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Greenhouse Gas Emission Impacts of Carsharing in North America

MTI Report 09-11

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GREENHOUSE GAS EMISSION IMPACTS OF CARSHARING IN NORTH AMERICA

June 2010

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16. Abstract

This report presents the results of a study evaluating the greenhouse gas (GHG) emission changes that result from individuals participating in a carsharing organization. The principle of carsharing is simple: individuals gain the benefits of private vehicle use without the costs and responsibilities of ownership. Carsharing is most common in major urban areas where transportation alternatives are easily accessible. Individuals typically access vehicles by joining an organization that maintains a fleet of cars and light trucks deployed in lots located within neighborhoods, public transit stations, employment centers, and colleges/universities. In this study, the authors conducted a survey of carsharing members across the country to develop a robust estimate of GHG emission impacts resulting from carsharing. The results illustrate the annualized change in GHG emissions among members within the largest carsharing organizations across Canada and the United States. GHG emissions from transportation are lower due to carsharing. The average change in emissions across all respondents is -0.58 t GHG per household per year for the observed impact, and -0.84 t GHG per household per year for the full impact. However, it is important that this result is understood in the context of the broad diversity of carsharing impacts. While carsharing does facilitate lower emissions, the reduction is not generalizable across all members or even a majority of members. Rather, carsharing as a system facilitates large reductions in the annual emissions of some households, which compensate for the collective small emission increases of other households. The results also show that respondent households exhibit significant reductions in vehicle ownership after joining carsharing.

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EXECUTIVE SUMMARY

This study evaluates the greenhouse gas (GHG) emissions impact that results from the travel lifestyles changes exhibited by members of carsharing organizations. Carsharing (short-term vehicle access) has been continuously operating in North America for about fifteen years. Just over ten years ago, carsharing emerged in select cities within the U.S. as a niche market alternative to offer members auto access without the costs of private vehicle ownership. Carsharing organizations operate by placing vehicles throughout urban neighborhoods, metropolitan centers, and colleges/universities. The vehicles are accessible to members through a reservation that is booked in advance by phone or Internet. Members can pay for carsharing services in a variety of ways depending on the organization and pricing plan to which they subscribe. Most members pay a monthly or annual fee in some combination with per hour and per mile charges.

Carsharing influences emissions by allowing members access to a shared automobile on an as-needed basis. Carsharing members may use the shared vehicles to conduct trips that are more convenient with the flexibility of an automobile. However, the pricing structure of carsharing largely encourages the use of shared-vehicles for non-work trips (outside of specialized business, campus, and governmental fleet packages). Commuting, as well as other short trips, are generally completed through walking, biking and public transit use. Carsharing can result in both increased and decreased emissions. Carsharing increases emissions by providing automotive access to people who were previously carless. These households drive more than before they joined carsharing. Carsharing also decreases emissions by permitting other people who were more reliant on personal vehicles to use automobiles in a more sparing and efficient manner. These households generally discard or shed one or more personal vehicles in substitute of a carsharing membership. These members adapt to a new travel lifestyle that is facilitated by carsharing. This lifestyle is usually characterized by a modal shift that generally leads to reduced emissions over the previous reliance on the personal vehicle owned by the household.

Because carsharing leads to emission increases in some households, and emission decreases in other households, a natural question arises pertaining to overall net impact of carsharing. This study explores this question on a large scale through a single survey of carsharing members within major organizations throughout North America. In cooperation with participating organizations, researchers surveyed carsharing members about their travel patterns during the year before they joined carsharing and at the time of the survey. This before-and-after analysis explores how the emissions of the household changed since joining carsharing. Researchers sent the Canadian and American respondents separate surveys due to the different distance and currency units used in the respective countries. The organizations that participated in the survey are listed in Table 1.

Table 1 Participating Organizations

Organization	Location
AutoShare	Toronto, Ontario, Canada
City CarShare	San Francisco/Oakland, California
CityWheels	Cleveland, Ohio
Community Car Share of Bellingham	Bellingham, Washington
CommnuAuto	Montreal, Province of Quebec, Canada
Community Car	Madison, Wisconsin
Co-operative Auto Network/The Company Car	Vancouver, British Columbia, Canada
IGo	Chicago, Illinois
PhillyCarShare	Philadelphia, Pennsylvania and Wilmington, Delware
VrtuCar	Ottawa, Ontario, Canada
Zipcar	United States and Canada

The organizations distributed the survey solicitations to their members through their own email lists. The email that the organizations sent out included a link to the survey at a third-party site. Two reminders were sent out via each organization, and the survey closed on November 7, 2008. Most organizations, which are located in a single city, distributed survey solicitations to all of their members. Because of Zipcar's size and geographic distribution, the solicitation was capped at a total of 30,000 randomly selected Zipcar members within specific markets. This included 5,000 each within New York City, New York; Boston, Massachusetts; Washington DC; Portland, Oregon; and Seattle, Washington. An additional 2,500 each in Canadian cities Vancouver and Toronto also received survey solicitations. In aggregate, the authors estimate that nearly 100,000 carsharing members received the survey solicitation. Based on the coverage, size, and selection of this population, the authors consider it to be random and representative of the carsharing population within North America. In total, 9,635 surveys were completed, constituting a response rate of about 10%.

The unit of analysis of this study is the entire household of the carsharing member, as an individual's carsharing use can affect the travel emissions of all household members. For example, an individual may join carsharing and shed (gets rid of) their personal vehicle that they used exclusively. But another member of the household retains his or her vehicle, which is subsequently shared with the carsharing member when it is available. The vehicle belonging to the non-member within the household is driven more than previously because two people are using it.

The survey calculated the GHG impacts that result from the change in annual overall automotive use. This consisted of the annual personal and carsharing automotive emissions of the household at the time of the survey minus the annual personal automotive emissions of the household during the year before joining carsharing. The result is a change in the annual rate of household emissions before and after carsharing. The population of study in this survey includes households that use carsharing within the neighborhood business model. The neighborhood business model places vehicles within urban residential neighborhoods and downtowns that are accessible to any and all members. This market is the predominate market within the carsharing industry and comprises the vast majority of members. The survey excludes members that use carsharing strictly within a business application and university students using carsharing within a college setting. These cohorts constituted 2% and 6% of the sample, respectively. The analysis also filtered respondents that indicated a move of home or work that significantly altered their overall driving. In addition, respondents that indicated that they did not use carsharing at all were filtered as “inactive” users. Inactive users are a cohort of carsharing members that do not use the service but retain their membership. Because their travel lifestyles are conducted without carsharing, they are assigned a zero impact in this study. Further discussion of data processing and respondent filtering is presented in the complete report. The influence of these cohorts on the overall results are also explored in a sensitivity analysis.

This study explores the GHG emission change through two distinct but related metrics. One impact is termed the “observed impact,” which describes the emission change that actually occurred. The observed impact considers the total household driving before the member joined carsharing and the total household driving at the time of the survey. A second impact is termed the “full impact,” which includes the observed impact but also an additional component of avoided emissions. To explain further, carsharing gives people who are considering purchasing a vehicle an alternative means in which to achieve “automobility.” As a result, some people who would have bought a car choose to join carsharing instead. The driving of the forgone personal vehicle would have resulted in some emissions that never then occur. The survey explores this dynamic with relevant respondents and estimates the additional emissions that were avoided due to forgone vehicles that were never acquired and driven. These avoided emissions, when added to the same emissions covered by the observed impact, constitute the full impact of carsharing. Because the full impact introduces an additional component of abstraction and measurement uncertainty, it is reported separately alongside the observed impact throughout the report.

The results show that overall net annual emissions of households joining carsharing are lower than they were before they joined carsharing. Across the 6,281 respondents that were applied in the final analysis, carsharing facilitates a decrease in annual emissions for some members and an increase in annual emissions among other members. The authors found that on balance, net carsharing emissions are negative and statistically significant for both the observed impact and full impact. Hence, GHG emissions from transportation are lower due to carsharing. The average change in emissions across all respondents is -0.58 t GHG per household per year for the observed impact, and -0.84 t GHG per household per year for the full impact. However, it is very important that the “how and why” of this result is understood in the context of the broad diversity of carsharing impacts. While carsharing does facilitate lower emissions, the reduction is not generalizable across all members or even a majority of members. Rather, carsharing as a system facilitates large reductions in the annual emissions of some households, which compensate for the collective small emission increases of other households. This dynamic is important for the construction of sound policy, which can encourage carsharing growth in a manner that provides mobility benefits and continued emission reductions within urban and suburban environments.

Exploring the data in more detail, the results show that a majority of households are increasing their emissions through carsharing—but the degree to which these households are increasing their emissions is very small. In contrast, the minority of households reducing their emissions are exhibiting changes that are of larger magnitude and greater variance. Figure 1 shows a histogram that illustrates the distribution of impacts by respondent count for both the observed and full impact.

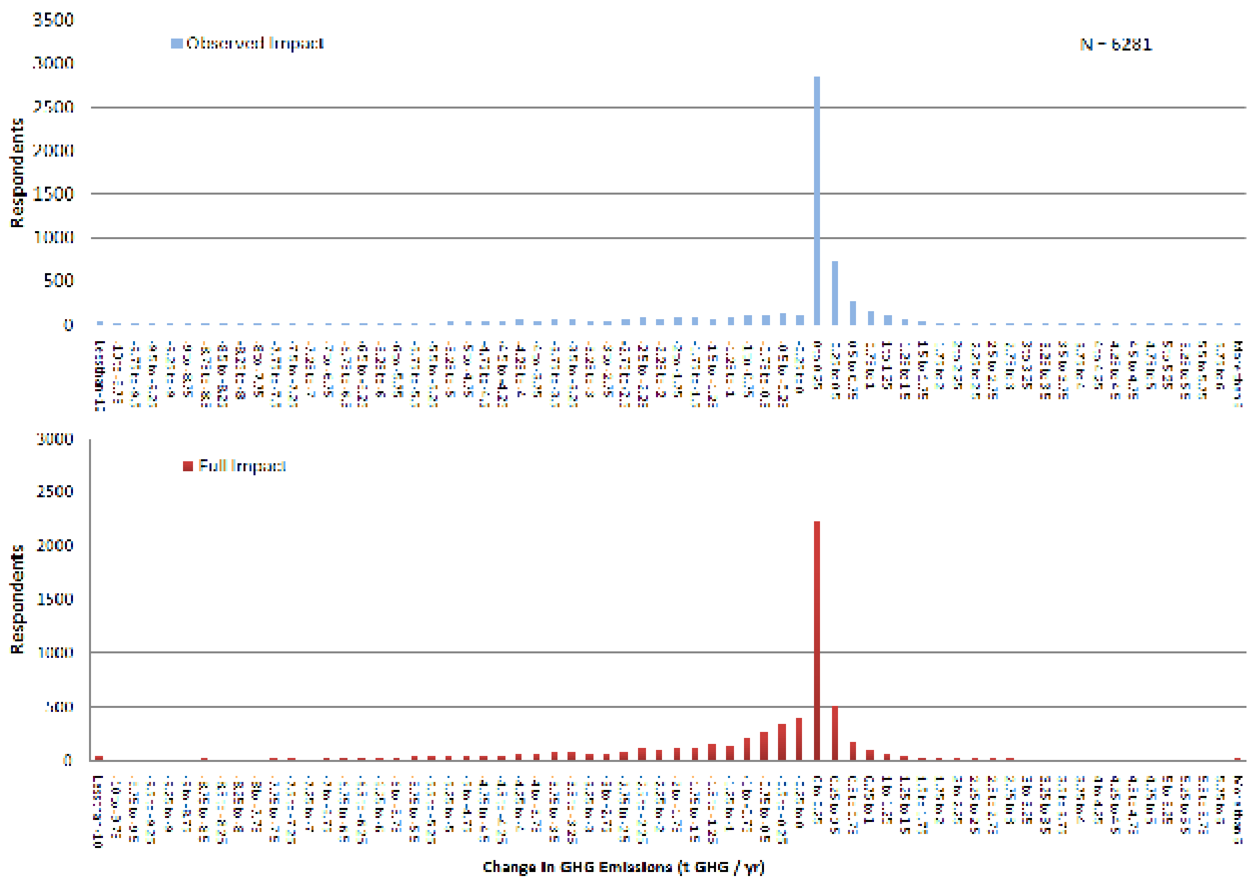


Figure 1 Distribution of Annual Household GHG Emission Impact

Distribution of Annual Household GHG Emission Impact

For both the observed and full impact, the distribution shows the large number of respondents increasing their emissions. This is evident with the high number of respondents that exhibit an increase in annualized emissions within the bounds of 0 and 0.25 t GHG/yr. The distribution of members lowering their emissions is far more evenly spread for both the observed and full impact. In total, 4,456 (71%) of respondents have a positive observed impact, while 1,825 (29%) have a negative observed impact. For the full impact, the balance is more evenly distributed by respondent frequency, as 3,281 respondents (53%) have a positive full impact while 2,953 respondents (47%) have a negative full impact.

The difference between the number of respondents decreasing their emissions in the observed impact and the full impact highlights the importance of considering the avoided emissions. The resulting shift of the full impact reduces the number of members with impacts greater than zero. Absent any consideration of avoided mileage, these respondents would appear to be increasing their net emissions through carsharing.

Most members drive carsharing vehicles very short distances over the course of a year. For example, 30% of all households report placing less than 250 miles per year on carsharing vehicles. An additional 16% reported driving between 250 and 500 miles, and 19% placed between 500 and 1,000 miles annually. In total, more than 80% of all households in the sample drive less than 2,000 miles per year on carsharing vehicles. In contrast, households decreasing their emissions were driving much longer annual distances in personal vehicles before adapting to a carsharing lifestyle. Figure 2 shows the distribution of personal vehicle miles traveled (PVMT) of the sample both before and after joining carsharing.

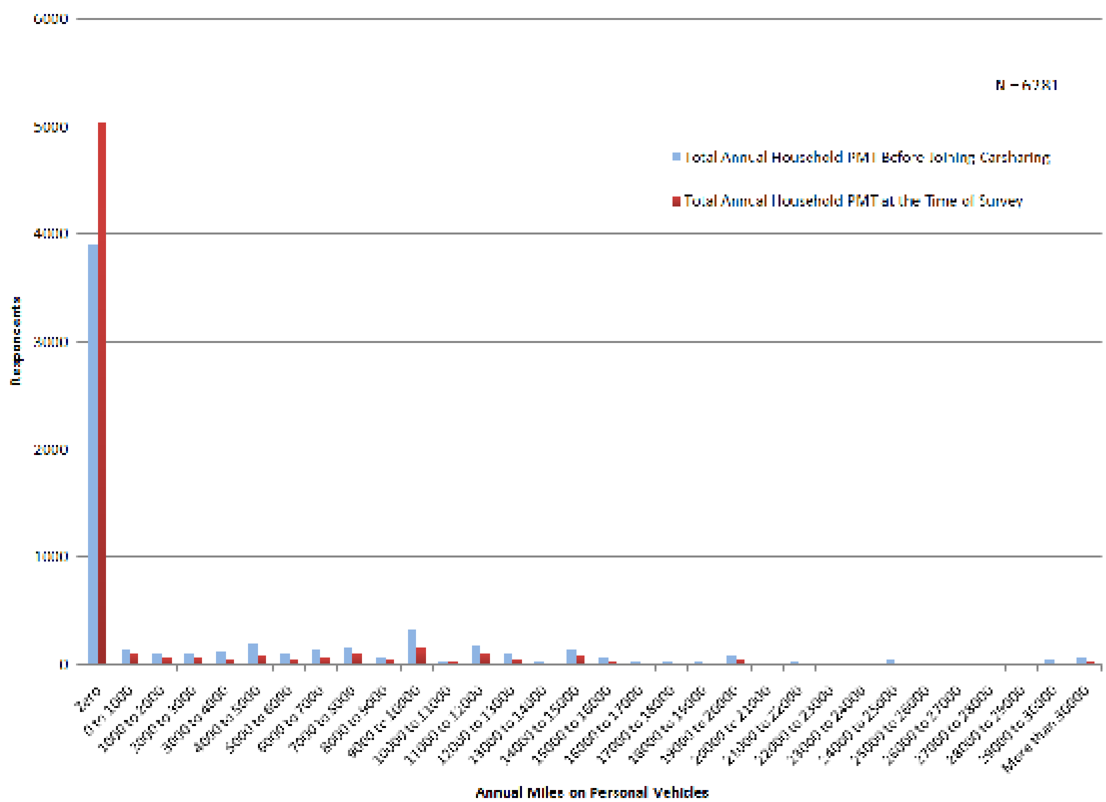


Figure 2 Distribution of Total Annual Personal Vehicle Miles Traveled by Household

The distribution within Figure 2 shows the overall shift of households toward lower personal vehicle driving. The “before-and-after” shift in the PVMT distribution shows a significant gain in the number of carless households, an increase of nearly 30%. The distribution of annual household PVMT distances shows a general decline of households driving all distances. This does not mean that no households reported an increase in household PVMT, some did. But most households lowered mileage by eliminating at least one vehicle.

When added together, the result of these collective movements provides a clear picture of the shape of the overall impact of carsharing. Figure 3 presents the same aggregate distribution of emissions change as Figure 1. But Figure 3 shows the impact as weighted by the annual emissions change for each respondent within the categorical bin. In other words, each categorical bin of the horizontal axis contains the summation of the annual change in respondent emissions. The result is a distribution that illustrates the cumulative net annual change in emissions for all survey respondents. The top graph in Figure 3 illustrates this distribution for the observed impact, and the bottom graph shows the full impact.

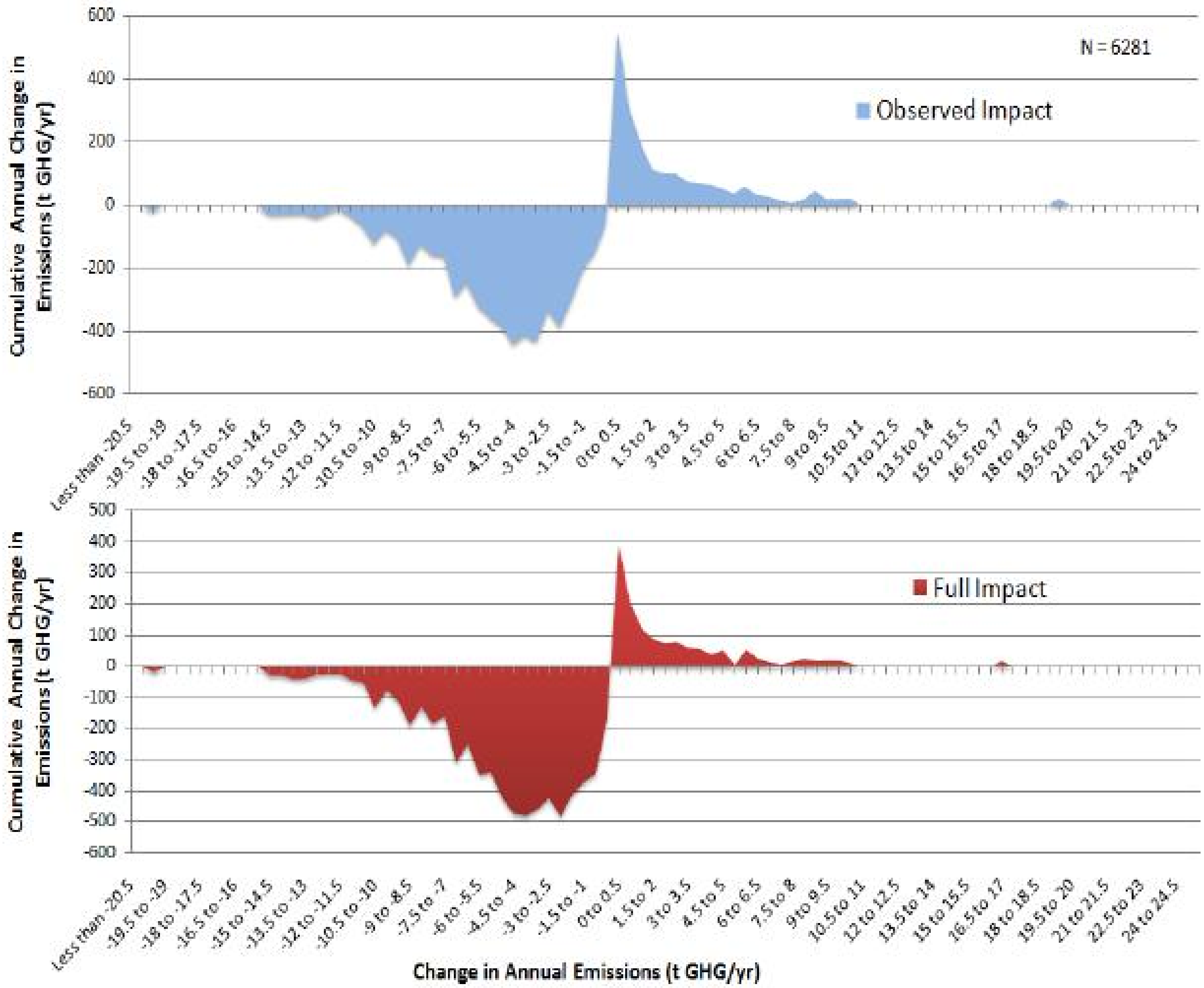


Figure 3 Profile of Cumulative Annual Change in GHG Emissions

For both the observed and full impact, Figure 3 makes it visually apparent that the area constituting emission reductions is larger than the area constituting emission increases. Thus, while the majority of respondent households are increasing annual emissions, the cumulative annual emissions change is negative and thus so is the average. The statistical significance of the average change in annual emissions is shown in Table 2 as given by the paired t-test.

