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Publication Date
2019-11-26

DOI
10.1080/13574809.2019.1686350

Peer reviewed

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Journal of Urban Design November 26, 2019

https://doi.org/10.1080/13574809.2019.1686350

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A Case Study of Peer-to-Peer (P2P) Carsharing in the US

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ABSTRACT

This paper advances the understanding of peer-to-peer (P2P) carsharing within the broader context of shared mobility and its connection to the built environment in the US through a survey conducted in 2014 (n = 1,151). Eleven percent of respondents used carpooling/ridesharing more, and 19% avoided a vehicle purchase due to P2P vehicle access in urban areas. Nevertheless, P2P carsharing has the potential to operate in a range of land-use environments and could be an important strategy to further deemphasize car ownership. Additionally, as the deployment of automated vehicles (AVs) is examined, sharing of privately owned AVs could mirror current P2P carsharing dynamics in important ways.

Keywords: Carsharing, Modal shift, Peer-to-peer (P2P), Shared automated vehicle (SAV), Urban design, Urban form, Vehicle ownership

1 INTRODUCTION

This study focuses on peer-to-peer (P2P) carsharing, which has emerged as an alternative transportation strategy that allows for the formation of carsharing networks comprised solely of privately owned vehicles. Hosts (P2P vehicle owners) profit from the transaction of sharing their vehicle with guests (P2P vehicle users). In most cases, a P2P third-party company facilitates the vehicle sharing and keeps a percentage of the profit. As compared to roundtrip and one-way carsharing, P2P carsharing offers a greater selection of pick-up and drop-off locations, vehicle types, and pricing rates. The P2P model can also significantly reduce operating costs. The avoided expense of vehicle capital comprises almost 70% of total operating expenses for roundtrip carsharing companies (Shaheen, Mallery, and Kingsley 2012). While the potential for P2P carsharing to expand into lower-density areas is promising due to lower costs, the initial target markets have been in dense urban centres primarily where roundtrip carsharing companies also operate.

The P2P carsharing industry has evolved since it initially launched in 2010. A few years after its deployment, P2P carsharing started to transition from short-term uses to longer duration trips (Geron 2013). This represented a shift away from the conventional short-term use case that roundtrip and one-way carsharing serves. In September 2013, longer duration/non-hourly trips were reported to comprise 95% of the P2P company RelayRide's marketplace, leading the company to discontinue hourly pricing altogether (Haddad 2013). In January 2017, an industry benchmarking report estimated that there were over 2,900,000 individuals participating in P2P carsharing with a shared fleet of 131,336 P2P vehicles among six operators in North America. P2P carsharing is even more prevalent in certain parts of Europe, including France and the Netherlands. In contrast, there is a relatively lower number of P2P carsharing vehicles in the United Kingdom most likely due to insurance regulations that restrict private vehicle rental (Munzel et al. 2019).

This paper advances the understanding of P2P carsharing within the context of shared mobility and urban form impacts, which could be highly salient as cities consider the potential future transition to shared automated mobility. While the initial launch of P2P carsharing systems has primarily focused on the urban core, there is notable potential for expansion. However, important distinctions among impacts in different land-use and built environments should be considered. The next section provides an overview of the literature related to shared-mobility impacts and their connection to urban form.

2 BACKGROUND

The degree of centralization affects the design and sequential use of transportation networks ("Transportation and the Urban Form" 2017). However, centralization alone does not comprehensively describe why people choose certain transportation modes over others. Service quality; infrastructure conditions; time and cost constraints; population, residential, and workplace densities; street design; and distance to public transit nodes all contribute to mode choice (Rode et al. 2017; Kortum et al. 2016; Ciari and Becker 2017; Clark, Chatterjee, and Melia 2016; Karim 2017).

The extent to which the objective aspects of urban form (e.g., infrastructure, intersection density, street length) impact travel behaviour is debatable (Klinger, Kenworthy, and Lanzendorf 2013; Wee and Handy 2016). Interventionists that favour policy actions to change transportation systems and sceptics preferring a free-market approach to system change have distinct perspectives on whether urban design affects behaviour. The former acknowledges that public agencies, through investments and infrastructure development, have a significant effect on mode choice. However, infrastructure improvements are timely, costly, and vastly underfunded across the US, which can reduce the ability for policy alone to impact urban areas. Some shared-mobility services (e.g., carsharing, scooter sharing, and transportation network companies (TNCs, also known as ridesourcing and ridehailing)) are increasing transportation options and changing mobility pat- terns without immediate investment in new infrastructure. This means that cities are not necessarily constrained by the 'lock-in effects' of hard-to-change infrastructure (Rode et al. 2017). Thus, shared-mobility services are blurring the lines between the sceptic and interventionist perspectives.

Additionally, urban form impacts may shift in significance depending on the transportation metrics in question. Trip length may depend more heavily on urban form, while trip frequency may be a function of socioeconomic constraints (Ewing and Cervero 2010). Conclusions on the impact of urban form on travel behaviour will also vary by study design (Wee and Handy 2016). Further, the geographic size of a study sample may conflate or deflate the built environment's impact on travel behaviour (Holz-Rau, Scheiner, and Sicks 2014). Geographic variability across study systems makes extrapolation challenging, since built environment characteristics, topography, city-level policies, and cultural norms vary by city.

Despite the constraints described above, certain aspects of existing studies can be interpreted to identify key urban form factors with discerned impacts on travel behaviour. Cervero and Kockelman (1997) coined the original 'three Ds,' which refer to density, diversity, and design. Destination accessibility and distance to public transit were added to this framework (Ewing and Cervero 2001; Ewing et al. 2009), with demand management and demographics later considered the sixth and seventh Ds, respectively. Table 1 focuses on a subset of these factors: density, diversity, design, and demographics.

Public and private entities are increasingly curious about which factors contribute to the success of shared-mobility systems in urban areas. Isolating these factors and their relationship to user behaviour is complex, as debates in the literature reveal. Objective factors, such as urban form, and subjective factors, including user habits and preferences, jointly affect whether populations use shared mobility (Wee and Handy 2016).

