Impacts of a new free-floating car-sharing system in Basel

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Abstract

Free-floating car-sharing is a new and fast-growing service. Since it differs from the well-studied station-based round-trip car-sharing service in many structural aspects, market potential analyses as well as estimates of environmental impacts are not necessarily transferable. This research attempts to estimate the environmental impact of free-floating car-sharing using a smartphone-based GPS-tracking approach. In this paper, the methodology of the study as well as the achieved data quality are discussed. Experiences from this study confirm, that smartphone-based GPS-tracking systems are already working well. However, participant's data privacy concerns are found to be a major obstacle in the method's implementation.

Keywords

free-floating car-sharing, Catch a Car, smartphone-based GPS tracking, prompted recall

1 Introduction

Mobile internet access using smartphones and other devices has a profound impact on people's life. By providing real-time communication irrespective of geographic distance, it changes the interactions within social networks and offers an opportunity for new business models. One of those is free-floating car-sharing, which overcomes the limitation of fixed car-sharing stations. Instead, customers locate and book a vehicle using a smartphone-app, access it with a smartcard and leave the car anywhere within a pre-defined service area at the end of their trip. Since its first introduction in Ulm, Germany, in 2009, free-floating car-sharing has enjoyed a high polularity.

As the concept of free-floating car-sharing differs substantially from station-based car-sharing, it does not necessarily have the same impact on e.g. car-ownership and vehicle-kilometers travelled. Indeed, first studies find user profiles and usage patterns different from station-based car-sharing (Schmöller *et al.,* 2014, Kopp, 2015). Moreover, research on the environmental impacts of free-floating car-sharing has produced inconclusive results (Seattle Department of Transportation, 2014). It has proven difficult to determine the net effect of the service using qualitative and retrospective member-surveys as the service may substitute for both transit and private car-trips. Hence, a more sophisticated approach is necessary to correctly account for the changes in travel behaviour.

The recent introduction of the new free-floating car-sharing service Catch a Car in Basel (Mobility International Inc., 2014) is a good opportunity to investigate the impacts of free-floating car-sharing in Switzerland. To properly address the challenges described before, a smartphone-based GPS-tracking system has been employed, which itself is a methodology enabled by the growing diffusion of smartphones. This innovative system allows to collect weeklong mobility diaries with a still reasonable response burden. Using this method in a two-wave longitudinal survey design including a control group, the impacts of the new free-floating car-sharing service can be measured.

This paper summarizes the relevant scientific literature (Section 2), presents details about the methodology used for this study (Section 3) and describes challenges in the data acquisition (Section 4). It concludes with an outlook onto the next steps of this research (Section 5).

2 Background

2.1 Free-Floating Carsharing

After its first occurrences in European cities in the late 1940s (Harms and Truffer, 1998), car-sharing fell into a deep sleep as private motorization became cheaper and easily available for broad parts of the population. The situation only changed in the 1990s when rising fuel prices and increasingly congested networks called for alternative modes of transport. However, car-sharing could only take off when technology was ready to provide user-friendly systems based on smartcards and online reservations (although some systems still request reservations via phone and use key boxes). Along with technological advances, various forms of car-sharing have evolved such as station-based car-sharing, peer-to-peer car-sharing or one-way car-sharing (Le Vine *et al.,* 2014).

Literature about car-sharing has grown since the early 1990s, when the services started to become increasingly successful, and covers mostly the classic case of station-based round-trip car-sharing (Millard-Ball *et al.,* 2005). In contrast, the case of one-way car-sharing is less common, but for example the optimal redistribution of vehicles has been investigated several times (Uesugi *et al.,* 2007, Correia and Antunes, 2012).

Although early studies predicting a membership potential in the order of 10% of the urban population for station-based car-sharing services (Steininger *et al.,* 1996, Muheim and Reinhardt, 1999) this turned out to be over-optimistic, even as car-sharing vehicles have reached a high visibility in many cities around the globe. Researchers agree, that they particularly attract young, affluent and well educated customers (Grasset and Morency, 2010) and are most successful in dense urban areas with good public transport supply (Stillwater *et al.,* 2008). Moreover, positive environmental impacts such as less vehicle travel and lower emissions (Martin and Shaheen, 2011b) or a reduced need for parking (Shaheen *et al.,* 2010) have been confirmed by various studies.

A most recent addition to the car-sharing family is free-floating car-sharing (Buchenau, 2008). Compared to traditional station-based round-trip car-sharing systems, free-floating car-sharing services offer their customers more flexibility (Table 1), which promises a much higher market potential. However, given the profound structural differences between the two systems, their environmental impacts may also not be the same. In fact, a recent British study suggests, that round-trip car-sharing generally complements public transport whereas point-to-point car-sharing is used instead of public transport (Le Vine *et al.,* 2014b).

