

**Predicting new forms of activity/mobility patterns enabled by shared-mobility services through a needs-based stated-response method: Case study of grocery shopping**

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## **ABSTRACT**

One-way carsharing systems are increasingly-prevalent in urban areas, though little is known about their impacts on activity-travel behavior, particularly their effects on usage of motorized and non-motorized travel. Such systems require privileged access to publicly-controlled street space, and in order to prepare suitably for negotiations regarding the price and terms of such access, transport planners require techniques to analyse their usage and impacts.

In contrast to previous methods, this study employs activity/mobility behavior as the quantity under study rather than aggregate travel distance. A stated-response method is presented to predict the impacts of one-way carsharing. The survey instrument is based on needs-based theory, in which multiple activity episodes undertaken in service of a broader personal objective are analyzed as a pattern of linked behavior. Food shopping was the activity type employed in the empirical analysis.

Substantive findings relating to the impacts of one-way carsharing are discussed, as well as limitations imposed by the survey protocol and limited sample size (n=72). It was found that non-car-owning respondents within our sample would use one-way carsharing to allow them to shop for food less frequently, would visit fewer distinct food shops, and would spend less time travelling for food shopping purposes. Instrument effects specific to this method are also discussed.

Key words: stated-adaptation, activity/travel patterns, needs-based analysis, one-way carsharing

## 1. Introduction

Shared-mobility systems are transitioning from a promising idea worthy of experimentation into a serious option for rationalizing urban mobility.

The most widespread form at present is ‘round-trip’ carsharing, in which a customer takes a shared-car (generally for a period of hours), performs a round-trip tour with it, and then returns it to its original location, thus ending the usage episode. The customer pays by the hour and reserves the car beforehand, as one would book a hotel room in advance.

A rapidly-emerging variant is ‘one-way’ or ‘point-to-point’ carsharing. In this operational concept, the customer takes a car from one point to another, and only pays by the minute while driving it, as with a taxicab. Usage is generally spontaneous rather than pre-booked; rudimentary reservation systems exist but provide no guarantee of access to a car at the requested place and time (Car2go 2013a). Other forms of shared-mobility include liftsharing (provision of car passenger travel in another person’s private car), bikesharing (short-term rental of bicycles, typically point-to-point), and peer-to-peer carsharing (provision of one’s personal car for other drivers to rent), as well as traditional car rental (more-detailed definitions of these services can be found at VTPI [2013]).

The first appearance of one-way carsharing appears to have been in Amsterdam in the early 1970s (Bendixson and Richards 1976), and at the time of writing such services operate in at least two dozen cities in North America and Europe (Car2go 2013b, Drivenow 2013, Autolib 2013, MultiCity 2013, Renault 2013). In many cases the contemporary operators are automotive manufacturers (BMW, Mercedes, Citroen, etc.), which is in contrast to traditional round-trip carsharing which emerged primarily in the form of start-up companies. As of mid-2013 there are over 100,000 members of one-way carsharing services in North America alone (Shaheen and Cohen 2013).

The literature shows that shared-mobility services affect both how and how much people travel. More evidence is available regarding the impacts of round-trip carsharing on mobility patterns (cf. Martin and Shaheen 2010, Sioui et al. 2012, with earlier studies discussed in Harms and Truffer [1998]), though the limited results available at present regarding one-way carsharing (cf. Le Vine 2011, Firnkorn 2012) strongly suggest its impacts are substantial and quite different from round-trip carsharing. On the basis of a large-sample survey of carsharing members, Martin and Shaheen (2010) show that the majority of customers of round-trip systems drive somewhat more than they would if carsharing did not exist, whilst a minority report that they drive less. They further show that the magnitude of the average effect is greater amongst those that drive less, such that on balance round-trip carsharing leads to less vehicle-kilometers of car travel. Comparable results have also been found in Britain (Harmer and Cairns 2012, Steer Davies Gleave 2013) using similar methods.

Even though in many cases the public sector does not directly deliver shared-mobility services, transport planners play a mediating role in these markets. While there are limited examples of shared-mobility services operating in politically-unfavorable environments (cf.

Robert 2000), these services in general depend on privileged access to street space, which can only be granted by the public sector. Thus transport planners are gatekeepers of the shared-mobility marketplace, in the position to allow the private-sector shared-mobility services to reach their customers or to preclude them from doing so.

In order to support decision-making that balances between protecting the public interest and providing an acceptable environment for the private-sector operators to invest, it is imperative for transport planners to understand the implications of shared-mobility services. There are indications that the shared-mobility marketplace may be at a point of inflection, as major commercial operations based on both the 'round-trip' and 'one-way' operating concepts are beginning to report profitability (Zipcar 2012, Reiter and Tschampa 2013.) It is also important to note that the shared-mobility paradigm is blurring a number of functional relationships within the automotive sector. Car rental firms, for instance, have been major customers of carmakers for many years, but they are now both beginning to compete for the same market in urban mobility services (Firnkorner and Muller 2012)

This paper's contribution is the use of patterns of activity/mobility behavior as the unit of analysis to assess the impacts of one-way carsharing systems. A novel stated-response method grounded in the emerging 'needs-based' theory of activity participation is proposed (Arentze and Timmermans 2006; Abou-Zeid and Ben-Akiva 2012). Previous studies of the impacts of shared-mobility services generally use aggregate travel distance (e.g. kilometers per year by various modes of transport) as the quantity under study (Communauto 2006, Martin and Shaheen 2010, Firnkorn 2012). Patterns of activity/mobility are more complex to work with, but this paper shows that the advantage of this type of data structure is that it can support richer and more insightful findings.

The rest of this paper is structured as follows: Section 2 presents methodological background and Section 3 presents the details of the survey instrument and administration. Results are in Section 4. Section 5 summarizes the findings, highlights the main conclusions, and discusses future research needs.