The use of shared-mobility services can have substantial impacts on travel behaviour. Studies have shown that carsharing systems encourage vehicle shedding, delay new vehicle purchases, and reduce overall vehicle miles travelled, which can reduce carbon dioxide emissions per capita (Shaheen and Cohen 2013; Shaheen, Cohen, and Zohdy 2016). Table 2 shows the reported social and environmental impacts due to carsharing.

Martin and Shaheen (2016) explored this more specifically for car2go one-way carsharing users in five North American cities. They found that car2go members shed one to three personal vehicles and suppressed four to nine personal vehicles per car2go vehicle, depending on the city. Cities with high population densities had the highest percentage of active users (Vancouver and Washington, D.C.), while lower-density cities exhibited lower percentages (San Diego). Notably, San Diego also showed the smallest aggregate impacts on vehicle ownership. The correlation between population density and the share of active users suggests that urban form and public transit accessibility impact how car2go is used (Martin and Shaheen 2016).

Table 1 Urban form factors impacting travel behaviour

Source	Category	Factor	Impact
Karim (2017)	Density	Street intersections	Walkable distances from public transit stops vary based on mode of transit; for carsharing stations, 530 meters is ideal.
Kortum et al. (2016)	Density	Development	Increased development density leads to a faster increase in free-floating carsharing system users.
Wang et al. (2012)	Diversity	Infrastructure	Bikesharing systems are more likely to be used, if they are in close proximity to workplaces.
Wang et al. (2012)	Diversity	Infrastructure	Bikesharing systems are more likely to be used, if they are in close proximity to food-related businesses.
Martin and Shaheen (2014)	Design	Transit	Bikesharing users shift away from public transit use and increase bikesharing use when bike trips can substitute for public transit trips.
Faghih-Imani et al. (2014)	Design	Infrastructure	Bike usage and bike flows (in and out of stations) increase when there are more bike facilities near a bike station.
Faghih-Imani et al. (2014)	Demographics	Population density	Bikesharing stations in areas with high-population density are more frequently used.
Deloitte (2014)	Demographics	Age	Younger urban dwellers are more likely to carshare and/or carpool.
Kortum et al. (2016)	Demographics	Household size	Each additional household member decreases one-way carsharing trips.

Table 2 Social and environmental impacts due to carsharing

Impact	Europe	North America	Australia
Carbon dioxide emission reduction	39 to 54%	27% (observed impact, based on vehicles sold) 56% (full impact, based on vehicles sold and postponed purchases)	N/A
Number of private cars a carsharing vehicle replaces (sold/forgone purchase)	4 to 10 cars	9 to 13 cars	7 to 10 cars
Sold vehicle due to carsharing	15.6 to 34%	25%	21.3%
Forgone vehicle purchase due to carsharing	N/A	25%	28.1%

Source: Shaheen and Cohen 2013

The same study probed the impacts of car2go on other transportation modes. Among respondents that changed the amount they use public transit as a result of car2go, more people reported a decrease in their urban rail and bus usage frequency. One exception was Seattle, where slightly more respondents reported an increase in urban rail use (Martin and Shaheen 2016). This finding is consistent with a GIS-based study that found light rail availability had a significant and positive relationship to carsharing demand in a larger metropolitan city (e.g., San Francisco, Seattle) (Stillwater, Mokhtarian, and Shaheen 2009).

Martin and Shaheen (2014) also examined the impact of bikesharing on public transit use in Washington, D.C. They found that bikesharing primarily acted as a substitute for bus and rail in high-density urban areas, while it complemented these modes in lower- density regions farther from the urban core. In this case, bikesharing provided first-mile/last-mile access to public transit in lower-density areas without expansive transit net- works, but it also competed with public transit in high-density areas with more extensive transit networks. It is important to note that bikesharing impacts will vary based on land- use context, including the availability of public transit networks and the built environment. The underlying dynamic is that bikesharing provides a competitive alternative for short trips that may have otherwise been completed by brief bus or rail rides, but it does not serve as a direct strategy for longer trips. Instead, bikesharing allows more users to access public transit for completing these longer trips to/from regions on the urban periphery. To this effect, bikesharing impacts may differ depending on the density and overall environment in which it functions (Martin and Shaheen 2014).

Infrastructure visibility and availability contribute significantly to roundtrip bikesharing system use (Faghih-Imani et al. 2014). If docking stations are located near restaurants, public transit hubs, and parks, their usage frequency increases (Wang et al. 2016). If one infers that strategically placed infrastructure encourages system use, dedicating urban spaces to shared vehicles may increase the service's visibility to the public, incentivizing usage.

There has also been a recent rise in the popularity of TNC services, such as Lyft and Uber. Clewlow and Mishra (2017) found that 9% of survey respondents disposed of one or more household vehicles due to TNC services. Hampshire et al. (2017) asked respondents about the impact of the Lyft/Uber service suspension in Austin. They found that 9% of survey respondents had acquired a personal vehicle due to the suspension, noting that a majority of respondents did not consider acquiring a vehicle (83%), and the remaining at least considered it.

Multiple studies have sought to understand how TNC services have impacted modal shift by asking survey respondents which travel modes they would have used had TNCs not been available. Table 3 shows the results of seven studies.

These results show that TNC services are possibly competing with public transit, but they could also be reducing the amount that people drive. It is important to note that these studies were conducted in different regions and vary in their methodological approaches, which likely accounts for some of the discrepancy in percentages. Most notably, some studies only report aggregate results spanning numerous cities, which can obscure important impact differences between cities and urban form effects. Thus, future research is needed to fully understand these interactions.

Research on P2P carsharing, in particular, is more limited – tending to focus on system market viability. Hampshire and Sinha (2011) conducted a simulation study using a reservation control policy for accepting or rejecting renter reservation requests. They found that this strategy leads to more revenue when the service is popular. Hampshire and Gaites (2011) conducted another simulation study applying queueing theory. They estimated that 14,460 potential members lived in viable markets within Pittsburgh, requiring a car host penetration rate between 0.06% to 25%. Ballús-Armet et al. (2014) conducted an intercept survey, which found that 60% and 75% of respondents would consider using a P2P vehicle in San Francisco and Oakland, respectively. Dill, Howland, and McNeil (2014) conducted a survey with P2P hosts in Portland; they found that P2P carsharing may reach more low-income households than roundtrip carsharing, indicating the potential to shift driving to off-peak times. Overall, there is a gap in P2P carsharing research on behavioural effects and the impact of urban form.

