Carsharing and sustainable travel behavior: Results from the San Francisco Bay Area

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Abstract

Over the past decade, carsharing has grown considerably in the United States, particularly in major metropolitan areas. This innovative business model offers individuals the opportunity to rent cars by the hour, providing them with greater flexibility for their mobility. Previous work on carsharing suggests that its adoption leads to a decline in household vehicle ownership, vehicle miles traveled, and associated greenhouse gas emissions. Utilizing representative data from the 2010-2012 California Household Travel Survey, this paper presents an analysis of travel behavior and vehicle ownership among carshare members versus non-members in the San Francisco Bay Area, focusing on a subsample of the population with access to carsharing at the U.S. census tract level. Consistent with previous findings on vehicle reduction, these results show that carsharing members own significantly fewer vehicles than non-members. However, lower levels of vehicle ownership are only found among households living in urban areas. In dense, urban neighborhoods, households with carsharing membership own 0.58 vehicles per household as compared with 0.96 vehicles of a control group. Suburban carshare members drive less than their non-carshare member counterparts – although the extent to which this difference can be attributed to self-selection it is unknown. This study also finds that among carsharing households that do own vehicles, a greater share of those vehicles are alternative vehicles (e.g., hybrid, plug-in hybrid electric, and battery electric). Among vehicles owned by the subsample examined in this study, electric drive vehicles represent 18.3% of those owned by carshare member households, as compared with 10.2% of the vehicles owned by non-carsharing households. This analysis finds that not only are urban carshare members likely to own fewer vehicles than the rest of the population, if they do own vehicles, they are more likely to own a vehicle with a smaller environmental footprint.

Keywords: carsharing; shared mobility; sustainable; travel behavior; vehicle ownership; hybrid vehicles; electric vehicles

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1 Introduction

Growing concerns about the energy and climate impacts of the transportation sector have prompted governments and cities to consider a broad array of strategies for a more sustainable transportation future. Alternative fuel vehicles, such as hybrid and electric vehicles, offer one pathway to reduce the greenhouse gas (GHG) emissions of personal transportation. An additional strategy that has potential to curb travel demand (and its associated energy and climate impacts) is carsharing - a model where users can rent cars for short periods of time. Previous research suggests that by providing occasional access to a personal vehicle, carsharing programs reduce automobile ownership as well as total vehicle miles traveled (Martin et al, 2010, Martin & Shaheen 2011b). Furthermore, policies implemented in California suggest that carshare fleets offer an opportunity to introduce alternative, lower emission vehicles to a broader consumer base.

Over the past decade, carsharing has grown significantly in popularity, particularly in recent years. Between January 2012 and January 2013, carsharing membership grew 24.1% in the United States. In January 2013, there were over 1 million carsharing members in North America and 15,603 shared vehicles (Shaheen & Cohen 2013b). The carsharing business model tends to work more effectively in metropolitan cities, where limited parking can lead to increased costs of personal vehicle ownership and higher population density allows for more efficient placement of shared vehicles. Previous research also suggests that carsharing may be complementary with public transit.

Recent California policies provide a link between carsharing and the adoption of alternative vehicles. Through the California Zero Emission Vehicle (ZEV) program regulations, auto manufacturers can earn transportation system credits by placing ZEVs and plug-in hybrid vehicles (PHEVs) in carsharing programs, effective 2012-2017 (California Air Resources Board 2011). The initial motivation behind this program was to increase exposure to new technologies without requiring vehicle purchase. Under the newer Clean Vehicle Rebate Project (CVRP), carsharing organizations are also eligible for rebates by placing ZEVs and PHEVs in their California vehicle fleets (California Air Resources Board 2013). Although several policies have been implemented that link carsharing and alternative vehicle placement, there is limited research on the extent to which these policies influence alternative vehicle adoption among consumers.

This study presents a comparison of the demographics and travel behavior of carshare members versus non-members utilizing data from the 2010-2012 California Household Travel Survey (CHTS). The CHTS collects detailed information about household demographics and travel activity for the purposes of modeling statewide and regional travel and GHG emissions. Rigorous sampling methods are employed in order to match key demographic and household population distributions. In the most recent survey, respondents were asked whether they were a member of a carsharing organization. Utilizing the response to this question, as well as detailed household and individual data, this analysis examines the differences in demographics, travel mode choice, and automobile ownership between carshare members and non-members.