Table 1: Comparison of station-based round-trip car-sharing and free-floating car-sharing

station-based round-trip car-sharing	free-floating car-sharing
round-trips only	one-way trips allowed
rentals on hourly basis	rentals on minute basis
charges per hour and distance	charges per minute
vehicles can be reserved days and weeks ahead	maximum reservation time 15 - 30 min
vehicles available at dedicated stations	available vehicles located via smartphone
fixed rental time	flexible check-out at the end of the trip

More than any other form of car-sharing, free-floating car-sharing systems depend on the support of the respective municipal authorities, i.e. for granting the required parking permits. Therefore, valid estimates of the environmental impact of free-floating car-sharing are required. In contrast to early studies expecting free-floating car-sharing to achieve a significant reduction in private vehicle ownership and emissions (Firnkorn and Müller, 2011), the actual implications seem to be more complex: Apart from customers giving up their private vehicle, there are also non-car-owners joining a car-sharing service and are therefore substituting transit or slow modes by car (Firnkorn, 2012). A similar pattern has also been observed for the case of round-trip-based car-sharing, where a substantially positive net impact could be found after all (Martin and Shaheen, 2011a). Yet, given its more spontaneous and flexible nature, a positive net impact may not occur for the case of free-floating car-sharing.

The ambivalence of the contrasting effects on different user-groups have also been found by authorities in Seattle examining the effect of car2go one year into its operation: Only a third of the members reported to travel fewer miles with their private car. In contrast, two thirds have not changed their private car VMT in addition to their car2go use. Moreover, nearly half reported to ride transit less frequently (Seattle Department of Transportation, 2014). Unfortunately, the study was based on a member survey and does not allow a quantitative calculation of a net impact. Another study from the city of Amsterdam found only slight contributions of car2go on congestion, parking and the environmental footprint of the transport sector as a consequence of the comparably small scale of the service (Suiker and van den Elshout, 2013).

Furthermore, one-way car-sharing (of which free-floating car-sharing is a special case) changes the mobility structure of its customers. For example, it lets non-car-owning members shop for groceries less frequently, visit fewer distinct food shops and spend less total time traveling for grocery shopping purposes (Le Vine *et al.*, 2014a). This makes its actual impact hard to determine. Furthermore, weather conditions and pricing structures have a significant effect on how free-floating car-sharing is used (Schmöller *et al.,* 2014, Ciari *et al.,* 2014).

2.2 GPS-Tracking in transportation research

As outlined above, a valid determination of the effect of free-floating car-sharing requires information about the changes of individual travel behaviour caused by car-sharing. Although surveys based on hypothetical scenarios or past behaviour produce consistent results (Firnkorn, 2012), they are not sufficient to accurately capture the interplay of the various effects of new transport modes (Schelewsky, 2014). A suitable way to accrue the collect data would be a mobility diary (travel log) as used in many household travel surveys. However, it has become clear, that such manual travel logs suffer from quality issues such as imprecision and under-reporting (Bricka and Bhat, 2006, Stopher *et al.,* 2007), although careful long-duration surveys have less problems in this regard (Axhausen *et al.,* 2002).

In order to enhance data quality, many researchers and transportation authorities integrated GPS-logging of private vehicle trips in their household surveys (Battelle, 1997) and found, that a good data quality can be achieved in combination with a lower response burden for the participants (Greaves *et al.,* 2011). As GPS-loggers became increasingly user-friendly, they were distributed to survey participants to be carried around as they traveled. This way, the double-benefit of more precise data and a lower response burden was expected for all travel modes (Ohmori *et al.,* 2005, Chen *et al.,* 2010). However, the method relies on the assumptions, that the participants carry the GPS logger on all of their trips, that the GPS records are correct and that all participants accurately fill out the associated prompted-recall survey. Despite the generally high level of acceptance of this method among the population (Oliveira *et al.,* 2011), those assumptions are hardy ever met. Moreover, the distribution and recollection of GPS-loggers has proven to be time-consuming and expensive (Montini *et al.,* 2013). In the meanwhile, various algorithms have been developed to deal with issues of record quality or missing data (Du and Aultman-Hall, 2007, Schüssler and Axhausen, 2008, Bohte and Maat, 2009, Montini *et al.,* 2014). Although much of the necessary post-processing can be done automatically or by the participants online (Li and Shalaby, 2008), the operational complexity and costs remain high, because loggers still need to be distributed and collected in addition to programming and then supporting and supervising the prompted recall survey.

In contrast to data loggers, mobile telephones are usually carried along. Despite a lower data quality even early studies using GPS-equipped mobile phones achieved promising results (Itsubo and Hato, 2006). In the meantime, technical features and applications of mobile telephones have grown massively as has their market penetration. Therefore, new possibilities arise for research by using smartphones as life-loggers (Aharony *et al.,* 2011) acquiring data with a quality and quantity not achievable with traditional survey tools. Whilst maintaining an acceptable data quality as well as a lower response burden, the administrative complexity can be significantly reduced when using smartphones, as a manual exchange of data loggers is no longer required. Instead, participants simply download an app on their private smartphone. Although some technical challenges such as the high battery consumption of the built-in GPS-sensor remain, smartphone-based GPS-tracking systems have become ready to be used in transportation research (Cottrill *et al.,* 2013, Kopp, 2015, Oliveira *et al.,* 2011, Wargelin *et al.,* 2012).

3 Methodology

The aim of this study is to analyze the impact of a new free-floating car-sharing service on the transport system. As reasoned above, this complex task requires data about the changes of individual travel behaviour. For this purpose, a *before*-and-*after* comparison using mobility diaries (travel logs) appears to be the most appropriate method. In order to capture socio-demographic data and information about the participant's general mobility behaviour as well, the mobility diaries are combined with a survey capturing this additional information.