Due to the variability in study design, data types, and transportation metrics, it is challenging to discern how urban form alone impacts travel behaviour (Clifton 2017). However, inferences from studies on shared-mobility services and travel behaviour literature generally provide insights into which factors are significant. While there is a growing body of research studying these connections, more research is needed. This paper aims to better understand the behavioural impacts of P2P carsharing after it was well underway in the US to provide a better context for how P2P carsharing compares with other shared-mobility services and how it connects to urban form and the built environment.

Table 3 Alternative modes of travel had TNCs not been available

Source Location / **Mode**	Rayle et al. (2016) San Francisco, CA	Henao (2017) Denver and Boulder, CO	Gehrke, Felix, and Reardon (2018) Boston, MA	Clewlow and Mishra (2017) Seven U.S. Cities	Feigon and Murphy (2016) Seven U.S. Cities	Hampshire et al. (2017) Austin, TX	Alemi et al. (2017) CA
Drive (%)	7	33	18	39	34	45	66
Public Transit (%)	30	22	42	15	14	3	22
Taxi (%)	36	10	23	1	8	2	49
Bike/Walk (%)	9	12	12	23	17	2	20
Would not have made trip (%)	8	12	5	22	1	N/A	8
Carsharing/Car Rental (%)	N/A	4	N/A	N/A	24	4	N/A
Other/Other TNC (%)	10	7	N/A	N/A	N/A	42 (another TNC) 2 (other)	6 (van/ shuttle)

3 METHODOLOGY

This study primarily involved an online survey to assess P2P carsharing effects on user behaviour and to better understand its operational challenges and opportunities, as well as market characteristics. The research involved conducting two focus groups with P2P carsharing hosts and guests prior to the survey to inform its design. The survey was distributed online in Spring 2014 through the participating P2P carsharing operators (RelayRides/Turo, Getaround, and eGo carsharing), who sent an email to their members containing a link to the survey URL. Across the three operators, a total of n = 1,151 survey responses were collected. To increase the survey response rate, respondents were offered a survey incentive. The incentive had a two-tiered structure; respondents were guaranteed US$10 if they were among the first n respondents (where n was adjusted depending on the operator population size), otherwise they were entered into a lottery for US$50. Each operator reviewed and contributed content to the questionnaire.

In the survey, respondents were asked how P2P carsharing altered their use of other transportation modes. Questions probed the ordinal-level direction of the modal shift, as well as the potential causality of P2P carsharing in facilitating it. The distribution of responses to this and similarly structured questions offers a self-assessed measurement of how P2P systems contribute to travel behaviour changes. The survey also included questions about vehicle ownership, among several other topics of interest. In addition to the survey, the research involved interviewing six experts from several P2P carsharing companies to gain an in-depth perspective of P2P carsharing operations and services.

There are some limitations to the study's methodological approach. Primarily, the results are based on self-reported survey data in contrast to activity data. While surveys lack the precision of activity data measurement, they have advantages with respect to probing causality and the reasons behind certain observed behaviour changes. In an effort to reduce human error, responses that were deemed implausible were excluded from the analysis. A control group of the general population was not included due to budget limitations. Naturally, members opt in to using carsharing systems, so the results reflect the estimated impacts on individuals who have chosen to use P2P carsharing because the service provides some mobility or economic benefit.

4 RESULTS

4.1 Demographics

Based on the survey, the demographics of P2P carsharing members reflect distributions that are very similar to those found in previous surveys of roundtrip carsharing and station-based bikesharing systems. The survey results were compared with aggregated demographic data from the American Community Survey (ACS) for the attributes of income, ethnicity, gender, age, education, and politics.

Figure 1 shows the comparative distributions of income, ethnicity, and gender among P2P users and the US population. Figure 1 suggests that, on average, P2P users have slightly higher incomes than the general US population. Figure 1 also shows that relative to the US population, Caucasian/White and Asian users were overrepresented by 5% and 15%, respectively. In contrast, African Americans and Latinos were underrepresented by 9% and 14%, respectively, which is consistent with previous shared-mobility surveys. Additionally, the survey sample included 54% men and 44% women, whereas the broader US population is slightly higher for women by two percentage points.