The remainder of this paper is organized as follows. Section 2 provides further review of the literature on carsharing and automobile ownership. Section 3 describes the methodological approach and CHTS data set utilized in this analysis. In Section 4, we present a comparison of carshare members and non-members, in terms of their demographics and travel behavior measures. Section 5 discusses the key findings from this analysis and potential policy implications.

2 Literature

Since the introduction of carsharing, a growing body of literature has emerged that examines the demographics of carshare members, as well as the potential impacts of carsharing on automobile ownership and travel behavior. Several early studies on carsharing were conducted by Cervero when City CarShare was launched in San Francisco in 2001, based on surveys of members (and non-members) three months, nine months, and two years into the program (Cervero 2003, Cervero & Tsai 2004, Cervero et al. 2007). Cervero found that early carshare adopters were in their thirties and had moderate incomes. Roughly three-quarters of these early adopters came from zero-vehicle households. While initial results indicated that carsharing appeared to induce travel by automobile among adopters (Cervero 2003), subsequent surveys revealed that as carshare adoption spread, members were 12% more likely to shed a vehicle, and on average experienced a net reduction in vehicle miles traveled (VMT) (Cervero et al. 2007).

Carsharing has grown substantially over the past 20 years, and recent research on the demographics and travel behavior of carshare members point to fairly similar results. Martin and

Shaheen conducted a survey of several North American carsharing organizations, gathering demographic, vehicle ownership, and travel data (Martin et al. 2010, Martin & Shaheen 2011a). Based on their 2008 survey, carshare members were found to be relatively young (67% between age 20 and 40), well-educated (84% with at least a bachelor's degree), and have moderate incomes (43% with incomes less than $60,000). Martin and Shaheen found that joining carsharing had a significant impact on vehicle holdings. In the U.S., the average number of vehicles per household was 0.55 for respondents before joining carsharing, and was reduced to 0.29 vehicles per household after joining. While a fairly large percentage of members (62%) reported that they were zero-vehicle households before joining carsharing, this number increased to 80% of households who reported that they fell into this category after becoming carsharing members.

Another dimension of travel behavior explored in the 2008 survey by Martin and Shaheen was the impact of carsharing on public transit and non-motorized travel (i.e. walking and bicycling). This study found that there was a slight net decrease in public transit use, and a significant increase in walking, bicycling, and carpooling after individuals joined carsharing. (Martin & Shaheen 2011a). However, there were significant variations in travel behavior across the different carsharing organizations whose members were surveyed. Another study by Stillwater et al examined the relationship between carsharing and public transit use, finding similarly ambiguous results (Stillwater et al. 2009).

A final topic that is of particular interest is the presence of hybrid, and more recently electric vehicles (EVs), in carshare organization vehicle fleets. Experts worldwide predict that emerging trend will be the expansion and integration of alternative fuel vehicles into these fleets (Shaheen & Cohen 2013a). Literature suggests that policies focusing on these early adopter niches are more efficient (Green, Skerlos, & Winebrake, 2014). While there are policies that link carsharing and alternative vehicles (hybrid, PHEV, and EV), there is relatively little research investigating the utilization of these vehicles and the extent to which their exposure through carsharing leads to greater adoption. On the general topic of alternative vehicle penetration, previous research has demonstrated that higher hybrid market penetration yields higher valuation of hybrid vehicles through the "neighbor effect" (Axsen et al. 2009).

Much of the previous work on carsharing has focused on the demographics and travel behavior solely of members, based on convenience samples where carsharing credit is offered as

a response incentive. This paper aims to build on the existing body of literature by examining a statistical sample of the general population that includes a significant percentage of carshare members. In doing so, this study provides an analysis of the differences in demographics, travel mode share, and automobile ownership between carshare members versus non-members.

3 Methods and Data

3.1 California Household Travel Survey

This paper presents a comparison of carshare members versus non-members in the San Francisco Bay Area using data from the 2010-2012 California Household Travel Survey (CHTS). The purpose of the CHTS is to collect in-depth information about household travel and activity patterns, which is then used to estimate, model, and forecast statewide and regional travel. The survey collects detailed information about the characteristics of households, including socio-demographic data such as education, income, and household structure. Respondents are also asked to report various travel-related data, including the number and type of vehicles owned, and the completion of an activity diary to record travel behavior. In the most recent CHTS, for the first time respondents were asked whether or not they were members of a carsharing organization, such as Zipcar or City CarShare.