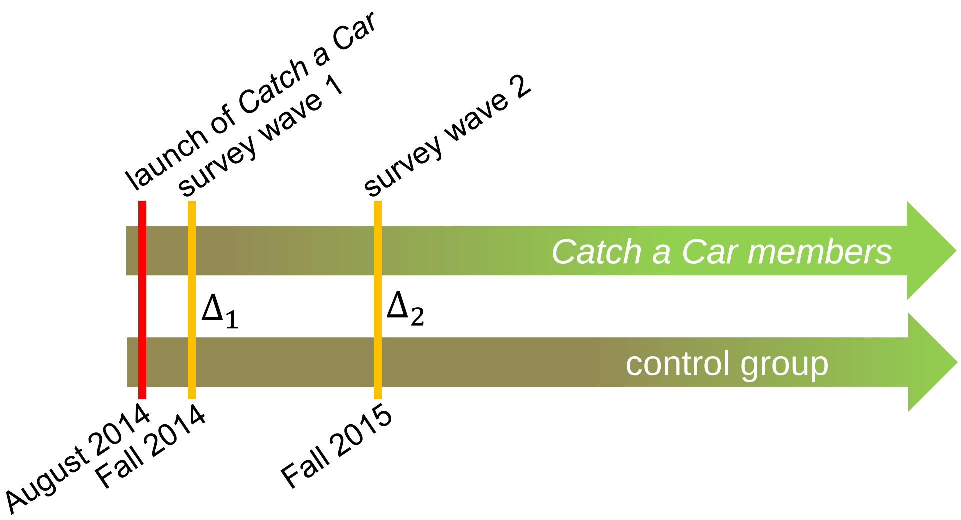
However, it is impossible to identify new customers of a free-floating car-sharing service before they have actually applied for membership. This makes it difficult to get a perfect *before*-sample. Yet, assuming that the actual change in travel behaviour sets in with some delay (testing the service, commitments to other subscriptions or private car not terminated that fast) a good baseline can also be achieved by surveying members shortly after they have joined. In the case of this study, the free-floating service *Catch a Car* started operations by end of August 2014 and the survey started in mid October 2014. The *after*-survey is scheduled for fall 2015 to allow one year for the initial effects of *Catch a Car* to take place.

In order to account for external effects on travel behaviour, a control group was required. For this study, the control group consists of both round-trip car-sharing members and non-members. The impact of the new free-floating car-sharing service can then be separated from external effects by comparing the differences in behaviour between the survey groups in the *before*- and *after*-survey. To enhance the validity of the comparison, a panel-based approach was chosen, such that the composition of the survey groups is constant. The method is summarzied in Figure 1.

As described above, three different groups of participants were surveyed:

1. local members of the new free-floating car-sharing service *Catch a Car*

Figure 1: Difference in difference method



Two survey waves are conducted. The first wave takes place soon after the launch of the free-floating car-sharing service *Catch a Car* followed by the second wave one year later. The impact of carsharing can be isolated from external effects by comparing the differences in behaviour over time (Δ_1 and Δ_2). The control group consists of both a group of members of the station-based round-trip car-sharing service *Mobility* and a representative sample of the local population.

2. local members of the established station-based round-trip car-sharing service *Mobility*
3. a representative sample of the local population holding a driver's licence

Whilst e-mail addresses of the car-sharing members were made available by the operators, members of the control group could only be contacted via surface mail. Addresses of the control group members were provided by the Cantonal Statistical Office of Basel-Stadt which drew it as a random sample from the local population above legal age.

3.1 Survey Design

In order to obtain general information about socio-demographic characteristics as well as detailed insights into the individual travel behaviour of the participants, participants are invited to fill in both a questionnaire and a mobility diary. Due to administrative reasons the survey preceded the mobility diary.

Unfortunately, at time of this study, the tracking system used for the mobility diary could not yet provide a complex enough survey tool. Therefore, the questionnaire and mobility diary had to be conducted on different systems. Data sets were keyed with the respondents' e-mail addresses.

Questionnaire

Due to the different forms of addresses available, there are two formats of the questionnaires. Car-sharing members, who could be invited via e-mail were asked to fill in an online-questionnaire via the SelectSurvey.NET system (Classapps, 2015). Members of the control group received the questionnaire in pencil-and-paper format via surface mail including a reply-paid envelope.

At the beginning of the questionnaire, detailed information about the study and the employed technology was provided. Participants had to sign or agree to a privacy declaration before starting their response. For all of the three groups, the questionnaire addressed sociodemographic status (such as age, household size and structure, employment status, education and household income), travel behaviour (mode to work, public transport subscriptions, vehicle ownership, mode choice) and attitude towards car-sharing. In addition, car-sharing members were asked to give information about their car-sharing usage including details about their last car-sharing trip, level of availability and membership motivations.

Upon completion of the questionnaire, participants were provided with detailed instructions on how to start with the mobility diary.