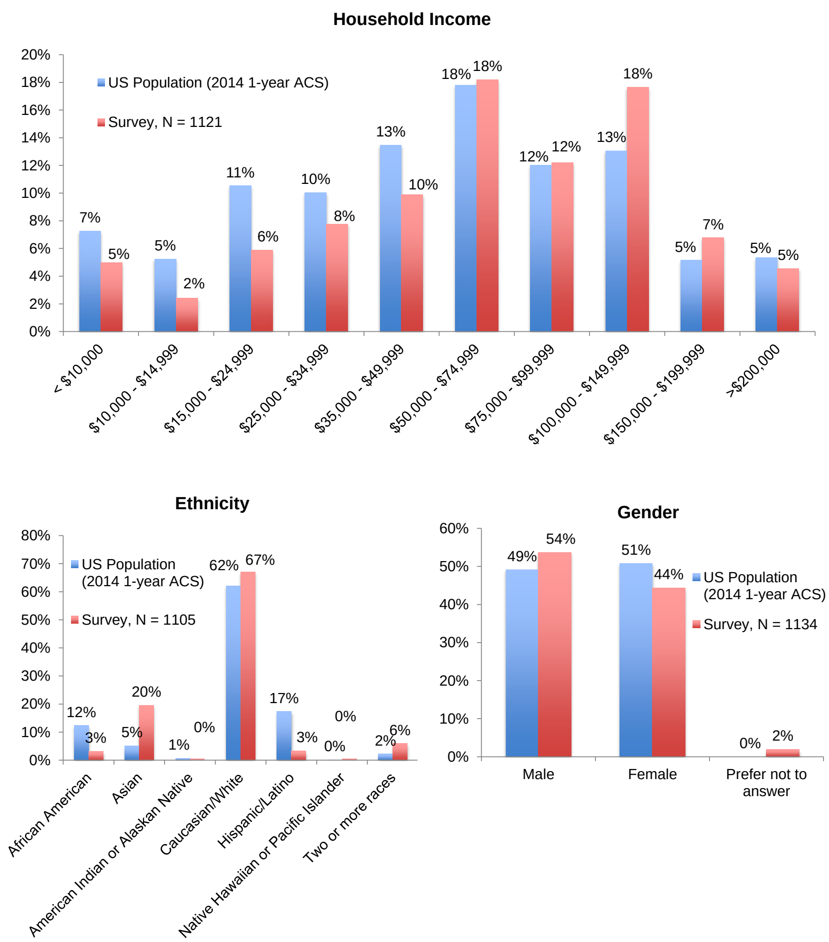

Fig. 1 Distribution of age, education, and political opinion

Figure 2 shows socio-demographics by age, education, and political opinion and indicates significant departures along key demographic attributes. The most significant is age, where a majority (55%) of the P2P carsharing sample is between the ages of 25 and 34, whereas only 17% of the US population falls within this age group. While this finding matches previous studies that have found carsharing users to be younger than the population at large, the extent of the age disparity found in this study is relatively large (Shaheen, Mallery, and Kingsley 2012; Martin and Shaheen 2011). Figure 2 also shows that the P2P carsharing sample is more educated relative to the US population, which is also consistent with previous research on shared mobility (Shaheen, Mallery, and Kingsley 2012; Martin and Shaheen 2011). Additionally, Figure 2 shows that, on average, respondents are more liberal than the political leanings of the US population (Pew Research Center 2014).

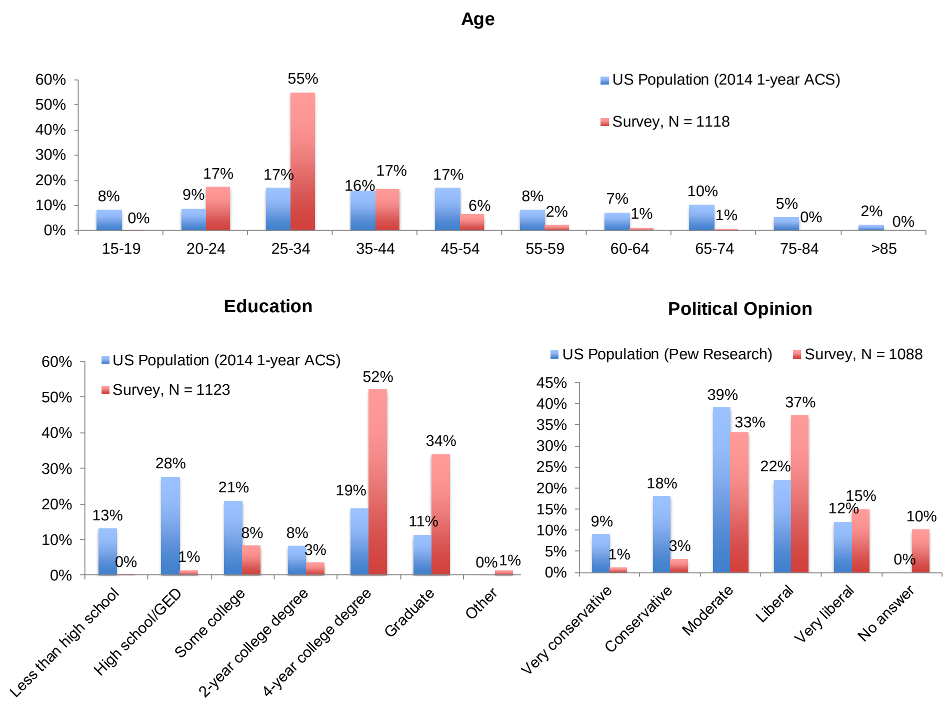

Fig. 2 Distribution of age, education, and political opinion

The distributions reflected in Figures 1 and 2 show common findings within the demographic profiles of shared-mobility services. In large part, these results are broadly driven by the fact that P2P carsharing, like many shared modes, primarily operates within larger cities. These markets are often concentrated with higher incomes, higher education levels, and more liberal political leanings. Other attributes, such as age and race, reveal a common tendency among many shared modes to be adopted more often by Caucasian/Asian ethnic groups and by younger populations. However, the P2P population is distinct among shared modes in that it is exceptionally young.

4.2 Modal shift

Table 4 shows the reported modal shift for driving, bus, urban rail, taxis, TNCs, carpooling, walking, bicycling, station-based bikesharing, and making trips (overall). For each shift by travel mode, the statistical significance of the shift is defined by the Wilcoxon Sign Rank Test. Note two answer choices were not included in the statistical tests (i.e., ‘I did not use this mode before, and I do not use it now’ and ‘I did change my use of this mode, but not because of P2P carsharing’). These served to capture potential situations that applied to respondents, but they were excluded from the significance testing since they did not denote a modal shift.

Table 4 Modal shift

Mode	Much more often	More often	About the same	Less often	Much less often	I did not use this mode before, and I do not use it now	I did change my use of this mode, but not because of P2P carsharing	Wilcoxon Sign Rank Test (*p*-value)
Drive	49 (4%)	258 (23%)	487 (43%)	162 (14%)	69 (6%)	N/A	107 (9%)	5.8x10^{-2}***
Bus	34 (3%)	69 (6%)	691 (61%)	85 (8%)	21 (2%)	157 (14%)	69 (6%)	0.25
Urban rail	23 (2%)	59 (5%)	681 (61%)	72 (6%)	17 (2%)	203 (18%)	68 (6%)	0.48
Taxis	8 (1%)	33 (3%)	571 (51%)	128 (11%)	47 (4%)	275 (25%)	57 (5%)	2.2x10^{-16}*
TNC	20 (2%)	74 (7%)	559 (50%)	89 (8%)	14 (1%)	315 (28%)	54 (5%)	0.46
Carpool/ ridesharing	15 (1%)	110 (10%)	479 (43%)	44 (4%)	13 (1%)	424 (38%)	40 (4%)	1.6x10^{-5}**
Walk	47 (4%)	121 (11%)	838 (74%)	28 (2%)	3 (<1%)	N/A	89 (8%)	2.2x10^{-16}**
Personal bicycle	27 (2%)	86 (8%)	548 (49%)	27 (2%)	8 (1%)	375 (34%)	48 (4%)	1.4x10^{-9}**
Public bikesharing	11 (1%)	23 (2%)	357 (32%)	23 (2%)	10 (1%)	672 (60%)	28 (2%)	0.43
Make trips (overall)	42 (4%)	368 (33%)	626 (55%)	82 (7%)	11 (1%)	N/A	N/A	2.2x10^{-16}**