This overall result that carsharing lowers emissions is robust to a variety of assumptions and key input modifications to the data. A sensitivity analysis given in the full report shows how the average and distribution of emission impacts will change given an alteration of key assumptions. For example, the sensitivity analysis illustrates how the emissions would change if the maximum annual PVMT value given by respondents is constrained with an upper bound that is gradually lowered to zero. In addition, the sensitivity analysis illustrates how the results change with the re-admission of filtered respondents, including movers, students, business users and inactive members. Overall, the inclusion of these cohorts increases the variance of the impacts, but they do not change the overall mean to a significant degree. Thus, by examining the data from several perspectives, the sensitivity analysis illustrates how the mean and statistical significance of the aggregate impacts vary with changes to key assumptions and data.

Table 2 Paired t-Test: Mean Difference from Zero

	Paired Sample t-test - Paired Differences							
	Mean	Std. Deviation	Std. Error Mean	99% Confidence Interval of the Difference		t	df	Sig. (2-tailed)
				Lower	Upper			
Observed Change in Emissions	-.58	2.23	.03	-.65	-.50	-20.479	6280	.000
Full Change in Emission	-.84	2.20	.03	-.91	-.76	-30.027	6280	.000

The emissions impacts described above are in large part driven by households shedding vehicles upon joining carsharing. As part of the survey, respondents were asked to provide the make, model, and year of each vehicle owned by the household before and after joining carsharing. These data permitted an analysis of the change in household vehicle holdings within the sample, which is presented in Table 3.

Table 3 Profile and Statistical Evaluation of the Change in Vehicle Holdings

Vehicle Change Category	Zero Car Households	One Car Households	Two Car Households	Three Car Households	Four Car Households	Five or more Car Households	Total
Vehicles Shed	0	1437	486	70	37	16	2046
Vehicles Retained	0	480	340	68	15	19	922
Vehicles Added	219	21	5	1	0	0	246
Vehicles Replaced	0	187	122	19	10	1	339
	0	0	0	0	0	0	0
Net Change (Added+Replaced-Shed)	219	-1229	-359	-50	-27	-15	-1461

Paired Test Variables	Paired Differences t-test							
	Mean	Std. Deviation	Std. Error Mean	99% Confidence Interval of the Difference		t	df	Sig. (2-tailed)
				Lower	Upper			
Vehicles After - Vehicles Before	-0.233	0.559	0.007	-0.251	-0.214	-32.955	6280	0.00

Table 3 illustrates how households with different quantities of vehicles before joining carsharing adjusted their vehicle holdings. When changing vehicle holdings, there are four possible actions that a household can take: the household can shed, retain, add, or replace a vehicle. Vehicle replacement involves the shedding and adding of a vehicle within the same household. For instance, in a household that sheds two vehicles and adds one, the added vehicle is counted as a replacement. Similarly, in a household that sheds one vehicle and adds two, one of the new vehicles is a replacement, and the other is an added vehicle. The results show that the sample of 6,281 households shed a total of 1,461 vehicles, which amounts to a statistically significant reduction in the average vehicles per household.

Further insights with respect to vehicle shedding are presented within a matrix that shows how households transitioned from different states of vehicle holdings before and after joining carsharing. Table 4 presents a cross-tabulation of household vehicle holdings “before” and “after” joining carsharing and shows how households within the sample transitioned to new vehicle holding states.

Table 4 Transition of Household Vehicle Holding States Among Carsharing Households

After Joining Carsharing / Before Joining Carsharing	Zero Car Household	One Car Household	Two Car Household	Three Car Household	Four Car Household	Five or more Car Household	Total
Zero Car Household	3686	182	14	3	0	0	3885 (62%)
One Car Household	1250	646	21	0	0	0	1917 (31%)
Two Car Household	68	228	112	5	0	0	413 (7%)
Three Car Household	7	11	8	19	1	0	46 (1%)
Four Car Household	3	2	3	3	2	0	13 (0%)
Five or more Car Household	2	1	0	0	1	3	7 (0%)
Total	5016 (80%)	1070 (17%)	158 (3%)	30 (0%)	4 (0%)	3 (0%)	6281

The column on the far right (“Total”) illustrates the distribution of household vehicle holdings before joining carsharing while the bottom row (“Total”) illustrates the distribution of vehicle holdings after joining carsharing. The cells within the table show the counts at each transition. As evident from the upper-left cell (the zero-car household to zero-car household transition), most households (3686) joining carsharing were carless and remained carless. The second largest count is within the cell immediately below, in which one-car households became carless households. Overall, the transition matrix shows that most of the changes in vehicle holdings were the result of a household shedding a single car.

In summary, this study completed a survey of members of carsharing organizations across the United States and Canada. The results of the data show that in aggregate, transportation emissions of households that join carsharing are lower after they join. The average change in annual emissions is consequently negative and statistically significant. The results also show that carsharing households lower their average vehicle holdings by a degree that is also statistically significant. The shedding of vehicles that were driven before household members joined carsharing plays a major role in driving the emission reductions.

It is important to recognize that in the context of carsharing, the "average" emissions change is not the same as the "typical" emission change. Carsharing provides mobility benefits to many members that come from carless households. These mobility benefits accrue directly to the member and offer their own internal advantages. But strictly from an emission perspective, carless households that drive more through a carsharing membership are increasing emissions. These households constitute a majority of the carsharing membership, but their contributions to emissions are small because carsharing vehicles are generally not driven long distances by members. Instead, carsharing vehicles are predominantly used for short non-work trips or the occasional long-distance day trip. Households that reduce their emissions through carsharing generally do so by shedding personal vehicles and placing far fewer emissions on carsharing vehicles. The combination of this dichotomous process results in an overall net reduction of emissions. This result is robust to a variety of assumptions and data modifications as conducted in a broad sensitivity analysis.

This study contributes to mounting evidence that carsharing is lowering GHG emissions by providing people with automotive access on an as-needed basis. The scope of the impacts evaluated is restricted to the household travel-based emissions. The sample population constitutes carsharing members that use the neighborhood business model of carsharing. No emission impacts from vehicle holding reductions or land-use changes are considered. The results and scope of the study have important implications for policy design. Carsharing systems provide environmental benefits. However, caution regarding the caveats of this study in any policy design and emission crediting is necessary. It is clear from the data that not all members reduce emissions. In addition, not all members of carsharing organizations are active members. Carsharing organizations contain some number of inactive members. These members use carsharing very infrequently and are only members for occasional events and emergencies. Carsharing provides a supplement to their lifestyle, but it may not influence or facilitate it in a major way. The share of these members within an organization could vary over time based on industry pricing plans as well as general economic conditions. The diversity of impacts across members suggests that credits for carsharing impacts should be certifiable in some form. Future studies should continue to evaluate carsharing trends, as they will likely evolve. Based on these results, as long as carsharing continues to thrive economically, its benefits are likely to grow, as more carholding households find carsharing to be an established and stable option for meeting automotive travel needs within North American cities.

INTRODUCTION

Mounting evidence of climate change and increasing energy costs are motivating many state and local governments to explore policy options that can simultaneously reduce petroleum consumption and greenhouse gas (GHG) emissions. Within the United States, transportation activity accounts for close to 30% of all anthropogenic carbon dioxide (CO_2)-equivalent GHG emissions and nearly 70% of all petroleum consumption. As a sector, transportation is almost exclusively petroleum dependent, as roughly 96% of all energy consumed in the U.S. is comprised of either gasoline or diesel.[1] Furthermore, a longstanding dependence on the private automobile for urban transportation has placed the U.S., and to a lesser extent Canada, in uniquely difficult positions to adjust travel in ways that mitigate the impacts of higher energy costs, air pollution, and global warming.

This study evaluates the GHG emission impact that results from changes in travel when households join a carsharing organization. Carsharing (short-term vehicle access) has been continuously operating in North America for about fifteen years. Just over ten years ago, carsharing emerged in select cities within the U.S. as a niche market alternative to offer members auto access without the costs of private vehicle ownership. Carsharing organizations operate by placing vehicles throughout urban neighborhoods, metropolitan centers, and colleges/universities. The vehicles are accessible to members through a reservation that is booked in advance by phone or Internet. Members can pay for carsharing services in a variety of ways depending on the organization and pricing plan to which they subscribe. Most members pay a monthly or annual fee in some combination with per hour and per mile charges.[2]

Since its inception, carsharing has grown rapidly under both non-profit and for-profit business models. Today, the industry is comprised of 42 organizations within North America, most of which have primarily focused on serving a single metropolitan region. As of July 1, 2009, there were 16 active programs in Canada and 26 in the U.S., with an estimated 378,000 carsharing members sharing approximately 9,818 vehicles in North America. In addition, 30% of the operators in the U.S. were for-profit (8 of 26), accounting for 86% and 88% of the members and vehicles, respectively. In Canada, 38% of Canadian carsharing operators were for-profit (6 of the 16) and represented 87% of members and 85% of the total fleet deployed.[3]

The consumer appeal of carsharing is fundamentally economic. Owning a car requires a considerable outlay of recurring fixed expenses, regardless of how much the vehicle is driven. In urban areas, fixed ownership costs are typically higher than the national average, while driving distances are typically lower than average. This dynamic makes transit rich urban areas among the most viable carsharing markets. Individuals who occasionally require a car for shopping can use a carsharing service, paying only for the time and distance that they need to travel.[4] Meanwhile, they avoid vehicle purchase/lease, gasoline, insurance, and storage costs, which are regularly associated with ownership.

In addition to the private economic benefits gained by consumers, past research has suggested that carsharing may offer considerable environmental and social benefits.[5] These benefits include GHG emission reductions and greater use of alternative modes, such as public transit, walking, and cycling. In the industry today, carsharing vehicles are newer relative to the average personal vehicle and generally have higher than average fuel economy.[6] Long-term land-use benefits may also arise as carsharing permits a single car to satisfy the mobility needs of multiple individuals. Among the most consistent findings of past research is that many users reduce or eliminate their household's vehicle holdings, reducing the total number of vehicles that need to be parked within an urban environment.[7] Thus, carsharing has been considered a promising transportation demand management tool capable of displacing gasoline consumption that would otherwise occur in its absence.

While past research suggests a link between carsharing and vehicle miles/kilometers traveled (VMT/VKT) and/or GHG emission reduction, many of the studies have evaluated this association using different methodologies and metrics that are difficult to compare. Defining a consistent system boundary that characterizes the bulk of measureable environmental impacts from carsharing remains a challenge. Furthermore, most studies have focused their evaluations on a single organization. While these past efforts are extremely valuable in contributing to the public knowledge, no study has applied a standard methodology for assessing the impacts of members across organizations or metropolitan regions. Past research exhibits a general consensus that carsharing results in lower VMT/VKT, private auto ownership, and lower emissions, but there is little agreement regarding the magnitude of those impacts. One important factor that has not been considered in any study to date is the potential link between a member's carsharing organization type and VMT/VKT reductions. There is variation within the industry, as profit and non-profit organizations operate carsharing organizations differently. These differences exist with respect to the design of pricing plans, the mix of vehicle fleets, and the distribution of vehicle networks.[8] The pricing plan determines the nature of the marginal cost to the consumer and likely influences their VMT/VKT.

This report presents the results of a survey of carsharing members across the North American continent. The objective of the study was to evaluate the change in GHG emissions that result from household members joining carsharing. The hypothesis of this study is that across all members, the net impact of carsharing is a reduction in emissions. The focus of this evaluation is the impact of the neighborhood model of carsharing on the transportation emissions of working households. That is, this study does not evaluate the GHG impacts of carsharing on members who are part of the college submarket or the business-use submarket. Explorations of these smaller submarkets require a separate survey design. The survey was conducted online in October and November 2008, with all of the major carsharing organizations in the U.S. and Canada. The survey asked about past and current vehicle holdings as well as travel patterns to estimate GHG changes that result from people joining carsharing.

This report proceeds with five main chapters. First, the authors present a review of earlier studies and surveys assessing the environmental impacts of carsharing, with an emphasis on North America, in "Past Research on Carsharing Impacts in North America." The next chapter, "Framework for Evaluating the Greenhouse Gas Effects of Carsharing," provides a theoretical framework to describe how GHG impacts are assessed within this study. This includes an overview of the dynamics that govern how carsharing can alter member emissions. The following chapter, "Survey Methodology," presents the methodological approach for this analysis, including an overview of the study instruments and participating organizations. This follows with a presentation of the analytical results in ”Results.” The results characterize the emission impacts of carsharing across several dimensions, including circumstances of joining, urban density, and organization type. In addition, the results section contains a series of sensitivity analyses that illustrate the robustness of the findings under a variety of circumstances. Following the sensitivity analysis, the impacts of carsharing on vehicle holdings is presented. The last subsection of the results applies the factors computed for both vehicles and emissions to an aggregate analysis. The last chapter of this report, “Conclusions and Policy Implications,” provide a dissemination of the information gleaned from the data and recommendations for carsharing agencies in the United States and Canada.

PAST RESEARCH ON CARSHARING IMPACTS IN NORTH AMERICA

Among the most consistent findings of past research is that carsharing reduces car ownership. The first demonstration of carsharing in North America started in San Francisco with the Short Term Auto Rental (STAR) program. Established in 1983, STAR was a 55-vehicle pilot designed to operate for three years but terminated after 18 months of operation. In the STAR evaluation, Walb and Loudon (1986) reported on changes in car ownership and travel among members. They found that 17% of members sold a vehicle, while 43% postponed a vehicle purchase. However, their assessment of travel changes raised doubts as to whether carsharing would result in more efficient travel as members reported increasing their travel slightly.[9] While the STAR program did not gain traction, lessons learned from that effort were used to inform and improve the launch of CarSharing Portland more than a decade later.[10] Similar to STAR, an early study of CarSharing Portland's impacts found that 26% of members sold a car, while 53% avoided a purchase.[11] The study also reported members using public transit, biking, and walking more. But similar to STAR, the early study found little change in VMT/VKT among members.[12] For a more extensive review on the history of the carsharing industry, see Shaheen et al., (2007) and Shaheen et al., (1998).[13]

Similar results from evaluations of carsharing programs persisted through the early years of this decade. Carsharing returned to San Francisco with the launch of City CarShare in March 2001. Cervero (2003) initiated a before-and-after study to evaluate the impacts of City CarShare of both member and nonmember travel behavior three months before the launch and nine months after.[14] A profile of the early members indicated that they were in their early 30s, college graduates, and worked in professional fields. Most significantly, two thirds of members came from zero-car households, while 20% came from one-car households. This early study found that mean daily VMT/VKT dropped for both members and nonmembers, but changes for both groups were not statistically significant. In addition, shares of walking and biking fell. Cervero's early results of City CarShare were consistent with past work in North America; they found similar demographics among members and that changes in VMT/VKT were not substantial. The early carsharing adopters were those who were primarily carless and used carsharing as a means to augment their mobility.[15]

Cervero's early work was soon followed by Lane (2005), which evaluated the first-year impacts of PhillyCarShare, a non-profit organization operating in Philadelphia since November 2002. One year after PhillyCarShare's launch, Lane administered a 500 member online and mail-in survey in November 2003. Roughly 60% of members who joined were from households with zero cars. Members were otherwise demographically similar to the early adopters of City CarShare. Lane evaluated vehicles sold as a result of membership as well as vehicles not acquired. He reported that each PhillyCarShare vehicle removed roughly 23 cars from the road. Finally, Lane discussed VMT/VKT drops among members, while acknowledging uncertainty in his estimate. He concluded that a typical reduction would amount to a couple hundred miles per month for members who gave up a car, but that there is considerable variance in his estimate.[16]

As carsharing evolved, research began to discern more pronounced effects on VMT/VKT. Cervero and Tsai (2004) and Cervero et al. (2007) revisited City CarShare impacts.[17] By the 2007 study, VMT/VKT reductions attributable to carsharing were becoming more evident as member VMT/VKT was found to decrease relative to nonmember VMT/VKT. VMT/VKT reductions among carsharing members appeared to occur during the first two years, but large variations existed within the group. Overall, mean mode-adjusted VMT/VKT, which accounted for occupancy levels, dropped 67% for carsharing members in contrast to a 24% increase among nonmembers.[18]

As carsharing has matured in North America, emerging evidence suggests the presence of considerable reductions in VMT/VKT among members. This trend may continue as carsharing continues to draw new members from households that fit the more traditional American profile of higher vehicle ownership and driving.

Research to date has yet to standardize the evaluation of GHG impacts due to carsharing. In addition, there are many factors influencing carsharing use that have not been explored, including the impact as categorized by members of different organization types. Furthermore, as carsharing networks expand into more diverse residential environments, the potential for VMT/VKT reductions may be greater. Lower density environments, where carsharing typically struggles economically, may offer greater gains as they enter markets with higher levels of car ownership and VMT/VKT. This research aims to address the magnitude and distribution of GHG emission change that are exhibited by members of carsharing organizations. In the following chapter, the authors present a conceptual framework for evaluating the GHG impacts of carsharing.

FRAMEWORK FOR EVALUATING THE GREENHOUSE GAS IMPACTS OF CARSHARING

The scope of this study is focused on evaluating how members of carsharing change their travel behavior. A change in travel behavior is the most direct and observable short-term impact that occurs when a household joins a carsharing organization. It is important to acknowledge that there are two other ways in which carsharing can impact GHG emissions. They include changes in vehicle ownership and changes in local land use. The change in vehicle ownership observed among members joining carsharing is evaluated in this study, but the analysis does not tie impacts from changes in vehicle ownership to GHG emissions. Such changes do occur, as the life-cycle impacts of vehicle production cause additional emissions to be released at the plant and upstream. In the long run, reduced personal vehicle demand would lower vehicle production and hence emissions, but tying such impacts to vehicles shed by carsharing households is subject to considerable uncertainty. Therefore, in the analysis presented here, changes in vehicle ownership are presented, but zero credit is given for changes in GHG emissions from reduced vehicle production.

