A new approach to predict the market and impacts of round-trip and point-to-point carsharing systems: Case study of London

Postprint of:

Scott Le Vine (levines@newpaltz.edu / slevine@imperial.ac.uk), Martin Lee-Gosselin (Martin.Lee-Gosselin@crad.ulaval.ca), Aruna Sivakumar (a.sivakumar@imperial.ac.uk), and John Polak (j.polak@imperial.ac.uk)
1. Introduction

Carsharing (CS) is a form of short-term car access made practical by the confluence of falling prices for the necessary information technologies, forward-looking entrepreneurs, and policy support from the public sector. CS systems began emerging at commercial scale in the mid-1990s, though experiments with small-scale demonstration projects took place as early as the 1940s (Harms and Truffer 1998). At the time of writing the number of CS subscribers globally is reported to be well over a million (Shaheen and Cohen 2013).

Two important sets of research questions regarding CS are 1) what is the size of the potential market for various types of CS services?, and 2) what are the knock-on effects on usage of other forms of transport?

This paper addresses these questions by drawing on techniques developed by the authors as part of a multi-year study investigating the methodological challenges posed by CS. It is the last of the series arising from this line of enquiry; earlier papers have presented: qualitative research (Le Vine et al. 2009), a novel strategic/tactical stated-choice survey instrument (Le Vine et al. 2011), a method for empirically-constrained efficient survey design (Le Vine et al. 2013a), and a framework for modelling carsharing behavior based on a concept of accessibility termed the Perceived Activity Set (PAS) (Le Vine et al. 2013b).

We present here the first empirical results from employing the PAS framework to investigate carsharing. The method is sensitive to CS’ distinctive combination of fixed and marginal (usage) costs, as well as its complex pattern of substitution/complementarity with other forms of transport. The latter issue is particularly relevant to calculating CS’ sustainability benefits: some users increase their car travel when they subscribe to a CS service, others decrease theirs, and these two effects must be netted against each other to identify the overall impact on car use and emissions (Martin and Shaheen 2010). Subscribers tend to use CS infrequently, much less often than car owners drive privately-owned cars, and the PAS-based technique involving trade-offs between fixed and marginal costs is particularly suitable for analyzing this aspect of CS.

The empirical analysis in this paper examines two forms of CS systems – the ‘round-trip’ business model, and the more recently-emerging ‘point-to-point’ business model. In this paper we consider centrally-owned fleets, as opposed to peer-to-peer CS services (Chen et al. 2014, Clark et al. 2014).

Round-trip CS describes systems in which the user must return the CS vehicle to its starting point at the end of their usage episode (Shaheen and Cohen 2013a). The episode thus includes both the travel to and from a destination(s) and the time spent whilst there. Paying during the time spent at an activity is analogous to time-based parking charges. Advance reservations are required, though at times of low utilization it can be possible to find an available vehicle on short notice. In certain instances, round-trip CS services are designed to serve specific market segments such as university campuses.

Point-to-point CS services do not require the customer to return a CS car to the same place it was taken from (Firnkorn 2012). There are exceptions, though in most cases usage in point-to-point CS systems is spontaneous, without an advance reservation. In comparison to round-trip CS, the user thus has more flexibility over when and for how long they use a CS car, but at the expense of a lower degree of assuredness that a car will be available when desired. The user pays by the minute whilst
they are traveling, and may be able to pay a reduced rate whilst parked at a destination if they wish to continue their exclusive access to the vehicle. In some cases cars can be picked up and dropped off only at fixed stations, whereas in other systems the vehicles can be kept in [nearly] any legal on-street parking space.

The empirical setting for this study is Greater London, England. Two datasets (one revealed-choice, the other stated-choice) with complementary properties are pooled to draw on their representative strengths. The sample sizes are modest, however, particularly for the stated-choice survey (n=704 respondents from 300 households in the revealed-choice dataset; n=72 respondents, each performing 4 repetitions of the choice task in the stated-choice dataset). The modest stated-choice sample size is due to the relatively high unit cost (£69/respondent), as the interview was more complex and longer in duration than typical stated-choice surveys, and required administration with an interviewer present. Therefore, despite re-weighting the data to match London’s car ownership and CS-subscription levels, the estimates of market size and impacts must be viewed as indicative-only. These are however the first empirical results arising from the use of this class of techniques to analyse carsharing, and an important item for the future research agenda is to implement these methods with larger-scale, nationally-representative datasets.

The remainder of this paper is structured as follows. Section 2 presents background regarding earlier methods to analyse the CS market and its impacts. Section 3 introduces the methods and empirical data used in this study. The results are in Section 4, and Section 5 concludes the paper.

2. Background
CS represents a very different form of access to car-borne mobility than private car ownership. Buying a car requires relatively large fixed costs (purchase, insurance, maintenance, etc.), as well as securing parking for it. Any fixed costs to subscribe to a CS service are much lower, but the usage costs of driving a CS car are in general substantially higher than operating a personal car. The subscriber also has less control over their access to use a car when and where they wish than they would with a personal car that they own. A person may of course also choose to neither purchase a car nor subscribe to a CS service; they incur no fixed costs from either car ownership or CS subscription, but are limited to much less flexible and reliable options if they wish to access a car. Each of these three states (car ownership, CS subscription, neither) therefore represent different bundles of fixed and per-usage costs and mobility characteristics.