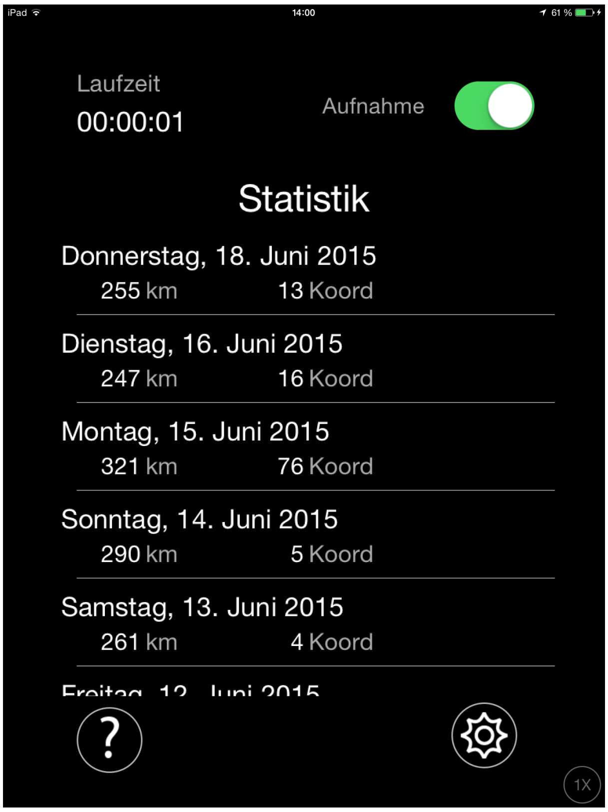
Mobility Diary

A week-long mobility diary was expected to give a good insight into a participant's travel behaviour. As outlined above, the most user-friendly and efficient way to record this is via a smartphone-based GPS-tracking system. At the time of this study, only few reasonably mature systems were available (Wargelin *et al.,* 2012, Cottrill *et al.,* 2013, Resource Systems Group (RSG), 2015, Sofistar, 2015). One of them was Sofistar's *Studio Mobilità* (Sofistar, 2015). It was chosen, because it offered a robust system and provided the most extensive options for users to review and edit their recorded tracks.

Participants were provided with individual access links to the *Studio Mobilità*. They registered on the website and received an e-mail with an activation link and further instructions about the app and the tracking procedure. Once, a participant's online account has been activated, he can download the app on his smartphone and log in using his credentials. The tracking then starts right away. Participants may check the tracking-status on the home-screen of the app (Figure 2).

At the end of each day, participants were supposed to review their records using the *Studio Mobilità* website as presented in Figure 3. Faulty or missing records could be easily corrected

Figure 2: *Studio Mobilità* App's Home Screen



using the tool bar on the left of the screen, additional information about mode, purpose, size of company, items carried and parking cost could be provided using drop-down fields in the list of tracks. A video tutorial was made available on the website to introduce participants to the system. Moreover, a dedicated helpline was operated during office hours.

Once, participants had completed their week of tracking, they were sent a final e-mail acknowledging their efforts and providing further information about their incentive.

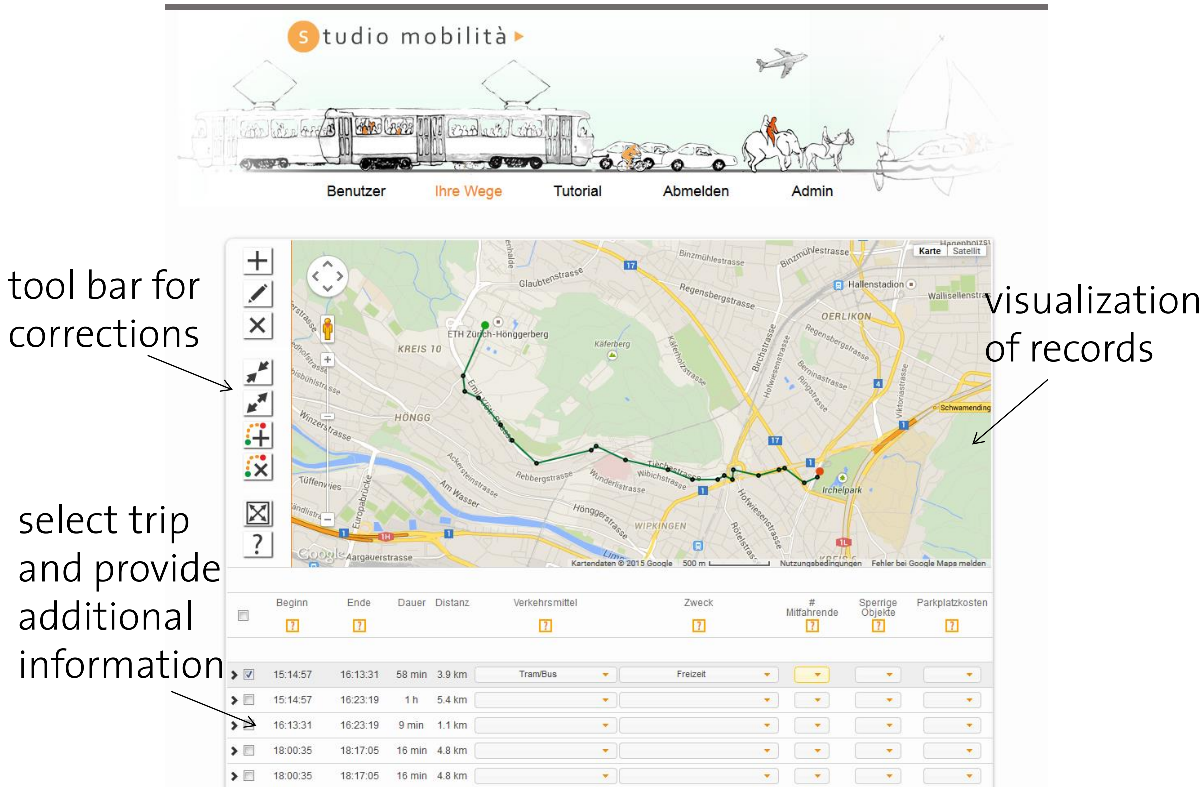
3.2 Technical Setup

Studio Mobilità is a platform for the GPS-assisted collection of data on personal mobility. It consists of a website linked with a smartphone-app.