The third impact that carsharing could have on GHG emissions relates to land use, which is subject to even greater uncertainty. As carsharing reduces the need personal vehicles, some land use effect may exist over time. This effect could be manifested in the form of reduced construction of parking and more compact urban environments. But the broad uncertainties and confluence of factors required to bring about land use change make an evaluation of GHG emissions with the instruments applied here infeasible. Therefore, it is appropriate to note that changes in GHG emissions resulting from changes in vehicle ownership and land use could occur. But because these impacts are very uncertain and manifested over a long-time horizon, they are given zero credit in this research and left to future study.

As this study is focused on the GHG impacts of changes in travel behavior, the authors now discuss the units by which this change is measured. The operating statistic of this study is the change in annual emissions that result from a household joining carsharing. This statistic describes the “change in annual GHG emissions” of the carsharing household. We discuss this measurement in units of metric tons of GHG per year (t GHG/yr).

This unit is chosen because it offers an intuitive illustration of the change in “state of travel” that carsharing facilitates among its member households. Members enter carsharing with a travel lifestyle suitable to them in the absence of carsharing. This initial travel lifestyle may have involved driving a personal vehicle or living as a carless household. Upon joining carsharing, members transition into a new travel lifestyle. This lifestyle might exhibit reduced driving for those households that join carsharing and discard or shed vehicles. Households may also transition into a state of increased driving, as happens with carless households that gain vehicle access through carsharing.

This unit is used both as a matter of simplicity and practicality in generating respondent information. A year is a natural time frame in which people think about travel and due to the practical limitations of the one-time survey, the researchers could not expect respondents to construct a cumulative year-by-year assessment of their travel behavior since joining carsharing. Such a survey would take an inordinate amount of respondent time. Furthermore, the change in annual emissions is a metric normalized by time that permits comparisons across organization types and regions. In addition, previous research indicates that adjustment in travel behavior that results from carsharing often occur rather quickly and remain stable.[19] Cervero et al. (2007) finalized their longitudinal study of City CarShare in San Francisco and found that most of the impacts on VMT occurred soon after respondents joined City CarShare. Intermediate and long-term effects occurred in increments that were less substantial.[20] This suggests that capturing the change in the annual emission rates provides an effective proxy for near-term changes facilitated by carsharing. The influence of member tenure within the organization on carsharing impact is further explored among other elements in a sensitivity analysis.

THE OBSERVED IMPACT AND THE FULL IMPACT OF CARSHARING

In this chapter, the authors explore two distinct classifications of impact by which we evaluate carsharing. The two classifications are measured in the same units but differ in the system boundary of impacts that they consider. The classifications are separated by the degree to which they consider emissions that would have occurred in the absence of carsharing. Carsharing facilitates people to change their travel lifestyles in ways that both increase and decrease emissions. Changes that are “observed” include decreases in emissions that result from a household that sheds a car and drives less overall, as well as increases in emissions that result from a carless household driving more due to the additional vehicle access offered by carsharing. These impacts constitute changes that actually happened and are directly measureable. Through the remainder of the report, the authors call this the “observed impact.”

Carsharing also provides an alternative to households that may substitute for actions that would occur otherwise in its absence. For example, a car owning household may join carsharing in substitute of acquiring an additional car. The vehicle that would have been acquired would have inevitably been driven some annual amount of miles for its forgone purpose. But a member of a household joins carsharing instead, which prevents this car from being acquired. Those miles and emissions never occur in the private vehicle because it is never purchased. Instead, miles to achieve the same purpose are placed on carsharing vehicles, and this alternative driving could be more or less than what would have happened, if carsharing were not available.

To consider impacts not manifested due to carsharing requires an additional level of abstraction. If a household joins carsharing and drives 1,000 miles a year instead of acquiring a private vehicle, and this vehicle would have also been driven 1,000 miles a year, then the net effect in terms of travel emissions would be close to zero (a function of the different fuel efficiencies). The only change is the reduction in vehicle ownership that is now satisfied by a shared vehicle. Alternatively, if the household drives 1,000 miles a year in a carsharing vehicle, but would have driven 2,000 miles a year in a private vehicle, then the availability of carsharing prevents 1,000 miles from being driven and the corresponding fuel consumption from occurring.[21]

The full impact accounts for new emissions that would have happened but do not because carsharing is available. Questions within the survey capture respondent estimates of this impact. The consideration of these additional non-manifested impacts, taken in sum with the observed impact is described in this report as the “full impact.” It should be understood that although the full impact is a real impact associated with carsharing, it will always be subject to a greater degree of uncertainty. The full impact ascertains what “would have happened otherwise” in carsharing’s absence. Respondents are asked to give a speculative answer with respect to the vehicles that they would acquire and the miles that they would drive on them. There is an elevated level of uncertainty associated with such stated responses. However, they are not entirely hypothetical either, as most people do have prior experience with driving distances based on previous travel patterns. For these reasons, the observed impact should be considered closer to a lower bound of carsharing emissions impact, whereas the full the impact is closer to the true impact. Throughout the report, the observed impact and the full impact are always presented separately, as there will always be a larger degree of uncertainty with respect to the measurement and precision of the full impact.

CARSHARING IMPACTS AND SHIFTS IN TRAVEL MODES

A household that joins carsharing may use other modes more or less than before joining carsharing. Naturally, the household that joins carsharing and sheds a car will shift some of their travel to carsharing and may increase their use of public transit, biking, and walking for transportation. But the carless household that joins carsharing will drive more and use a car for trips that were previously accomplished with alternative modes.

Given these diverse shifts in travel behavior, it is important to consider how shifts to and from other modes would impact net GHG emissions. Some cases are simple. For instance, shifts to non-motorized modes, such as walking and biking, exhibit no increase in GHG emissions. With respect to public transit, the impact on GHG emissions is more complicated. Fixed rail and bus routes operate regardless of capacity utilization. Energy conservation does dictate that a single additional person switching to public transit has to increase GHG emissions by some marginal amount. As a person steps onto a bus or train, the transit vehicle must exert more energy than otherwise to move that person to his or her destination. However, because public transportation is traveling regardless of the presence of the additional passenger, a rider is only responsible for the marginal emissions caused by his or her presence on the bus or train. To provide some perspective, a typical empty bus in North America weighs about 40,000 pounds; hence, an additional 200 pound person increases the machine’s weight by only 0.5%.[22] The ratio is even smaller for a train. Because the contribution of an additional passenger contributes a small amount of marginal energy use, this study counts emission impacts of marginal public transit shifts to be negligible. Furthermore, if a trip has to be made within an urban region (e.g., a commute), and non-motorized travel is infeasible for such a trip, traveling by public transit on an established network is the most efficient decision an individual can make from an energy and emissions perspective. There are circumstances that could arise in which a new route might be added to handle excess capacity. But the complexity of forecasting these long-term dynamics is outside the scope of this study.

With emissions from motorized public transit minimal at the margin, the evaluation of GHG emission impacts attributable to carsharing is determined by the change in mileage traveled by private vehicles and carsharing vehicles. Prior to a member joining carsharing, this consists primarily of private vehicle mileage, but it also includes some local usage of rental cars (as opposed to vehicles rented for travel in a distant city) and local taxis, if any. After joining carsharing, motor vehicle use is more complicated, consisting of personal autos that still remain in the household (if any), carsharing vehicles, local rental vehicles, and local taxi trips.

This study collects vehicle VMT/VKT measurements pertaining to automotive travel. The measurements are segregated by vehicle such that appropriate fuel economy factors can be applied to determine the gallons of gasoline consumed by each vehicle driven by household members. Once the total gallons of gasoline consumed by the household is known, the GHG emissions are computed using a standard methodology published by the U.S. Environmental Protection Agency (EPA).[23] The EPA methodology was published to help establish a standardization of GHG analysis within the United States. The methodology accounts for the CO_2 generated from gasoline combustion as well as trace emissions from other more potent GHG emissions, such as methane (CH_4), nitrous oxides (N_2O), and hydrofluorocarbons (HFCs) from leaking air conditioners. The simplified estimation method assumes that these trace emissions account for 5% of the global warming potential produced by the combustion of a gallon of gasoline. This assumption includes the adjustment for the increased potency of these pollutants.[24] The EPA assumes that the average amount of CO_2 produced by a gallon of gasoline is 8.8 kg (19.4 lbs.).[25] The total GHG potential from a gallon of gasoline is adjusted to account for other pollutants by multiplying CO_2 emissions by a factor of 100/95. The adjusted GHG potential of a gallon of gasoline computed in this study is 9.3 kg (20.4 lbs.) CO_2-e/gallon. The CO_2-e (GHG) emission change that results from carsharing within a household is the difference between the annual travel emissions exhibited by the household during the year before joining carsharing and the annual travel emissions exhibited by the household at the time of the survey.

SURVEY METHODOLOGY

The authors generated the study data from an online survey sent to carsharing members within organizations across the United States and Canada. There were two primary objectives pursued in the survey design. First, researchers needed the survey to collect enough data from the respondents such that GHG emission changes could be evaluated for the respondent households. Second, the survey design had to efficiently capture this information from carsharing members and ask questions that the respondents could reasonably answer, so as to maximize response rates and stay within the time tolerances of as many participants as possible. The survey took on average 15 minutes to complete.

The unit of analysis in the survey was the household, as an individual's carsharing use can affect the travel decisions of all household members. There are several reasons why a household level analysis is more complete and appropriate than an individual level analysis, even if only one member of the household is a carsharing member. For example, an individual may join carsharing and shed their personal vehicle that they used exclusively. But another member of the household retains his or her vehicle, which is subsequently shared with the carsharing member when it is available. The vehicle belonging to the non-member within the household is driven more than previously because two people are using it. Another example could occur with vehicle switching. Consider a situation in which two working spouses each have their own vehicle. One spouse works in a downtown region, joins carsharing and switches to public transit for the commute. But because this spouse regularly drives the newer of the two vehicles, that vehicle is retained within the household and transferred to the other spouse, who requires a car to commute to work. The vehicle normally driven by the other spouse is shed, even though this person does not join carsharing. These and other situational permutations are plausible and require that the travel behavior of the entire household is assessed in order to evaluate how carsharing is influencing overall emissions. In addition, many organizations permit members of the same household to share a joint account. Joint membership plans permit multiple members of a household to use the same credit card, but they have unique membership IDs and otherwise operate independently. In addition, growth in carsharing business accounts adds an additional complication, as employers may cover a range of employee carsharing usage costs.

PARTICIPATING ORGANIZATIONS

Researchers sent the Canadian and American respondents separate surveys due to the different distance and currency units used in the respective countries. As an incentive, each respondent was entered into a drawing for a $100 U.S./Canadian credit to a member's carsharing account. At least one member from each organization was selected as a winner. Additional incentives were drawn from the total respondent pool. A total of $2,200 credits were dispersed. The organizations that participated in the survey and are listed in Table 5.

Table 5 Participating Organizations

Organization	Location
AutoShare	Toronto, Ontario, Canada
City CarShare	San Francisco/Oakland, California
CityWheels	Cleveland, Ohio
Community Car Share of Bellingham	Bellingham, Washington
CommnuAuto	Montreal, Province of Quebec, Canada
Community Car	Madison, Wisconsin
Co-operative Auto Network/The Company Car	Vancouver, British Columbia, Canada
IGo	Chicago, Illinois
PhillyCarShare	Philadelphia, Pennsylvania and Wilmington, Delware
VrtuCar	Ottawa, Ontario, Canada
Zipcar	United States and Canada

The organizations distributed the survey solicitations to their members through their own email lists. The email that the organizations sent out included the survey link. A third-party online survey program hosted the survey. Two reminders were sent out via each organization, and the survey closed on November 7, 2008. Most organizations, which are located in a single city, distributed survey solicitations to all of their members. Because of Zipcar's size and geographic distribution, the solicitation was capped at a total of 30,000 randomly selected Zipcar members within specific markets. This included 5,000 each within New York City, New York; Boston, Massachusetts; Washington DC; Portland, Oregon; and Seattle, Washington. An additional 2,500 each in the Canadian cities of Vancouver and Toronto also received survey solicitations. In aggregate, the authors estimate that nearly 100,000 carsharing members received the survey solicitation. Based on the coverage, size and selection of this population, the authors consider it to be random and representative of the carsharing population within North America. The size of the membership base of each individual organization is proprietary information and cannot be reported. For similar reasons, it is not possible to compare demographics of respondents with demographics of the organizations. As with all surveys (including the U.S. Census), respondents must consent to being surveyed and take the time to be surveyed. This injects some self-selection into the sample. However, in the case of this study, this self-selection applies to the propensity of the respondent to take an online survey. Among regular carsharing users, how this propensity is distributed is considered to be random. However, there is a cohort within the population that are carsharing members, but they do not use the service on a regular basis. This cohort, which the authors term "inactive users," are less likely to take a survey about a carsharing service that they use infrequently. As explained in more detail later, this cohort exhibits zero impact from carsharing, but their share of the sample is likely an underrepresentation. This has implications for the aggregate results that will be addressed in more detail within the sections that follow. In total, 9,635 surveys were completed, constituting a response rate of approximately 10%.

THE SURVEY QUESTIONNAIRE

The questionnaire began by soliciting basic parameters of the respondent's membership. See "Appendix" for the complete questionnaire. The survey asked for the year and month the member joined carsharing; this revealed the respondent's membership tenure at the time of the survey. The survey also collected the pricing plan to which the member subscribed within their organization, as this determines their marginal cost of carsharing vehicle use. Following the collection of these basic parameters, the respondent was asked to characterize the circumstances in which they joined carsharing. These circumstances play a critical role in defining the nature of GHG impacts that would be expected from carsharing participation. The question and the circumstances listed in the survey appear in Table 6

Table 6 Categorical Circumstances of Respondent Membership

Question: Please select the statement that best characterizes the household circumstances under which you joined carsharing.
• A car of mine stopped working, and instead of replacing it I joined carsharing. • I am in college, and I joined carsharing to gain access to a vehicle while in college. • I live in an apartment bulding with a designated carsharing vehicle, and I joined through its membership arrangement. • My employer joined carsharing, and I joined through my employer. • My household did not have a car, but changes in life required a car and I joined carsharing instead. • My household did not have a car, but joined carsharing to gain additional personal freedom. • Owned at least one car, but needed an additional car for greater flexibility, and joined carsharing instead of acquiring an additional car. • Owned more than on car. Got rid of at least one car and joined carsharing. • Owned one car, but I joined carsharing and got rid of the car. • I joined carsharing for reasons other than those listed above. Please explain:

These circumstances are reflective of the transportation lifestyle that the respondent was leading prior to joining carsharing. They are succinct sentences that describe a specific situation pertaining to the role that carsharing serves for the household. These circumstances also capture the personal motivations for joining, which exist independent of personal demographics. Understanding member circumstances is important because carsharing can facilitate new travel patterns that fit with a household's travel needs. For example, two households living in the same neighborhood could appear demographically identical with the household's wage earners holding the same occupations. However, their travel patterns are dictated by their employment locations, which may require different transportation needs. Carsharing may effectively fit into the transportation lifestyle of one of the households, with commuters working in an area well served by public transit. Yet, the other household may have travel needs that cannot be effectively served by carsharing because an automobile is required to commute to one or more work locations. For this reason, the circumstances of joining carsharing are very important for classifying carsharing's household impact.

PERSONAL VEHICLE DRIVING AND CARSHARING USAGE

Next, respondents were asked about the vehicles owned by their household. Two questions addressed personal driving. The first question asked about the number of vehicles owned prior to joining carsharing. Specifically, the question asked about the vehicles owned by the household during the year prior to joining carsharing. Researchers solicited the vehicle make, model, and year, along with an estimate of how many miles the vehicle was driven during the year immediately prior to joining. In a second question, researchers asked for the same information but pertaining to their current driving (at the time of the survey). For all questions in which distance was relevant, American respondents were asked to think and respond in terms of miles, and Canadian respondents were asked to think and respond in terms of kilometers. For simplicity, the remaining methodological discussion is given in terms of miles.

To aid respondents in computing the annual mileage driven on each car, researchers provided descriptive text to walk the respondent through a rudimentary calculation that would produce a reasonable estimate. Respondents were given the option of following the calculation, if the annual mileage for a household vehicle was not a value immediately known (see Appendix). The text also reinforced the idea that annual mileage on each vehicle was the desired response in contrast to odometer readings. Most respondents rounded their answers to the nearest thousand.

The make, model, and year of each vehicle were used to determine the fuel economy of the vehicle, which is required to estimate the gallons of gasoline consumed as result of a given mileage. Each vehicle dating back to 1978 was linked to an appropriate entry in the EPA fuel economy database. When a vehicle model had trims with two different engines sizes, the fuel economy of the smaller engine was applied. The combined fuel economy rating for each vehicle entry was applied to compute the gallons consumed, which could then be converted to GHG emissions. A small minority of vehicle entries was incomplete, as not all respondents knew the model name of the vehicle within their household. Typically such cases were accompanied with the year and vehicle make, absent the model name. For these entries, the average fuel economy for all passenger cars within the given year was applied as a proxy. Vehicles older than 1978 are not listed in the EPA's fuel economy database; these vehicles were given a standard combined fuel economy of 15 miles per gallon. Motorcycles and scooters were also requested to ensure that all motor vehicle travel was accounted for; however, no public database currently holds certifiable fuel economy numbers for each model over time. There is an additional complication associated with the emissions of motorized two-wheeled vehicles. Scooters exhibit a wide range of environmental impacts. While scooters are often touted as fuel efficient (~90 mpg), the proliferation of two-cycle engines within leading scooter brands can result in a considerable degradation of emissions quality.[26] While four-cycle scooter models are growing in number, at the time of the survey, leading brands of new scooter vehicles could still be purchased with two-cycle engines. Motorcycles present similar emission problems in spite of elevated fuel efficiency relative to most automobiles.[27] Because of these issues with two-wheeled motor vehicle emissions, it is not representative of the true GHG impact to apply the nameplate fuel efficiency factors. As an adjustment, scooter vehicles and motorcycles were assigned a fuel economy factor of 30 miles per gallon as a proxy to account for the degraded emissions per gallon. This factor is close to the fuel economy implied by the CO_2-e emission factor of motorcycles used for the EPA to generate the annual U.S. Greenhouse Gas Inventory Report.[28] While these vehicles received special consideration in the assignment of factors, they account for a small share (~5%) of all unique vehicles held by respondent households.

Following completion of personal driving questions, the survey asked respondents about their carsharing usage. Many carsharing organizations supply their members with monthly billing statements that provide miles driven, so the survey framed the carsharing questions to solicit information on monthly driving. To gauge usage, reservations per month and miles per month were solicited for all household members. Carsharing permits members to use a diversity of vehicles, and many members take advantage of this variety by using different vehicles throughout the year. However, many members will gravitate toward specific vehicles, often governed by the convenience of the "point of departure" (or pod) location that they access most frequently. Researchers asked respondents about the carsharing vehicle that they drive most often. This vehicle was used as a proxy factor for the efficiency of miles driven in carsharing vehicles. Specific efficiency factors were applied for the given make and model, but researchers did not expect the respondent to know the year of the carsharing vehicle that they drove most often. Most carsharing vehicles are relatively new, and fuel economy varies little from year to year for the same model. Hence, the year 2007 was assumed as a proxy for the carsharing vehicle model. Exceptions were made for vehicles that did not exist in 2007, such as the Toyota Echo used by a carsharing organization in Montreal. For these vehicles, the last year of production (2004 for the Echo) was applied as a proxy.