## **2. Background**

The stated-response survey design employed in this study draws on needs-based theory of activity participation, which is predicated on the notion that the activities people do are driven by [unobservable] underlying human needs (which in principle include discretionary desires as well as 'needs'.) Thus mobility is viewed as a derived demand, arising from activity participation, whilst activity participation itself is conceptualized as a second level of derived demand arising from [unobservable] needs/desires. The first two of these elements (mobility and activity behavior) are in principle observable; this is in contrast with needs, which are latent. Questionnaires may however be used to probe certain dimensions of the links between perceived needs/desires and executed activity/travel behavior (Nijland et al. 2010).

Previous applications of needs-based theory have employed various forms of simulated activity/travel data (Marki and Axhausen 2012), revealed-behavior data (Abou-Zeid and Ben-Akiva 2012, Marki et al. 2012, Nijland et al. 2012; Pattabhiraman et al. 2012), and stated-response data structures (Nijland et al. 2011; Khademi et al. 2012). In many of these studies activity types that are observed to have rhythmic patterns of execution have been used to parameterize utility functions which depend on, among other variables, elapsed time. Bhat (2005) analyzed the correlates of inter-episode participation in recurring activity types, and provides an overview of earlier attempts at representing multi-day rhythms in activity participation patterns.

Needs-based theory directly addresses several relatively under-appreciated aspects of activity participation. First, it is sensitive in principle to the interdependencies between activity episodes, either of the same class of behavior (standard categories include work, leisure, social obligations, shopping, etc.) or others. An example of linkages across different classes of behavior would be work-activity episodes leading to increased need/desire for leisure-activity episodes. Second, activity participation is explicitly analyzed to depend on the episode-specific attributes of earlier activities, beyond simply being conditional on the elapsed time since the previous episode of the same class. For instance, in the framework proposed by Arentze and Timmermans (2006) activity participation is sensitive to the degree to which previous episodes satisfied the underlying need as well as the elapsed time since the relevant earlier activities took place.

The empirical study reported here investigated food shopping behavior. It is recognized that food shopping is a somewhat coarse treatment of a human 'need', where nourishment for biological metabolism could be seen as the more fundamental relevant 'need'. Acquisition of the raw materials required for nourishment could conceivably be met by any of a number of means, such as others (a spouse, parent, child, etc.) shopping for the food that a person eats, eating prepared food at a restaurant or canteen, or even through nutrients provided intravenously. Further, 'food' as a category encompasses a large set of heterogeneous items. It is also important to note that food *shopping* is but one aspect of the complete supply chain leading to nourishment and is temporally separated from the metabolic processes; one purchases groceries at some arbitrary point that will be prepared and consumed at later points in time. Despite the complexities of the link between food shopping and nourishment, however, this study provides empirical evidence that the heuristic of treating food shopping as a 'need' which is met through flexible patterns of activity execution is tractable. It is noted that the needs-based stated-response technique proposed in (Nijland et al. 2012) distinguishes only between 'daily' and 'clothes' classes of shopping activities, whereas (Pattibhiraman et al 2012) do not disaggregate the shopping class of activities at all. It therefore remains an item for the future research agenda to determine whether subtler needs-definition is feasible in the stated-response context of hypothetical behavior.

This study develops a structured stated-choice/adaptation instrument (Lee-Gosselin 1996). In each replication of the experiment, respondents *choose* whether to use a one-way carsharing

service, and if they do they then indicate how they would *adapt* their pre-existing behavior in a *structured* way (along a small number of dimensions) to make use of it.

The revealed behavior that respondents report is in the form of a stylized pattern, as they indicate their ‘regular’ food shopping behavior rather than specific recent instances of food shopping. This allows the recall period to be longer than the period that would be possible if specific activity episodes were under study (e.g. Weis and Axhausen forthcoming), but it has the drawback that the stylized behavior that respondents report may be not simply an imprecise representation of their executed behavior, but different in systematic ways. For instance, it explicitly excludes ‘non-regular’ food-shopping episodes. In this respect this instrument is similar to the design proposed by Khademi et al. (2012), in which respondents are asked to report their stylized pattern of participation in a set of different activity classes. In the present study it was decided, however, that requesting respondents to recall (and then adapt) a single type of activity episode in a stylized fashion (rather than multiple types simultaneously) was on balance more likely to minimize any discrepancies between stylized and executed behavior.

There is substantial heterogeneity in the motivations for the types of activities people perform, which presented another design challenge. The instrument was designed to focus on a class of behavior in which a large share of people take part, while at the same time behavior was sought in which people’s participation could be adequately described by a relatively homogeneous and small set of salient dimensions. Food shopping was chosen as the representative personal need for the following reasons:

- a large proportion of people shop for groceries
- food shopping activities are undertaken relatively frequently
- food shopping activities generally take place at a relatively few specialized locations, of which people are generally aware
- nourishment is non-discretionary and hence acquisition of food cannot simply be cancelled or postponed for very long
- it is somewhat suited to use of a car (for ease of transporting groceries after purchase)

Gaming-simulation techniques (see Jones 1979, Lee-Gosselin 1990) are the richest available method for capturing how people would adapt in response to stimuli to their activity/travel behavior. Adaptation can be captured at the household-level (if, as is frequently the case, all household members take part) and importantly these techniques employ face-to-face interviews, frequently with tactile representations of behavioral constraints, in which proposed adaptation is verified for spatio-temporal feasibility. Such techniques are rather resource-intensive, however, meaning that there is a role for intermediate methods that can be applied in a straightforward self-administered manner. In practice, methods of this class that analyze activity/travel behavior (e.g. Arentze and Timmermans 2004, Khademi et al. 2012, and the method outlined herein) allow respondents to adapt their behavior in ways that are

more flexible than stated-choice methods allow, but leave the consideration of spatio-temporal constraints to the respondent's judgment.

### 3. Survey instrument and administration

This section describes the design of the survey instrument and its administration.