Website

The website consists of three parts:

Figure 3: *Studio Mobilità* Website



1. a public section containing an overview of the research project, data privacy policies, contact details and a log-in box to enter the user section
2. a secured user section for the participants to manage their accounts, respond to smaller surveys and review their daily records (as shown in Figure 3)
3. an administrator's section allowing to configure the project and to monitor the progress of the data collection

The frontend usability of the Website is enhanced through advanced and extensive JavaScript use. Browser support is wide and includes all recent versions of the common browser types.

App

The app exists in two native versions, one for Android and one for iPhone. Compatibility is wide and includes almost all devices and operating systems released within the last five years.

The app's main function is to record the participant's location and to periodically send the data to the server. In principle, this is a simple task for a smartphone: It only requires the app to turn on the smartphone's built-in GPS-sensor and to read out, store and eventually transmit the data. However, the type of this research demands a minimal response burden for participants as well as a good data quality.

One step towards minimizing the required effort is a user-friendly app design. As shown in Figure 2, the home-screen of the app is clearly structured, such that a participant can immediately see whether it is logging his trips. Options to start or stop data collection are easily accessible as are options to enhance the GPS data collection or to manually transmit the records to the server. Moreover, it was ensured, that the app runs smoothly in background mode and notifies users by itself, when there is a problem (e.g. low battery shut down).

Unfortunately, there is a conflict between a higher data quality and user-friendliness, because the GPS receiver has a high energy consumption when turned on. Hence, a simple tracking may significantly affect the battery life and therefore annoy participants.

The problem was addressed by implementing an algorithm which turns the GPS on and off as required. This algorithm combines inputs from the GPS itself (if turned on), the accelerometer, the gyroscope and the Wi-Fi scan results to detect movement and speed. Thanks to this algorithm and improvements in hardware and operating systems, the battery life of a smartphone running the *Studio Mobilità* app is up to 16 hours. Since this is enough for a daylong operation, the burden imposed to participants is limited. Users without battery life problems, who prefer to see more detailed results, can force the GPS to remain turned on all the time.

Even when the GPS is turned on, it is necessary to record the optimal number of GPS-points to save battery as well as server capacity on the one hand and to ensure a clear and easy recognition of the actual path on the other hand, which usually requires about 25 GPS points per track or one GPS point per 300 m. To achieve a higher resolution for short walk legs and save resources on longer car trips, *Studio Mobilità* uses a "speed table", which tunes the minimum distance and time between two points according to the speed at which the user is moving. Moreover, outliers are removed according to filters, which account for accuracy and distance of the last registered point as well as other empirically defined criteria.

Post-Processing

As outlined above, the app collects and transmits GPS points. However, mobility is expressed in tracks. In order to minimize the users' effort, a server-based algorithm was implemented to automatically combine points into tracks. In *Studio Mobilità*, a track is characterized by a minimum total distance of 200 meters and starts/ends if the user stays in the same place for at least 20 minutes. However, it is important to note that the definition cannot be transposed exactly into an algorithm, as this relies on points that are collected with a given frequency and that anomalies such as missing GPS signals in canyons must be considered. A series of empirically validated corrections was added to account for those effects. The user can in any case modify tracks manually by joining them, splitting one and/or changing the location of points. Based on the number of manually modified tracks, we estimate the efficiency of the track recognition algorithm to 70%.

3.3 Impact Analysis

The ecological impact of *Catch a Car* can be evaluated using the differece-of-the-difference approach described in Figure 1. Whilst the quantitative analysis relies on the (tactic) travel behaviour observed in the mobility diaries, the structural changes captured in the questionnaires will allow to predict a future trend.

For the quantitative impact estimation, the CO_2 emissions per participant were defined as variable of interest. The emissions are calculated using the relation

$$CO_2 \text{ per participant} = \sum_{\text{modes}} \text{distance}_{\text{mode}} \cdot CO_2\text{-coefficient}_{\text{mode}}$$

where the CO_2 coefficients of private vehicles can be obtained from Bundesamt für Energie (BFE) (2015) individually for each participant using the make and model of the private vehicle(s) he reported in the questionnaire. The average individual CO_2 emission can then be compared between the survey groups. However, to allow valid conclusions, the *Catch a Car* members must be compared with an adequate control group corrsponding to its socio-demographic characteristics. Hence, a Heckman correction (Heckman, 1979) will be employed to prevent sample bias from affecting the result.

It is important to note, that the full effect of *Catch a Car* will not be visible after only one year. For example, Cervero and Tsai (2004) found, that the user profiles and usage patterns differ greatly between early adopters and customer groups joining the service later. In an attempt to predict a future trend of the effect of *Catch a Car*, the questionnaire addresses the participants mobility tools and an individual outlook on their future behaviour.

