Response rates per participant groups

	free-floating	control group
Invitations sent	1 218	6 000
Surveys completed	366	594
with drivers license	366	447
Response rate of the eligible	37.4%	9.1%
Diaries completed	91	226
Response rate of the eligible	24.9%	50.6%
Valid diaries	37	35
Response rate of the eligible	10.1%	14.5%

For a better comparability, members of the control group, who do not hold a drivers license, were excluded from the analysis.

In order to correct for selection bias concerning gender and age, statistical weights have been applied to the individual responses. The respective marginal distributions were obtained from the address lists provided by the operator as well as the local distributions from the Swiss micro-census *(28)* for the control group. Also the spatial distribution of the home locations has been studied. However, since only minor discrepancies were found, spatial effects were neglected, given the excellent access to public transportation throughout the study area.

Also the records from the travel diaries were carefully prepared for the analysis. In a first step, all responses recording less than three full days per survey period were dropped and only the remaining diaries were regarded as complete. In a second step, respondents who have completed the prompted recall for less than 75% of their trips were also excluded. All remaining travel diaries were then carefully reviewed manually to ensure validity of the records and comparability of the two survey periods (e.g. exclude effects from holidays). As shown in Table 1, only few valid diaries were left after this process. However, the observations allow a deep insight into changes in individual travel behavior induced by free-floating car-sharing.

CAR OWNERSHIP IMPACT

In a first step, data from the surveys has been used to estimate the impact of the free-floating car-sharing scheme on its members' car ownership levels.

It was found, that already from the beginning, free-floating car-sharing members owned substantially fewer cars than the control group (0.27 vs. 0.84 vehicles per household in first survey wave) and this difference is significant ($t = -10.7$). Within the first year of operation of the free-floating car-sharing scheme, both groups slightly decreased their levels of car ownership to 0.24 and 0.83 vehicles per household although those reductions are not statistically significant.

Given that in the first (before) survey wave, 3% of the free-floating car-sharing members stated, that they had planned to buy an additional car, comparing only the actual numbers of cars

may be misleading. Therefore, the anticipated number of cars was introduced as a new reference. The anticipated number of cars is based on the actual number of cars in the first wave to which one car was added or substracted in case the member stated plans to buy or sell a car within twelve months from the first survey wave. Anticipated car ownership averaged at 0.29 vehicles per free-floating car-sharing household and at 0.80 vehicles per control group household. Again, the within-group differences between anticipated and second-wave car-ownership levels are not significant.

Using a difference-in-differences approach, the change in car ownership levels of the free-floating car-sharing households can be compared to the control group. Whilst no significant effect was found comparing the second-wave level to the actual first-wave level of car ownership, making use of the anticipated level of car ownership yields a significant difference in differences ($t = -2.34$). Using anticipated car-ownership as a reference, free-floating car-sharing members have therefore decreased their level of car ownership compared to the control group by 0.07 vehicles per household.

However, a simple comparison of the group means does not necessarily reveal the true impact of a free-floating car-sharing membership, because the observed changes may also be due to changes in other, e.g. socio-demographic characteristics. In order to correct for such influences, three covariates which are expected to have an impact on vehicle ownership were added to the model *(29)*. As shown in Table 2, when controlling for household income, GA travelcard holdership (a subscription allowing for unlimited use of public transportation across Switzerland) and home location (city center vs. agglomeration), the difference in differences is significant for both reference cases: Free-floating car-sharing members reduced their level of car ownership by 0.08 cars compared to their actual before-level (significant at the 10% level) and by even 0.13 cars compared to their anticipated level (significant at the 1% level).

Both models presented in Table 2 consistently indicate, that free-floating car-sharing members reduce their level of car ownerhip compared to the control group. Yet, the first model ignores initial intentions towards a change in the level of car ownership, the second model assumes that there are no deviations from those initially stated intentions. In order to overcome the limitations of the two models, a simple population-averaged poisson model for the actual level of car ownership has been estimated.