Subsequent to qualitative exploration of people's grocery shopping patterns (which is not reported here – see Adamou, 2012) a web-based self-administered survey instrument was designed. The instrument consisted of the following relevant steps for respondents who reported not using a personal car to regularly perform any of their journeys to/from food shops (the steps were similar for car-users; they are not discussed further as this paper reports findings only relating to non-car-users. Further details on the complete instrument package can be found in (Adamou 2012):

- 1) Collection of demographic information from the respondent. (Despite the risk of introducing response bias by gathering of demographic information at the start of the interview, it was decided to do so in order to ensure that demographic information would be available from respondents who did not complete the full survey.)
- 2) Collection of the respondent's existing food shopping pattern
- 3) The respondent is advised that they have been given a car to use for free (except the cost of fuel), on the pretext that a relative living nearby had moved away for six months and asked them to watch their car.
- 4) They are asked to indicate a new pattern of how they would carry out their food shopping in this set of circumstances (with their relative's car available to use if they wish)
- 5) They are then advised that their relative had returned home unexpectedly and is taking their car back.
- 6) They are presented the generic attributes of a one-way-usage carsharing service (see Figure 1)
- 7) They are presented with the specific attributes of a one-way-usage carsharing service and asked whether they would use it.
- 8a) If the respondent indicates that they would *not* use it, the first round of their stated-choice/adaptation game is complete and the survey proceeds to step #9
- 8b) If the respondent indicates that they would use it, they are then asked to indicate a new pattern of how they would perform their food shopping with the use of the one-way-usage carsharing service.
- 9) Steps #7 and 8 were repeated nine more times (for a total of ten replications)

There is an important asymmetry in this design. As can be seen in step #8, there is an asymmetric burden imposed on respondents in each replication depending on their stated choice; this is addressed in the analysis as discussed in Section 4.

Non-car-users first indicate (in step #4) whether and how they would use an almost-free-to-use private car (their 'relative's car'.) This offered an efficiency in terms of respondent

burden, as it allowed respondents who had indicated that they would use their relative's car to indicate "*I would use this car service the same way as my relative's car*" in later replications where they choose to use the carsharing service. They are thus able to do this rather than to complete a new pattern each time, if they wish.

Respondents characterize their existing and prospective grocery shopping patterns along the following dimensions:

- The *number* of food shops that they regularly visit (this was limited to a maximum of three shops)
- The *frequency* at which they visit each of these food shops
- The *access mode* they use to get to each of these food shops
- The *egress mode* they use to leave from each of these shops
- The *duration* of each of these access and egress journeys

In order to facilitate gathering this 'pattern' information from the respondent, they were first asked to type in the name of the shops that they regularly visit. Subsequent questions were adapted to the shop names they reported. (e.g. "*How often do you go to \_\_\_\_\_*") Figure 1 shows a sample game board for collecting respondents' existing grocery shopping pattern.

The listing of access modes to/from grocery stores from which respondents chose (See Figure 1) included a single category 'car' which we intended respondents to interpret to encompass both private car *driving* and private car *passenger* travel. In a replication where a respondent had indicated that they would use a carsharing system and were then asked to input their new grocery shopping pattern, they were presented with the additional option 'this car service'. (It appears that many respondents did not distinguish between the 'car' option and 'this car service' options as we had intended. In the discussion of results below the two categories are combined into a single 'car' mode of transport.) This design was not sensitive to participation in online grocery shopping activities; a respondent would have left any online shopping off of their [either existing or modified, as appropriate] grocery shopping pattern. Future applications of this method could address these design choices in different ways.

The one-way carsharing services varied along five dimensions (the design variables):

- Cost per one-way journey (£1, £3, and £5 / journey)
- Cost per annual subscription (£0, £30, and £100)
- Average walking distance to nearest available carsharing car (2-3, 5, and 8 minutes)
- Whether carsharing cars are permitted to drive in bus lanes (yes or no)
- Type of vehicles (Volkswagen Polo, Toyota Prius, and VW Touran van)

The survey instrument provided respondents with attributes of one-way carsharing only – not other modes of travel. In this way the protocol relies on the respondent's knowledge of the costs (and other attributes) of other modes of travel to access the grocery stores at which they

shop, and therefore does not require providing this attribute information to respondents as in a more-typical mode-choice experiment.

By asking the respondent to indicate how they shop for groceries, and whether and how this might change under stimulus, the design avoids placing the respondent in an unfamiliar synthesised urban environment. Instead, the respondent indicates their choice in the context of the opportunities and constraints of their own surroundings and proximity to grocery stores, with the only hypothetical change being the introduction of one-way carsharing.

How often do you go to each store? \*

	Daily	3-4 times a week	1-2 times a week	2-3 times per month	once a month
Store A	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Store B	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Store C	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>

How do you GET TO each shop most often?

	Walk	Cycle	Bus	Tran / Tube	Car	Taxi	Other
Store A	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Store B	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Store C	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>				

How do you GET BACK FROM each shop most often?

	Walk	Cycle	Bus	Tran / Tube	Car	Taxi	Other
Store A	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Store B	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Store C	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

How long does it take to GET TO each shop with the method you described above? \*

	1-2 minutes	less than 5 minutes	5-10 minutes	10-15 minutes	more than 15 minutes
Store A	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Store B	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>
Store C	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

How long does it take to GET BACK FROM each shop with the method you described above? \*

	1-2 minutes	less than 5 minutes	5-10 minutes	10-15 minutes	more than 15 minutes
Store A	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Store B	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Store C	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>

Next

**Figure 1: Sample screen for reporting an existing food shopping pattern**

An orthogonal experimental design was employed. In the results presented below the ‘type of car’ variable is not analyzed, resulting in the four design dimensions discussed in Section 4.