4 Data Acquisition

The start of the first survey wave needed to be scheduled to satisfy two constraints: Firstly, the number of *Catch a Car* members had to be high enough to promise a reasonable number of survey participants. Secondly, the travel diary must not be kept during vacations as this would render it impossible to draw conclusions about a normal travel behaviour. Therefore, the survey could not commence before the end of the autumn holidays in Basel in late October 2014. Technical difficulties encountered in various pre-tests in fact delayed the start by another few weeks.

The low number of responses from the group of *Catch a Car* members motivated an additional survey in spring 2015.

4.1 Recruitment

As of the end of June 2015, 1 218 *Catch a Car* members, 2 224 *Mobility* members and 6 000 members of the control group of the representative population sample were invited to take part in the study. Whilst members of the two car-sharing groups received an invitation via e-mail directly from the car-sharing operator and could access the online-survey using a personalized link, members of the latter control group were sent an invitation already including the pencil-and-paper questionnaire and a reply-paid envelope via surface mail.

Car-sharing members were offered a 15 CHF credit on their next bill for participating in both parts of the study (questionnaire and mobility diary), members of the control group were promised a 15 CHF voucher for the Apple or Android App Store. Due to company policy reasons, the incentive for car-sharing members was announced upon completion of the questionnaire, whereas members of the control group received all the information right from the start.

Apart from a few addresses of control group members used for a pre-test in early October 2014, participants were invited to take part in the study in weekly waves from calender weeks 43 to 50 in fall 2014. A few days after the surveys had been sent, members of the control group were contacted via telephone and offered assistance. However, only a small share could be reached. In the last week, reminders have been sent out to all those car-sharing members who had failed to answer the survey on schedule by then. Moreover, participants, who were overdue in completing their mobility diary were offered assistance. An additional survey wave for *Catch a Car* members took place in calendar weeks 16 and 23 in spring 2015.

Table 2: Invitations across the groups by week

Year	Calendar week	*Catch a Car*	*Mobility*	Control Group
2014	43	100	100	200
	44	100	400	500
	45	50	100	500
	46			
	47	50	400	500
	48			1 000
	49	227	1 224	3 300
	50	366^r	$1\,821^r$	
2015	16	582		
	23	109		

The wave-structure of distributing the survey has two advantages: It allows to correct for weather and one-time effects (e.g. an OECD meeting and several fairs were scheduled to take place during the survey period) as well as to continuously improve the setup according to feedback from the participants. The distribution of the waves is detailed in Table 2.

4.2 Response Rate

Table 3 summarizes the response rates of the three survey groups. Unfortunately, the addresses of the non-member control group could not be filtered by driving license holdership. Hence, the calculation of the response rate of the eligible members of the control group needed to be corrected by a licence holding rate of 82%. For the calculation of the response rates for the diaries, smartphone-ownership needed to be considered. According to the results of the survey, the smartphone-ownership rate is 73.4% for the control group. The same value was assumed for *Mobility* customers. Since *Catch a Car* members are required to have a smartphone in order to be able to use the service, their smartphone-ownership rate was considered to be 100%.

As shown in the table, the response rate of *Catch a Car* members is the highest. Especially, when considering the questionnaires only, there is a substantial difference to the *Mobility* customers and members of the control group. This hints at a high level of identification with or interest in the new system, whereas the *Mobility* customers' feelings towards their service seem to be more settled. Also the drop towards the members of the control group can be easily explained: Whilst

Table 3: Response rates per survey group

Status	*Catch a Car*	*Mobility*	Control Group
Invitations sent	1 218	2 224	6 000
Questionnaires completed	366	571	594
with drivers license			447
Response rate of the eligible	37.4%	25.7%	9.1%
Diaries completed	91	96	226
Response rate of the eligible	7.5%	5.8%	6.3%