The results of this model are given in Table 3. In order to improve efficiency, some covariates from the difference-in-differences models were dropped and replaced by new variables. The model indicates, that university graduates and people living in areas well connected by public transportation own fewer private cars (Transit levels as defined in the Swiss standard SN 640 290. Level A is the highest level of transit connectivity and requires a maximum departure interval of 5 min per main load direction at rail stops in a 500m perimeter). In turn, car ownership increases with household income. The effect of a free-floating car-sharing membership was then estimated separately for the respondents who claimed that they had intentions to buy an additional car and for those, who stated no intentions for a change in car ownership. As a result, members without car plans decreased their level of car ownership by almost 20%, whereas members with car plans substantially expanded their fleet. Thus, free-floating car-sharing generally reduces car ownership, except among those members who have already planned to expand their fleet upon joining.

TABLE 2 Difference-in-Differences Approach for Car Ownership

Reference	actual car ownership		anticipated car ownership	
	Coeff.	t	Coeff.	t
Household income [kCHF]	0.028***	4.55	0.027***	4.45
GA travelcard	-0.195***	-3.58	-0.208***	-3.82
City center home	-0.134***	-2.57	-0.133**	-2.53
Baseline diff.	-0.535***	-9.35	-0.479***	-8.24
Follow-up diff.	-0.614***	-11.41	-0.611***	-11.33
Diff.-in-Diff.	-0.079*	-1.89	-0.132***	-3.06
	$N = 790$		$N = 790$	
	$R^2 = 0.27$		$R^2 = 0.26$	

*Significance codes: 0.10 * 0.05 ** 0.01 ****

TABLE 3 Population-Averaged Poisson Model for Car Ownership

	Coeff.	z
# of cars in household		
University degree	-0.241**	-1.99
Household income [kCHF]	0.033***	2.76
Home at transit level A	-0.422***	-3.49
Free-floating member	-0.218***	-3.80
Free-floating member # car intentions	0.699***	3.66
Time dummy	0.066	1.64
Constant	-0.614***	-11.41
	$N = 790$	
	Wald $\chi^2(6) = 65.47$***	

*Significance codes: 0.10 * 0.05 ** 0.01 ****

USE CASES

The second step consisted of a qualitative analysis of the completed travel diaries to learn more about how free-floating car-sharing is used by its members. To this end, all recorded days containing at least one free-floating car-sharing ride were identified. For each of those observations, a second recorded day with a similar activity chain, but without car-sharing use was looked for to allow a pairwise comparison.

In total, 60 recorded days containing 96 free-floating car-sharing rides were available for the analysis. Only for 17 of the 60 recorded days with car-sharing use, a corresponding trip without car-sharing use could be found for another day. This indicates, that the scheme is mainly

used for non-regular activity patterns. In fact, 17% of the free-floating car-sharing trips were leisure trips and 7% were escort trips. Shopping and errands covered another 11% of the trips each. Regular purposes such as work or education were served by only 13% of the trips. 40% of the trips had their destination home. 21% of the trips occurred at night between 10pm and 6am. Moreover, 25% of the trips started or ended outside the service area, which means, that they are part of a tour including at least one more (return) free-floating trip. In fact, on half of the recorded days, free-floating car-sharing was used for more than one trip.

The 17 car-sharing uses, for which a corresponding record was found, can be clustered into three general types, which are presented in Figure 1.

- Regular user type A is a long-haul commuter. He uses free-floating car-sharing on his commute to or from the train station, when he has to catch an early train or arrives home late. In the example presented in Figure 1, the train runs 40 minutes earlier than usual, which would involve an unfavourable tram connection on the first mile to the train station. 15% of the recorded trips either started or ended at the central train station.
- Regular user type B usually follows a tour with two activities during his day - work and leisure. He uses free-floating car-sharing in case he needs to insert a third activity between the two. In the example presented in Figure 1, he usually commutes by public transportation. However, on one day, he needed to make a stop at home between his work and leisure activity, which probably is, why he uses free-floating car-sharing.
- Regular user type C is an occasional car user replacing his car use by both public transportation and free-floating car-sharing. In the example presented in Figure 1, he usually commutes to work by bike. When there was a need to do shopping on the way home, he usually took the car to work to be able to shop on the way back home. After the launch of the free-floating car-sharing scheme, he continues to commute by bike. But on his shopping-days, he takes public transportation to work and uses free-floating car-sharing to do the shopping on his way home.