The survey instrument was piloted in early spring 2011, and fieldwork took place between April and June 2011. As this application was exploratory of the survey method, the sample was not representative. A sample of 72 non-car-owning respondents was recruited from three sources (number of respondents in brackets):

- Fourth-year civil engineering undergraduate students at Imperial College (29)
- Masters students (9)
- Londoners at large, via a social networking website (34)

The survey instrument restricted each IP address (i.e. computer connected to the internet) to no more than one response. Available resources did not permit providing incentives to respondents. All respondents were screened for 1) holding a drivers license, and 2) reporting that they ‘regularly’ shop for groceries; those not meeting both of these criteria were not permitted to perform the survey.

#### 4. Results

A total of 563 responses were obtained from the 72 respondents who were not car owners (a small number of other respondents owned cars; they are not included in this analysis.)

58% of the sample were men; 53%, 42%, and 6% of respondents were aged 18-24, 25-34, and 35-59, respectively. 34% of respondents indicated they were employed.

The overall response rate is not knowable due to the electronic recruitment methods, though amongst the undergraduate portion of the sample the 29 surveys imply a 25% response rate amongst this group. The results may be subject to sampling bias as the sample is not representative, and this must be borne in mind when interpreting the statistical results.

46% of respondents chose to use the carsharing service at least once. Carsharing services were selected in 16% of replications; the gender gap was small, with men selecting it 17% of the time and women 15%. 55% of respondents using carsharing services indicated they would use it in the same pattern as their 'relative's car', with the rest choosing to provide a distinct grocery shopping pattern when using one-way carsharing. 27% of respondents using one-way carsharing chose to switch only travel mode while maintaining the frequency of their grocery shopping and visiting the same stores; the other 73% indicated that they would change one or both of these aspects.

Carsharing was chosen 5% less frequently for trips *to* grocery stores than *from* them; one interpretation of this is that people find the cargo-carrying capacity of a car to be more attractive when they are burdened with groceries.

The analysis strategy consisted of two parts. First, binary choice models were estimated to identify the effects of the design variables and respondents' personal characteristics on the tendency to use one-way-usage carsharing services. The second part of the analysis strategy was more complex and analyzed how people would take advantage of carsharing to restructure their grocery shopping patterns. Descriptive results regarding people's patterns are presented, followed by analysis of how they would change on several dimensions using seemingly-unrelated regression techniques to account for the possibility of correlated errors across them.

It is worth emphasizing that the data produced by this method is different than is typically used in mode choice models. No information is given to respondents (or gathered from them) regarding travel times and journey costs for various alternative modes of transport. Further the full set of pattern options (which would be a very large set) is not observed; rather the only patterns observed are a respondent's existing pattern and their adapted pattern after one-way carsharing is introduced.)

#### Participation in one-way carsharing

Binary choice models were estimated with the respondent's choice specified to be, for each replication which they completed, whether or not they indicated that they would use a

carsharing service (Bierlaire 2003). The results are presented in Table 1. p-values for the estimated parameters are in parentheses; p-values are not shown for effects that are significant at the 0.05 level. Due to the properties of the data sample (described above), it cannot be unambiguously asserted that the specific empirical findings extend beyond this sample of respondents.

	<b>Baseline binary choice model</b>	<b>Binary choice model with gender interaction effects</b>
Null log-likelihood	-390.24	-390.24
Log-likelihood	-155.21	-150.24
Adjusted $\rho^2$	0.577	0.584
Constant (not using the carsharing service)	-0.064	-0.20
Variance of the constant for not using the service	2.70	2.85
Fatigue effect: parameter for ln(replication number)	-0.55	-0.60
Respondent is a full-time student	2.12	2.17
Service allows use of bus lane network	0.87	0.88
Service cost per journey (£)	-0.67	-0.50
Service cost per year (£)	-0.022	-0.024
Average walking time to service cars (mins.)	-0.29	-0.48
Frequency of food shopping activities per month currently performed by respondent	-0.078	-0.084
Number of hours per month respondent currently travels to/from food shopping	0.65	0.71
Service cost per journey (£,interaction with male gender)	--	-0.40 (0.10)
Average walking time to service cars (mins. interaction with male gender)	--	0.32

**Table 1: Results from binary choice models of the decision to use a one-way-usage carsharing service**

The choice model was a mixed logit form (1000 draws) to account for the panel data structure; as expected we found significant heterogeneity in people's propensity to use one-way carsharing services (this is captured by the significant value for the variance of the constant for not using a carsharing service.)

This model specification also accounts for the previously-noted asymmetry in the survey design. Less effort was required for a respondent to indicate 'no' in any given replication than to indicate that they would use the carsharing service, as after indicating 'yes' they were

then asked to report what their restructured activity pattern would be. It was therefore hypothesized that respondents would learn this and in later replications would *ceteris paribus* have a greater tendency to indicate 'no'. This hypothesis was confirmed (within our data sample) and it was found that an exponential functional form best represented this fatigue effect (power and linear-decay forms were also tested; results are available from the authors on request).

More frequent grocery shopping was associated with less likelihood of using the carsharing service. The opposite was found for the amount of time per month that a person spends traveling to and from grocery stores. With regard to the former effect one may speculate that less-frequent food shopping could mean more groceries to carry on each occasion, thus making the use of car a more attractive proposition. The latter effect could be interpreted to mean that people who spend more time getting to/from grocery stores find the relative speed offered by a car more appealing.

Vehicle type did not have a significant effect on propensity to use a carsharing service, though in the baseline binary choice model (in the left-hand column of Table 1) the estimated sign of parameters for all other design variables was as expected. Saving time and money were both valued by respondents. This provides *prima facie* support for the data collection strategy; respondents behaving in unexpected ways with regard to these standard attributes would have raised questions about the survey technique.

Being a full-time student was found to be associated with an increased tendency to use one-way carsharing. The right-hand column in Table 1 presents results when gender is interacted with the design variables. Men were less sensitive to the walking distance to carsharing cars and more sensitive to the cost per journey, though the latter effect is statistically-significant at  $p=0.10$ , not  $p=0.05$ .