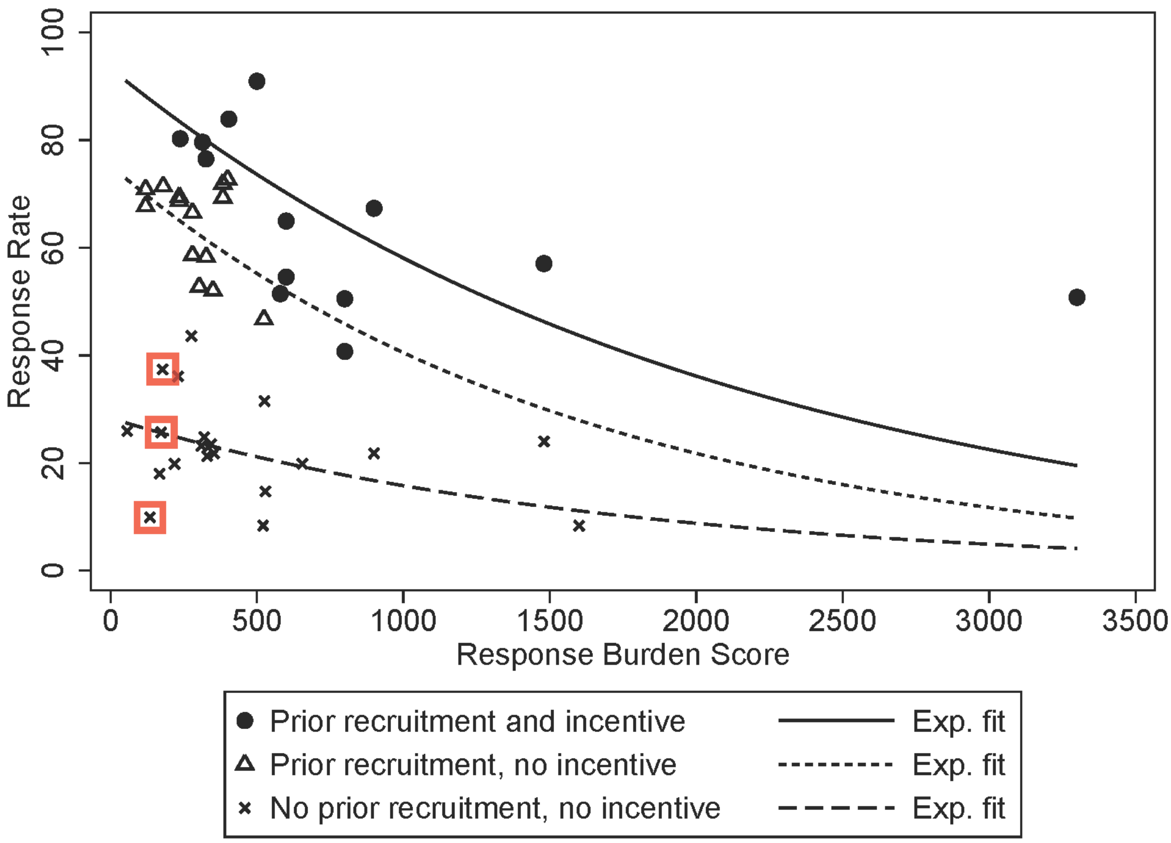
the car-sharing members were approached by an organization they are members or customers of, this did not apply to members of the control group (despite the reputation of ETH Zurich in Switzerland). In addition the different delivery method (e-mail vs. surface mail) may have played a role.

Astonishingly, the response rates converge when looking at the response rate for the diaries. In particular, this means that eligible control group members who had filled in the questionnaire were the most likely to also complete the diary (69%), whereas only one out of five car-sharing members did so. The divergence may most likely be explained by the different way of communication: Car-sharing members were first invited to the survey and received a separate invitation to the diary upon completion of the survey. Instead, members of the control group were given all the information including the diary at the beginning of the survey, such that a pre-selection might already have been taken place in the first part. This would in turn explain part of the lower survey-response rate for the members of the control group.

Due to the online-form of the survey for the car-sharing members, the response behavior of the participants could be monitored. It was found, that about one third of the car-sharing members, who clicked on their personalized invitation link gave up and that almost all of the dropouts occured in the first question, which was the data privacy declaration. Moreover, only a part of the eligible participants, who have completed the survey, registered for the mobility diary. As shown in Table 3, this behaviour results in a very low response rate for the mobility diary.

This reluctance and subtle, however irrational, feeling of insecurity is the largest challenge in implementing this new survey method in European countries: Given the intense public discussion about NSA cyber espionage, many participants were not willing to download the *Studio Mobilità* app on their smartphone due to data protection concerns. Even the provision of comprehensive data privacy information and a university institute running the study were not

Figure 4: Response rates in comparison with other comparable studies.



Adapted from Axhausen *et al.* (2015). The response rates of the questionnaires of the three survey-groups are highlighted by red rectangles.

sufficient to build trust among a large share of the invitees.

An effective, but costly and time-consuming way to reduce this burden and build more trust would be to organize workshops with all participants in small groups as done by Kopp (2015). This, however, would increase the organizational effort of the researcher counteracting the major advantage of smartphone-based GPS-tracking systems. More efficient trust-building measures still need to be identified.

Those participants, who completed the online-survey, needed an average of 21 minutes with a standard error of 8 minutes to do so. The response burdens of the surveys were calculated to 178 (*Catch a Car*), 173 (*Mobility*) and 135 (control group) according to (Axhausen and Weis, 2010). When compared to reference values (c.f. Figure 4), it can be seen, that the response rates for the *Mobility* customers is on the expected level, whereas the *Catch a Car* groups fares well above and the control group far below the expected value. Possible reasons for this behaviour are as discussed earlier.

The perceived response burden for the mobility diary generally depends on the level of a participant's mobility and his computer skills. Using the average number of recorded trips, it was calculated to a value of 362 for a full week of tracking and revision. Regarding the diary as a separate survey addressed at participants priorly recruited using the survey, the response rates can be calculated as 20% (*Catch a Car*), 23% (*Mobility*) and 52% (control group). Compared to other experiments with prior recruitment and incentive as shown in Figure 4 the response rates for the diary are much lower.

4.3 Data Quality

To ensure valid results, two possible biases need to be excluded: Firstly, the respondent sample needs to be reasonably representative for the respective group (selection bias) and secondly, their responses must reflect their actual behaviour (response bias).

In order to test for a selection bias, the age and gender distribution of the samples were compared to their corresponding populations. For the car-sharing members the information could be obtained from the address lists provided by the operators, whereas for the control group, the distributions from the Swiss Microcensus 2010 (Swiss Federal Statistical Office (BFS), 2012) were used.