Given the low number of observations, the results from this analysis are only qualitative in nature. In particular, the shares of trip purposes or daytimes cannot be assumed to be representative for the overall use of the scheme. Nevertheless, the data allows three interesting insights: First, free-floating car-sharing is mostly used for non-regular trip patterns. Second, if used in a regular trip pattern, it replaces both car and public transport trips with the latter being replaced mostly for early morning, late evening or longer intra-urban trips. Third, none of the free-floating car-sharing members was found to directly substitute active modes or public transport without any further alterations in the trip chain.

MODE SHARE IMPACT

In a third step, the valid diaries (c.f. Table 1) are used to understand, how free-floating car-sharing affects its members' overall mode choice behaviour. Table 4 presents the average distances travelled per weekday by mode. Given the high variation in individual weekend travel behaviour, Saturdays and Sundays as well as public holidays were excluded from the analysis.

To validate the records, the total distance travelled can be compared to the results of the Swiss microcensus 2010 *(28)* for the city of Basel. When excluding long-distance travel, the microcensus reports an average distance travelled of 24.7 km per day (compared to 18 km per day among the control group). Given the small sample size of the travel diaries and the fact, that the microcensus average contains weekend and holiday trips which are usually longer than

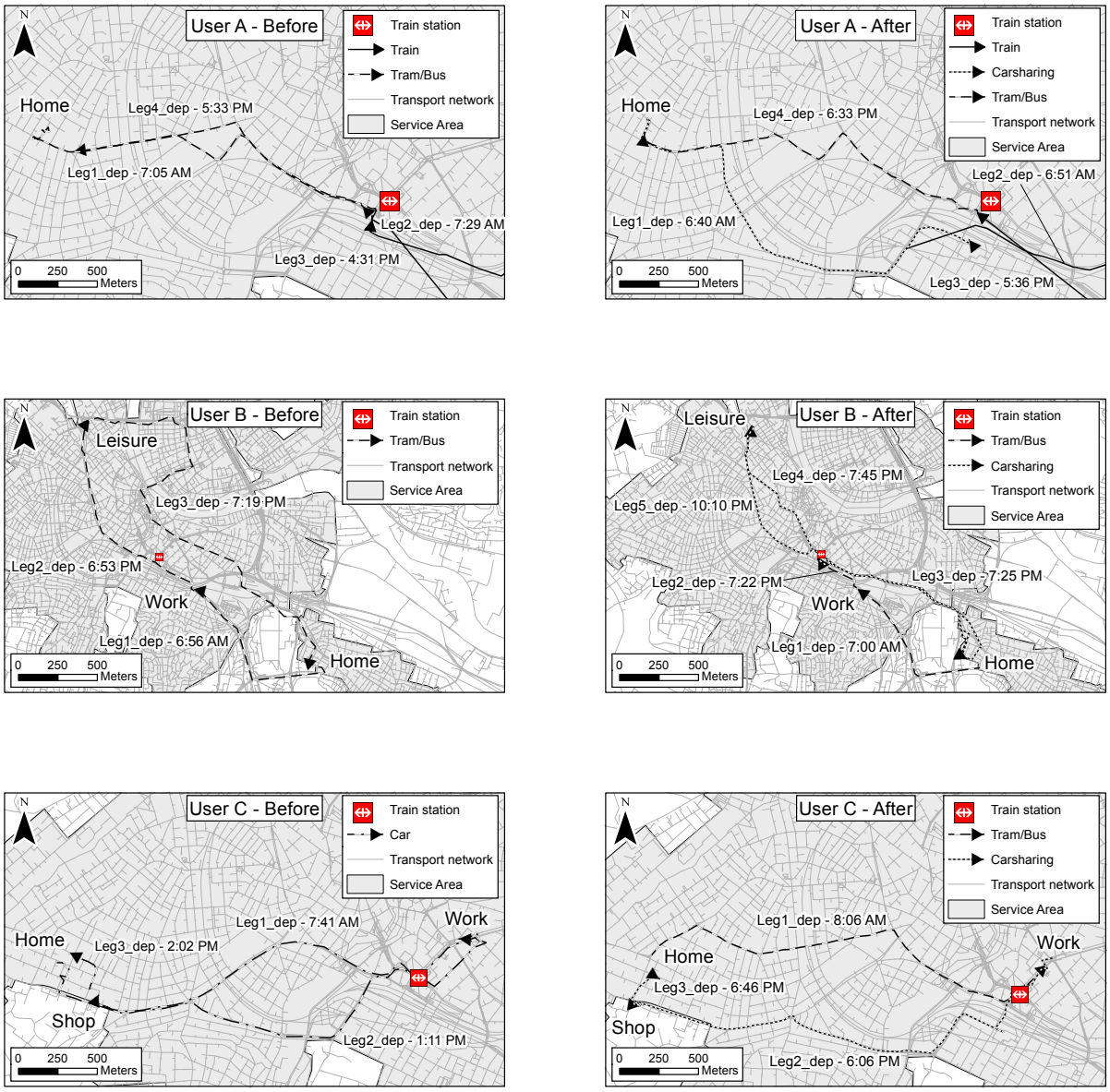

FIGURE 1 Car-Sharing Use for Regular Activities

weekday trips, the results of the travel diaries can be assumed to be in the correct range.

As a first insight, Table 4 shows, that on average, free-floating car-sharing members travel much longer distances per weekday than the control group. This large difference is mainly caused by a significant share of free-floating members commuting long distances by train. In addition, the results show, that free-floating members travel fewer kilometers by car and use public transportation or active modes more often than the control group. However, given the small sample size and large individual variation, none of these differences is statistically significant.

When looking at the time evolution, it can be seen, that whilst the total distances remain constant, the contributions of the single modes change. Whilst the control group decreases its train travel and increases its car use, free-floating members decrease their car travel and use local transit and car-sharing more often. However, it is interesting to note, that the increase in