The CS market has important public policy implications. In addition to the possibility of helping to deliver emissions reductions from the transport sector, other possible benefits include increased active travel (i.e. walking and cycling) and reduced parking needs for privately-owned cars. Conversely, vehicles in a CS fleet themselves require parking; the net impact on parking needs arises from a balancing among countervailing effects, and empirically it is typically found that overall parking needs are reduced (cf. Table 2 in Shaheen and Cohen 2013b). There is also keen interest from policymakers as these services typically require the support, or at least acquiescence, of the public sector. This is most frequently for privileged access to on-street parking space, which in many CS-served neighborhoods is limited and politically-contentious.
The first recorded CS system was in Zurich, Switzerland in 1948, using the round-trip CS operating model. Readers are referred to (Harms and Truffer 1992; Parvianen 1983; Shaheen et al. 1998; Britton 2000; Robert 2005) for listings and descriptions of early CS programs, and detailed discussion of the history of CS. The first point-to-point CS service is thought to be the Witkar project in the Netherlands (Bendixson and Richards 1976.) After a lull in activity, the first commercial point-to-point system entered service in 2009, and at the time of writing services operate in more than two dozen cities in North America and Western and Central Europe (Car2go 2014, DriveNow 2014, Autolib’ 2014).

London at present is home to a fleet of approximately 2,200 round-trip CS cars (Carplus 2013). From December 2012 to May 2014, a small-scale system of approximately 30 point-to-point CS cars operated within limited the boundaries of one of London’s 33 boroughs (car2go 2014). There were plans to expand subject to wider agreement with street-network-management agencies for access to on-street parking spaces, but the service was withdrawn in May 2014 when the operator withdrew the service as it was unable to obtain the access rights to on-street parking space that it had sought (Taylor 2014).

2.1 Carsharing market analyses

Though techniques to forecast car ownership levels have a long history (cf. Chow 1957, Mogridge 1967, Tanner 1980, Hensher et al. 1992, de Jong et al. 2002) few studies have attempted to do the same for CS (Millard-Ball et al. 2005).

One technique to identify the market for CS has been to identify potential subscribers to be those who drive a car for less than a threshold level of annual distance traveled (Schuster et al. 2005.) A more-sophisticated version of this strategy is to identify prospective CS participants as those that could benefit financially from carsharing in lieu of a household vehicle; Duncan (2010), for instance, employed a strategy that was sensitive to the relationship between the temporal characteristics of vehicle-tours and the costs of round-trip CS usage. A third approach has been to identify people with particular socio-economic characteristics as likely subscribers and project rates of penetration for each segment. (e.g. Steinginer et al. 1996, Muheim 1998, Dallaire et al. 2007, Clark 2010.) Such studies are limited in that they attempt to predict an outcome (whether a person subscribes or not), without taking account of the drivers of the decision-making process that leads to it. Rabbit and Ghosh (2013) present an innovative study that combined demographic segmentation with analysis of people’s multi-week pattern of revealed travel behavior, to estimate whether individuals would derive a financial benefit from subscribing to a CS service. An important new research direction was introduced by Ciari et al (2011); the authors employ an activity-based microsimulation model to predict carsharing take-up, thus explicitly accounting for the complex links between people’s travel needs, carsharing usage, and the demand for other forms of travel. In addition to literature in the public domain with known methodologies, other market forecasts for which the methods are not publicly-available have been widely-quoted (cf. Ziegler 2009, Zhao 2010). Though the forecasts from these studies come from a variety of points in time and spatial contexts, and hence cannot be directly compared, they implication is that the number of CS subscribers could range from low single digits up to approximately 20% of the population in a variety of Western countries.

Whilst there have been relatively few rigorous efforts to forecast the potential market for carsharing, a more-common approach has been to quantify the impacts of round-trip CS on the
travel patterns of current subscribers (and hence their transport-related emissions). Katzev (2003) reports that a large majority of round-trip CS subscribers in Portland, Oregon either sold their car before subscribing or indicated that they were able to avoid a purchase they otherwise would have made. Zhou (2012) found that the frequency of CS usage relates positively with provision of commuter benefits. A wide-ranging study (Martin and Shaheen 2010) systematically investigated the impact of round-trip CS services across North America. The authors report that whilst most round-trip CS subscribers are driving somewhat more than they would if they did not have a round-trip CS subscription, the minority who are driving less are on average driving a lot less, and that on balance round-trip CS leads to less overall driving. Martin and Shaheen (2010) also report a net reduction in private car ownership. Similar results have been found in Britain (Harmer and Cairns 2011, SDG 2013) where CS subscribers are surveyed annually. Loose (2010) reported several distinct environmental benefits of round-trip CS on the basis of a survey of European round-trip CS operators, including car ownership reductions, use of comparatively low-emitting vehicles in CS fleets (relative to privately owned cars), and CS subscribers’ relatively high use of non-car forms of transport. Firnkorn (2012) reports from a study in Ulm, Germany that the net impact of point-to-point carsharing was to reduce the use of all other forms of transport measured in the study, including private cars, public transport, and active travel.