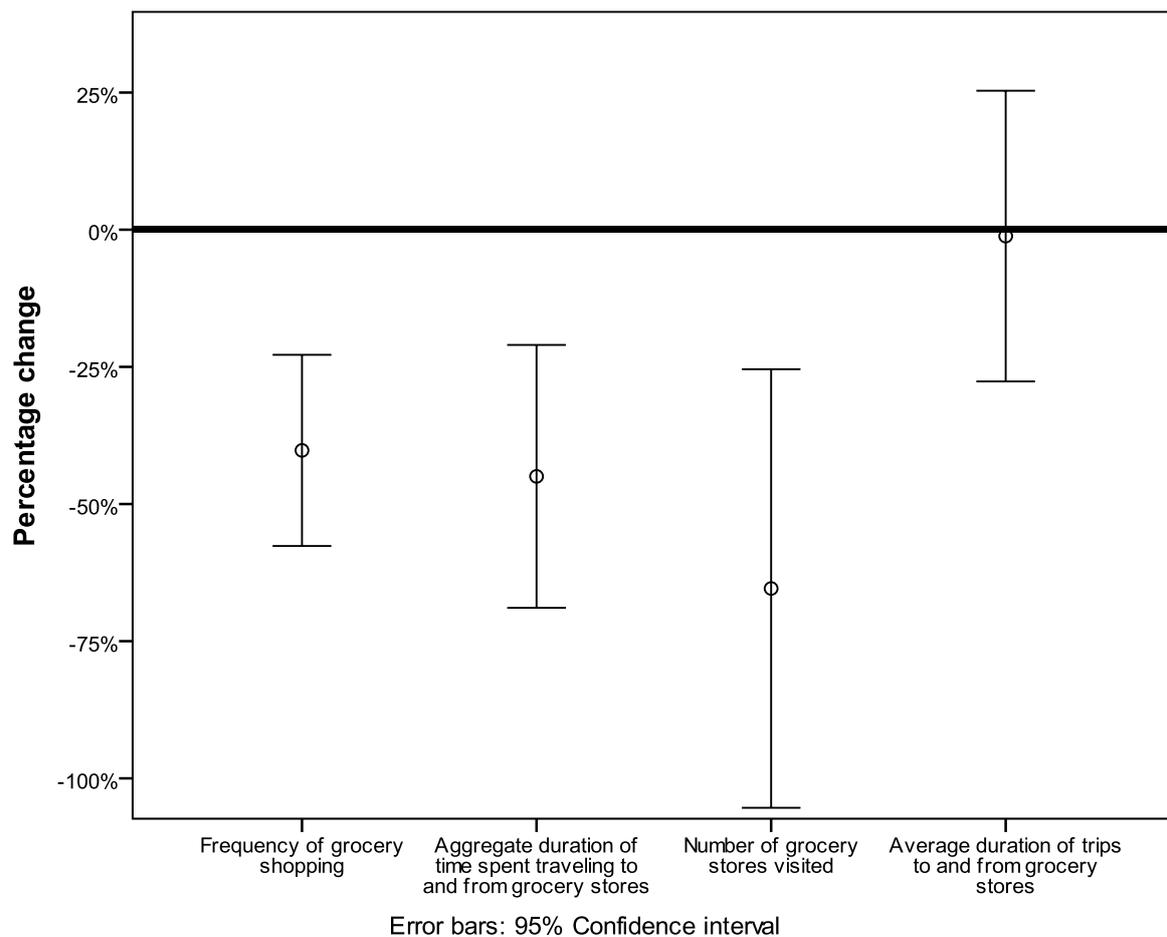
### **Descriptive results of food shopping patterns**

Table 2 presents descriptive results for respondents' food shopping patterns.

Variable	Existing patterns (all respondents)		Existing patterns (respondents that chose to use a one- way carsharing service at least once)		Patterns when choosing to use a one-way carsharing service	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Frequency of grocery shopping, per month	12.9	7.9	12.7	7.3	7.6	6.4
Aggregate duration of travel to and from grocery stores, minutes per month	153.6	132.7	180.8	154.3	99.5	113.5
Number of different stores visited	1.9	0.8	2.1	0.9	1.6	0.7
Number of walking journeys	20.8	17.2	19.8	16.2	5.2	11.7
Number of bicycling journeys	1.7	6.0	2.2	7.3	0.1	0.4
Number of bus journeys	1.8	5.9	2.1	5.4	0.1	0.8
Number of train/metro journeys	0.3	1.8	0.7	2.6	0.4	2.3
Number of taxi journeys	0.1	0.8	0.2	1.1	<0.05	0.1
Number of one-way carsharing journeys	--	--	--	--	9.5	7.8
Aggregate time spent on walking journeys (minutes)	103.7	117.5	120.2	138.4	33.0	73.3
Aggregate time spent on bicycling journeys	11.7	42.1	16.6	54.3	0.3	1.2
Aggregate time spent on bus journeys	21.4	68.3	27.0	69.7	2.7	15.7
Aggregate time spent on train/metro journeys	5.1	29.1	11.1	42.6	8.1	45.2
Aggregate time spent on taxi journeys	1.1	9.6	2.5	14.1	0.0	0.0
Aggregate time spent on one-way carsharing journeys	--	--	--	--	55.3	45.9