car-sharing activity is smaller than the parallel decrease in private car use. Again, given the large within-group variation and small sample size, none of the changes are statistically significant.

Since the weather in Basel in fall 2015 (wave 2) and fall 2014 (wave 1) was largely comparable (only minor deviations in precipation, temperature and wind), it is assumed that it did not affect the overall mode choice behaviour. Moreover, only an insignificant share of respondents stated in the first wave, that they intended to change their travel behaviour within the following twelve months. Given that all observations with a home location or job change have already been excluded from the sample, membership in the free-floating car-sharing scheme is assumed to be the only factor causing the observed change in travel behaviour.

Again, a difference-in-difference approach is used to estimate the impact of the free-floating car-sharing membership on travel behaviour. As presented in Table 5, free-floating car-sharing members reduce their car travel and active modes, but increase their use of car-sharing and public transport. Although none of the differences is statistically significant, the results give a first indication of what is happening. In particular, the hypothesis, that free-floating car-sharing induces more car travel (both private and free-floating) can be rejected at the 25% significance level. Since none of the free-floating car-sharing members who have sold their only car, are represented in the valid diaries, the actual effect can be expected to be stronger.

Given the small sample size, the estimation of a population-averaged model to better understand the effect of free-floating car-sharing on vehicle miles travelled is not feasible. Instead, a Wilcoxon rank sum test has been applied. The test confirms the results of the t-tests above by indicating, that the hypothesis, that free-floating car-sharing generates a net increase of car travel can be rejected at the 20% significance level.

In order to calculate the environmental impact, detailed information about the respondents' vehicles (make, model and fuel type) was used to determine the individual energy consumption and CO_2 emissions. It was found, that although free-floating car-sharing members own fewer cars, their vehicles have a higher-than-average fuel consumption (7.5l vs. 6.7l gasoline equivalent per 100 km, $t = 0.83$). Yet, it was also found, that owners of cars with a higher fuel consumption drive shorter average distances and that this effect is stronger for car-sharing members ($\rho = -0.40$) than for the control group ($\rho = -0.16$).