Such studies are based on reported car ownership and driving distance before and after subscribing, and in many instances also a hypothetical comparison of current behavior against hypothetical current behavior if a CS service did not exist. A more sophisticated experimental design was employed by Cervero and colleagues in a series of studies (Cervero 2002, Cervero and Tsai 2003, Cervero et al. 2006.) A group of people wishing to join a CS service but unable to do so because their neighborhood was not served by CS was retained as a control group for surveying over multiple waves. The authors found that CS subscribers reduced their driving distance significantly relative to this control group. It is also worth noting the introduction of life-cycle analysis principles by Crane et al. (2012) to quantify CS’ impact on emissions (including emissions from vehicle manufacturing and scrappage, in addition to usage).

3. Methods and data
The line of research encompassing this study began with qualitative inquiry to investigate people’s views regarding subscribing to and using CS services. This was then followed by quantitative modeling that we report here, which developed techniques to forecast the potential number of subscribers, level of usage, and impacts on usage of other forms of transport. Readers interested in the qualitative research are referred to Le Vine et al. (2009).

3.1 Modelling concepts
The modelling framework outlined in this section was introduced in (Le Vine et al. 2013b), which examined its theoretical properties but did not make use of it to investigate CS.

We define mobility resources as products or services that enable travel in some way. Examples include personal cars, fuel, driver’s licences, public transport tickets (whether pay-per-journey or unlimited for a given time period), bicycles, walking shoes, membership in a frequent-flyer programme, etc. In principle such resources are not restricted to market products and would also include knowledge such as that of a network’s topology / operating characteristics. For instance,
using public transport requires both some sort of a ticket product and knowledge of how the system works; driving one’s personal car requires owning the personal car and having a driver’s licence and requisite driving knowledge. In this study we focus on a subset of market-traded mobility resources which have moderate-to-high fixed costs, thus requiring a substantial level of commitment, and are durable (though not permanent) since they can be used over a large set of journeys:

- Personal cars
- Bicycles
- Public transport season tickets
- Two types of subscriptions to CS services
  - Round-trip CS
  - Point-to-point CS

Mobility resources are not mutually exclusive; a person may own none, one, or several. It is specified that people choose which portfolio of resources to own on the basis of a weighing between the fixed costs of acquiring the resources, and the marginal costs and mobility benefits they enable over a set of journey needs.

A person’s choice of resource portfolio is termed strategic, and their choices of travel modes tactical. The strategic choice conditions a person’s options for making future tactical choices, whilst the strategic choice is made on the basis of an expectation of the constraints they would set on future tactical choices.

These ‘future tactical choices’ are a person’s expected travel needs/desires. We now introduce the term Perceived Activity Set to refer to the out-of-home activities associated with this set of journeys. The PAS is formally defined as the array of activities which a person views, at a particular point in their life, as encompassing their travel needs.

The general model structure is:

\[ U_d^i = V_{d, \text{non-travel}}^i + V_{d, \text{travel}}^i + \epsilon_d^i \] (1)

We introduce the indices \( i, r, d, m, \) and \( j \) to represent people, mobility resources, mobility resource portfolios, modes of travel and journeys, respectively. The utility of portfolio \( d \) to person \( i \) is specified as a summation of a systematic component of utility associated with acquiring and maintaining portfolio \( V_{d, \text{non-travel}}^i \), a second systematic component of utility which relates to the use of modes of travel enabled by portfolio \( d \) on journeys within a person’s PAS \( V_{d, \text{travel}}^i \), and an error term \( \epsilon_d^i \). Equation 1 shows a person’s weighing between the (dis)utility (hassle, expense, etc.) of acquiring and/or maintaining the resources contained within a portfolio and the (dis)utility of using the travel modes which it enables to access activities in their PAS.

The terms on the right-hand-side of Equation 1 can be de-composed in the following manner:

\[ U_d^i = \sum_{r=0, r \in d}^R V_{d, \text{non-travel}}^i + \left( \sum_{j}^J y_{ji} \right) \frac{1}{\lambda \text{travel}} \ln \left( \sum_{m \in \mu_d} \sum_{d, \text{travel}}^M e^{V_{m, \text{travel}}^i} \right) + \epsilon_d^i \] (2)
The first term on the right-hand-side of Equation 2 \( \sum_{r=0}^{R} V_{r}^{i,\text{non-travel}} \) shows that the fixed utility arising from the expense/hassle of owning some portfolio of resources is specified to come from summation across this utility arising from the resources within that portfolio.