Led by the California Department of Transportation (Caltrans), the 2010-2012 CHTS was sponsored the California Strategic Growth Council, California Energy Commission, and several regional transportation planning agencies, including the Metropolitan Transportation Commission (MTC) of the nine-county San Francisco Bay Area. The region is comprised of the Alameda, Contra Costa, Marin, Napa, San Francisco, San Mateo, Santa Clara, Solano, and Sonoma counties.

The 2010-2012 CHTS was conducted between January 2012 and January 2013 by NuStats LLC in collaboration with several sub-consultants. The survey data utilized in this analysis was collected from households through either a computer assisted telephone interview or an online survey response form. A total of 63,082 complete and partially complete statewide responses were collected, with a recruit response rate of 4.9% (California Department of Transportation 2013). For the purposes of this study, a subsample of the statewide data was

selected to examine carsharing membership and travel behavior in the Bay Area region based on carsharing availability.

3.2 San Francisco Bay Area Sample

The Bay Area was selected as the focus of this study for several reasons: 1) the availability of carsharing in this region; 2) the availability of public transportation; and 3) the presence of very dense, urban and less dense, suburban neighborhoods. Carsharing services have been present in the San Francisco Bay Area for well over a decade. City CarShare, a non-profit carsharing program was founded in San Francisco in 2001; Zipcar, the largest carsharing network in the U.S., opened an office in 2005, and now provides services throughout the Bay Area. A focus on this metropolitan region allows for a comparison of members and non-members where carsharing has widespread availability. Second, in this analysis of automobile ownership trends, it is important to consider the transportation alternatives available to both carshare member and non-member populations. The Bay Area, as compared with other regions in the state, has a variety of pubic transportation options, including bus, light rail, and commuter rail services. Third, this analysis considers the impact of the built environment on automobile ownership and VMT. The Bay Area includes several counties that have a high population density (e.g., San Francisco), and other counties that are more suburban in nature (e.g., San Jose).

This analysis examines data reported at the household level as well as the individual level. Survey responses include household level data such as income, number and type of vehicles owned, and residence type. In addition, the survey reports data for each individual household member, including education, age, and travel activity. Carsharing membership was reported in the survey at the individual level. For the purposes of this analysis, a household is considered a "carsharing household" if at least one person in the household is a carsharing member. Table 1 summarizes key demographic characteristics of the Bay Area sample.

Table 1: Demographic Data for the Bay Area Sample

		Households		Individuals	
		Actual	%	Actual	%
Total number		9,719		24,030	
Household size	1	2,208	22.7		
	2	3,776	38.9		
	3	1,614	16.6		
	4 or more	2,121	21.8		
Household income	Less than $24,999	830	8.5		
	$25,000 to $74,999	2,703	27.8		
	$75,000 to $149,999	3,207	33.0		
	$150,000 to $249,999	1,444	14.9		
	$250,000 or more	574	5.9		
	DK/refused	961	9.9		
Education level (21+)					
	Not HS graduate			327	1.7
	HS graduate			1,061	5.6
	Some college			1,899	10.1
	Assoc. degree			1,672	8.9
	Bachelor's degree			5,876	31.1
	Graduate degree			7,941	42.1
	Other/DK/refused			91	0.5
Household vehicles					
	0	633	6.5		
	1	2,982	30.7		
	2	4,332	44.6		
	3 or more	1,772	18.2		
Licensed drivers (16+)					
	0	266	2.7		
	1	2,666	27.4		
	2	5,324	54.8		
	3 or more	1,463	15.1		
Carsharing member (21+)					
	Yes	332	3.4	399	2.1
	No	9,374	96.5	18,181	97.4
	DK/refused	13	0.1	90	0.5

Due to the rigorous sampling methodology of the CHTS survey data collection, the demographics of the Bay Area sample are well matched to general population statistics (as reported by the American Community Survey and U.S. Census). Household incomes are higher than the average U.S. city, with 59.7% of reported households earning $75,000 or more a year. The sample is also highly educated, with 73.6% of the reported population 21 and older having obtained a Bachelor's degree or higher. Because the majority of carsharing organizations limit membership to those age 21 and older (unless affiliated with a partner college or university), this study focuses on this age group.

Based on the estimated number of carsharing members in North America (Shaheen & Cohen 2013), less than 1% of the U.S. population are carshare members. However, as illustrated by the 2010-2012 CHTS survey data, the incidence of carsharing membership is much higher in San Francisco and the Bay Area. In the Bay Area, 2.1% of individuals sampled (and 3.4% of households) are carshare members. In San Francisco, 9.1% of individuals sampled (and 15.1% of households) are carshare members.