*One-Tailed Wilcoxon Signed Rank Test, Decline Statistically Significant at 99%; **One-Tailed Wilcoxon Signed Rank Test, Increase Statistically Significant at 99%; ***One-Tailed Wilcoxon Signed Rank Test, Increase Statistically Significant at 90%

The results show a statistically significant increase in driving, with 27% of respondents indicating that they drove more as a result of P2P vehicle access. This is likely related to the fact that the results show a statistically significant increase in the number of trips made overall, with 37% of respondents reporting that they made more trips due to their P2P membership. Hence, P2P carsharing is inducing trips, likely due to improved mobility among members, allowing them to make trips that otherwise would not have occurred.

P2P carsharing is not causing many within the sample to alter their travel behaviour overwhelmingly towards or away from bus and urban rail. While not statistically significant, there is a small net shift away (1%) from both modes, similar to previous roundtrip and one-way carsharing analysis (Martin and Shaheen 2011, 2016). There is, however, a notable and statistically significant decline in taxi use (15%) and increase in carpooling (11%). The shift was evenly split for TNC use (9% in both directions). In terms of active transportation modes, the results show that more respondents increased, rather than decreased, the amount they walk (15%) and ride a personal bicycle (10%) – both are statistically significant. However, the shift was small and evenly split for station-based bikesharing (3% in both directions).

In short, these results show little to no change in public transit, TNC, and bikesharing use. However, there is a significant decrease in taxi use and increase in driving, carpooling, walking, bicycling, and overall trips.

4.3 Vehicle holdings

Respondents were asked if they had gotten rid of vehicles since joining P2P carsharing. Figure 3 shows that about 14% of the entire sample reported doing so, but only 3% attributed this vehicle reduction to their P2P membership. Among those that did, the vast majority (92%) stated that P2P carsharing was somewhat to very important in this decision. Thus, while a portion of users shed a vehicle since joining a P2P carsharing service, very few of them recognize their membership as an influential factor.

Figure 4 displays responses to questions probing the opposite effect: whether P2P carsharing increased vehicle purchases. Two percent of respondents reported that they purchased a vehicle due to P2P carsharing, with 45% of that subgroup stating that it was because they wanted to loan a car in a P2P carsharing service.

Figure 5 shows the impact that P2P carsharing has had on a member's vehicle purchase suppression. The results show that both P2P carsharing and carsharing more broadly (roundtrip and one-way) are having a pronounced effect on avoided vehicle acquisitions. Among the entire sample, 44% of respondents reported that the disappearance of roundtrip, one-way, or P2P carsharing would likely cause them to purchase a vehicle. Among this subgroup, another 44% indicated that the disappearance of P2P carsharing, in particular, would likely result in the same effect. This represents about 19% of the total sample.

The results of Figures 3–5 suggest that the most prominent effect of P2P carsharing comes in the form of avoided impacts (suppressed vehicle purchases) versus observed impacts (sold vehicles). This could reflect the state of shared mobility at the time of P2P carsharing's introduction (around 2010 in the US). Roundtrip carsharing had been well established and operating for 10+ years before P2P carsharing systems came to fruition. It is possible that many of the direct vehicle reduction impacts could have already occurred. It is important to note that given the wide array of well-developed choices in shared mobility, it is logical that avoided impacts (i.e., vehicle suppression) will become increasingly important, while observed impacts will be less significant due to the array of options.