The second term \( \left( \sum_{j=1}^{J} \gamma_{j}^{i} \right) \right( \frac{1}{2^{\text{travel}}} \ln \sum_{m=1}^{M} e^{(V_{mij}^{i,\text{travel}} + \mu_{d})} \right) \) shows the specification for utility relating to a person’s expected travel needs. It is hypothesised that a person views how well a portfolio would perform in providing access to a particular activity to be how well the ‘optimal’ mode enabled by this portfolio would perform to access the activity, which is then summed across all activities within the person’s perceived activity set. The selection of the optimal mode from within the set of all modes enabled by portfolio \( d \ (\mu_{d}) \) is reflected by the logsum form. The \( \gamma_{j}^{i} \) terms are ‘importance’ terms; they capture the possibility that people may place higher priority on being able to access certain types of activities than others. For the empirical model estimation the five journey-purpose classes were: escort, shopping/personal-business/other, social, leisure, and work/education. Four \( \gamma_{j}^{i} \) terms were estimated with the fifth fixed at zero for normalisation purposes.

In the empirical analysis, three modes of transport are available regardless of the portfolio chosen (walking, taxi and public transport) whereas each mobility resource enables its corresponding mode of travel. For instance, use of a point-to-point CS service is only possible if a person holds a portfolio of mobility resources that includes a subscription to point-to-point CS, use of a personal car is only possible if a person chooses a portfolio that includes owning a personal car, etc. The set of portfolios is combinatorial and therefore consists of \( 2^5 \) or 32 distinct portfolios.

One important limitation of this specification of the PAS concept relates to induced car use. In this study people’s activity patterns – the frequency, timing and locations of their activities – were assumed to be fixed and independent of the resources they own, though this assumption could in principle be relaxed in further research. What little empirical evidence there is highlights the fluidity of people’s activity patterns: Cervero and colleagues (2006) report that roughly 30% of carsharing journeys would not be made if the service were unavailable, and Le Vine et al. (2013c) show evidence of non-car-owners re-structuring their grocery shopping patterns to take advantage of the capabilities offered by CS services.

### 3.2 Data

This quantitative data employed in this analysis consisted of a combination of datasets, one database from the British National Travel Survey [NTS] and a second database from a purpose-designed stated-choice survey. In the empirical analysis the unit of analysis is the individual; interpersonal interactions within households are neglected.

London (see Figure 1) is the United Kingdom’s largest and most economically important urban area, with a resident population of 8.2 million (as of the 2011 Census); 6.4 million residents are age 17 or over (GLA 2012). Inner London contains the central business district, including the financial district, and is more intensely urbanized than Outer London. At 105 persons/hectare, average residential density in Inner London is approximately 2.5 times that of Outer London. Outer London comprises nearly four times the land area of Inner London, however (GLA 2014). In 2010, 42% of Inner Londoners held a full car driving licence and 18% indicated that they were the ‘main’ driver of a car.
(i.e. they drive a particular car more than anyone else drives it) (authors’ analysis of NTS microdata). The corresponding numbers for Outer London were 55% and 38%, respectively. Also in 2010, the NTS shows Inner Londoners’ modal split (main mode, percentage of the number of journeys) to have been 12% car driving, 10% car passenger, 42% public transport, and 35% other. The mode split for Outer Londoners was more heavily weighted towards car use, with 32% of journeys by car driving, 19% as car passengers, 23% by public transport, and 26% other (authors’ analysis of NTS microdata).

Figure 1: Map of Greater London. Boundaries of London’s 33 local authorities are shown as thin black lines. Heavy black line is the boundary between Inner and Outer London (Source: authors’ own, using data from sources listed on map)

The NTS is based on a seven-day travel diary instrument, as well as an additional three-week diary of long-distance travel (journeys over 50 miles). For each NTS respondent, the data contains the mobility resources which they own as well as their use of travel modes during the weeklong period. These features make it a particularly appealing data source to study CS as most subscribers do not use CS vehicles on a daily basis. Data from 704 individuals living in 300 randomly-selected households living in Greater London were used, sourced from the 2004/05 editions of the NTS (Abeywardana et al. 2006.) Online journey planning services (www.transportdirect.info, journeyplanner.tfl.gov.uk) were used to enhance the NTS ‘as-performed’ journey-level data with the characteristics of alternative itineraries by other methods of travel that were not used. This technique provides finer spatial and temporal granularity than the traditional methods of using PC-based transport network models to generate time/costs of possible journey itineraries.
The NTS records personal travel and some types of business travel (with business journeys defined as those made on behalf of one’s employer in the course of work; commuting journeys fall within the definition of ‘personal’ journeys). Journeys made in the course of one’s work where the purpose of the journey is for the travel to transport him/herself (e.g. a professional traveling to attend a business meeting) are recorded, but other types of business travel are not (e.g. a journey to deliver a parcel or any other item, made on behalf of one’s employer). The implication for this study is that prospective CS usage for certain types of business journeys is not within the scope of the analysis; furthermore this analysis does not take account of the unique behavioral processes associated with business travel (e.g. whether or not one’s employer decides to provide a carsharing subscription is likely to be outside of the control of an individual employee). All travel (both personal and business) within London by non-residents, including workers who live outside of London, is also not taken into account in this study.