**Table 2: Summary of people's food shopping patterns, existing and after adopting a one-way-usage carsharing service**

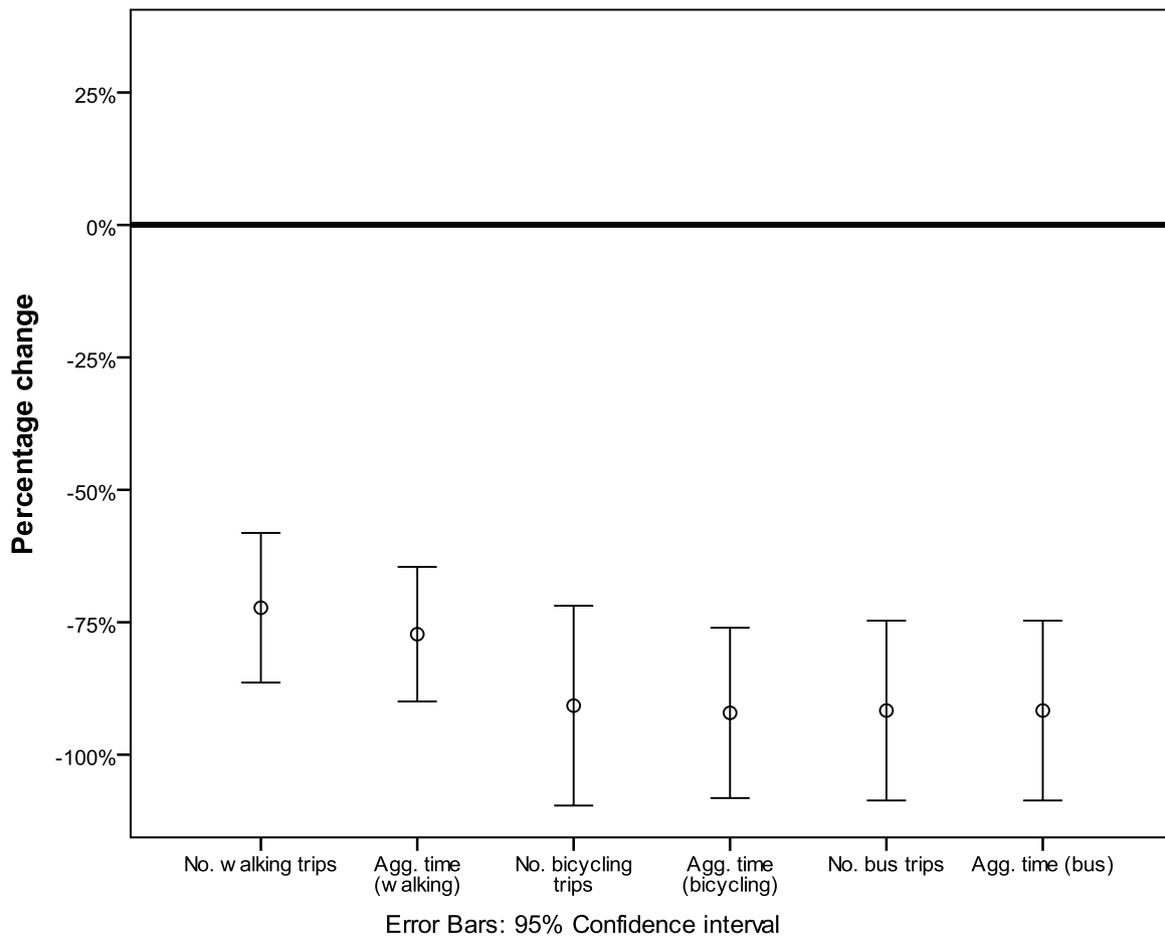
Respondents opting to use the one-way carsharing service tended to shop less frequently, spend less time traveling, and visit fewer food stores than they do in its absence (see Figure 2.) This may indicate shopping at ‘big box’ stores rather than neighborhood shops, though this cannot be known for certain as store type was not captured in the survey instrument. The effects along these three dimensions (frequency of food shopping, aggregate time spent travelling, and number of stores visited) were highly correlated: the three correlation coefficients ranged between 0.50 and 0.75. Also shown in Figure 2 is that no significant effect was found on average trip duration, which was roughly six minutes both before and after introducing the service.



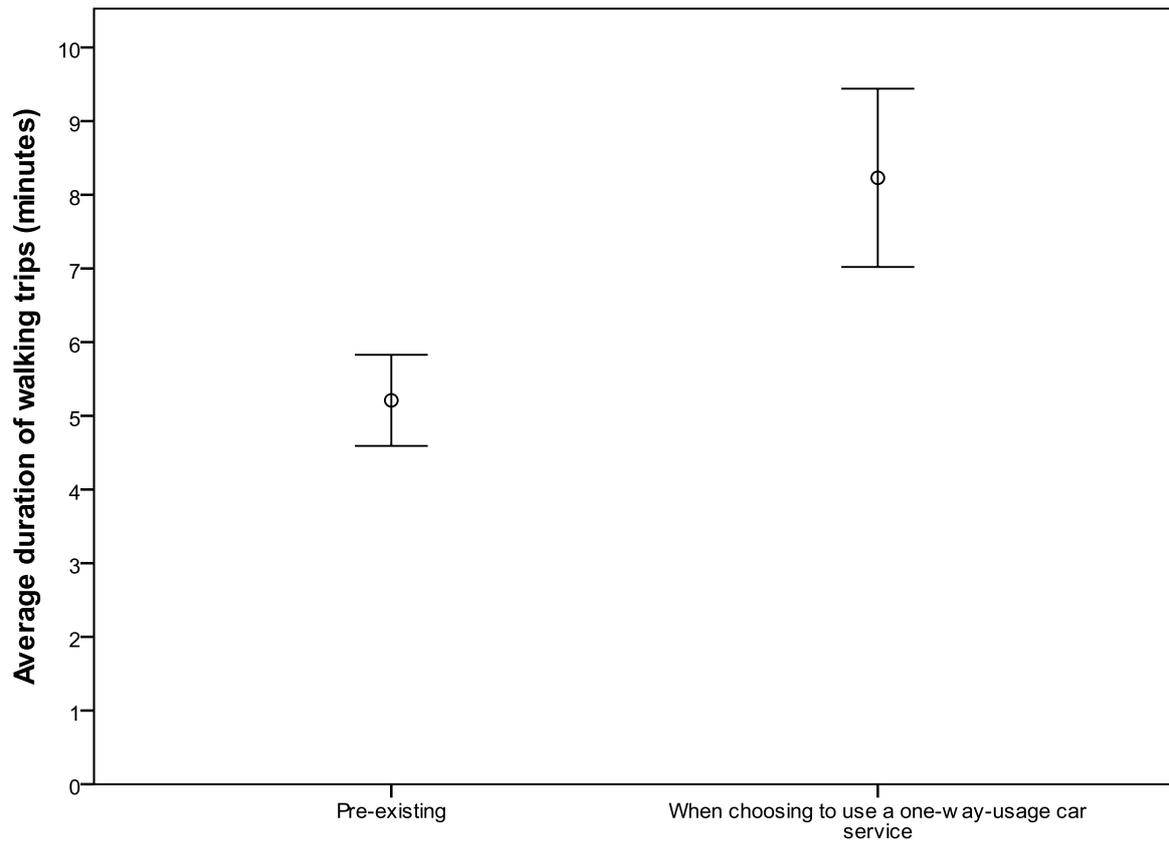
**Figure 2: Effects on people's food shopping patterns from introducing a one-way-usage carsharing service**