3.3 Subsample of Carshare Accessible Households

For the purposes of this analysis, the Bay Area sample has been further segmented to compare carshare members to a control group of non-members who have access to carsharing. The control group is defined as households and individuals residing within U.S. 2010 Census tracts that include at least one carsharing vehicle. Census tracts, which provide more granularity than ZIP codes, are small subdivisions of a county or equivalent entity that typically have a population size of 1,200 to 8,000 individuals. Not surprisingly, the majority of carsharing households in the Bay Area sample, 79.3%, live in a census tract with access to a carsharing vehicle or pod. The resulting "carshare accessible" subsample includes a total of 1,280 household responses and 2,719 individuals. Within the subsample, 19.8% of reported households and 13.9% of reported individuals are members of carsharing; the non-member households are treated as the control group in this study. Unlike previous studies of carsharing, this control group is unique in that it accounts for the availability of carsharing, as well as other built environment factors, at a small geographic scale.

3.4 Statistical Tests

Tables presented below that include observed categorical frequencies were compared using the Pearson's Chi-squared test with Yates' continuity correction to determine whether deviations between the observed and expected counts are too large to be attributed to chance. Wilcoxon Rank Sum tests were utilized to compare the distributions between groups (e.g., vehicles per household, daily vehicle miles traveled).

4 Demographics and Travel Behavior of Carshare Members

This analysis illustrates key differences between carshare members and a non-member control group, including basic demographics, travel mode choice, and vehicle ownership, based on travel survey data from the San Francisco Bay Area. For the purposes of this study, we refer to "carshare members" as either individuals (where survey data are collected at the individual level) or households (where data are collected at the household level). The "non-members", which represent over 80% of the "carshare accessible" Bay Area population, are those individuals or households that do not hold carsharing membership. In this section, statistical results are presented based on analytic weights that were computed at the household and person level for the CHTS. The weights were calculated to reflect the different probabilities of selection of respondents and align the sample distributions to population distributions from the latest available census data. Several of the survey results presented here are consistent with previous findings on carsharing, with exceptions and additions as noted below.

4.1 Demographics

Based on the survey data, carshare members tend to be more educated and have higher incomes than the non-member population, as illustrated Table 2 ($p<0.001$). Consistent with previous findings, the sample of carshare members are more highly educated, with 83.5% holding at least a bachelor's degree, as compared with 69.5% of the non-member population. While previous studies have found that carshare members tend to have low or moderate incomes, this analysis finds that their household incomes tend to skew higher. Among the carshare member population, 59.0% of households have annual incomes of $100,000 or more, compared with 37.2% of non-member households. One factor that likely impacts these trends are the partnerships that many

carsharing organizations, such as Zipcar, have established with college, university, and corporate campuses.

Table 2. Demographics of Carshare Members vs. Control (% of group total)

Age	Carshare N = 232	Control N = 1625
16 to 20	1.5	6.2
21 to 30	12.9	9.3
31 to 40	24.6	18.5
41 to 50	25.7	18.4
51 to 60	22.0	19.0
61 to 70	9.7	17.6
71 and older	3.5	11.1
Education	Carshare N = 248	Control N = 1625
12 grade or less	3.5	3.3
High school	2.1	10.1
Some college	8.0	11.7
Associate degree	2.9	5.4
Bachelor's	38.0	33.7
Graduate degree	45.5	35.8
Household Income	Carshare N = 214	Control N = 928
Less than $9,999	1.7	3.6
$10,000 to $24,999	5.3	12.3
$25,000 to $34,999	2.5	7.3
$35,000 to $49,999	3.5	11.5
$50,000 to $74,999	14.6	15.1
$75,000 to $99,999	13.4	13.0
$100,000 to $149,999	19.6	14.5
$150,000 to $199,999	19.4	8.7
$200,000 to $249,999	13.3	5.4
$250,000 or more	6.7	8.6

4.2 Travel Mode Choice

The CHTS provides a rich set of data on travel behavior, collected by asking survey respondents to complete an activity diary recording all places they travel to during a 24-hour time period, including which mode they used for each trip. Table 3 provides an overview of the differences

between carshare members and the non-member control group with regard to this primary dimension of travel behavior: mode share. The table shows the percentage of total trips reported by survey respondents that were made by automobile, transit, walking, bicycling, or other modes. In the CHTS, a total of 29 modes were provided as options to respondents (California Department of Transportation 2013). For the purposes of this analysis, "taxi/ hired car/ limo" and "rental car/ vehicle", which may or may not include carshare vehicles depending on the survey respondents' interpretation, are categorized under the "automobile" category. Travel by "motorcycle/ scooter/ moped", "wheelchair/ mobility scooter", "airplane", and "ferry" have been classified as "other" modes in the table below.