The NTS dataset was on its own insufficient for this analysis, however, as it lacks information on subscription to and use of CS services. A stated-choice survey was thus designed to provide data which mimicked the NTS data, but including the possibility of using CS services. Survey respondents were tasked with selecting a pattern of choices simultaneously, which included both composing a portfolio of mobility resources to acquire and which methods of travel to use for accessing each activity in a set of five (see Figure 2.) Each respondent performed four replications of this choice task; in the first two replications round-trip carsharing was available and in the latter two both round-trip and point-to-point carsharing were available. The design and administration of this survey is described in detail in (Le Vine et al. 2011.) In order to ensure that respondents understood the choice tasks, the survey was administered via computer-aided personal interview (CAPI). Respondents were required to complete a practice choice task before the ‘real’ choice tasks, during which the interviewer followed a script to lead the respondent through the functionality of the survey instrument.

Owing to the complex interview and therefore a relatively high level of expense per stated-choice survey respondent (£69/interview), a modest sample size (n=72 respondents, 288 portfolio-choice observations, 1440 mode-choice observations) was achieved; during post-processing survey data were weighted to reflect the known proportions (amongst driving-licence-holding adult Londoners at large) of car owners and round-trip CS service subscribers. Pooling the stated-choice data with the revealed-preference NTS data during the subsequent model estimation minimizes biases associated with hypothetical stated-choice data (Louviere and Hensher 2000).
A quota-based sampling protocol was administered with the sample frame defined as Londoners that hold a full car driving licence. The target and achieved sample consisted of:

- Residents of Greater London who have their own car (target of 25; achieved sample of 18)
- Residents of Greater London who hold a driving licence but do not have their own car (target of 25; achieved sample of 32)
- Residents of Greater London who are current subscribers to a CS service (target of 25; achieved sample of 22)

The descriptive statistics of the stated-choice survey’s 72 respondents (prior to the re-weighting described above) were as follows. For comparison purposes the same descriptive statistics for driving licence holders in London are shown in brackets:

- 54% of stated-choice sample are males (55% of Londoners with a driving licence are males)
- 67% under age 40 (47%)
- 42% live with their partner (64%)
- 81% do not live with children in their household (69%)
- 71% in employment (73%)

Two scale terms are required to account for the use of two datasets in a single estimation. One scale term $\eta$ is included in the estimation that accounts for the different scales of utility in the two datasets, in keeping with standard practice when combining datasets in a joint estimation. A second scale term $\nu$ accounts for differences in the number of observed activities between the two datasets.
(always five in the case of the stated-choice survey; variable in the case of the NTS according to the number of observed activities during each person’s diary week).

4. Results

Using the joint dataset from pooling the NTS and stated-choice data, the model system described in Section 3 was successfully estimated to identify the parameter set shown in Table 1.

<table>
<thead>
<tr>
<th>Null log-likelihood</th>
<th>-2,447.7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Log-likelihood at convergence</td>
<td>-1,976.17</td>
</tr>
<tr>
<td>(Portfolio Choice level) Alternative-specific constant: Own a bicycle</td>
<td>-0.343</td>
</tr>
<tr>
<td>(Portfolio Choice level) ASC Own a car</td>
<td>6.50</td>
</tr>
<tr>
<td>(Portfolio Choice level) ASC Own a public transport season ticket</td>
<td>1.01</td>
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<tr>
<td>(Portfolio Choice level) ASC Subscribe to round-trip carsharing</td>
<td>-4.82</td>
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<tr>
<td>(Portfolio Choice level) ASC Subscribe to point-to-point carsharing</td>
<td>-0.293 (0.51)</td>
</tr>
<tr>
<td>(Mode Choice level) ASC Ride a bicycle</td>
<td>-0.431 (0.22)</td>
</tr>
<tr>
<td>(Mode Choice level) ASC Drive a car (NTS)</td>
<td>0.411 (0.11)</td>
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<tr>
<td>(Mode Choice level) ASC Drive a car (stated-choice)(b)</td>
<td>1.23(b) (0.14)</td>
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<tr>
<td>(Mode Choice level) ASC Drive a round-trip carsharing car</td>
<td>16.3</td>
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<tr>
<td>(Mode Choice level) ASC Drive a point-to-point carsharing car</td>
<td>-1.66 (0.07)</td>
</tr>
<tr>
<td>(Mode Choice level) ASC Shared modes</td>
<td>0*</td>
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<tr>
<td>Fixed holding costs in GBP per month</td>
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<tr>
<td>Fare costs in GBP per journey</td>
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</tr>
<tr>
<td>Travel time in minutes (Drive a car, NTS)</td>
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</tr>
<tr>
<td>Travel time in minutes (Drive a car, stated-choice)(b)</td>
<td>0.0368 (0.27)</td>
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<tr>
<td>Travel time in minutes (Ride a bicycle)</td>
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<tr>
<td>Travel time in minutes (Drive a round-trip carsharing car)</td>
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<tr>
<td>Travel time in minutes (Drive a point-to-point carsharing car)</td>
<td>-0.0570 (0.44)</td>
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<tr>
<td>Travel time in minutes (Shared modes)</td>
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<tr>
<td>(\gamma) for ‘escort’ journey purpose</td>
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<tr>
<td>(\gamma)(leisure)</td>
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<tr>
<td>(\gamma)(shopping, personal business, and other)</td>
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<tr>
<td>(\gamma)(social)</td>
<td>0.100</td>
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<tr>
<td>(\gamma)(work and education)</td>
<td>0.216</td>
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<tr>
<td>Scale term ((\nu)) for all (\gamma) terms (appears only for observations from the stated-choice dataset)</td>
<td>1.67</td>
</tr>
<tr>
<td>Scale term ((\eta)) for systematic utility (appears only for observations from the NTS dataset)</td>
<td>1.30</td>
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<tr>
<td>Logsum term ((\lambda_{travel}))</td>
<td>1.0*</td>
</tr>
</tbody>
</table>