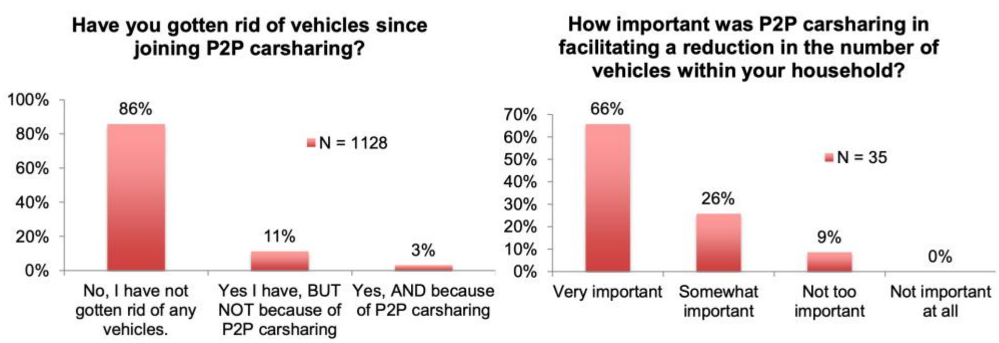

Fig. 3 Vehicle shedding

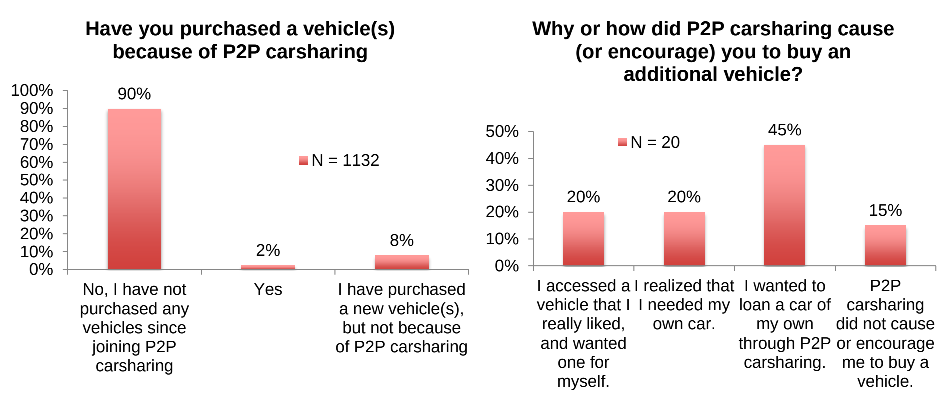

Fig. 4 Vehicle acquisitions

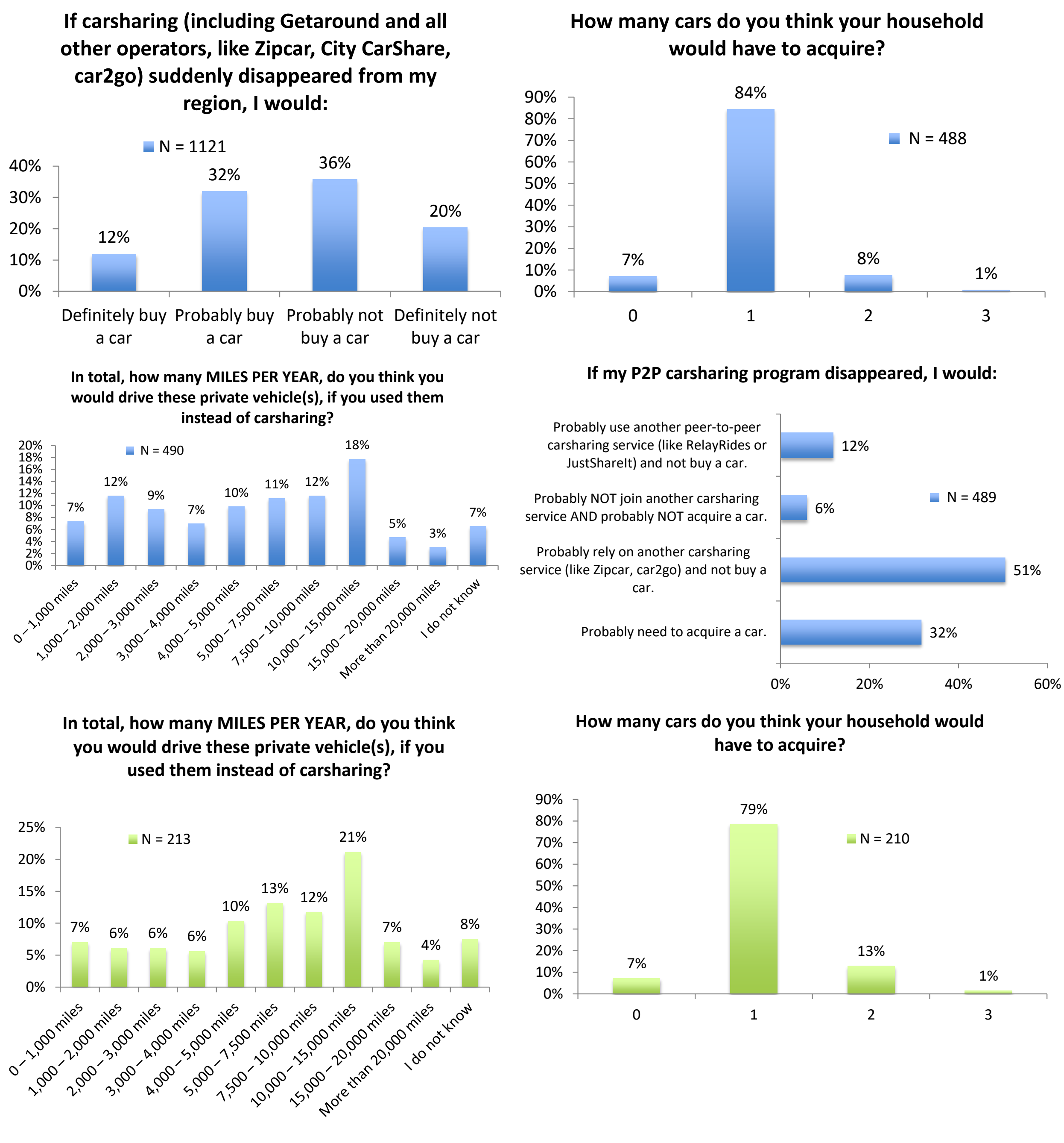

Fig. 5 Vehicle suppression

4.4 Other shared-mobility services

Indicative of the integrated nature of the sharing economy, three-fourths of respondents reported being a part of at least one other shared service, including systems such as Airbnb, Zipcar, Lyft, and Uber. This means that rather than replacing one another, P2P carsharing and other shared modes could likely complement each other and provide a variety of mobility options that meet the needs of specific circumstances. Indeed, almost 40% of the P2P carsharing survey respondents reported using Zipcar more than once a month, demonstrating a considerable overlap in members that use both P2P and roundtrip carsharing. In Figure 6 the frequency of use for a variety of shared services is summarized.

Of the respondents that use TNCs, roughly three-fourths take them more than once a month across providers (e.g., Lyft, Uber). One-third of respondents use Lyft and Uber more than five times a month. Overall, the survey shows that P2P carsharing users are generally active participants in a variety of shared services.