Not all respondents were comfortable providing the name of the vehicle that they used most often, and they were given an option to indicate this as a response. As a backup, these respondents were diverted to a follow-up question that asked about the general type of vehicle that they used most. General categories of vehicles were given as available responses, and an appropriate combined fuel economy factor was applied in the case of each possible answer. Table 7 illustrates the efficiency factors that were applied for each generic vehicle type.

Table 7 Generic Vehicle Types and Assumed Fuel Efficiency Factors

Generic Vehicle Category	Model Vehicle Year	Model Vehicle	City	Combined	Highway
2-door car	2007	Yaris	29	31	35
2-door microcar (Mercedes-Benz Smart)	2009	fortwo coupe	33	36	41
4-door sedan	2007	Matrix	25	27	31
4-door sedan hybrid	2007	Civic Hybrid	40	42	45
Cross-over	2008	Rogue	21	23	26
Hatchback (or liftback)	2007	Yaris	29	31	35
Luxury sedan	2007	IS 250	21	24	29
Minivan	2007	Odyssey	16	18	23
Pick-up truck	2007	Tacoma	19	21	25
Regular SUV	2007	Explorer	14	16	20
Small SUV	2007	Escape	18	20	23
Wagon	2007	Focus station wagon	23	26	31
Other, please specify	User Stated				

RENTAL VEHICLES AND TAXI USAGE

Carsharing member use of rental vehicles and taxis could also contribute to GHG emissions, and carsharing can impact the degree to which a member uses either mode. In assessing carsharing impacts, only local trips in rental cars and taxis are important. Travel by these modes, which is initiated away from the carsharing member's city of residence (for example, in a distant city to which a person would have to fly), is outside the scope of carsharing impacts because such travel would occur regardless of a person's carsharing membership in their hometown. Generating information for these two vehicle modes, however, posed unique challenges for the survey and the respondent. While carsharing and personal vehicle use is governed by annual lifestyle routines and regular travel, local rental car and taxi use is far more erratic. This makes recollection and accuracy more challenging for the respondent. Thus, researchers hypothesized that the overall net impact of changes for these two modes would be small. At the same time, researchers were also concerned about respondent survey fatigue because such questions can tax the respondent for small analytical gain. To address these concerns, a subsample of respondents was asked questions about their taxi and rental car use before and after joining carsharing. About 20% of each sample opted out of the question, stating that they did not know the mileage of one or both modes during the year before they joined carsharing or currently. Those that did offer complete responses provided researchers with a subsample to evaluate the range and distribution of mileage changes that occurred after carsharing. The results, presented later, show that the net changes in rental car and taxi use are very small and make an insignificant overall contribution to emission change among carsharing users.

SUPPORTING DATA

Supporting data collected by the survey permitted researchers to characterize carsharing impacts in richer detail. Researchers collected demographic information at the end of the questionnaire, including location information (e.g., home zip code in the U.S. and Canadian postal code). The location information permits an analysis of carsharing impacts by urban density.

Not surprisingly, a change in work or home location can seriously disrupt the imputed results from previous responses, and moving often coincides with many important life events. Nevertheless, some moves exhibit trivial impacts on overall automotive travel needs, while other moves induce significant impacts that are either positive or negative. Respondents that moved a home or work location were asked a follow-up question that prompted them to self-assess the degree to which their driving mileage change was a result of the move or due to carsharing. Specifically, respondents were asked: “What would you say has contributed more to your overall change in driving? The move (of home or work) OR the availability of carsharing?” There were five possible responses. Respondents who stated “Mostly carsharing” or “More carsharing than the move” were retained for the emission analysis. While respondents stating “Equally carsharing and the move,” “More the move than carsharing,” or “Mostly the move” were dropped from the final analysis because their move to a new home or work played a significant part in the driving change. Due to the complexity of travel changes that can be induced by a significant move, the survey did not attempt to collect information to correct for the isolated impact of the move. Because many people are mobile in both home and work, the follow-up question was designed to preserve as many respondents as possible from being removed from the analysis as a result of this important confounding factor. A section detailing how the main results would differ had all movers been included or extracted is presented in a sensitivity analysis of the results.

DATA PREPARATION

Overall, the respondent was given a fair degree of freedom to compose responses within the survey. The data required careful attention to ensure that each survey was complete. Due to the University of California, Berkeley’s Human Subjects regulations, the survey was not permitted to force any answer of the respondent before proceeding. Respondents were free to skip answers to any question but still complete the survey. The data were filtered of records with extreme outliers or missing responses of key questions that would make individual calculations impossible. Responses filtered for any of these reasons are not included in the final analysis. In total, respondents completed 9,635 surveys across all organizations, and 6,281 are applied in the final analysis. The filtering of the data is discussed in this section, detailing who was removed and why.

The most prominent cause for respondent filtering was due to a household move. As explained earlier, a move can have significant impacts on overall mileage and many people move home locations or change jobs. The main motivation of this filter was to prevent GHG impacts that result primarily from a move of home or work to be attributed to the carsharing impacts. Respondents were asked whether they had moved their home or work location during their time with carsharing. If they had, they were asked a follow-up question regarding the nature of the move’s impact on driving mileage. Those indicating that the move had an equal or greater share of the responsibility than carsharing for mileage changes were dropped from the analysis. Among the 3,484 who indicated either a home or work move, 1,572 respondents were exclusively filtered from the analysis for indicating that the move was a prominent factor in altering their mileage driven.

The second most prominent cause for respondent filtering was due to carsharing use. The survey revealed that some respondents use carsharing very infrequently. A sizeable share of respondents clearly indicated that they use carsharing as a back-up travel option as opposed to a necessary component of their travel lifestyle. These members are referred to as “inactive members,” which can exist in carsharing organizations with membership plans that have small or zero fixed annual cost. As such, households can hold memberships in case a spare car is needed, and low fixed- cost plans allow them to do this with little penalty. While carsharing provides them with a benefit in this respect, it would be challenging to argue that such members reduce their emissions due to carsharing because their travel lifestyle is manageable without it.[29] Researchers filtered a total of 488 respondents from the final analysis exclusively because they indicated no use of carsharing even though they were members.

A critical question asked of respondents pertained to household vehicle holdings and annual driving distances for each vehicle. Because of this question’s importance in evaluating the overall change in household GHG emissions, the survey offered guidance in advising respondents on how to calculate a good estimate of annual vehicle miles for a vehicle. If respondents did not already know the annual miles placed on their vehicles, they could follow the textual guidance to develop an estimate.[30] Under this design, a vast majority of respondents answered the question appropriately. Even so, some inevitably reported mileage numbers that were clearly odometer readings for the vehicle. Researchers removed these records from consideration in the analysis by establishing an upper bound on annual mileage. A conservative cutoff was chosen to implement the filter. Any respondent that reported an annual mileage larger than 30,000 miles per year for any vehicle was filtered from the analysis. This threshold was suggested by the data and by practical limits on annual driving. Annual driving distances greater than 30,000 miles per year are feasible but extraordinary. For example, the average annual distance driven by an American is 12,300 miles per year, and the average in Canada is 8,800 miles per year.[31] In total, researchers filtered 192 respondents (2% of all completed surveys) exclusively for stating annual driving distances that exceeded this established threshold. Because many of these high mileage drivers were driving such distances before they joined as opposed to after, their exclusion lowers the potential emission reduction exhibited by carsharing. To illustrate the impact of this cut-off on the results, a sensitivity analysis is later presented that explores the influence of this threshold.

As mentioned earlier, the focus of this study is on the impact that the neighborhood carsharing model on the GHG emissions of working households. There are two other submarkets in the carsharing industry that constitute smaller shares of the carsharing market. This includes the college submarket and the business use submarket.

A total of 632 university/college students took the survey of which 349 were filtered exclusively because they were college students. The remainder also had other filters apply. The college market is not addressed in this study because the survey was not designed to simultaneously handle all of the nuances associated with college life.

University life is a dynamic time of frequent moving, as well as changes in roommates, employment, course schedules, and vehicles. University students often live in different cities and households during different times of the year as they go home for a break. It is a time when social objectives and travel lifestyle can be very different from one year to the next. Because of all the confounding variables associated with university/college life, researchers did not design the survey to isolate these impacts. A separate study that is focused on this changing market is recommended.

Strict business use is another submarket of carsharing that was not addressable through the existing survey design. This filter was applied to respondents that used carsharing exclusively for business use. Respondents that used carsharing for both home and business use were retained because the neighborhood model still applied, and separate questions sorted respondents that were strict business users from home and business users. A total of 100 respondents were filtered exclusively for using carsharing solely for work-related trips.

As shown in Table 8 which lists the circumstantial categories that respondents could choose, an “Other” category was provided in which respondents could write out the circumstances of their carsharing membership, if one of the given categories did not fit. With the “Other” response, respondents could explain their circumstances, as appropriate. A total of 481 respondents that were not filtered for any other reason provided an “Other” response. Researchers reviewed each of these responses, and most of them generally fell into the other categories provided. Relatively few (21) provided responses that suggested that they should not be included in the analysis. One common reason for removal was the circumstance in which the respondent actually lived in a city far from carsharing services. Many of these respondents were carsharing members so that they could use the service when they were in a city that they visited frequently (such as when visiting a son or daughter).

Other exclusive reasons for filtering respondents had small effects on the usable sample size. This included 34 respondents that were filtered because they indicated that they did not know how far they drove in a carsharing vehicle and declined to give any estimate. Researchers eliminated another six responses because their estimate of carsharing mileage was far outside reasonable distances that would be traveled in any vehicle. The authors also designed the survey with particular questions to detect duplicate or redundant responses from households. This would occur if two members of a joint account took the same survey, duplicating the household activities. Several questions were used to construct a unique eight-digit ID that would match across household members but no one else. Researchers filtered a total of 16 responses because they were duplicated by two different people from the same household that took the survey.

Finally, the numbers discussed thus far describe respondents that were filtered for only a single reason. But a fair number of respondents were filtered due to some combination of reasons, including moving, non-use, outlier personal mileage or carsharing data, and unavailable carsharing use estimates. That is, if one filter was not active, then another filter would still have removed these respondents from the analysis. Researchers filtered a total of 576 respondents for some combination of reasons. The collective impact of the filters reduced the initial dataset for 9,635 to a core of 6,281 households. Table 8 illustrates how the filter altered the balance of circumstantial responses by respondent share for both the complete and core sample.

Table 8 Balance of Circumstantial Responses Before and After Data Filters

Circumstantial Category		Percent of Respondents Completing the Survey (N = 9635)	Percent of Respondents in Final Dataset (N = 6281)
1	Owned at least one car, but needed an additional car for greater flexibility, and joined carsharing instead of acquiring an additional car.	9%	8%
2	I am in college, and I joined carsharing to gain access to a vehicle while in college.	6%	0%
3	Owned one car, but I joined carsharing and got rid of the car.	13%	14%
4	My household did not have a car, but joined carsharing to gain additional personal freedom.	43%	51%
5	My household did not have a car, but changes in life required a car and I joined carsharing instead.	6%	7%
6	My employer joined carsharing, and I joined through my employer.	5%	3%
7	A car of mine stopped working, and instead of replacing it I joined carsharing.	8%	8%
8	Owned more than one car. Got rid of at least one car and joined carsharing.	3%	3%
9	I live in an apartment building with a designated carsharing vehicle, and I joined through its membership arrangement.	0%	0%
10	I joined carsharing for reasons other than those listed above. Please explain:	9%	7%

Question: Please select the statement that best characterizes the circumstances under which you joined carsharing.

For most circumstantial categories, the balance of respondents changes very little. The largest change in sample share is Category 4 in Table 8, which includes people who did not have a car and joined carsharing to gain additional personal freedom. This shift is in fact unfavorable for finding a reduction in GHG emissions for carsharing because this category consists of people who can only increase their “observed” emissions as they were not driving prior to joining carsharing. Overall, the comparison shows that the data filtering process does not shift the circumstantial balance of respondents in other significant ways. Further discussion follows in the next chapter ”Results,” showing similar comparative results among the demographics of the complete and final dataset. A sensitivity analysis within the results section illustrates how the results vary according to key assumptions and respondent inputs, including an analysis of how the balance of results would change had certain filters not been active.

RESULTS

The survey results illustrate how carsharing interacts with different households in different ways, and the aggregate results show that carsharing generates a wide distribution of impact on personal annual GHG emissions. Across all respondents, carsharing facilitates decreases in annual emissions for some members and increases in annual emissions among other members. The authors found that on balance across all survey respondents, the net carsharing emissions are negative and statistically significant for both the observed impact and the full impact. GHG emissions from transportation are lower due to carsharing. The average change in emissions across all respondents is -0.58 t GHG/yr for the observed impact, and -0.84 t GHG/yr for the full impact. However, it is very important that the “how and why” of this result is understood in the context of the broad diversity of carsharing impacts. While carsharing does facilitate lower emissions, this result is not generalizable across all members or even a majority of members. Rather carsharing as a system facilitates large changes in the annual emissions of some households, which compensate for the collective small emission increases of other households. This dynamic is important for the construction of sound policy, which can encourage carsharing growth in a manner that provides mobility benefits and continued emission reductions within urban and suburban regions.

DEMOGRAPHICS

Researchers logged a total of 9,635 completed surveys across the U.S. (N_{US} = 6,895) and Canada (N_{CAN} = 2,740). Basic demographics of the respondent pool illustrate a diverse population using carsharing. Carsharing serves a wide diversity of household incomes, education, and age groups. In the following discussion, the authors present sample sizes (N) within the figures to describe the demographics of both the complete and cleaned data. These will vary and be slightly less than the total survey population, as some respondents inevitably skipped or declined to respond to certain demographic questions. The demographics figures show the complete dataset ($N_{complete}$ = 9,635) as well as the final cleaned dataset ($N_{cleaned}$ = 6,281), which includes only those respondents who remained after all filters were applied. The purpose of the comparison is to show that the filter applications did not significantly alter the demographic mix of the dataset. The main differences include a slight shift toward older populations and commensurately a slight shift toward higher incomes.

The respondent age distribution shows that carsharing still remains relatively more popular with younger adults between the ages 25 and 40. The average age of all respondents was 36.6 years, with a median of 33 and mode of 28. Figure 4 illustrates the distribution of age groups among respondents.

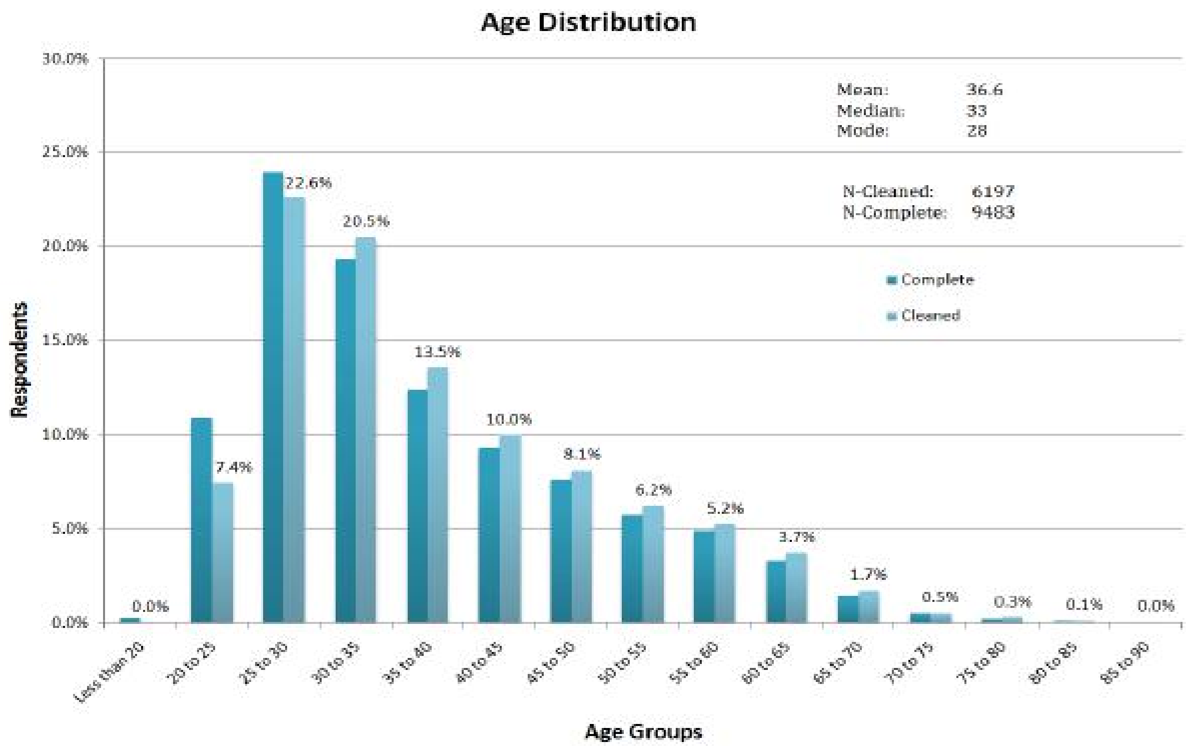


Figure 4 Age Distribution of Respondents

While the distribution shows that carsharing members are skewed toward the young adult demographic, there is considerable representation among older respondents. Both datasets show that at least a third of respondents are over 40 years old.

The income and education of respondents illustrates a similar level of diversity. Respondents were asked to provide their 2007 household income within $10,000 intervals denominated in their respective home currency. The intervals of $30,000 to $40,000 and $40,000 to $50,000 were selected with near equal frequency, but the remaining responses varied across a wide range of household income levels. Figure 5 illustrates the distribution of income and education levels among the respondents that answered the question.

The income response of all respondents in the U.S. and Canada are listed together. During much of 2007, the currencies of the two countries traded at near parity within a $.20 range around 1, (1 USD = {.95 to 1.15} CAD). Incomes during this time between the two countries were close to nominal equivalence. The median interval is $50,000 to $60,000, which indicates that nearly 50% of the respondents had household incomes greater than $60,000. Thus, carsharing is a service that is shared by a wide range of household incomes. In terms of education, the respondent distribution is skewed toward higher education levels. More than 80% of respondents hold at least a bachelor's degree, and nearly 40% had completed some form an advanced graduate degree.