Figure 3 shows, amongst respondents who would use a one-way carsharing service, the changes on their walking, bicycling, and bus usage associated with the introduction of the service. Bicycling and bus travel each fell by 90%, with the number of walking journeys falling as well but not as sharply. The fall in use of active transport (walking and bicycling) suggests that introducing innovative shared-car services could negatively affect physical activity levels, at least amongst people who are not car owners.

Given the growing attention directed to the interaction of transportation networks and physical activity, the impacts on walking levels were investigated further. Figure 4 shows that residual walking trips for some food shopping journeys were on average significantly longer-duration than pre-existing walking trips. In other words one-way carsharing was found to disproportionately displace short walking journeys, which is indicative of the consolidation of food shopping activities from more-frequent episodes accessed on foot to less-frequent car-accessed episodes. Figure 5 illustrates this finding by comparing the before-and-after trip-duration distributions for people who said they would use one-way-usage carsharing.

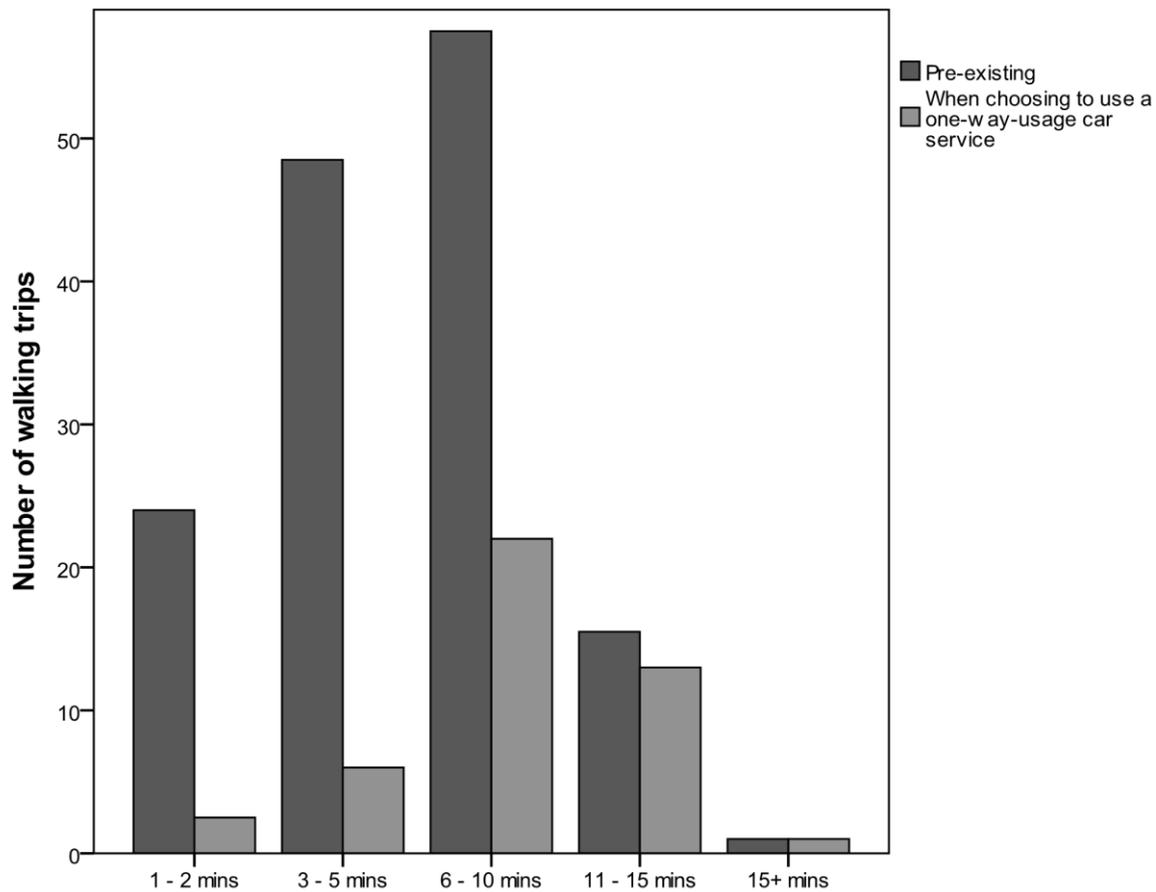


**Figure 3: Effects on people's use of transport modes (number of journeys and aggregate time traveling) associated with introducing a one-way-usage carsharing service**



Error Bars: 95% Confidence interval

**Figure 4: Average duration of walking trips in existing and modified food shopping patterns, amongst respondents choosing to use a one-way-usage car service**



**Figure 5: Trip-duration distribution of walking trips in people’s existing and modified food shopping patterns, amongst people choosing to use a one-way-usage car service**

### **Multivariate analysis of changes in food shopping patterns**

A set of three linear regression models was prepared to analyse the changes in the structure of food shopping patterns. Each regression model independently predicted change along one of three dimensions (frequency, aggregate travel duration, and number of stores visited).