Table 3. Percentage of Trips by Mode: Carshare Members vs. Control

Mode	Carshare	Control
Automobile	41.5	61.8
Auto/Van/Truck	39.6	61.0
Carpool/Vanpool	0.2	0.3
Taxi/Hired Car	0.7	0.4
Rental Car	1.0	0.1
Transit	14.5	10.3
Public	13.9	9.9
Private	0.7	0.4
Walk	34.9	23.0
Bike	8.0	4.0
Other	1.0	0.9

Analysis of the data illustrates significant differences between carshare members and non-members in terms of their travel mode ($p<0.001$). The control population respondents make a majority (61.8%) of all their trips by automobile, as compared with 41.5% of the carshare member population. Carshare members in the Bay Area make a fairly large (34.9%) of their of their trips by walking, whereas non-members make 23.0% of their trips by walking. Perhaps more interesting, carshare members make 8.0% of their trips by bike, while this is only true for 4.0% of non-members. Based on the data, it is clear that carshare members are truly more multi-modal than their non-members counterparts in the Bay Area. However, it is unclear to what extent their multi-modalism is a result of their lack of car ownership, residence location, underlying attitudes that affect their travel and residential decisions, or some combination of these factors.

4.3 Vehicle Ownership

Several studies on carsharing have found that households tend to maintain or reduce their vehicle holdings after becoming carshare members (Cervero et al. 2007, Martin et al. 2010). Consistent with previous work, this analysis of the CHTS demonstrates that on average carshare members own significantly fewer vehicles than non-members ($p<0.0001$). Based on the entire Bay Area sample, 30% of carshare members are zero-vehicle households, compared with 8% of non-members. Table 4 summarizes the average number of vehicles per household in the entire Bay Area sample, a San Francisco subsample, and the "carshare accessible" subsample of the Bay Area.

The average number of vehicles among carshare member households is significantly lower than that of the non-member households ($p<0.0001$). These figures are not particularly surprising, as some portion of carshare members join carsharing because they do not own a vehicle. However, it is notable that the vehicle ownership rates are significantly higher than previous carsharing research has demonstrated. While much of the previous research on carsharing is based on surveys administered to carsharing members through a carsharing organization, this study is based on a representative sample of the general population. The number of respondents in this sample who indicated that they are members of carsharing includes those with *high utilization* of the service, as well as those with *low utilization* (or none at all). On the other hand, respondents to a survey administered by a carsharing organization (where carsharing credit is the response incentive) are more likely to be higher utilization customers – and thus, more likely to not own a vehicle. There are some advantages to utilizing this survey of the general population (it is representative), as well as disadvantages (carsharing utilization rates are unknown).

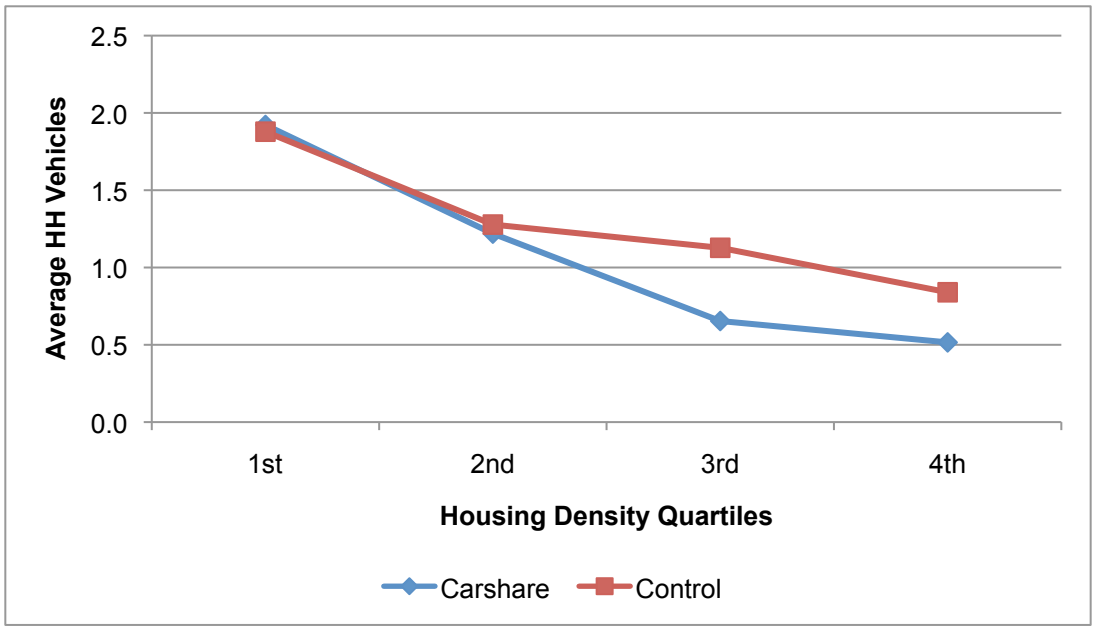
Table 4. Average Household Vehicles: Carshare Members vs. Control