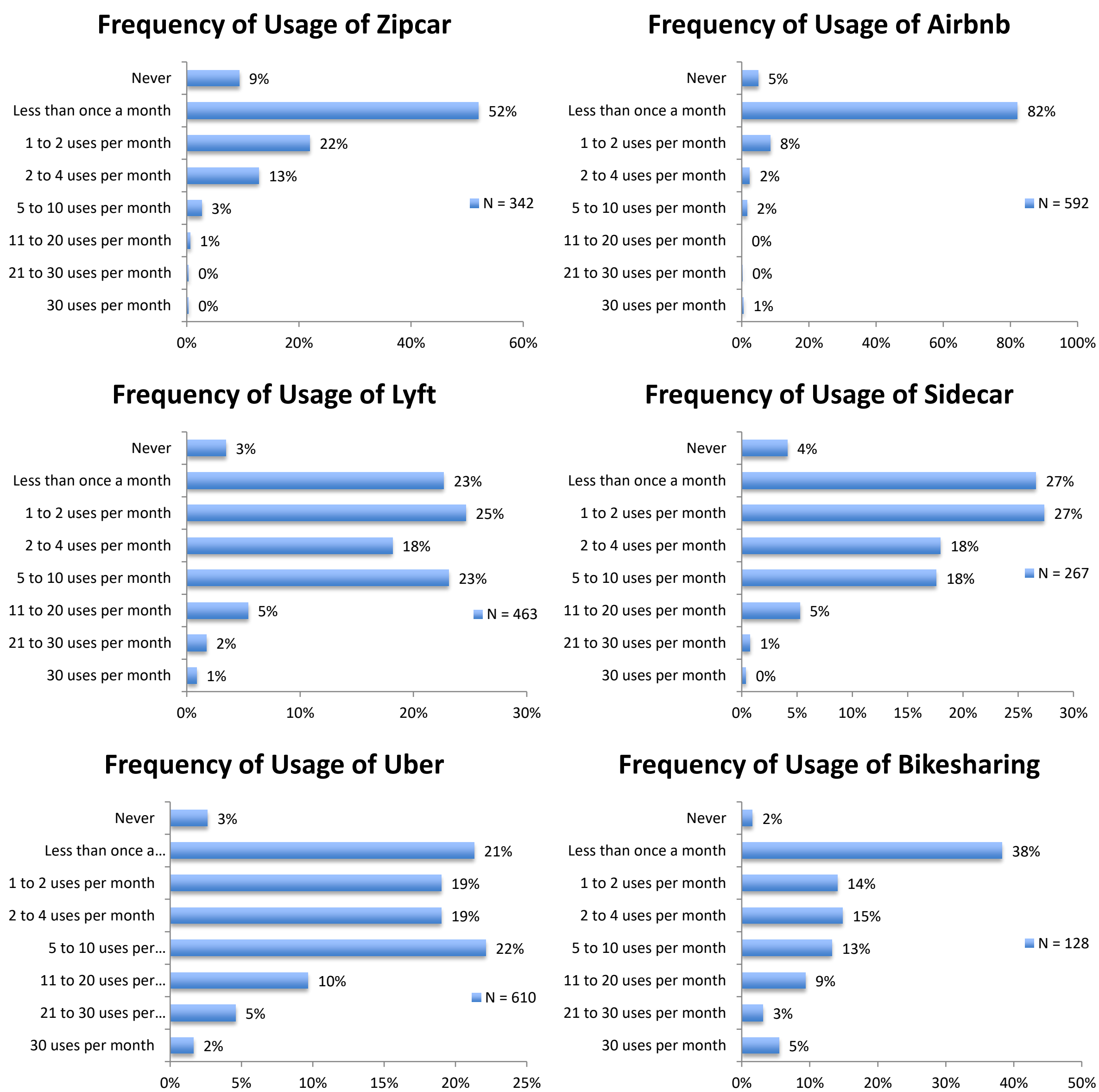

Fig. 6 Frequency of use of other shared services

5 DISCUSSION

As part of this study's expert interviews, one expert noted a promising dynamic of P2P carsharing is the potential to introduce carsharing to rural markets. P2P carsharing's use of existing, underused vehicles does not require significant capital to establish a vehicle network, so implementing P2P carsharing is generally cheaper. However, deploying P2P carsharing in remote areas can be more challenging, as there is a more limited supply (hosts) and demand (guests). Personal vehicles are needed to meet virtually all travel needs, and P2P vehicles are distantly spaced. As such, companies have predominantly focused on launching P2P carsharing in urban markets. Nevertheless, P2P carsharing presents a unique opportunity to expand the reach of shared mobility into suburbs, edge cities, and exurbs. Given the promise of expanding into lower-density regions, it is important to assess how P2P carsharing impacts might vary depending on market density.

Although this study found minimal shifts to and from public transit due to P2P carsharing, there were slightly more respondents that used bus and urban rail less often rather than more often. As indicated by the literature, this is consistent with other shared modes within the urban environment. In this case, P2P carsharing is likely providing some users with either more convenient or cost-effective (or both) travel options within the cities it operates. As a result, it is substituting for some public transit trips. However, these findings could be more reflective of urban areas. Impacts could vary as P2P carsharing expands, potentially in similar ways to other shared modes. For instance, research has established a complementary relationship between public transit and bikesharing in lower-density regions. Could a similar dynamic be observed in P2P carsharing?

Yet, the lowest density regions – truly rural areas – may reflect a different response to P2P carsharing. Public transit often does not extend to such environments, particularly in the US. In such cases, introducing P2P carsharing may in fact just increase the number of trips by car, without having a positive impact on public transit or contributing to a broader shift toward more sustainable transportation. Nevertheless, this may still increase general mobility, providing vehicle access to those who could not afford to purchase their own car. Researchers and city planners should weigh these potentially conflicting effects in future research, which will become more possible as P2P carsharing further evolves. To start, researchers could look to other shared modes that are more mature and more broadly studied.

Other shared modes, such as TNC or microtransit (e.g., Via), have followed similar deployment patterns. These modes were first introduced in denser urban environments, but they have been spreading gradually to lower-density markets as their popularity has increased. Uber, which has steadily grown from its inception in 2009, can now be found in smaller cities and towns throughout the world. Via, which currently operates in Chicago, New York City, and Washington D.C., has launched a pilot project in West Sacramento. If this service continues, it would mark the first successful expansion of microtransit into an edge city. However, the impacts that accompany this outward service migration to smaller cities and suburbs are not well understood. The literature indicates varying results and important gaps in understanding across a wide range of city types and land-use environments. There are also questions as to whether these initiatives will have sustained success. P2P carsharing may be able to fill an important niche that other services cannot meet in less dense land-use environments.