NB: Values in parentheses are p-values; values smaller than 0.05 are suppressed.

*a Value fixed during estimation for normalisation

Table 1: Parameter estimates

All parameter signs are in keeping with a priori expectations, with the exception of the parameter in the stated-choice data for car driving duration. This parameter is positive, but it was not found to be statistically significant (p=0.27). There are plausible reasons that may explain the inability to identify a statistically-significant estimate of this parameter, which relate to the research team having perfect knowledge of fuel and parking costs in the stated-choice experiment (due to control over the
experimental design) but not in the NTS dataset. The possibility of this parameter leading to counter-intuitive marginal effects in the market forecasts is precluded however as the forecasting does not make use of parameters which relate only to the stated-choice dataset.

Also, in the stated-choice experiment respondents were provided with the same set of usage fees for CS in all replications: respondents were presented with £5/hour charges for round-trip CS and 20 (GBP) pence/minute charges for point-to-point CS. Thus the experimental design means that marginal utility for per-minute travel time and per-minute usage costs of CS cannot be distinguished statistically from each other; in Table 1 the travel time parameters for CS reflect the disutility of both travel time and per-minute expense, i.e. the full disutility of using a CS car for each minute.

Following model estimation, sample enumeration (cf. Ben-Akiva and Lerman 1985) was employed using the estimated parameter set and the empirical observations in the NTS dataset, with household-level weighting of the individuals in this dataset to represent the population of Greater London. (Though both the NTS and stated-choice datasets were used in model estimation, only the NTS dataset was used in sample enumeration as it is more representative of Londoners than the stated-choice sample.)

Table 1 presents the results from the application of the model to generate market forecasts for CS services in London. Three representative scenarios were analysed:

1. Scenario #1: Round-trip CS services introduced into Inner London
2. Scenario #2: Round-trip CS services introduced across all of Greater London (Inner and Outer)
3. Scenario #3: As Scenario #2, with the additional introduction of a point-to-point CS service across all of Greater London

It must be noted that the model is designed to produce estimates of market potential; it provides no formal guidance regarding when they might be reached. In the forecasting task, as elsewhere in this study, the universe of potential CS subscribers was restricted to holders of a full car driving licence (1.4 million residents of Inner London and 2.8 million residents of Outer London).

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1 Journey origins and destinations in the publicly-released NTS data are known only at the Government Office Region level of geography; all of London comprises one GOR (Abeywardana et al. 2006). It was therefore not possible to run a scenario with point-to-point CS available only in Inner London.
The remainder of this section considers four distinct dimensions of the CS market in turn: the number of people that are forecast to subscribe to CS, the impacts on the rate of car ownership, use of various modes of transport, and subscribers’ socio-demographics.

### 4.1 Forecasted carsharing subscriptions

Drawing on the sample enumeration results, we forecast that the future market potential for round-trip CS across Greater London is approximately 430,000 subscribers. By way of comparison, at the time of writing there are approximately 131,000 active subscribers to round-trip CS services in Greater London (Carplus 2013).

Point-to-point CS is forecast to have a substantially larger level of take-up in London: 1,570,000 subscribers are forecast; this is roughly three-and-a-half times as many as are forecast for round-trip CS. (The number of subscribers to London’s existing point-to-point CS system of approximately 30 vehicles is not published.)
4.2 Forecasted impacts on car ownership

With the introduction of both types of CS, Londoners’ holdings of all other mobility resources (public transport season tickets, bicycles, and personal cars) are forecast to decrease. In the case of public transport season tickets and bicycles this is a somewhat counter-intuitive finding given that CS services are generally reported to be complementary to non-car methods of travel (e.g. Martin and Shaheen 2010, SDG 2013).

However, in all three scenarios the number of cars owned by Londoners is forecast to be reduced at a rate several times larger than the decrease in the number of bicycles and public transport season tickets. This implies rather intuitively that introducing CS services tends to substitute most strongly on people’s ownership of cars (in comparison to bicycles and season tickets). Introducing round-trip CS across London is forecast to lead to a 3.5% reduction in the number of cars owned by Londoners.