	Carshare	Control	*p*-value
Bay Area	1.31	1.86	$p<0.0001$
San Francisco	0.99	1.57	$p<0.0001$
Carshare Accessible Census Tracts	1.10	1.37	$p<0.0001$

Numerous studies have found a strong link between residential location and travel behavior, with residents of higher-density neighborhoods owning fewer vehicles and driving less

than those in lower-density, single-family neighborhoods (Crane & Crepeau 1998, Cervero & Duncan 2003, Cao et al. 2009). In this study, further analysis of household vehicle holdings was conducted to control for these built environment factors. Figure 1 summarizes the average household vehicles by housing density quartile for the "carshare accessible" subsample. Housing density, the number of residential units per square mile, was calculated using the American Community Survey (ACS) 2013 5-year average and 2010 Census land mass areas by census tract. The lower quartiles represent less dense, somewhat suburban neighborhoods, whereas the higher quartiles represent dense urban centers.

Figure 1. Average Household Vehicles by Housing Density: Carshare Members vs. Control



As expected, the average number of household vehicles is lower in higher density census tracts. After controlling for this built environment measure, the relationship between carsharing and average household vehicles is more nuanced. Carshare members in the more urban census tracts (third and fourth quartiles) have significantly fewer vehicles than their non-member counterparts living in the same areas ($p<0.0001$). In these more urban neighborhoods, the control group households own 0.96 vehicles as compared with only 0.58 vehicles among carshare member households. However, among carshare members versus non-members in the more suburban census tracts (first and second quartiles), there is no statistical difference in the number of vehicle holdings ($p>0.10$). While previous research has suggested that one carsharing vehicle

can replace 9 to 13 vehicles, the findings presented here suggest that the potential for reducing vehicle ownership is strongly tied to the built environment: housing density, transit accessibility, and most likely, the availability of parking.

4.4 Reasons for Not Owning a Vehicle

Through the CHTS, households that did not own a vehicle were prompted with a question inquiring *why* they do not own a motor vehicle. The results comparing carshare members and control of the "carshare accessible" subsample are provided in Table 5. Respondents were allowed to select multiple pre-defined, unordered responses to the question. Based on the data, there is no method to determine a respondent's primary reason for not owning a vehicle, thus the table results below summarize all responses provided by respondents.

Table 5. Reason for Not Owning a Vehicle: Carshare Members vs. Control

	Carshare	Control
Don't need a car	18.0	23.0
Too expensive to buy	12.2	11.9
Too expensive to maintain	15.3	12.4
Health/ age related	0	3.5
Can't get insurance	0	0
Concerned about environment	14.8	6.6
Get rides from other people	3.7	2.7
No parking	10.1	7.1
Use transit/ carshare/ bike/ walk	23.3	17.7
No license	0	4.4
Can't drive	0	6.2
Other	2.6	4.4

Among both carshare members and the control within the "carshare accessible" subsample, two of the most common reasons for not owning a vehicle were "don't need a car" and "use transit/ carshare/ bike/ walk." Cost-related reasons ranked high on the list, with "too expensive to buy" and "too expensive to maintain" accounting for 27.5% of carshare members' reasons and 24.3% of non-members' reasons.