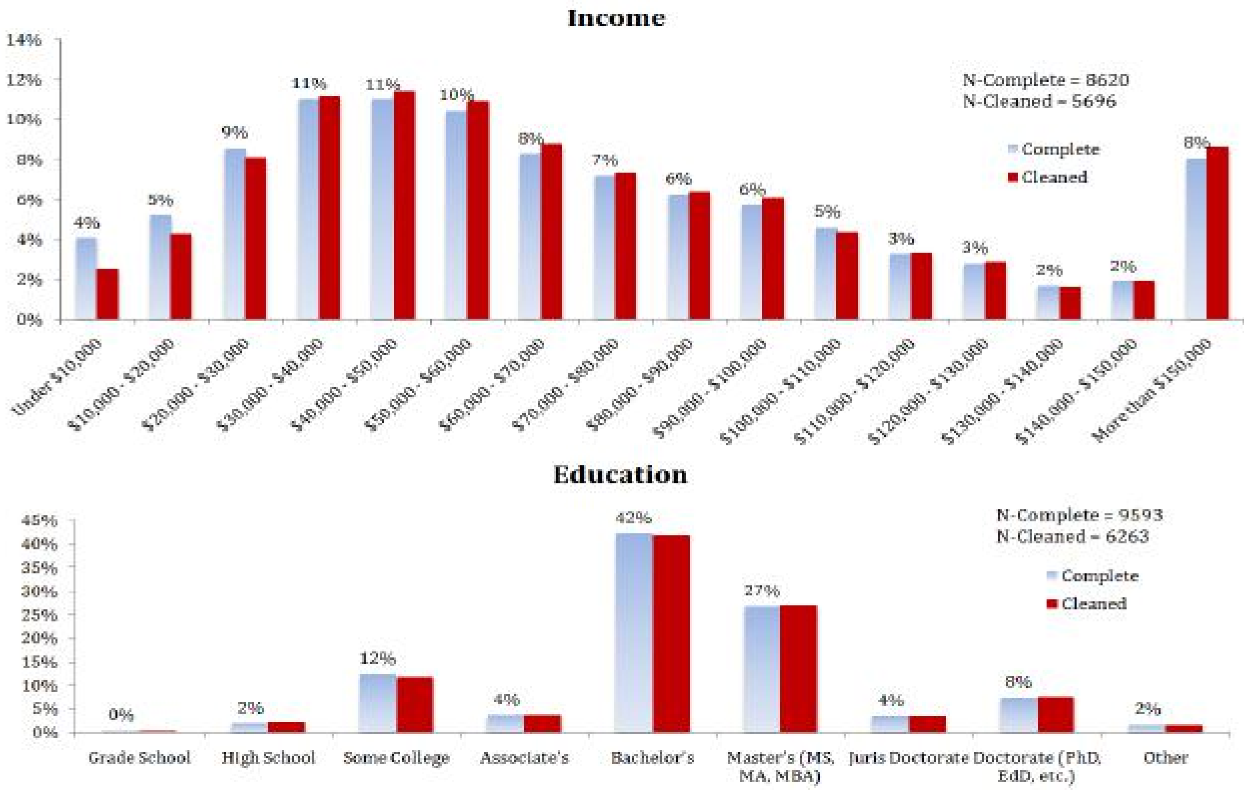


Figure 5 Income and Education Distribution of Respondents

The size of respondent households tend to be smaller than average. The average household size in the U.S. is 2.6, whereas the average among all respondents was 1.9 persons.[32] This difference is in part driven by the fact that cities have smaller household sizes. The mode of household size is one, while the median is two. The gender balance of respondents is slightly dominated by females at 57% to 43% males.

CARSHARING EMISSIONS IMPACTS

The respondent distribution for the change in annual household GHG emissions shows the wide diversity of GHG impacts exhibited by carsharing members. Carsharing members both increase and decrease their annual emissions, and the distribution shows that a majority of carsharing members are increasing their annual emissions. But across all 6,281 respondents, the results show that carsharing's net effect in North America is a reduction in annual GHG emissions. As mentioned earlier, this average is -0.58 t GHG/yr for the observed impact, and -0.84 t GHG/yr for the full impact. The discussion that follows presents the dynamics of this result in more detail.

Figure 6 presents the distribution of annual emission impacts by respondent frequency for both the observed and full impact of carsharing. The horizontal axis define "bins" of annual GHG change in metric tons of GHG per year (t GHG/yr), while the vertical axis defines the count of respondents within each bin.

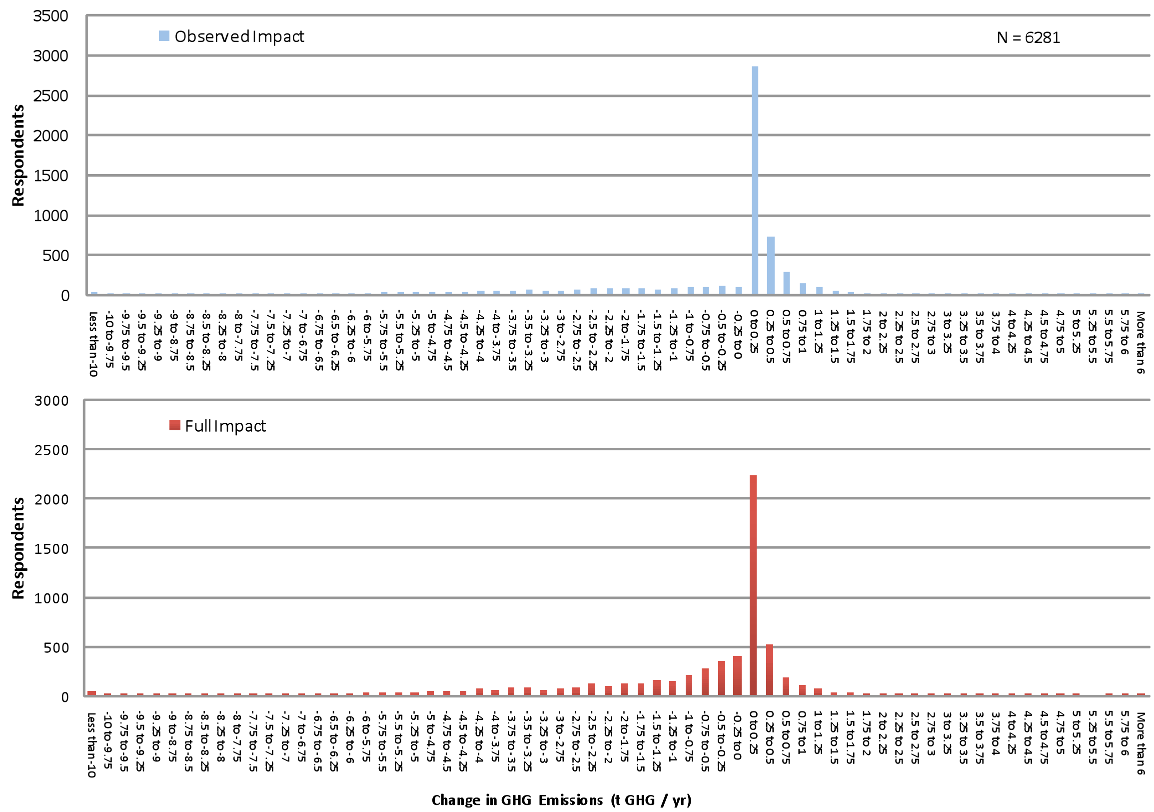


Figure 6 Distribution of Annual Household GHG Emission Impact

A striking feature of the distribution is the high number of respondents that exhibit an increase in annualized emissions within the bounds of 0 and 0.25 t GHG/yr. The spike is evident within both the observed impact and the full impact. Members increasing their annual emissions by some amount under 0.25 t GHG/yr outnumber the frequency of any other bin along the horizontal axis. Another notable feature is the distribution of members increasing their emissions, which follows an exponential trend of respondent frequency decline as the rate of annual emissions increases. This decline is far faster to the right of zero than it is to the left. The decline is rapid enough such that the frequency of respondents exhibiting a change of 1.25 to 1.5 t GHG/yr (n = 58) is smaller than the frequency of respondents altering their annual emissions by -1.25 to -1.5 t GHG/yr (n = 78) and for all bins extending to positive and negative infinity. The distribution of members lowering their emissions is far more evenly spread for both the observed and full impact. In total, 4,456 (71%) of respondents have a positive observed impact, while 1,825 (29%) have a negative observed impact. For the full impact, the balance is more evenly distributed by respondent frequency, as 3,281 respondents (53%) have a positive full impact while 2,953 respondents (47%) have a negative full impact.

The difference between the number of respondents decreasing their emissions in the observed impact and the full impact highlights the importance of considering the avoided emissions. These are emissions that would have occurred in the absence of carsharing but do not because carsharing is available. The resulting shift of the full impact reduces the number of members with impacts greater than zero. Absent any consideration of avoided mileage, these respondents would appear to be increasing their net emissions through carsharing. Simply put, there exist some members of carsharing who would acquire a car and drive it some distance, but instead join carsharing. Because these emissions on the acquired car are never manifested, the observed impact calculation only shows an increase in emissions for this type of respondent. The full impact takes into account the offset of what would have happened otherwise.

The exponential drop in annual emissions to the right of zero suggests that those joining carsharing for access to automotive mobility do not drive much. To illustrate this point in more detail, Figure 7 presents the distribution of the annual miles driven by carsharing members for all respondents of the survey.

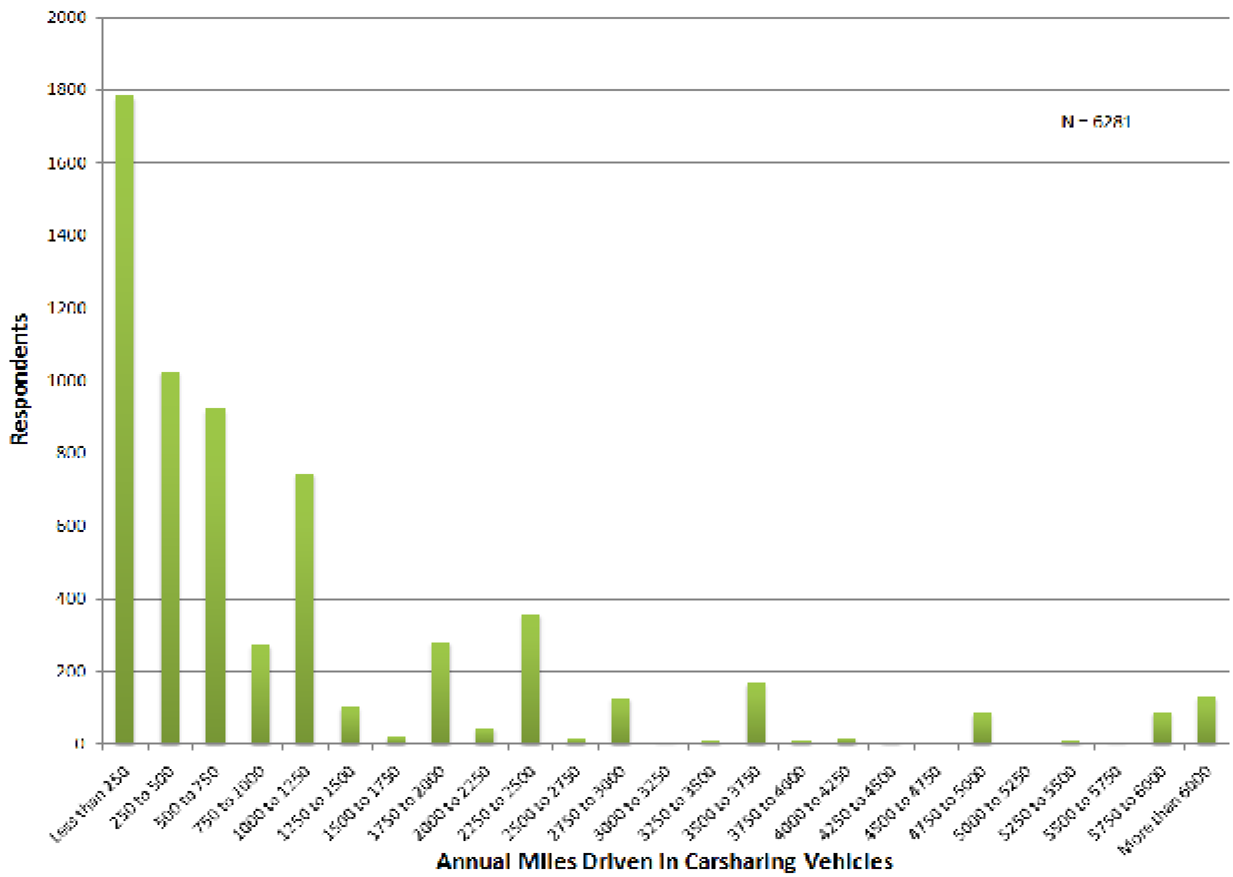


Figure 7 Distribution of Miles Driven by Carsharing Members

Figure 7 shows that most households place very low annual mileage on carsharing vehicles. In theory, this suggests that households that transition from driving more typical distances in private vehicles into carsharing have the potential to impose considerable reductions in annual GHG emissions. The miles placed on carsharing vehicles by households are generally small. Nearly 30% of all households report placing less than 250 miles per year on carsharing vehicles. An additional 16% reported driving between 250 and 500 miles, and about 19% placed between 500 and 1,000 miles annually. In total, more than 80% of all households drive less than 2,000 miles per year on carsharing vehicles. Figure 7 shows that the potential increase in driving by carless households is generally small. The change in the distribution of personal vehicle miles traveled (PVMT) illustrates how carsharing simultaneously shifts overall driving in private vehicles. Figure 8 presents the distribution of the annual mileage placed on personal vehicles by households before joining carsharing and at the time of the survey. The mileage shown in Figure 8 is the total mileage across all vehicles held by the household during the given period.

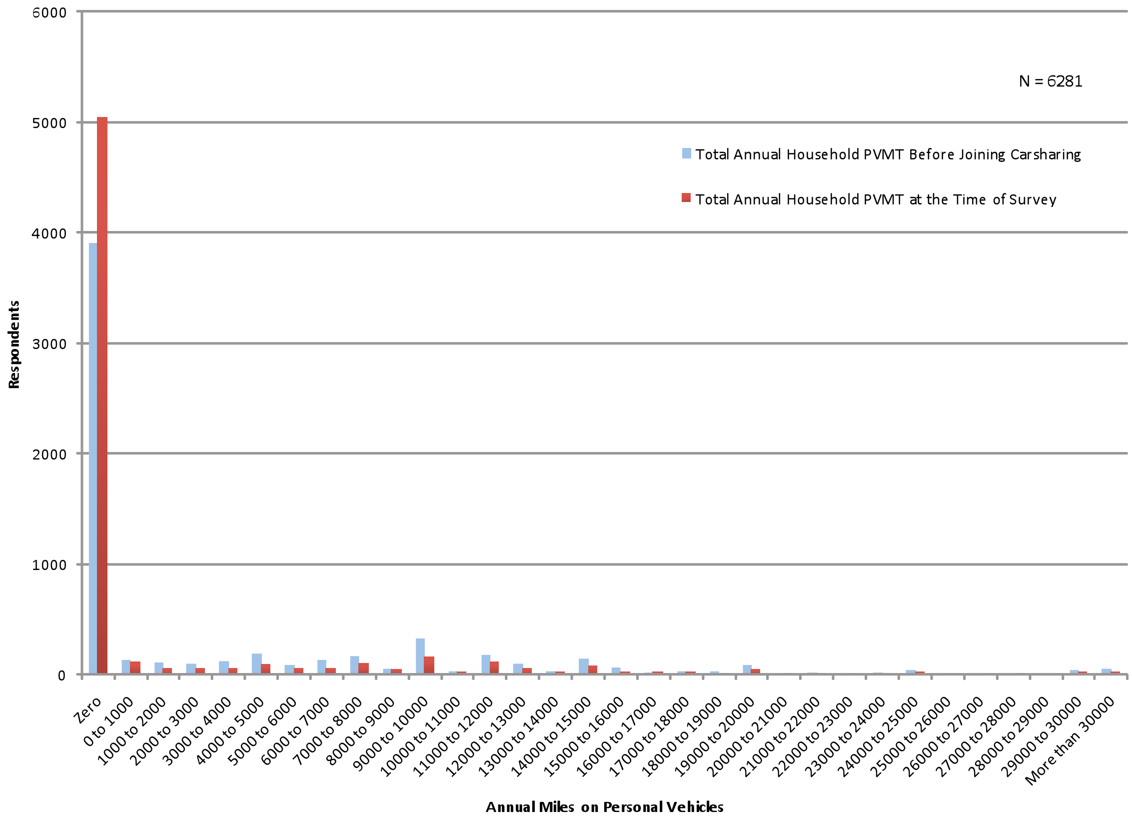


Figure 8 Distribution of Total Annual Personal Vehicle Miles Traveled by Household

Figure 8 shows that the majority of households joining carsharing drove zero personal miles. These are essentially carless households, and the only miles they drive are on carsharing vehicles. The “before-and-after” shift in the PVMT distribution shows a significant gain in the number of carless households, an increase of nearly 30%. The distribution of annual household PVMT distances shows a general decline of households driving all distances. This does not mean that were no households reporting an increase in household PVMT, some did. But most households achieved the shift in mileage by eliminating at least one vehicle. From Figures 7 and 8 the derivatives of the unique shape of Figure 6 begin to become apparent. The large number of carless households that joined carsharing are now driving a little more, giving rise to the shape of the distribution to the right of zero in Figure 6. Households reducing their driving from a range of annual PVMT distances and vehicles create the long tail to the left of zero.

Figure 6 illustrates the GHG impact on the horizontal axis and the respondent count on the vertical axis; the majority of respondents are increasing their emissions in the full and observed impact categories. But the net impact of carsharing remains unclear, as the long tail of respondents reducing their emissions exhibits greater reductions with greater distance from zero. Figure 9 presents the same aggregate distribution weighted by the annual emission change for respondents. Each categorical bin of the horizontal axis contains the summation of the annual change in respondent emissions. The result is a distribution that illustrates the cumulative net annual change in emissions for all survey respondents. The top graph in Figure 9 illustrates this distribution for the observed impact, and the bottom graph shows the full impact.

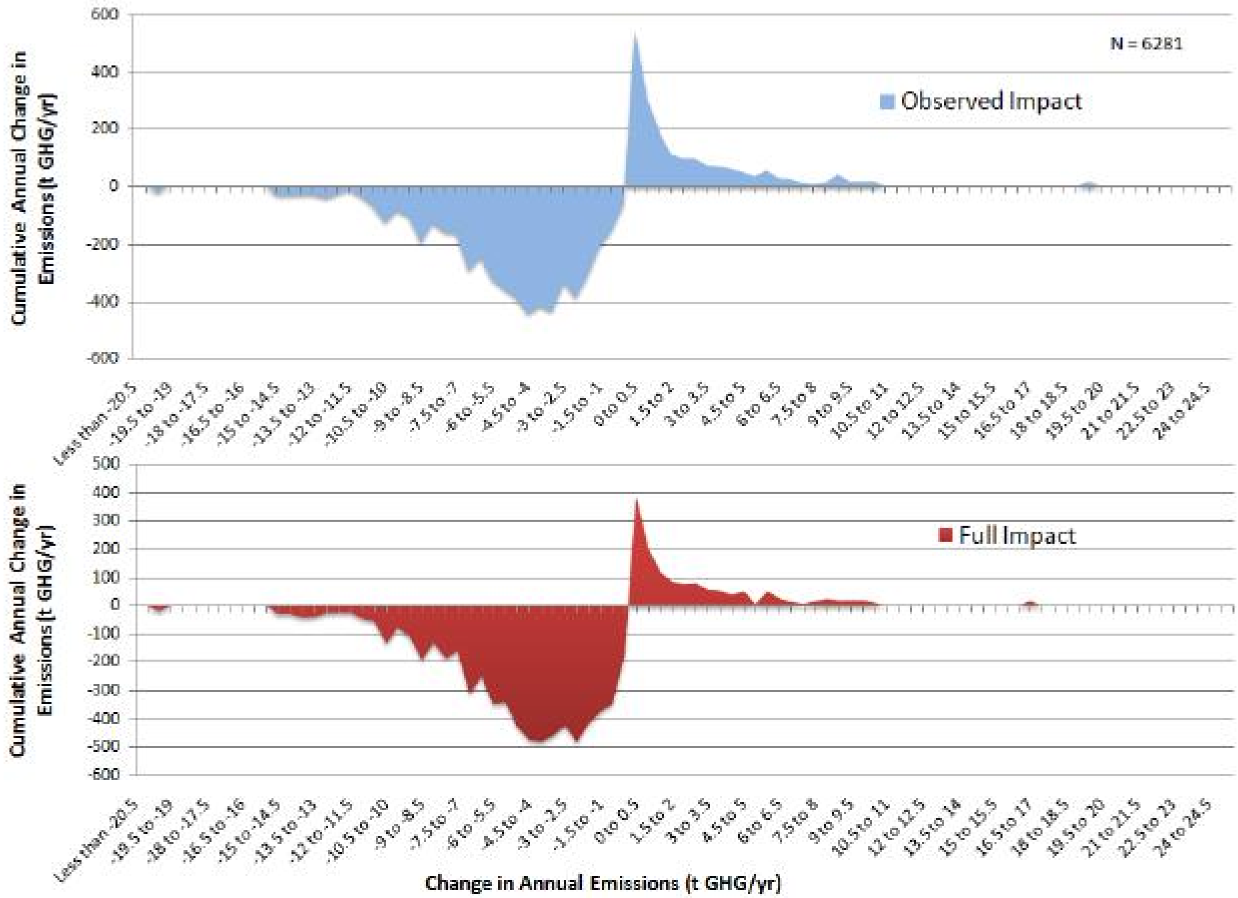


Figure 9 Profile of Cumulative Annual Change in GHG Emissions

The horizontal axis of Figure 9 is in the same units of Figure 6, and the respondents represented within each bin are exactly the same for both figures. The difference between Figure 9 and Figure 6 is that the vertical axis is the sum of the annual change in emissions (in t GHG/yr) of each respondent within each bin. Figure 9 graphically shows a clear perspective on the overall net change in annual emissions observed among all respondents. For both the observed and full impact, it is visually apparent that the area constituting emission reductions is larger than the area constituting emission increases. Thus, the results show that while the majority of respondents are increasing annual emissions, the cumulative emissions change for carsharing is negative.