Table 5 presents the resulting differences-in-differences in gasoline consumption and CO_2 emissions. The calculated values factor in both private vehicle miles combined with the consumption and emission characteristics of the respondent's private vehicle as well as the vehicle miles driven in a car-sharing vehicle combined with the characteristics of the car-sharing fleet (which consists of only one vehicle type). Public transportation was neglected in this calculation assuming that such small changes in demand do not justify responses on the supply side. The results indicate, that free-floating car-sharing members reduce their gasoline consumption by 0.04l and their CO_2 emissions by 125g per day. The results are supported by a Wilcoxon rank sum test indicating, that the hypothesis, that free-floating car-sharing leads to higher fuel consumption and emissions can be rejected at the 30% significance level. Again, the small sample size limits the significance of the results. Moreover, as shown above, the actual impact of free-floating car-sharing may be lower than this observed effect.

TABLE 4 Average weekday mode use in km per day

	free-floating		control group	
	wave 1	wave 2	wave 1	wave 2
private car	4.0	3.2	6.4	7.6
car-sharing	0.4	0.9	0.0	0.0
train	22.5	22.1	5.4	4.5
local transit	3.4	4.4	2.2	2.3
active modes	4.9	4.4	3.5	3.6
other	0.5	0.9	0.4	0.2
total	35.7	35.9	17.9	18.2

TABLE 5 Difference-in-Differences Approach for Mode Use

	Diff.-in-Diff.	*t*
private car	-2.0 km	-0.90
car-sharing	0.5 km	1.67
train	0.6 km	0.24
local transit	0.9 km	1.16
active modes	-0.6 km	-0.42
gasoline consumption	-0.04 l	-0.23
CO_2 emissions	-125 g	-0.32

Values given are per person per weekday.

DISCUSSION

The results presented in this paper provide further insights into the travel behaviour impact of free-floating car-sharing. It was shown, that free-floating car-sharing members reduce both their level of car-ownership as well as their car use. However, as indicated by earlier research *(4)*, the impacts are less strong than for station-based car-sharing.

In a first step, the results from the car-ownership model are to be compared to the survey results. In the survey, 8% of the free-floating car-sharing members stated, that they would buy an (additional) car if free-floating car-sharing was not available. The model results indicate, that free-floating car-sharing reduces the level of car ownership by 20% for those members, who did not explicitly plan to buy a private car. Given the ex-ante level of car-ownership of 0.27 vehicles per household, this effect corresponds to a reduction of 0.05 vehicles per household. Moreover, the stated reduction of 8% is the same as the observed reduction (before-and-after comparison of actual levels of car-ownership) of 0.08 vehicles.

Thus, the results indicate, that the stated effect in car-ownership matches the observed change. However, according to the model, the actual impact of the car-sharig scheme is lower by a third.

In addition, the analysis shows, that using the intended level of car-ownership as a reference leads to inflated results.

Although the car-ownership impact of free-floating car-sharing is substantial, it is lower than the impact of station-based car-sharing, where 15-20% of all joining households are expected to give up private car ownership *(10)* based on a (probably biased) stated-reduction approach.

A similar pattern can be observed when regarding mode use. Whilst station-based car-sharing members in Switzerland were estimated to reduce their vehicle miles travelled by 5.5km per day and increase their use of public transport by 4.4km per day *(10)*, free-floating car-sharing was found to reduce car travel by 1.5km and increase public transport use by 0.9km per weekday. Yet, when looking at the relative change, the expected 36% reduction in vehicle miles travelled for station-based car-sharing *(10)* is almost reached by free-floating car-sharing (34%). However, the validity of the latter ratio particularly suffers from the small sample size of the valid diaries.

The insights gained from the qualitative analysis of free-floating car-sharing use cases show, that the scheme is mostly used for non-regular activity patterns. In particular, a substantial share of free-floating trips actually are multi-stage or return trips, which indicates, that free-floating car-sharing is also used for trip patterns station-based car-sharing was originally designed for.

In the rare cases, it is used within a regular routine, it does not directly substitute public transport or active modes, but only in connection with an earlier or later departure time or other alterations to the routine. Yet, it allows some of its members to replace a car-only routine by both public transport and car-sharing. Thus, the observations from the travel diaries support the notion, that free-floating car-sharing does not necessarily lead to more car traffic.