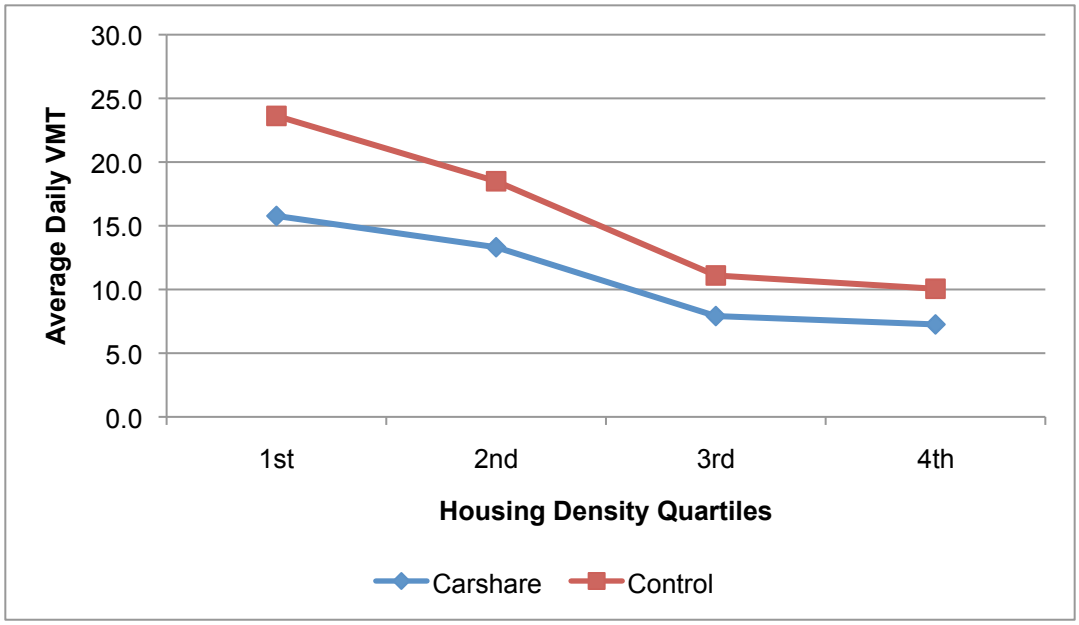
The most interesting result is the significantly higher portion of carshare respondents who indicated that they were "concerned about impact on the environment." Among all carshare member households that responded to this question, 41% indicated that they did not own a

vehicle because they were "concerned about impact on the environment" as compared with only 13% of the control group (p<0.001). Given that the reasons provided by respondents were unordered, and this question was only asked of zero-vehicle households, it is difficult to determine whether environmental concern is a significant factor influencing a households' total vehicle ownership. Nonetheless, this finding provides evidence of a likely correlation between carsharing membership and environmental attitudes.

4.5 Vehicle Miles Traveled

Previous research on carsharing has found a significant decline in the average vehicle miles traveled (VMT) after a member joins carsharing. Utilizing the CHTS subsample of "carshare accessible" individual respondents, and housing density quartiles described in Section 4.3, the average daily VMT of carshare members versus the control group is compared in Figure 2.

Figure 2. Average Daily Vehicle Miles Traveled by Housing Density: Carshare vs. Control



The data illustrates that carshare members have a lower average daily VMT than their non-member counterparts; however, this result is only significant for those members residing in the lower density (first and second quartile) neighborhoods (p<0.05). One might argue that this is where VMT reductions are most important, as average daily VMT rates of these populations is generally higher than those of urban residents. In the most suburban neighborhood from the

subsample, carshare members averaged 15.8 vehicle miles per day versus 23.6 vehicle miles per day of the control group ($p<0.10$).

4.6 Electric Drive Vehicle Ownership

The final dimension of travel behavior examined in this study is the ownership of electric drive vehicles, including hybrid electric vehicles, plug-in hybrid electric vehicles (PHEVs), and battery electric vehicles. In its inventory of household data, CHTS collects detailed information about all vehicles owned. Table 6 summarizes the breakdown of vehicles in the "carshare accessible" Bay Area subsample, classified by whether they are owned by carshare members or non-members. Although the total number of vehicles owned by carshare members is smaller (in part due to the low incidence of carshare adoption and also due to the fact that this sub-population owns fewer vehicles), it is notable that the portion of electric drive vehicles is significantly larger among the carshare member population ($p<0.001$). Among vehicles owned by carshare members, 18.3% are hybrid, plug-in hybrid or battery electric vehicles, as compared with 10.2% of those vehicles owned by non-members.