It follows that the average emissions change across all respondents is also negative. The distribution of the sample population is not normal. The respondent distribution exhibits high kurtosis and is negatively skewed. However, the Central Limit Theorem (CLT) and the large sample size establish the appropriate conditions for a paired t-test to evaluate the statistical significance of the aggregate mean impacts. The CLT establishes that as sample sizes become large, the distribution of the sample mean converges to a normal distribution.[33] This permits the application of parametric statistical tests, such as the t-test, to determine the mean significance. This point can be illustrated with a technique called the bootstrap method. The bootstrap method applies computer simulation to replicate distributions of specific statistical moments when an analytical approach is difficult or intractable. For evaluating the mean, the bootstrap method simply draws a large set of respondents from the sample, computes the mean, stores the value, and repeats this many times. The stored mean values then constitute a simulated sample mean distribution. At a high number of draws, the simulated distribution converges to the actual distribution. Figure 10 shows an implementation of the bootstrap method using 6,000 draws from the sample of this study to compute the sample mean distribution using MATLAB. Figure 10(a) on the left, shows the simulated distribution of the sample mean for the observed impact; 10(b) on the right shows the same distribution for the full impact. Both distributions can be seen to resemble the shape of the normal distribution.

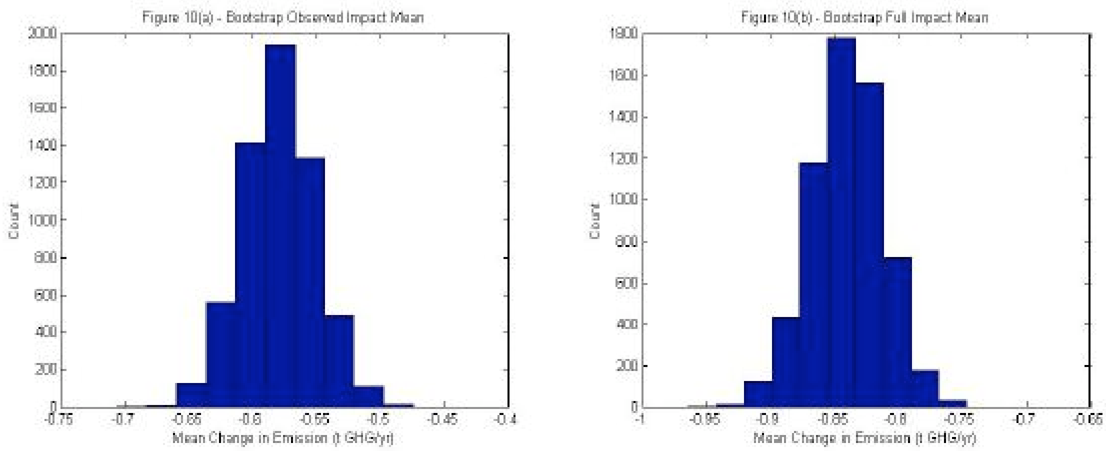


Figure 10 Simulated Distribution of the Sample Mean of the Emissions Change

It can be seen from Figure 10 that both mean impacts are negative and statistically significant from zero. The results of a paired t-test of the aggregate mean impact is presented in Table 9. The null hypothesis is that the mean change in emissions is zero.

Table 9 Paired t-Test: Mean Difference from Zero

	Paired Sample t-test - Paired Differences							
	Mean	Std. Deviation	Std. Error Mean	99% Confidence Interval of the Difference		t	df	Sig. (2-tailed)
				Lower	Upper			
Observed Change in Emissions	-.58	2.23	.03	-.65	-.50	-20.479	6280	.000
Full Change in Emission	-.84	2.20	.03	-.91	-.76	-30.027	6280	.000

While carsharing members are shown to have both positive and negative changes of annual household GHG emissions, the observed impact across all respondents is an average of -0.58 t GHG/yr/household. The average full impact of -0.84 t GHG/yr is naturally further away from zero, as it includes avoided emissions. In both cases, the collective magnitude of reductions by those decreasing their emissions outweighs the collective magnitude of those increasing emissions.

Table 9 shows that the mean impact of carsharing is statistically significant. The observed impact is contained within a 99% confidence interval of -0.50 to -0.65 t GHG/yr, while the full impact is contained between -0.76 to -0.91 t GHG/yr. Thus, the overall survey results indicate that carsharing has facilitated a net reduction in the annual rate of GHG emissions of members across North America.

Distributions of Subsamples by Circumstances of Membership

The aggregate carsharing impact is the composition of a far more complex and diverse set of relationships governing how individual households alter their emissions under carsharing. GHG emission changes arise from members joining under different circumstances and taking unique actions as they adjust to a lifestyle that uses carsharing.

The nuances within the aggregate distribution Figure 6 and Figure 9 become more apparent with a disaggregate analysis that illustrates the distribution of respondent subpopulations. Interestingly, the overall trends governing the aggregate responses are very apparent within the subcategories that describe the circumstances in which a respondent's household joined carsharing. As outlined in Table 6, respondents were asked early in the survey to characterize as best as possible the circumstances in which their household joined carsharing. These circumstantial categories offer important insights as to which subpopulations drive the overall emissions change that is observed in aggregate. Figure 11 presents the distribution of emissions change for respondents who joined carsharing when a household vehicle stopped working. The units of the axes of Figure 11 and all subsequent figures in this section are the same as in Figure 6, with respondent counts on the vertical axis. The exact response selected by the respondent in the survey is listed at the top of each graph.

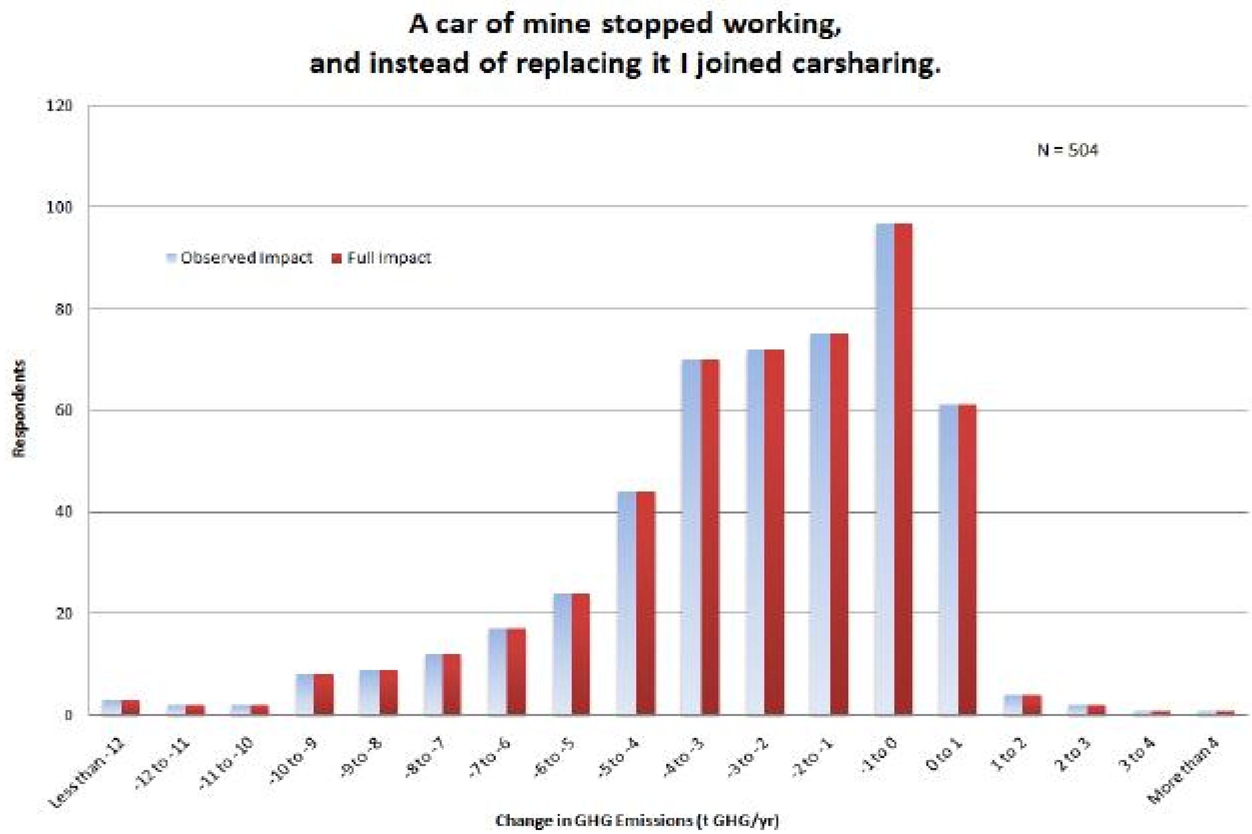


Figure 11 Vehicle Stopped Working and Joined Carsharing

Figure 11 shows that a large share of respondents within this circumstantial category (86%) report reductions in annual GHG emissions. The reduction range is large, although a majority of respondents are reducing emissions between 0 and 6 t GHG/yr. To put this range in perspective, a 25-mpg vehicle driven 15,000 miles per year would produce 5.6 t GHG/yr. Reductions larger than 6 t GHG/yr come from a minority of households that drove further distances or shed multiple vehicles. It is important to note that respondents within this category exhibit equal observed and full impacts. This is a function of the methodological calculation to prevent the full impact from being overstated. As respondents in this category are already shedding vehicles, the application of avoided driving factors stated by respondents would constitute a previous driving replacement. Thus, the application of avoided emissions to members of these circumstances would be double counting. For this and other categories in which a vehicle was shed, similar computational rules are followed.

Further examination of other circumstantial subsamples reveals more detailed insight into the nature of emission impacts exhibited by households that enter carsharing without vehicles. Figure 12 presents the graphs of two such categories in which households were carless prior to joining. The avoided emissions that generate the full impact are applicable for both categories as both respondent subsamples have no prior personal vehicle emissions to replace.

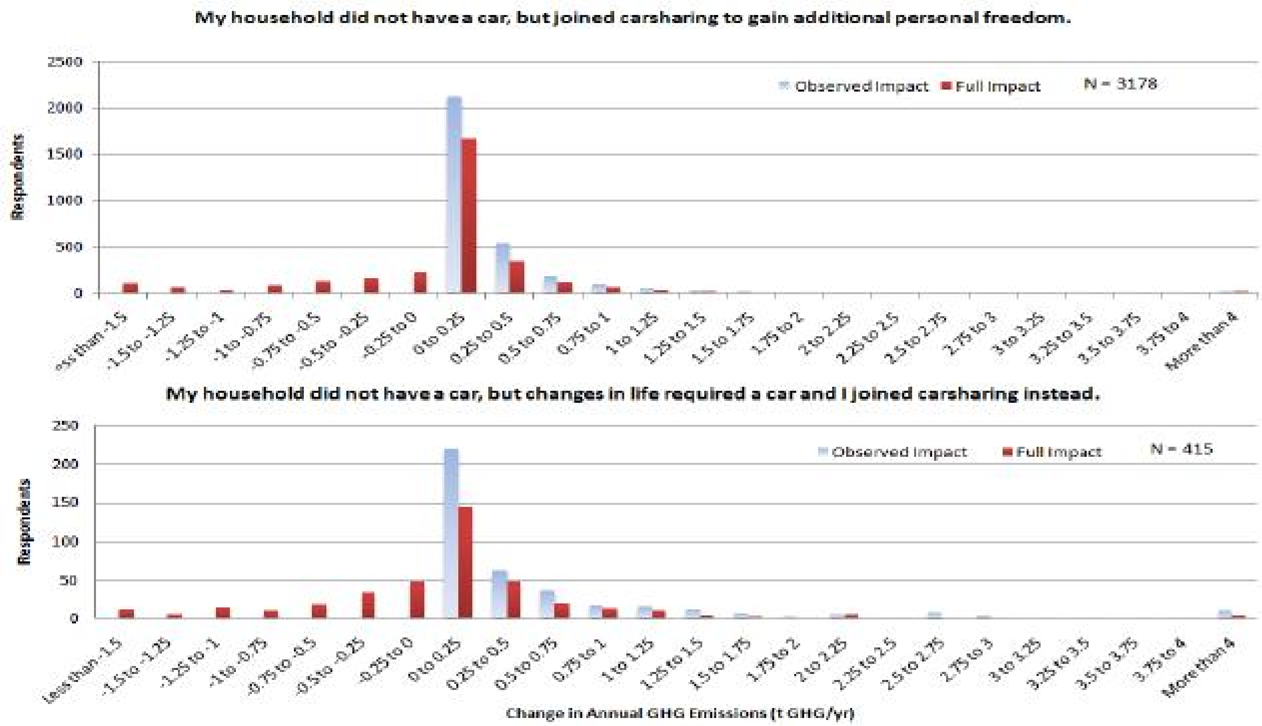


Figure 12 Respondents Entering Carsharing Without a Vehicle

The shift in the distributions of annual change in GHG emissions illustrates the importance of capturing the latent effects. Nearly 35% of respondents using carsharing as an explicit substitute for vehicle acquisition would report higher emissions in the absence of carsharing. Similarly, for the broader population of members that joined carsharing for greater mobility, 26% suggest that carsharing is resulting in lower emissions than would otherwise occur. While it is clear that carless households joining carsharing are by-in-large increasing emissions as a result of their membership, the avoided emission impact that would occur otherwise is an important component offsetting this increase. Another key distinction of both distributions is the range of emissions change observed on both sides of zero. The changes exhibited by households that enter carsharing without a history of personal vehicle holdings are contained within a small range relative to the aggregate data. More than 90% of observed and full impacts are contained with +/- 2 t GHG/yr, thus emphasizing that emission increments generated by carless households are small.

As a related circumstance of membership, carsharing can also serve as a means for car-owning households to avoid the acquisition of an additional vehicle that may become necessary within the household. Figure 13 illustrates the distribution of annual emissions impact for a circumstantial category in which the households may be both vehicle shedding and avoiding the acquisition of additional vehicles.

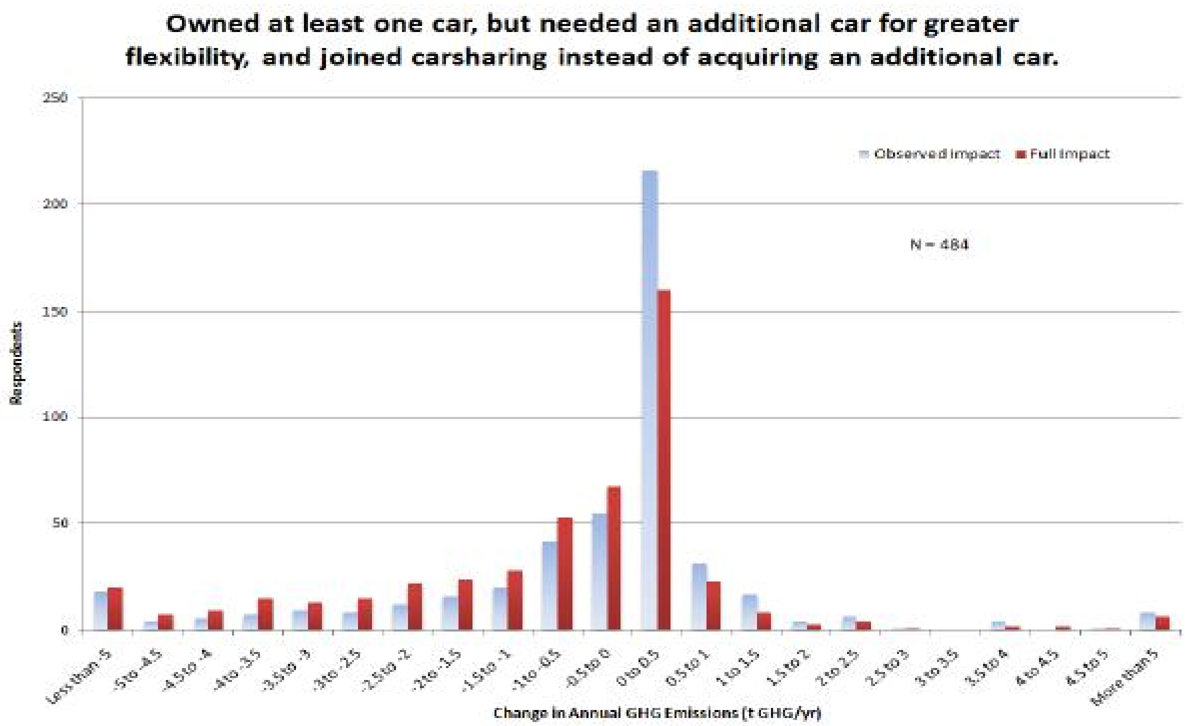


Figure 13 Households Owning Vehicles but Avoiding Future Purchases

The distribution illustrates the combined effects of some vehicle shedding as well as the shift from the avoided impact. As with the aggregate distribution, a majority of respondents (59%) in this category are increasing their emissions according to the baseline impact. While their impact is overwhelmingly contained within the range of a 0 to 2.5 t GHG/yr increase, the tail of negative emission changes extends much further. As indicated by the circumstances of the respondents, the avoided impact shifts emissions considerably, and the balance of change decreases emissions for a majority of respondents (57%).

Finally, Figure 14 illustrates the distribution of changes in emissions yielded by respondents that entered carsharing with vehicles that they subsequently shed. Both graphs within Figure 14 illustrate how households that drop vehicles after entering carsharing can exhibit large GHG emission changes per year. These changes, along with those in Figure 11 and Figure 13, drive much of the net reduction observed in the aggregate distribution.

Both distributions in Figure 14 are characterized by a significant majority of respondents reducing annual GHG emissions. Among multi-vehicle households shedding cars, 88% of respondents reduced emissions. Similarly, among single-vehicle households shedding cars, 93% exhibited a negative emission change. Figure 14 illustrates how a large majority of respondents reduced emissions by an amount less than 5 t GHG/yr. A total of 73% of all vehicles shed were driven 10,000 miles or less. An additional 17% of all vehicles shed were driven between 10,000 miles and 15,000 miles per year. Thus, 90% of all vehicles shed were driven 15,000 miles per year or less. Although shed vehicles are not the only source of impact, the distribution of GHG impacts largely reflect the mileage distribution of shed vehicles as most of the respondents in both categories report reductions between 0 and 5 t GHG/yr.