One important study finding is that P2P carsharing can reduce vehicle ownership, particularly with respect to vehicle suppression. This is also consistent with the reported impacts of other shared modes. As P2P carsharing and other shared modes become more popular, this could have a notable effect on land use in terms of parking demand. As the number of privately owned vehicles is reduced, there could be less need to occupy parking and curb space. Ultimately, the need for curb- side parking and dedicated lots can diminish, and this freed space could be repurposed to other uses.

Furthermore, P2P carsharing encourages more carpooling use, according to the survey results. Members also engage in the sharing economy in a multitude of different ways. These results highlight how P2P carsharing can complement other shared modes and reduce dependency on private-vehicle ownership. The study also found that P2P carsharing users decrease their taxi use, implying less of a need for curb space designated solely for taxis. Finally, the survey indicates a notable rise in walking and biking. In light of today's rapid mobility changes, cities should consider transportation infrastructure changes, such as more expansive sidewalks or separated bike lanes, that deemphasize car ownership and support other transportation modes. Together, these effects can advance the adaptation of land use to fit the changing needs of residents and support the mainstreaming of shared modes, as appropriate.

6 THE FUTURE OF P2P CARSHARING: SHARED AUTOMATED VEHICLES (SAVs)

Given the amount of financial and intellectual capital being invested in automated vehicles (AVs) today, it seems likely that driverless cars could become a significant part of future mobility. While still largely in a testing mode, many envision fleets of shared AVs (SAVs) as an alternative to private-vehicle ownership and use. Of the range of SAV business models, two include P2P carsharing:

- **P2P with a Third-Party Operator:** Similar to how P2P carsharing exists today, this model would entail individually owned AVs that are made available for use on a short-term, on-demand basis. Private operators would, as they do currently, host platforms to arrange usage periods and manage financial transactions.

- **P2P with Decentralized Operations:** Although largely similar to the first option, this scenario entails AV hosts and guests arranging and paying for usage periods via a public, open-source ledger, such as those that employ blockchain technology (Stocker and Shaheen 2018).

In February 2018, Waymo (an AV company owned by Google's parent company, Alphabet) received its first permit to operate a TNC service in Arizona – joining General Motors, Lyft, and Uber in testing AVs in a shared-mobility service in the US. More recently, in early December 2018, Waymo launched its SAV commercial service in Phoenix. This service still includes safety drivers and is only available to early test riders, with expected roll-out to the broader public over time (Lee 2018).

While mainstream deployment could be years, if not decades, away, P2P carsharing models can help to inform the transition to P2P SAV services, as well as public familiarity with privately owned shared vehicles. Naturally, there are also concerns as to whether automation will support the sustainable transportation goals of urban planning or whether it will increase congestion and pollution. P2P carsharing plays an important role within this healthy scepticism, providing a specific lens through which to view automation that embraces sharing and sustainability and shifts the focus away from convenience and emerging technology alone. The findings presented in this paper can shed light on P2P carsharing and provide early insights into opportunities and obstacles for shared private AVs in the future.

7 CONCLUSIONS AND RECOMMENDATIONS

P2P carsharing represents another evolution in the sharing economy in which shared mobility transitioned from the sharing of a commercial vehicle fleet to personal vehicles. This transition was a critical point in the development of the sharing economy toward P2P models (e.g., AirBnB, Lyft, UberX).

While expanding the P2P shared-mobility model outside the urban core can present operational challenges, growth into suburbs and rural areas has the potential to extend the reach of shared mobility and reduce dependency on privately owned vehicles. Policies that deter personal-vehicle ownership, such as parking that is free for shared vehicles and expensive for private automobiles, might compel individuals to re-evaluate the necessity of car ownership and entertain the idea of P2P carsharing or other transportation modes. For example, San Francisco has a shared-vehicle parking programme that administers parking permits to dedicated shared vehicles (SFMTA 2018), allowing them to park in curb spaces that were previously public. While this programme does not currently apply to P2P carsharing, it is possible that this policy could expand to include it. These types of policies and others (e.g., road pricing with discounts/incentives for higher occupancy vehicles and shared modes) would encourage sharing, and P2P carsharing would likely benefit from their implementation.

With shared automobility comes the need for curb-side use, including pick-up and drop-off zones. San Francisco has implemented a dynamic curb programme that reserves curb space for carpooling and pooled TNCs at different times of the day (City of San Francisco 2018). P2P carsharing, given its potential to reduce demand for private-vehicle parking and complement other shared modes, could be an important strategy to support more pooling behaviour.

Looking forward, it is important to consider P2P carsharing's adoption, benefits, draw- backs, and policies as they relate to the potential future deployment of AVs and SAVs. While personal ownership of AVs is still generally considered many years away, the adoption of P2P carsharing by cities could influence the pace and deployment of SAV roll- out in both urban areas and less densely populated environments. Early understanding of P2P carsharing and its impacts in urban areas can help to shed light on P2P carsharing's potential evolution to areas outside the urban core and coupled with driverless vehicle technology. Indeed, if SAVs deliver a cheaper transportation option per mile, can self-drive to wherever a guest is located, and are markedly safer, then P2P carsharing could be considerably more attractive to travellers in a wider range of land-use and built environments, providing more alternatives to 'current-day' private-vehicle ownership and use in an automated future.

This paper has provided context to P2P carsharing as it relates to urban form and the built environment and its place within the larger mobility portfolio of shared transportation modes. In particular, the paper addresses the potential use case of P2P carsharing as a form of shared-automated mobility, which is relevant in light of the current hype surrounding vehicle automation. As P2P carsharing grows and potentially expands past the urban periphery, this presents an opportunity for researchers to study this mode in different densities and land-use environments to determine how it can best support mobility given existing infrastructure and the push toward automation.

ACKNOWLEDGEMENT

The authors would like to thank the University of California Transportation Center (UCTC), the U.S. Department of Transportation (U.S. DOT), and the California Department of Transportation (Caltrans) for sponsoring this research. This paper reflects the views of the authors. It does not reflect the views of UCTC, U.S. DOT, or Caltrans. The authors would also like to thank the P2P carsharing operators and members that participated in this study. Thanks also go to Ingrid Ballus- Armet, Madonna Camel, Christopher Chin, Matthew Christensen, Mark Jaffe, Marcel Moran, and Juliet Wilson of TSRC who assisted with this research.

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