As described in Section 1, sustainable transportation strategies in California have attempted to link carsharing and alternative vehicle adoption. Under the California Zero Emission Vehicle (ZEV) program, auto manufacturers are able to earn transportation system credits by placing ZEVs and PHEVs in carsharing programs. There is evidence to suggest that vehicles in carsharing fleets experience higher utilization rates as compared with non-shared vehicles, hence they have the potential to displace vehicle miles traveled (VMT) that might otherwise be made by vehicles with a higher carbon footprint. In addition, proponents of such policies argue that by placing electric drive vehicles in carsharing fleets, they are exposed to a broader consumer base, which may lead to faster adoption of these vehicles. Although it is unclear from this data whether carshare members were more likely to purchase alternative vehicles because of their carsharing membership, these results do show that there is a significant correlation between carshare use and the ownership of hybrid, PHEV, and battery electric vehicles.

Table 6. Vehicle Type Share: Carshare Members vs. Control

	Carshare	Control
Gasoline	78.1	88.6
Hybrid	14.4	9.6
PHEV	1.4	0.3
Electric	2.5	0.3
Diesel	2.9	1.1

Given limitations of the data, the extent to which potential exposure to (and experience driving) electric drive vehicles in carsharing fleets actually leads to greater adoption of these vehicles cannot be determined. It is certainly possible that individuals who opt into carsharing are more environmentally-oriented and open to new technology and experiences, hence the correlation between carsharing and electric drive vehicles. Further research as to the reasons for the correlation between carsharing membership and ownership of electric drive vehicles found in this study is needed.

5 Conclusions

Based on this analysis of a statistical sample of households in the Bay Area, there is evidence that carsharing is linked to several measures of sustainable travel, including: 1) higher modal shares of transit, walking and biking; 2) lower household vehicle ownership in dense urban neighborhoods; 3) lower vehicle miles traveled (VMT) in suburban neighborhoods, and 4) higher rates of electric drive vehicle ownership. By developing a control group of individuals and households with access to carsharing at the U.S. census tract level, comparisons are drawn between carsharing members and their non-member counterparts.

First, this analysis presents evidence that carsharing is linked to multi-modal travel behavior, with carshare members making a significantly greater share of their trips by public transit and non-motorized travel than their non-member counterparts. Controlling for carshare-accessible locations, in the Bay Area carshare members made only 41.5% of their trips by car, as compared with 61.8% of non-members. Carshare members made 14.5% of their trips by transit and 34.9% of their trips by walking, as compared with 10.3% and 23.0% of the control population trips, respectively.

Second, this study finds continued evidence that carsharing is linked with lower levels of automobile ownership and driving. In very dense, urban neighborhoods, carshare members own

significantly fewer vehicles than their non-member counterparts: 0.58 household vehicles versus 0.96 household vehicles. These results are not particularly surprising, given that many carshare members join to gain access to a vehicle in the first place, as noted by previous studies (Martin et al. 2010). Although this study does not find that carsharing significantly reduces vehicle holdings among suburban (versus urban) households, it does find evidence that carsharing membership is correlated with lower levels of *driving*. In a suburban subsample, carsharing members drove an average of 15.8 miles per day versus the 23.6 miles per day of a non-member. These nuanced findings on vehicle ownership and VMT suggest that as carsharing increases in popularity, distinguishing between occasional, low-utilization carshare members versus high-utilization members may highlight significant variations in travel behavior. In addition, there are significant differences in how carsharing affects vehicle holdings and VMT depending on whether a household lives in a high-density urban neighborhood versus one more suburban in nature.

Finally, this study finds that there is a correlation between carsharing adoption and the purchase of alternative vehicles, including hybrid electric vehicles, plug-in hybrid electric vehicles, and electric vehicles. Among vehicles owned by carshare members in the "carshare accessible" subsample, 18.3% were electric drive vehicles, as compared with only 10.2% of those vehicles owned by non-members. This study finds that not only are carshare members likely to own fewer vehicles, they are more likely to own more sustainable vehicle technologies. Based on this data, it is not possible to discern whether carshare members have underlying attributes (e.g., environmental preferences) that lead them to purchase alternative vehicles at a higher rate, whether exposure to alternative vehicles through carsharing leads to the purchase of such vehicles, or some combination thereof. Future before-and-after studies controlling for demographic and attitudinal variables may help to shed light on the extent to which placing alternative vehicles in carsharing fleets leads to greater adoption of these technologies.

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