The *seemingly-unrelated regression* (SUR) technique is appropriate in the case of correlated errors of this type, as it provides efficiency gains relative to standard linear regression. Table 3 shows the results.

As expected the errors were positively correlated: if a person’s observed change in frequency was under-predicted, it was likely that their change along the other two dimensions was as well (the correlations between the three vectors of error terms were in the range between 0.52 and 0.56.) Two-way interaction terms were investigated. p-values for the estimated parameters are in parentheses; all effects shown are significant at the 0.05 level.

	Net change in frequency of grocery shopping, per month	Net change in aggregate duration of travel to and from grocery shops, minutes per month	Net change in number of different stores visited, per month
$r^2$	0.64	0.48	0.71
Constant	6.66	18.05	0.095
Respondent is male	--	--	0.55
Respondent is a full-time student	--	74.69	0.37
Number of food shopping activities per month respondent currently performs	-0.31	4.74	-0.039
Number of minutes per month respondent currently travels to/from food shopping	-0.037	-2.02	0.0053
Number of different stores visited at present, per month	-3.21	--	-0.34
Interaction of frequency and aggregate duration	--	--	0.00013
Interaction of frequency and number of stores	--	-3.24	--
Interaction of aggregate duration and number of stores	--	-0.63	-0.0028

**Table 3: Results from seemingly-unrelated regression analysis of changes in food shopping patterns**

The SUR analysis shows that net change along each dimension is negatively associated with the corresponding aspect of a person's existing pattern. In other words, people who shop for groceries frequently are predicted to have the largest decreases in their frequency of grocery shopping (*ceteris paribus*), with analogous effects for aggregate travel time and number of stores visited.

Being male was associated with a positive change in the number of stores visited, and being a full-time student had a positive effect on both the net change in aggregate duration of travel and the number of stores visited. Several interaction effects were found to be significant, though their interpretation is not discussed here in the interest of space.

## 5. Conclusions

The discussion of conclusions begins with findings relating to how respondents interacted with the stated-response instrument. The survey design imposed an asymmetric burden which depended on whether or not a respondent chose in any given replication of the survey to use a one-way carsharing service. This introduced an identifiable fatigue effect into the results which took the form of a *ceteris paribus* decreasing propensity to choose to use a service as a respondent proceeds through the experiment.

The findings relating to the impacts of one-way carsharing are only applicable to non-car-users; car users were excluded from the analysis. The results must also be viewed as indicative, as the sample of respondents was not representative of the population at large. Within the sample, a positive relationship was found between the amount of time one spends traveling to and from food stores at present and their propensity to use a prospective one-way carsharing for grocery shopping. Using the service led to less-frequent grocery shopping, and while one-third of respondents using one-way carsharing said they would also walk for some food shopping trips, they would spend significantly less time walking. This last point has important implications as, due to growing concerns about public health, transportation planners must increasingly consider the impacts of their actions on people's physical activity levels. The results relating to modal usage are consistent with previous evidence showing that subscription to one-way carsharing is associated, amongst people who do not own a car, with less walking, bicycling, and public transport usage (Firnkor 2012).

This study was designed to establish and quantify a limited number of effects relating to patterns of grocery shopping and the outcomes associated with them. Issues not addressed here that require further enquiry include demographic and attitudinal indicators, investigating the types of food stores (big box, supermarket, convenience, ethnic, etc.) that people visit, as well as the possibility that the perceived quality of food shopping activities could change when new forms of transport become available. It is also of interest to understand how at times of flux people may choose to re-allocate food shopping responsibilities amongst family members.

We now turn to the implications for using techniques based on activity/travel patterns in service of personal needs to predict the impacts of new forms of transport or other supply-side changes.

First, this research contributes to the growing set of evidence showing that people react to new mobility offers in ways that are more far-reaching than can be represented by the current generation of activity-based models of personal mobility. It highlights the need for such methods to be sensitive to the links between temporally-separated activity episodes that together may form a sort of strategy for addressing a broader personal (or group) need/desire. Failing to incorporate such links could lead to bias and hence misleading inferences. This research also provides support for the proposition that researchers and public agencies should consider moving towards multi-day activity/travel diaries as the standard rather than one- or

two-day diaries, in order to better capture rhythms in activity/travel behavior. An important issue for the research agenda, therefore, is how to most appropriately collect information from respondents regarding the interdependencies between their activities.

Second, this work contributes to the body of evidence showing that needs-based analysis can fruitfully be integrated in the stated-response context, and the results support enriching the types of choice situations typically used in stated-response methods. Patterns of activity/travel behavior are simple in concept yet powerful, as highly-detailed information can be represented as the combination of scalar data on a small number of dimensions. Issues to do with people's ability to accurately recall activity/travel behavior, however, take on increased urgency. There is the possibility for unique forms of bias due to people collapsing the full complexity of their activity/travel patterns – which may well not be stable over time – into a small set of dimensions. Grocery shopping was selected for this experimental research as it has intrinsic features that align well with these techniques; it is less clear how they would work with other types of people's wants/needs which may be more variable from person-to-person and perhaps less rhythmic (e.g. leisure pursuits.) Though this application excluded second-order effects, in principle they ought to be taken into account. For instance it would be of substantive interest to explore what a person would do with the freed-up time if they would shop for food less frequently.

Transport planners face increasing requirements to quantify the impacts of emerging shared-mobility services (of which one-way carsharing is one example). Private-sector operators cannot access the public street space that they require without negotiations with public-sector road network management agencies regarding the prices and terms of this access. But setting optimal prices and terms is a non-trivial task. Hence understanding – as richly as possible and at as fine a level of granularity as possible – how changes in mobility options may result in people re-structuring their activity/mobility patterns remains an important stream of transport research with practical implications. This paper develops a set of techniques in this regard, though further work will be required to determine the degree to which they are generalizable to other contexts in which the stimulus under study could be much weaker than the introduction of an entirely new mode of transport.

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