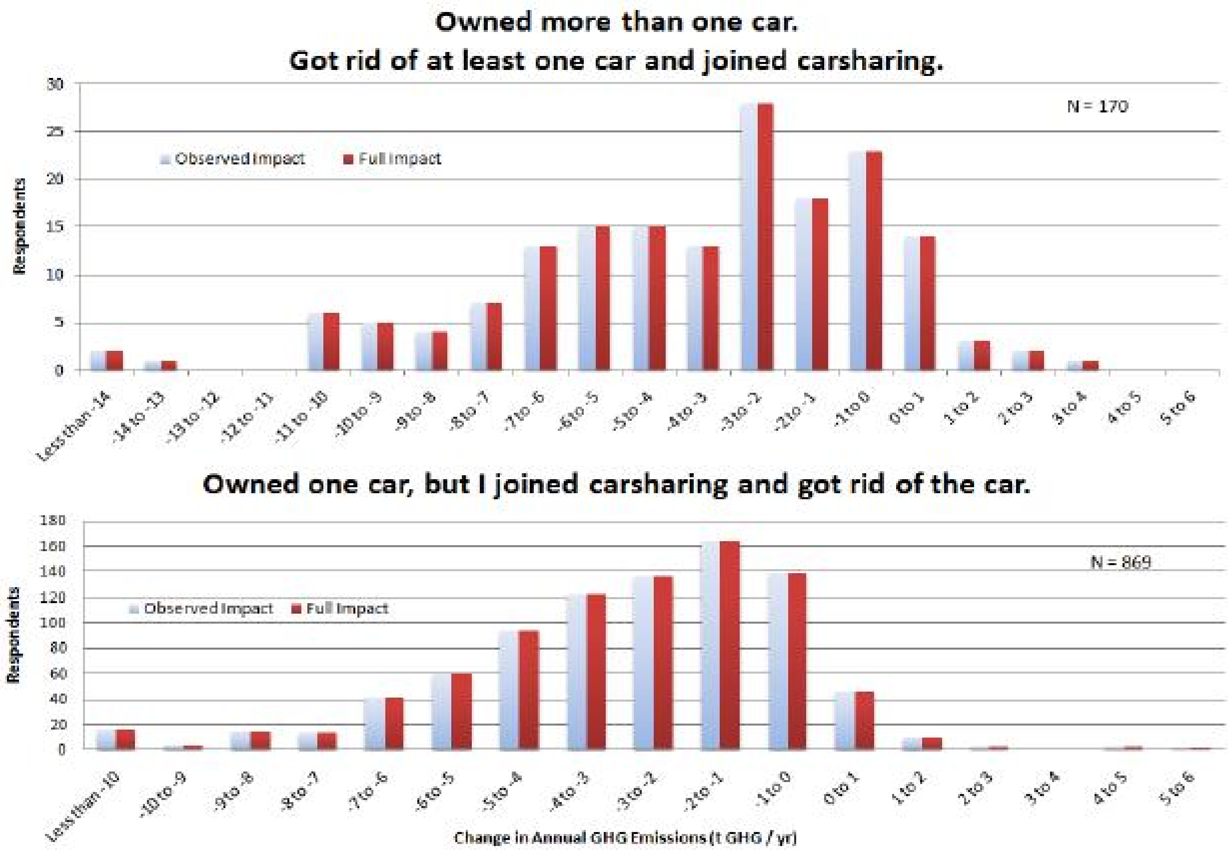


Figure 14 Joined Carsharing and Shed Vehicles

The disaggregation of key categories within the aggregate distribution illustrates the underlying circumstances that drive carsharing impacts. Households that are reducing their observed emissions through carsharing are outnumbered seven to three, but those households are reducing their emissions by magnitudes that far outweigh the small increases in emissions that are incurred when carless households join carsharing.

Impacts from Changes in Local Taxi and Rental Car Use

As discussed in the methodology, the authors asked a respondent subsample questions regarding their local car rental and taxi use. The motivation for pursuing a subsample of respondents was based on concerns regarding respondent fatigue and limitations in respondent knowledge. The subsample results confirmed the hypothesis that local rental car and taxi use changes do not influence aggregate carsharing impacts. This is not to say that some people do not change their local taxi or rental car use due to carsharing. However, the average change is statistically indistinct from zero or negligible. As expected, a sizeable proportion (20%) of respondents within the subsample could not recall their local car rental or taxi use in the past. For those that could, the distribution of change in t GHG/year is within a tight range close to zero. Figure 15 illustrates the impact distribution with respect to local taxi and rental car use. The majority of respondents reported zero change for both modes.

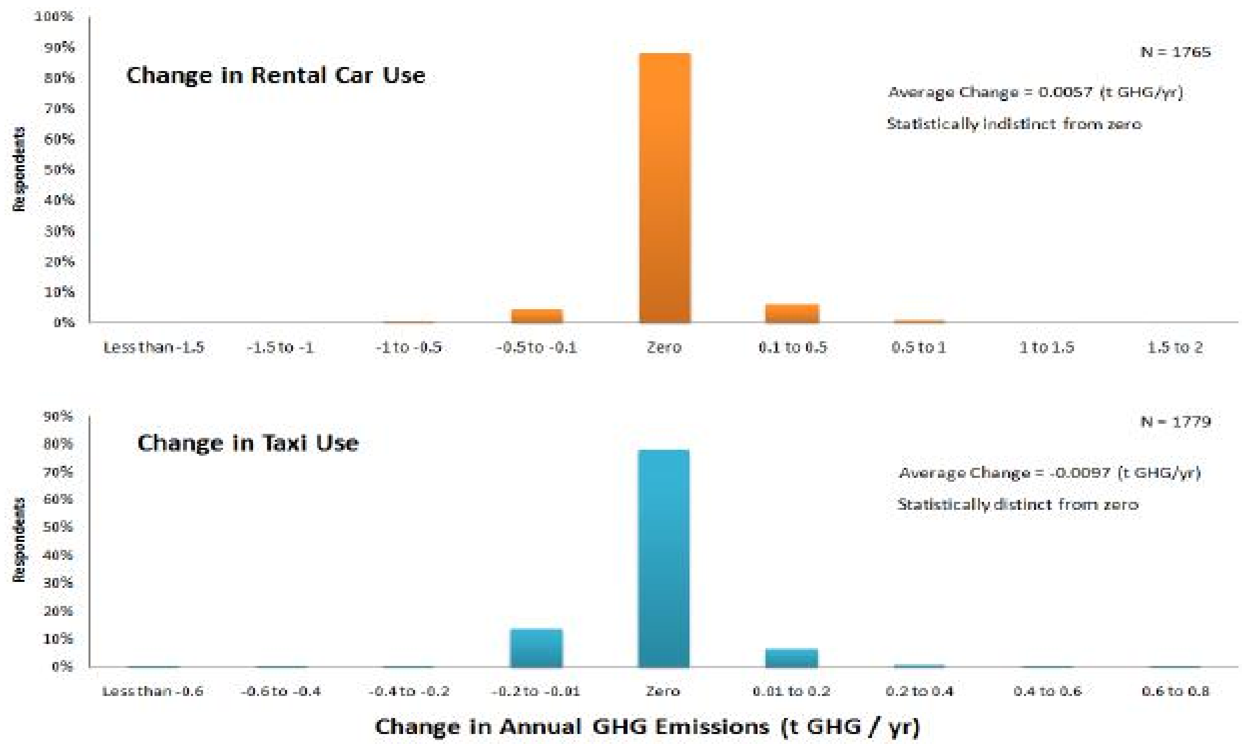


Figure 15 Distribution of Change in GHG Emissions From Local Taxi and Rental Car Use

Figure 15 illustrates two distributions that reflect the reported change in mileage from using local taxi vehicles and rental cars before and after carsharing. The distributions show that the average impacts are small. The average GHG change from local rental cars is less than 0.01 t GHG/yr and is statistically insignificant. The average GHG change from taxi use is -0.0097 t GHG/yr and is statistically significant. However, this is negative, suggesting that taxi use tends to fall after people join carsharing. Because the magnitude of these impacts is close to zero, they are negligible in influencing the overall carsharing impact.

SENSITIVITY ANALYSIS OF AGGREGATE EMISSION CHANGE

The results of the aggregate analysis are striking in that the mean observed and full carsharing impact are negative and statistically significant in spite of the fact that a majority of respondents technically increased their emissions due to carsharing. It is natural to wonder how much this result depends on the presence of households reporting very significant emission decreases. To show how this result varies with assumptions and data, this section presents a sensitivity analysis to illustrate how the mean and statistical significance of impacts change when the most influential observations are adjusted to dampen their impact on the mean. This section also explores how the results change if key filters, such as the removal of respondents that had moved, are altered.

The Passenger Vehicle Miles Traveled Filter

As mentioned earlier, the threshold of 30,000 PVMT per year was chosen as a benchmark for the upper bound of PVMT responses. Any respondent that indicated that a personal mileage exceeding 30,000 miles per year on any vehicle was filtered from the analysis. While this benchmark is somewhat arbitrary, it was chosen to prevent very high PVMT responses (true or not) from drastically shifting the mean impact. This would result in a small number of respondents playing an outsized role in characterizing the average carsharing impact. But what if the maximum permitted PVMT value was higher, how would this affect the mean impacts? Figure 16 shows a sensitivity analysis of the observed and full impact mean were the maximum PVMT raised to 100,000 annual miles traveled.

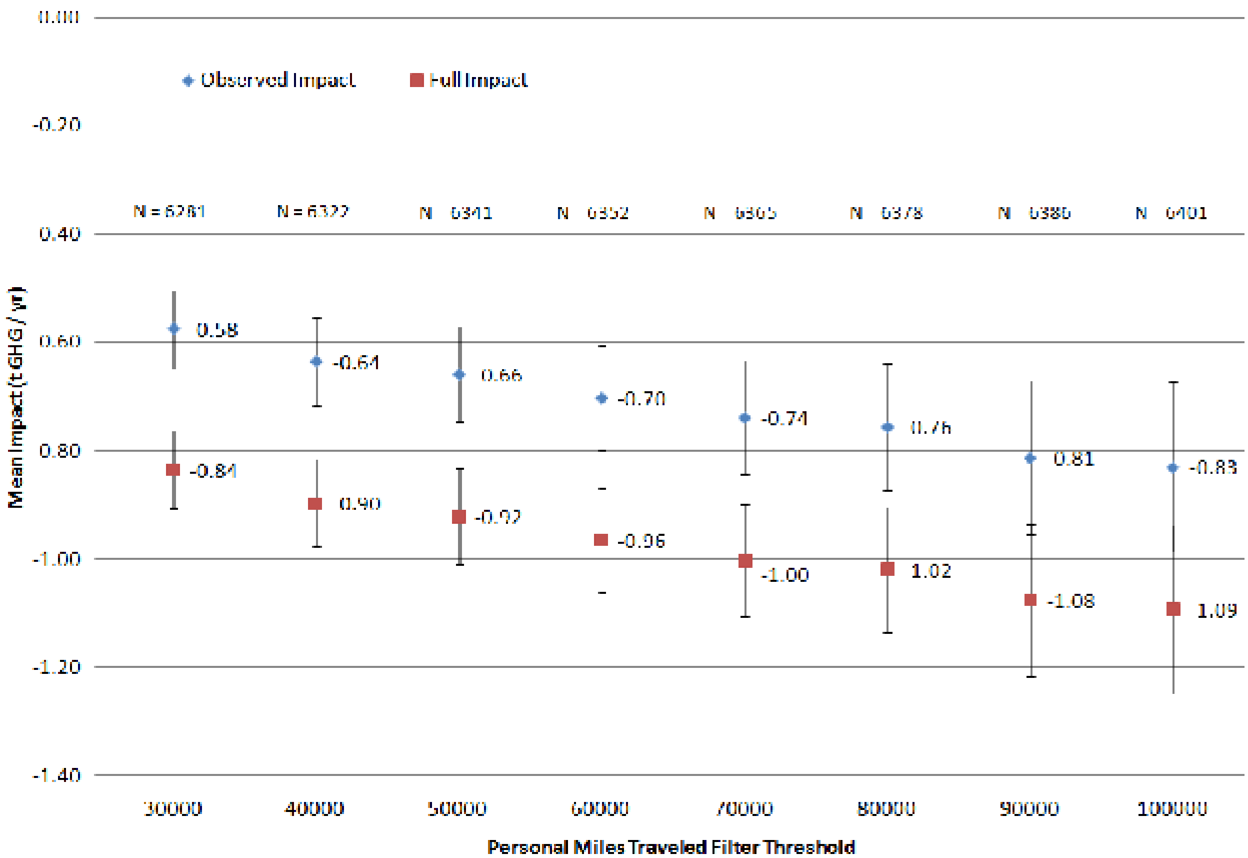


Figure 16 Sensitivity of Mean Impacts to PVMT Filter Threshold

The trend in Figure 16 shows how the results would vary had the PVMT filter been set higher. The error bars indicate the 99% confidence interval about the mean and the leftmost data points present the baseline analysis averages. The *N* values above indicate what the sample size would have been with the adjusted threshold. That is, as the threshold is raised, more respondents would be added to the sample indicating PVMT values at or below the threshold. This trend illustrates that carsharing would be evaluated as more effective in reducing emissions with a higher PVMT filter threshold. The filter does not discriminate between before or after responses of PVMT. If a respondent indicates a PVMT value above the threshold for any vehicle in the household before or after joining carsharing, the filter is activated. The trend with higher PVMT values is downward because the majority of newly included respondents were shedding cars. Thus, Figure 16 shows that the 30,000 PVMT filter is conservative with the data. There are of course people who could driver longer distances legitimately. However with higher PVMT, it becomes more difficult to verify whether the respondent was accurate, mistakenly indicated an odometer value, or simply offered a gross overestimate. The problem with such ambiguities at high PVMT values as opposed to low PVMT values is that that they can shift the result more drastically. Thus, the conservative PVMT threshold of 30,000 mitigates this effect and prevents a small number of respondents with higher PVMT values (true or not) from shifting the average carsharing impact significantly.

An Upper Bound on Personal Miles Traveled Responses

A similar sensitivity analysis evaluates the potential impact of overestimation of PVMT values on the aggregate results. In this section, we evaluate how the average aggregate impacts would change if the maximum allowable PVMT response (a PVMT ceiling) is gradually lowered to zero. In this analysis, any respondent that indicates a particular vehicle was driven more than this upper limit has the value truncated to match the limit. For example, if the established limit is 20,000, then all responses within the final data set containing PVMT values higher than 20,000 are subsequently reset to 20,000. The aggregate observed and full impact is evaluated with these modified terms. Unlike the previous sensitivity analysis, the sample size remains the same at 6,281, as no additional respondents are trimmed from the data. This approach permits the acknowledgement of a respondent's direction of emission change, but the magnitude of change is dampened as the PVMT ceiling is lowered. Simply put, the sensitivity analysis states to a respondent that: "while you claim that you drove some *Y* annual miles prior to joining carsharing, we assume that you could have driven no more than *X* miles (with $X < Y$), and we will evaluate your contribution to the aggregate impact under this assumption." The sensitivity analysis incrementally adjusts the *X* of this statement and evaluates the resulting mean and statistical significance of the observed and full impact. As is apparent in Figure 6 on page 38, the spread of those reducing emissions is far wider than the spread of those increasing their emissions. This method of truncation mitigates the impact of those respondents reducing their emissions far more than it mitigates the impact of those increasing their emissions. Figure 17 illustrates this sensitivity analysis with the PVMT ceiling given on the horizontal axis, and the value of the mean impact given on the vertical axis. The blue and red *X* marks indicate the point of the mean at each max-PVMT, while the bar passing through the *X* indicates the 99% confidence intervals surrounding the given mean.

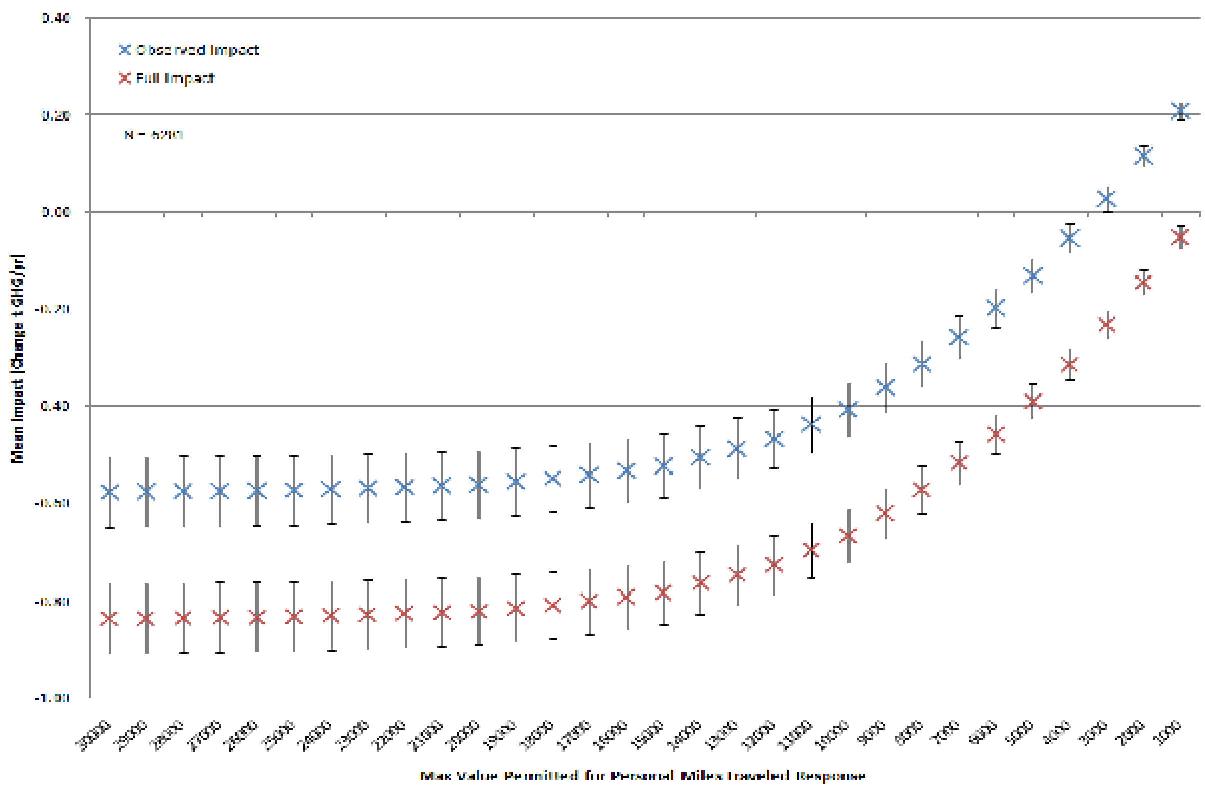


Figure 17 Sensitivity Analysis of Carsharing Impacts Given PVMT Ceiling

The trends shown in Figure 17 offer some insights about the robustness of the aggregate carsharing impact. The shallow slope of the trends from 30,000 miles to 20,000 miles indicates that the respondents stating PVMT distances above 20,000 are not influential on the magnitude of the aggregate impacts. The mean aggregate impacts increase only gradually, and the confidence intervals of the means within this range overlap. From 20,000 to 10,000, the slope of the aggregate impact trend starts to increase more rapidly as a larger number of respondents have their PVMT levels reduced.