Introducing a point-to-point CS service is forecast to have a quite modest impact on car ownership levels when round-trip CS services are already in operation, of only an additional 0.5% beyond the previous 3.5% reduction. The model suggests that most Londoners who would give up a personal car in exchange for a CS subscription would already have done so due to the introduction of round-trip CS, and that there is little additional reduction in car ownership due to introducing point-to-point CS afterwards. From this analysis it is not knowable whether this is due to the functional differences in the two types of CS services, and if so which specific differences. Further research is required to shed light on this point.

4.3 Forecated use of carsharing vehicles and impacts on other methods of travel

Subscribers to round-trip CS services are forecast to use the services an average of 1.6 times per week (3.3 journeys per week at a nominal rate of two journeys per round-trip tour): this forecast suggests that over time the rate of use-per-subscriber-per-time will increase; SDG (2013) show that at present the average frequency of use in the UK is roughly once per subscriber per month.

Whilst point-to-point CS services would have many more subscribers, they are forecast to be used less intensively: 0.3 trips per subscriber per week. This is somewhat counter-intuitive as point-to-point services are more suitable for commuting journeys, and further research into how CS cars are used is needed to confirm this finding.

Figure 3 shows the distribution of journey purposes for the two types of CS in the stated-choice survey. The same distributions for personal car use and taxi use are included for comparison. It can be seen that survey respondents selected the point-to-point CS service for commuting much more intensively than round-trip CS; respondents predominantly selected the latter for shopping journeys.
The model forecasts that introducing round-trip CS services into Inner London would have very little impact on car-driving vehicle-kilometers of travel (VKT), but that when brought into service across all of London the effect would be an overall reduction in driving. When we simulated the subsequent introduction of point-to-point CS we found more car driving VKT than without it, though there were still fewer VKT than in the baseline simulation when no CS services operated. It can also be seen that when both types of carsharing are in operation the model predicts a reduction in the number of journeys by public transport. It should be noted that this analysis forecasts that round-trip CS and point-to-point CS implemented together led to a net reduction in VKT; it is not knowable from this analysis whether this is also the case for introducing point-to-point CS on its own.

Using driving VKT as a proxy for environmental impacts, we conclude that the greatest environmental benefits were achieved by introducing round-trip CS into Outer London. This analysis suggests that introducing round-trip CS into Inner London, and point-to-point CS across London, would lead to wider access to car use but fewer environmental benefits.

Martin and Shaheen (2010) report that CS subscribers who were previously car owners are a minority of CS users in North America, and that the negative impact of CS on their car driving VKT is larger on a per-subscriber basis than the corresponding increase in VKT amongst CS subscribers who did not previously own a car. Our findings in this study concur with these results from Martin and
Shaheen when analyzing the forecast usage patterns of round-trip CS in Inner London. Only 24% of predicted CS subscribers previously owned a car and were forecast to trade it for a CS subscription. The other three-quarters of predicted CS subscribers previously did not own a car. But these two groups of people changed their travel patterns in quite different ways when subscribing. People who had previously owned a car were found to drive CS cars for 11.3 fewer journeys per week than they had driven their personal car (an average of 16.3 personal car driving journeys/week), but people who did not own a car were found to only drive the CS car for 2.8 journeys per week. While Loose (2010) does not provide results that can be directly compared to the above, it is worth noting that Loose shows that some European carsharing operators indicate that previous-car-owners are a minority of their CS subscribers, while others (e.g. Mobility Carsharing in Switzerland) report that they are the majority.

4.4 Characteristics of predicted round-trip and point-to-point CS subscribers
To summarise results presented earlier in this section, round-trip CS services in London are predicted to have fewer subscribers than point-to-point CS services, but each round-trip user is predicted to use the service more frequently. Table 3 compares demographic characteristics of people that are predicted to subscribe to round-trip CS services and those that are predicted to use point-to-point CS. It can be seen that males are predicted to be under-represented amongst round-trip CS users (relative to adult Londoners at large), but over-represented amongst point-to-point CS users. A minority of users of both CS operating models are predicted to be under age 40 (33% of predicted round-trip users; 48% of point-to-point users); this is counter-intuitive as empirical studies of CS users have generally found that today’s CS users tend to be younger adults. Whether this is indicative of how the CS market may evolve in the future is an important question for the research agenda.

There is a sharp distinction between round-trip and point-to-point CS users in the employment status, with employed adults under-represented among round-trip users and vice versa for point-to-point CS. Predicted users of both types of CS services tend to be better-off financially (in terms of annual household income) than average adult Londoners, and this is a stronger effect for point-to-point CS users (37% live in households with income greater than £50,000, compared to 31% of predicted round-trip CS users and 28% of adult Londoners at large).