Whilst this research is able to determine the car-ownership impact of free-floating car-sharing, the significance of the results concerning the mode choice and environmental impact are limited by the small sample size. Given the substantial variation in individual travel behaviour, a sample size of 600 valid travel diaries would have been required to precisely determine the effect of free-floating car-sharing on car use and fuel consumption. Yet, despite the small sample size of valid travel diaries, the results of this research clearly indicate, that free-floating car-sharing causes a net reduction in car travel.

CONCLUSION

Station-based car-sharing enables its members to shift from a car-oriented to a public transport-oriented lifestyle by providing a car on an as-needed-basis *(2)*. Given that free-floating car-sharing, due to its flexibility, is less predictable and therefore less reliable from a customer's point of view, the question was, whether it has a similar leverage effect on travel behaviour as station-based car-sharing.

By using quantitative, empirical data, this research allows a first estimation of the net travel behaviour impact of free-floating car-sharing. It was able to reveal, that free-floating car-sharing substantially and significantly reduces its members level of car-ownership and triggers a modal shift towards public transportation.

Although the savings in vehicle miles travelled and energy consumption could not be pre-

cisely determined given the low number of valid travel diaries, the results give a clear indication, that its net effect is negative, i.e. there is no net increase in car travel caused by free-floating car-sharing. It is particularly interesting to note, that such an effect is observed already after one year of operation. This is in contrast to station-based car-sharing, which was found to generate more car traffic within its first year *(16)*.

Moreover, the results suggest, that the actual impact of a car-sharing scheme may be lower than observed or stated changes in car ownership or travel behaviour. The difference is significant and stresses the importance of not solely relying on survey results for a valid impact estimation.

Eventually, the travel diaries allow first insights into use cases for free-floating car-sharing. It is shown, that in most cases, it is used for extraordinary trips or in cases of major changes to a regular routine. Since a substantial share of the free-floating car-sharing trips are multi-stage or round trips, the scheme not only complements, but partially competes the existing station-based car-sharing scheme.

ACKNOWLEDGEMENT

The study was commissioned by Mobility Switzerland and involves a parallel Swiss National Fund project (National Research Program 71: Managing Energy Consumption, project number 407140_153807).

REFERENCES

1. Seattle Department of Transportation (2014) 2013 Seattle Free-Floating Car Share Pilot Program Report, *Technical Report*, Seattle Department of Transportation, Seattle.

2. Shaheen, S. A. and A. P. Cohen (2013) Carsharing and Personal Vehicle Services: Worldwide Market Developments and Emerging Trends, *International Journal of Sustainable Transportation*, **7**, 5–34.

3. Litman, T. (2000) Evaluating Carsharing Benefits, *Transportation Research Record*, **1702**, 31–35.

4. Le Vine, S., O. Adamou and J. Polak (2014) Predicting new forms of activity/mobility patterns enabled by shared-mobility services through a needs-based stated-response method: Case study of grocery shopping, *Transport Policy*, **32**, 60–68.

5. Shaheen, S. A. and A. P. Cohen (2015) Innovative Mobility Carsharing Outlook, *Technical Report*, Transportation Sustainability Research Centre, University of California, Berkeley.

6. Firnkorn, J. and M. Müller (2011) What will be the environmental effects of new free-floating car-sharing systems? The case of car2go in Ulm, *Ecological Economics*, **70** (8) 1519–1528.

7. Firnkorn, J. (2012) Triangulation of two methods measuring the impacts of a free-floating carsharing system in Germany, *Transportation Research Part A*, **46** (10) 1654–1672.

8. Suiker, S. and J. van den Elshout (2013) Wirkungsmessung Einführung car2go in Amsterdam, paper presented at the *Nationaler Verkehrswissenschaftskongress*, Amsterdam.

9. Martin, E. and S. Shaheen (2011) Greenhouse gas emission impacts of carsharing in North America, *Intelligent Transportation Systems*, **12** (4) 1074–1086.

10. Muheim, P. and E. Reinhardt (1999) Carsharing: The key to combined mobility, *World Transport, Policy & Practice*, **5** (3) 58–71.