A Cramér-von-Mieses-test (Anderson, 1962) was performed for the comparison of the age distribution. It was found, that age-wise, the response groups of the car-sharing respondents can be regarded as a suitable representation of the respective member population (p-value 0.05 for *Mobility* and 0.18 for *Catch a Car*) when shifted by three years in the age variable. Although older members are slightly overrepresented in the response group, it is assumed that a shift of three years would incur only small changes in a person's travel behaviour. Hence, the validity of the data does not seem to be affected. Moreover, the age distributions of both the car-sharing member populations are met with only a 1% deviation. Therefore, both car-sharing samples are regarded as representative.

For the control group, only respondents with a drivers license are considered, since they are possible car-sharing members and can therefore be affected by the new free-floating service. Again, participants of the age group 55 to 65 years are overrepresented rendering the result of the Cramer-von-Mieses-test insignificant. Yet, there is good reason to regard the response group as sufficiently representative: As is shown in Table 4, the quartiles of the age distribution are only slightly shifted, which also hints at only small differences in travel behaviour. Also when

Table 4: Age distribution for control group and population above legal age

	Population	Control group
Mean	50	50
σ	19	17
Minimum	18	18
1st quartile	33	36
Median	48	50
Mean	50	50
3rd quartile	64	63
Maximum	112	91

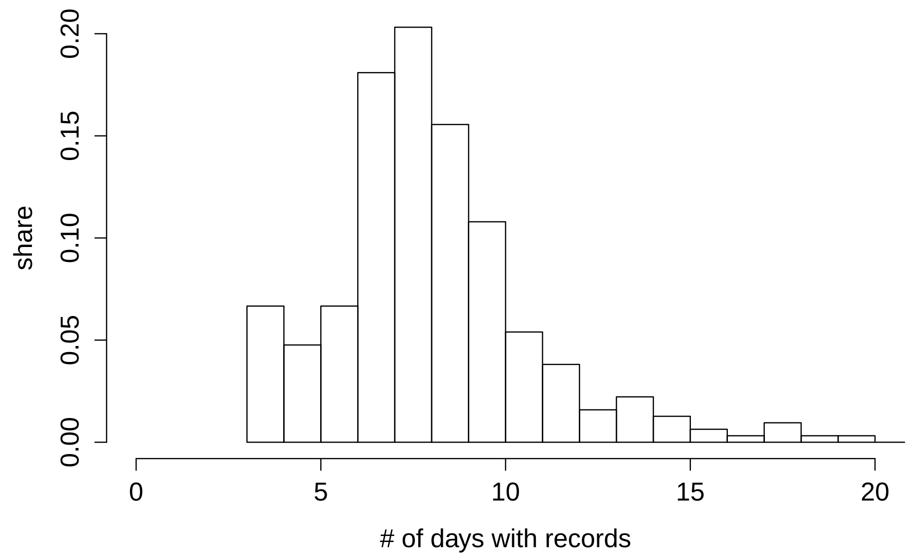
considering the gender distribution, the response group matches well the actual population of driving license holders (44.5% females vs. 45.5% females).

Concerning the response bias, three measures were taken to ensure data quality of the survey. Firstly, only completed questionnaires were considered for the analysis. Secondly, it was ensured, that none of the car-sharing members took less than seven minutes (a third of the average time) to complete the questionnaire. Thirdly, unreasonable answers (e.g. negative birth years) were omitted on a per-question basis.

The two challenges in data quality also apply for the mobility diaries. It was found, that both car-sharing samples can still be regarded as representative with respect to age and gender, whereas the control group respondents of the diary are on average seven years younger than the respondents of the survey. Although the sample can therefore not be regarded as representative anymore, its age distribution now matches the one of the *Catch a Car* members allowing a better comparability between the two groups.

Although participants were asked to record a set of seven consecutive days, some participants delivered more and some delivered less data as shown in Figure 5. On average, participants kept their diary for 8.4 days (σ = 3.4) with an average of 3.6 tracks per day. 70% of all trips were revised by the participants in the prompted recall. In order to minimize a response bias due to incomplete records, only diaries consisting of at least three full days of records were considered for the further analysis.

Figure 5: Number of days with records in completed diaries



5 Conclusion and Outlook

Free-floating car-sharing has become the most visible and most popular kind of car-sharing in terms of membership. Its environmental effects are however still unclear. This paper proposes a new method to collect data which will eventually allow a quantification of the system's impact. At the same time, it is shown, that smartphone-based GPS-tracking is already working well and indeed allows the collection of week-long mobility diary data at reasonable administrative cost.

According to preliminary analyses, the collected data allows to clearly identify the different user-groups and motivations of station-based and free-floating car-sharing members in both socio-demographic variables and travel behaviour. Moreover, using the wealth of diary data, it can be observed, when and how members of the different survey groups use specific transport modes. Although some substitution effects can already be read off the data, only a comparison of the behavioural change after the second wave in late 2015 will produce reliable results.

From a methodological point of view, a major obstacle seems to be the low level of acceptance of a smartphone-app as a means of research. Although personal contact with the subjects seems to be an effective means of building trust, it counteracts the principal aim of reducing the effort for the researcher. The experience from this study shows, that a personal contact via telephone increases the odds of a participant to thorougly complete the survey.

Technologically, the battery consumption of the app could be reduced to an acceptable level. Apart from a few participants reporting problems, the system worked smoothly and collected data well-useable for the desired analyses.

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