Finally, it was found that people predicted to use round-trip carsharing live in postcode sectors with marginally higher residential density than either predicted users of point-to-point CS or adult Londoners at large.
<table>
<thead>
<tr>
<th>Predicted users of round-trip CS services (introduced across all of London)</th>
<th>Predicted users of a point-to-point CS service across all of London</th>
<th>All adult Londoners in the sample-enumeration dataset</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent that are male</td>
<td>41%</td>
<td>57%</td>
</tr>
<tr>
<td>Percent under age 40</td>
<td>33%</td>
<td>48%</td>
</tr>
<tr>
<td>Percent that are employed</td>
<td>40%</td>
<td>78%</td>
</tr>
<tr>
<td>Percent that live in an apartment</td>
<td>38%</td>
<td>38%</td>
</tr>
<tr>
<td>Percent that live in a household with annual income less than £25,000</td>
<td>29%</td>
<td>29%</td>
</tr>
<tr>
<td>Percent that live in a household with annual income between £25,000 and £50,000</td>
<td>40%</td>
<td>34%</td>
</tr>
<tr>
<td>Percent that live in a household with annual income greater than £50,000</td>
<td>31%</td>
<td>37%</td>
</tr>
<tr>
<td>Average residential density of postcode sector (persons/hectare)</td>
<td>68.9</td>
<td>66.4</td>
</tr>
</tbody>
</table>

Table 3: Summary of demographic statistics of predicted round-trip and point-to-point CS subscribers

5. Conclusions

In this paper we report on the first empirical application of a new method to evaluate the market and impacts of carsharing. The proposed technique explicitly analyses CS in the wider context of people’s travel needs and the mobility resources they own. The innovation is that the choices of subscribing to and using a CS service are modelled in a strategic-tactical framework, using the Perceived Activity Set concept.

The analysis is structured such that a person makes a ‘strategic’ choice of whether to subscribe to a CS service on the basis of the extent to which they expect to make use of it in the future. Then, conditional on this strategic choice, CS subscribers are specified to make downstream ‘tactical’ choices of whether to use a CS service to perform individual journeys.
Three important caveats must be borne in mind when interpreting our empirical results. First, relatively expensive personal interviews (£69/respondent) were employed to gather the necessary stated-response data. This dataset therefore had a smaller sample size (n=72 respondents) than would typically be the case for stated-response surveys that are less complex to administer. Second, the analysis focused on prospective users of CS services for personal travel; certain types of business travel were not within the scope of the analysis (due to the British NTS’ journey-recording conventions). Third, this analysis was not sensitive to the possibility of people changing the frequency, timing and location of the out-of-home activities in which they participate.

Subject to these limitations, the empirical results suggest that in London, England the round-trip form of CS has addressed only one-third of its potential market of 430,000 subscribers (out of London’s total 2011 population of 8.2 million residents). But the market for point-to-point CS, a newer type of service, is forecast to be several times larger, at approximately 1,570,000 subscribers.

The results suggest quite intuitively that point-to-point CS in London is likely to be used for very different journey purposes than round-trip CS. Our survey respondents indicated they would use point-to-point CS for commuting at a much higher rate than round-trip CS – an expected finding given their cost structures, but one that raises concerns about impacts on congestion and public transport patronage.

Of three scenarios, we found that the largest environmental benefits from carsharing, as measured by reduced car driving VKT, arise from introducing round-trip CS into Outer London. The principal benefits of round-trip CS in Inner London were found to be in the form of wider access to car use. The model also suggests that the benefits from introducing point-to-point CS would be in the form of widened car access rather than reductions in VKT. Distinctive socio-demographic profiles were found for round-trip and point-to-point CS, both relative to each other and also relative to adult Londoners at large. In some case the predicted socio-demographics align with empirical studies of today’s CS subscribers, but in others they differ. A particularly noteworthy difference is that empirical studies tend to find that CS users are younger adults, whereas this analysis suggests an older age profile. Further evidence will be required in order to establish whether or not these results are indicative of future shifts in the CS market.

We cannot know for certain whether the forecasts reported here will come to pass, in part due to the limitations described above, and in part due to the pace of evolution in CS service types. We can conclude, however, that this modelling framework proved fruitful for analyzing the CS marketplace, and there remain important directions that require future research. An important direction of methodological advancement is to extend the specification of the PAS concept to accommodate activity-pattern restructuring. Techniques are required that are sensitive to, for instance, the possibility that CS subscribers may choose to take part in car-accessed activities (e.g. a weekend in the countryside) in which they otherwise (if they did not have access to a car) would not take part. Finally, further research is needed to understand the economic welfare implications of CS, to enable public-sector agencies to calculate economically-efficient prices for renting road space to operators.

Policymakers have a full spectrum of options relating to CS. At one extreme a system can be publicly-funded and administered, and at the other extreme policymakers have latitude to effectively preclude some types of CS from operating. It is hoped that the techniques developed in this study will help remove some of the unknowns around carsharing and its impacts, enabling public
agencies to make better-informed decisions regarding their contractual relationships with CS operators. Nevertheless the rapid growth and evolution of CS means that in the near term there will necessarily be much experimentation on the basis of little a priori certainty about impacts.

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