11. Mishra, G. S., R. Clewlow and P. Mokhtarian (2016) Effect of Carsharing on Vehicle Holdings and Travel Behavior: Propensity Score and Causal Mediation Analysis of San Francisco Bay Area, paper presented at the *95th Annual Meeting of the Transportation Research Board*, Washington, D.C.

12. Kopec, J. A. and J. M. Esdaile (1990) Bias in case-control studies. A review, *J Epidemiol Community Health*, **44** (3) 179–186.

13. Lane, C. (2005) PhillyCarShare - First-year social and mobility impacts of carsharing in Philadelphia, Pennsylvania, *Transportation Research Record*, **1927**, 158–166.

14. Rydén, C. and E. Morin (2005) Environmental assessment: Report WP 6, *Technical Report*, Trivector Traffic, Stockholm.

15. Martin, E., S. A. Shaheen and J. Lidicker (2010) Impact of Carsharing on Household Vehicle Holdings, *Transportation Research Record: Journal of the Transportation Research Board*, **2143**, 150–158.

16. Cervero, R. and Y. Tsai (2004) City CarShare in San Francisco, California: Second-Year Travel Demand and Car Ownership Impacts, *Transportation Research Record*, **1887** (1) 117–127.

17. Cervero, R., A. Golub and B. Nee (2007) City CarShare: Longer-Term Travel Demand and Car Ownership Impacts, *Transportation Research Record*, **1992**, 70–80.

18. Bricka, S. and C. R. Bhat (2006) A comparative analysis of GPS-based and travel survey-based data, *Transportation Research Record*, **1972**, 9–20.

19. Stopher, P., C. FitzGerald and M. Xu (2007) Assessing the accuracy of the Sydney Household Travel Survey with GPS, *Transportation*, **34** (6) 723–741.

20. Montini, L., N. Rieser-Schüssler and K. W. Axhausen (2013) Field Report: One-Week GPS-based Travel Survey in the Greater Zurich Area, paper presented at the *Swiss Transport Research Conference*, Monte Verita.

21. Wargelin, L., P. Stopher, J. Minser, K. Tierney, M. Rhindress and S. O'Connor (2012) GPS-Based Household Interview Survey for the Cincinnati Ohio Region, *Technical Report*, Abt SRBI Inc., New York.

22. Oliveira, M. G. S., P. Vovsha, J. Wolf, Y. Birotker, D. Givon and J. Paasche (2011) Global Positioning System-Assisted Prompted Recall Household Travel Survey to Support Development of Advanced Travel Model in Jerusalem, Israel, *Transportation Research Record*, **2246**, 16–23.

23. Cottrill, C. D., F. C. Pereira, F. Zhao, I. F. Dias, H. B. Lim, M. E. Ben-Akiva and P. C. Zegras (2013) The Future Mobility Survey: Experiences in developing a smartphone-based travel survey in Singapore, *Transportation Research Record*, **2354**, 59–67.

24. Kopp, J., R. Gerike and K. W. Axhausen (2015) Do sharing people behave differently? An empirical evaluation of the distinctive mobility patterns of free-floating car-sharing members, *Transportation*, **42**, 449–469.

25. Sofistar (2015) Studio Mobilità, `www.studio-mobilita.ch`.

26. Comparis (2016) Drei von vier Schweizern sind smart unterwegs, Webpage (last accessed: 24.07.2016), `https://www.comparis.ch/comparis/press/medienmitteilungen/artikel/2016/telecom/smartphone-studie-2016/smartphone-verbreitungsstudie-2016.aspx`.

27. Axhausen, K. W., B. Schmid and C. Weis (2015) Predicting response rates updated, *Technical Report*, **1063**, Institute for Transport Planning and Systems, ETH Zurich.

28. Swiss Federal Statistical Office (BFS) (2012) *Mobilität in der Schweiz - Ergebnisse des Mikrozensus Mobilität und Verkehr 2010*, Swiss Federal Statistical Office (BFS), Neuchatel.

29. van Eggermond, M., A. Erath and K. W. Axhausen (2016) Vehicle Ownership and Usage in Switzerland: Role of Micro- and Macroaccessibility, paper presented at the *95th Annual Meeting of the Transportation Research Board*, Washington, D.C.