The mean observed impact is -0.41 t GHG / yr at the 10,000 PVMT limit and is statistically different from zero. That is, if all respondents reducing their emissions by joining carsharing were permitted to drive no more than 10,000 miles per year prior to joining carsharing, the impact would still constitute an emission reduction that is statistically significant. In a more extreme case, the observed carsharing impact is still negative and statistically significant even if the PVMT responses of all respondents are restricted to be no larger than 4,000 miles per year. At a restriction of 3,000 miles per year, the mean of the observed impact turns positive but statistically indistinguishable from zero. When PVMT responses are restricted to 2,000 miles per year or less, those joining carsharing from carless households begin to dominate, and the observed impact becomes positive and statistically significant. The mean full impact is always negative and statistically significant regardless of the restriction.

The importance of this result from the sensitivity analysis merits further discussion. The driving patterns of carsharing members prior to joining are a critical input into the overall carsharing impact. If carsharing was entirely populated by people who were not driving prior to joining, then the observed impact could only be positive, as carsharing would provide additional automotive access to people who were not driving before. Under such a hypothetical case, carsharing could only reduce emissions through the full impact (i.e., where potentially higher emissions that would have occurred are displaced). However, the sensitivity analysis shows that even when hypothetical but significant restrictions are placed on the magnitude of emission reductions of respondents when joining carsharing, the aggregate impact is still negative and statistically significant. The sensitivity analysis shows that the statistical significance of the mean is maintained with significant restrictions on potential emission reductions. The conclusion that carsharing facilitates emission reductions, appears rather robust from this result. The large sample size of the data provides a strong foundation for conclusions about the mean impacts. The sensitivity analysis, which makes hypothetical adjustments to the data that reduce carsharing's impact, indicates that carsharing would be found to reduce overall emissions in all but the most extreme hypothetical circumstances.

Sensitivity to Overestimation of Passenger Vehicle Miles Traveled

The data within this report is derived from the estimation of personal vehicle miles traveled of vehicles within the respondent household. Personal estimates of annual driving distances are subject to some degree of uncertainty and error. The alternative to personal estimates is odometer readings, which reflect the precise amount of driving over any given period. Limited research has been done on the comparative accuracy of odometer data and personal estimates of annual driving. This is in part because consistent annual odometer data are rarely collected alongside surveys soliciting respondent estimates of annual miles driven. However, one opportunity arose with 1994 Residential Transportation Energy Consumption Survey conducted by the U.S. Energy Information Administration (EIA) and the 1995 National Personal Transportation Survey conducted by the Federal Highway Administration (FWHA). A comparative analysis of data within these surveys suggest that people have a reasonably accurate understanding as to how far they drive on an annual basis.[34] This analysis suggested that on average people may overestimate their annual driving by 4% to 11%.[35] A sensitivity analysis applied here explores how the results would vary, if respondents had overestimated their personal mileage by a spectrum of percentage factors. Figure 18 shows how the results of the final dataset vary, if the annual mileage responses are overestimated by a percentage as defined on the horizontal axis. The plot shows the average impacts from zero percent overestimation to 40% overestimation of all estimates, along with 99% confidence intervals.

The results of Figure 18 show that respondent overestimation would reduce the average carsharing impacts. But the trend also shows that even if large overestimations were made, the emission change would still be negative and statistically significant by a considerable margin. Hence, the sensitivity analysis shows that if respondent overestimation of magnitudes were consistent with past research, the margins of change are rather small and do not greatly alter the overall result.

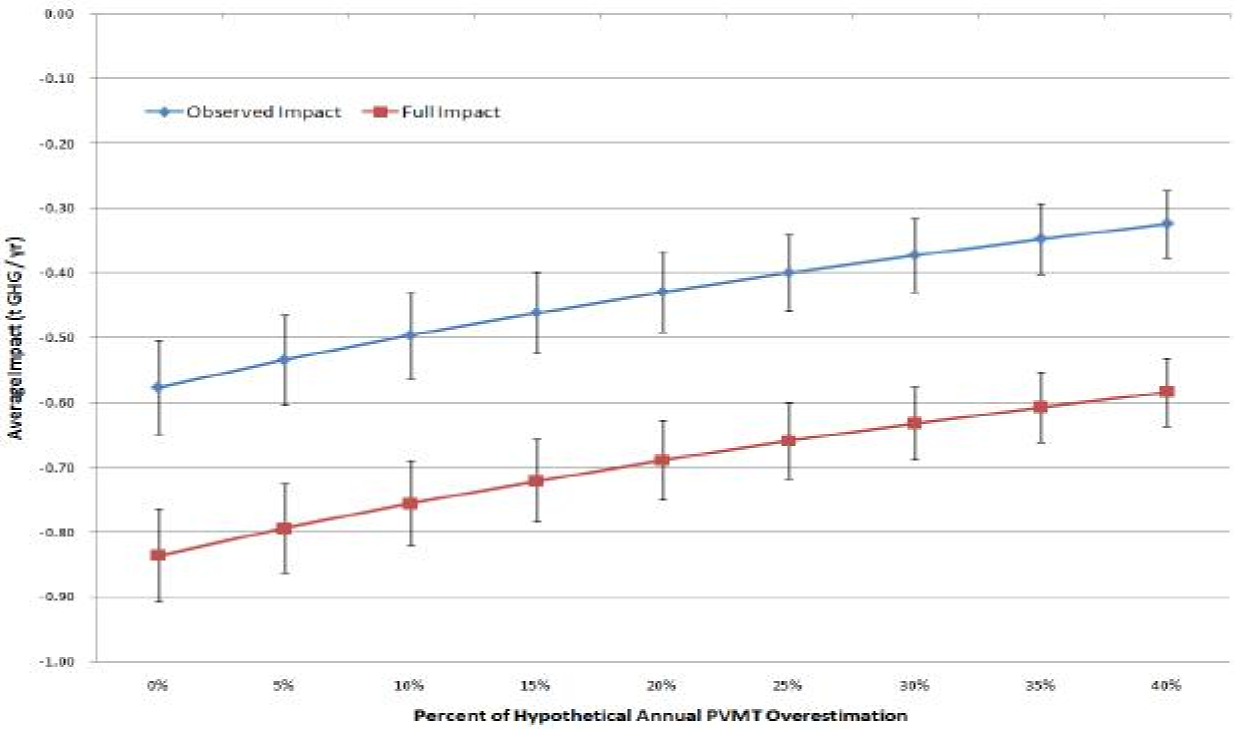


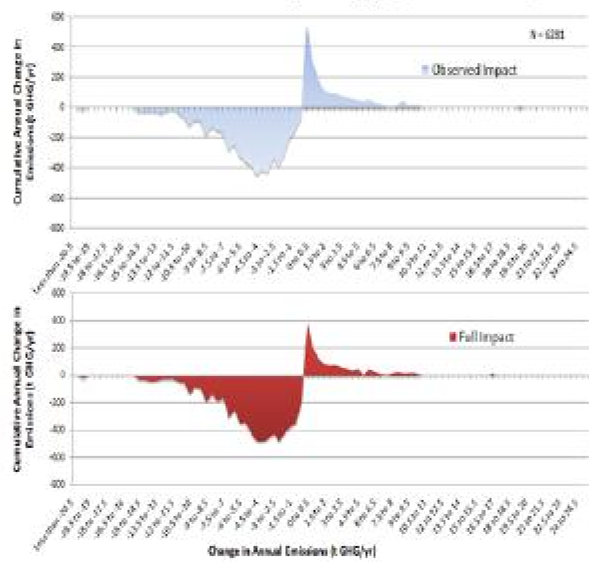
Figure 18 Sensitivity of Impacts to PVMT Overestimation

Deactivating the Move Filter

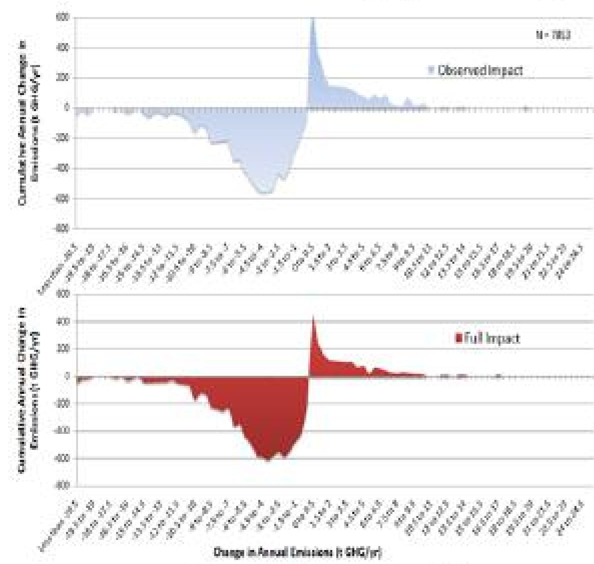
As explained in the survey methodology chapter, the survey was designed to identify respondents that had made a significant move of home or work. This action was taken because such moves can have significant impacts on travel patterns, and it is not appropriate to ascribe such impacts to carsharing if a person moves closer to their job. Because society is mobile, a large number of respondents had moved their home or work, and this filter was the single largest reason for a respondent's removal from the final dataset. It is natural to wonder whether this large group of respondents held any sort of systematic bias with respect to their computed emission change. This section addresses this question by exploring how the results would have appeared under two different scenarios. First, the authors explore how the aggregate results would have looked had all the respondents that had moved been retained in the analysis. Then, the authors explore how the results would have changed had all the respondents been removed regardless of whether the move was substantial or not substantial. The cumulative emissions profile, as presented in Figure 9, offers an efficient way to illustrate the effects of adjusting these filters on the distribution of GHG impacts.

Figure 19 presents a collection of three subfigures and a table. The format of each subfigure is the same as Figure 9, which sums the change in emissions of respondents within each bin along the horizontal axis. The baseline analysis (subfigure *a*) shows a replica of Figure 9 and the final dataset for comparative purposes. To the right of the baseline (subfigure *b*) is how Figure 9 would have appeared had the move filter not been activated at all (or the question never asked). The resulting sample size of 7,853 shows the 1,572 respondents that were readmitted to the dataset. The mass of emissions within this figure is larger than the baseline analysis because of these additional respondents. Subfigure *c* below the baseline analysis illustrates how the results would have appeared had all movers been extracted without consideration of the follow-up question. Here, the sample size is smaller at 5,017 and hence so is the mass of emissions change. In both of these alternative cases, the shape of the cumulative emissions profile is preserved, with the bulk of change occurring in the form of reductions. The Impact Summary (subfigure *d*) of Figure 19 shows the average GHG impact under each circumstance. The summary shows that the inclusion or exclusion of movers has little overall effect on the average. The average observed impact exhibited by the baseline analysis is the least favorable. But as evident from the confidence intervals presented earlier, these impacts are statistically indistinguishable.

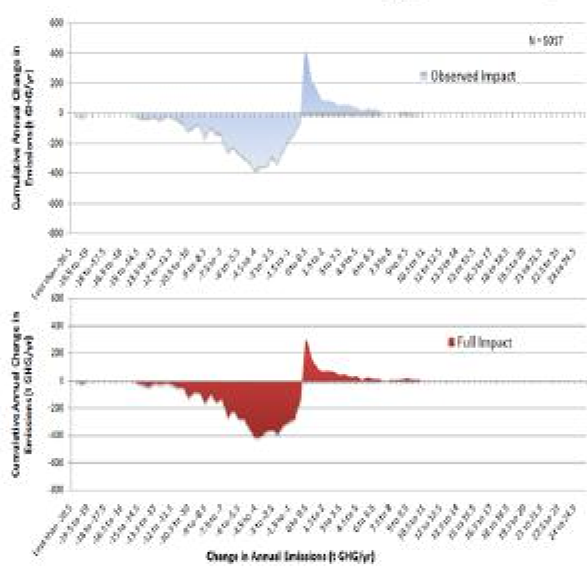
Baseline Analysis (a) [N = 6821]



All Movers Included (b) [N = 7853]



All Movers Extracted (c) [N = 5017]



Impact Summart (d)

Analytical Category	Observed Impact	Full Impact	N
Baseline Analysis	-0.58	-0.84	6281
All Movers Included	-0.59	-0.81	7853
All Movers Extracted	-0.62	-0.87	5017

Figure 19 Sensitivity of Profile of Cumulative Annual Change in GHG Emissions to the Activation of the Move Filter

The move of a respondent's home or work can either increase or decrease personal mileage independent of carsharing. For this reason, indiscriminately including movers presents an analytical challenge because many people in urban environments move jobs and homes quite regularly. Carsharing does have an impact on people that move, but discerning the relative magnitude of how a move impacted mileage versus carsharing for any household is a complicated analytical task requiring a considerable array of information. In this survey alone, nearly 3,000 people moved in some way, constituting roughly a third of all completed surveys. The follow-up question that asked respondents whether the move or carsharing was a greater contributor to any changes in mileage driven, was instituted to preserve some of this sample, which was anticipated to be large. As a result, 1,200 respondents were preserved in the final dataset. Ultimately, this collection of movers yielded the least favorable average observed impact and the second least favorable full impact among the three options.

This sensitivity analysis shows that those removed as a result of the move filter did not exhibit changes in emissions that were systematically skewed in any way. In a sense, this is a useful result, in that conclusions with respect to the magnitude of the observed and full impact do not rest on a specific treatment of moving individuals when the sample is large. When movers are universally included, the spread of impacts do increase as is evident by the increased mass on the edges of the distribution of Figure 19's subfigure *b*. But this collection of respondents was found to increase and decrease their emissions in a fashion that was generally consistent with the patterns of the core data. Future studies should continue to evaluate the presence of a respondent move when evaluating carsharing regardless of the directional change the move exhibits on travel emissions, as it would be inaccurate to ascribe such a change due to carsharing.

Including College Students, Business Respondents, and Inactives

A similar analysis illustrates the effect of including student and business respondents. Overall, the inclusion of these groups within this dataset does not influence the data in a way that departs significantly from the baseline result. These populations introduce additional variance into the result, but this variance does not disturb the core shape of impacts. Figure 20 illustrates the cumulative profile of emissions change, if all filters are not activated. The result is the familiar shape but with an increased spread on the tails of each distribution.

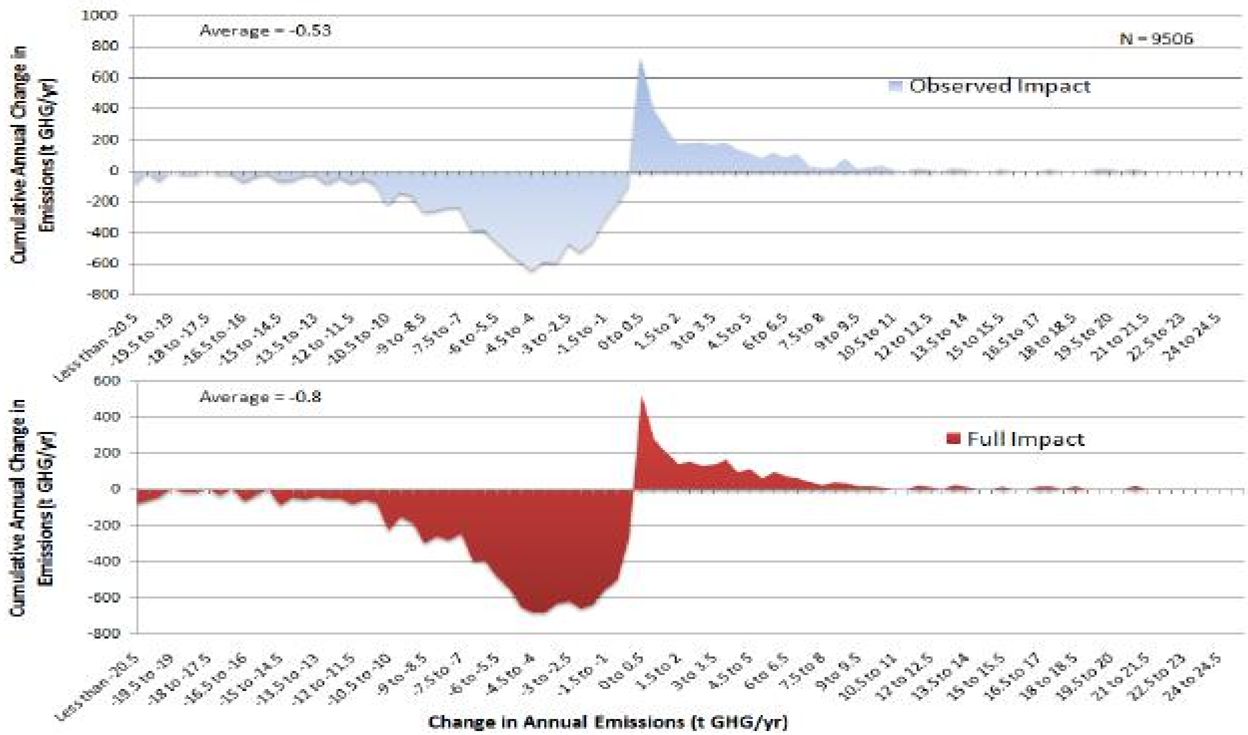


Figure 20 Cumulative Annual GHG Emissions Change with No Filters Active

The average observed and full impact are indicated in the upper left hand corner of each graph. Both averages are statistically significant with confidence intervals of (-0.59, -0.46) for the observed impact and (-0.86, -0.73) for the full impact. The respondents (N = 9,506) included in Figure 20 include all respondents except those completed surveys that were duplicates or gave responses that did not render calculations possible. This amounts to 98% of the completed survey sample. This sample is shown to illustrate that the filtering described previously does not alter the baseline result significantly. But it clearly alters the spread of impacts, as greater quantities of respondents are exhibiting large reductions and emissions increases. This spread is indicative that within this included population, considerable influences other than carsharing are playing a role in their emissions change, which was the cause for their initial exclusion. However, it is important to recognize that that the overall distribution and share of this cohort does not alter the core result that members of carsharing organizations are lowering their emissions.

Membership Duration and Carsharing Impacts

As explained in the methodology, the survey implemented in this study offers a static before-and-after snapshot of the respondent household emissions. Respondents were asked to characterize their annual travel “currently,” at the time of the survey, so as to avoid respondents self-assessing the time frame of their annual travel “after” joining carsharing. Some respondents could have interpreted such language as pertaining to “immediately after,” where as others might choose a more contemporaneous time frame. By asking for current travel, the moment of assessment is normalized across respondents, while the tenure of membership of the respondent in the organization varies. Each respondent was asked the month and year in which they joined carsharing, and thus the tenure of membership of each respondent was known. These data allowed the authors to evaluate the impacts by membership duration to draw insight as to the persistence of carsharing impacts among the sample. Previous work has explored this issue in a different way. Cervero et al. (2007) evaluated carsharing impacts on the travel of City Carshare members through a longitudinal study and found that most impacts on travel occurred a short time after a person joined and then persisted over time.[36] To explore this issue within the capabilities of these data, we evaluate carsharing impacts over time through a cross-sectional analysis defined by the membership duration of respondents. That is, respondents are divided into subsamples as defined by their time as members of their organizations, and the impacts are evaluated in the context of these subsamples. Figure 21 presents two graphs that show the cross-section of computed impacts by the respondent's time as a member of the organization. The scatter plot shows the average within each subsample as well as the 99% confidence interval about the average. At the top of the graph is the sample size within each six-month bin. The sum of the subsamples is less than the total sample of 6,281 because 17 people did not provide the date at which they joined the organization but still completed the survey.

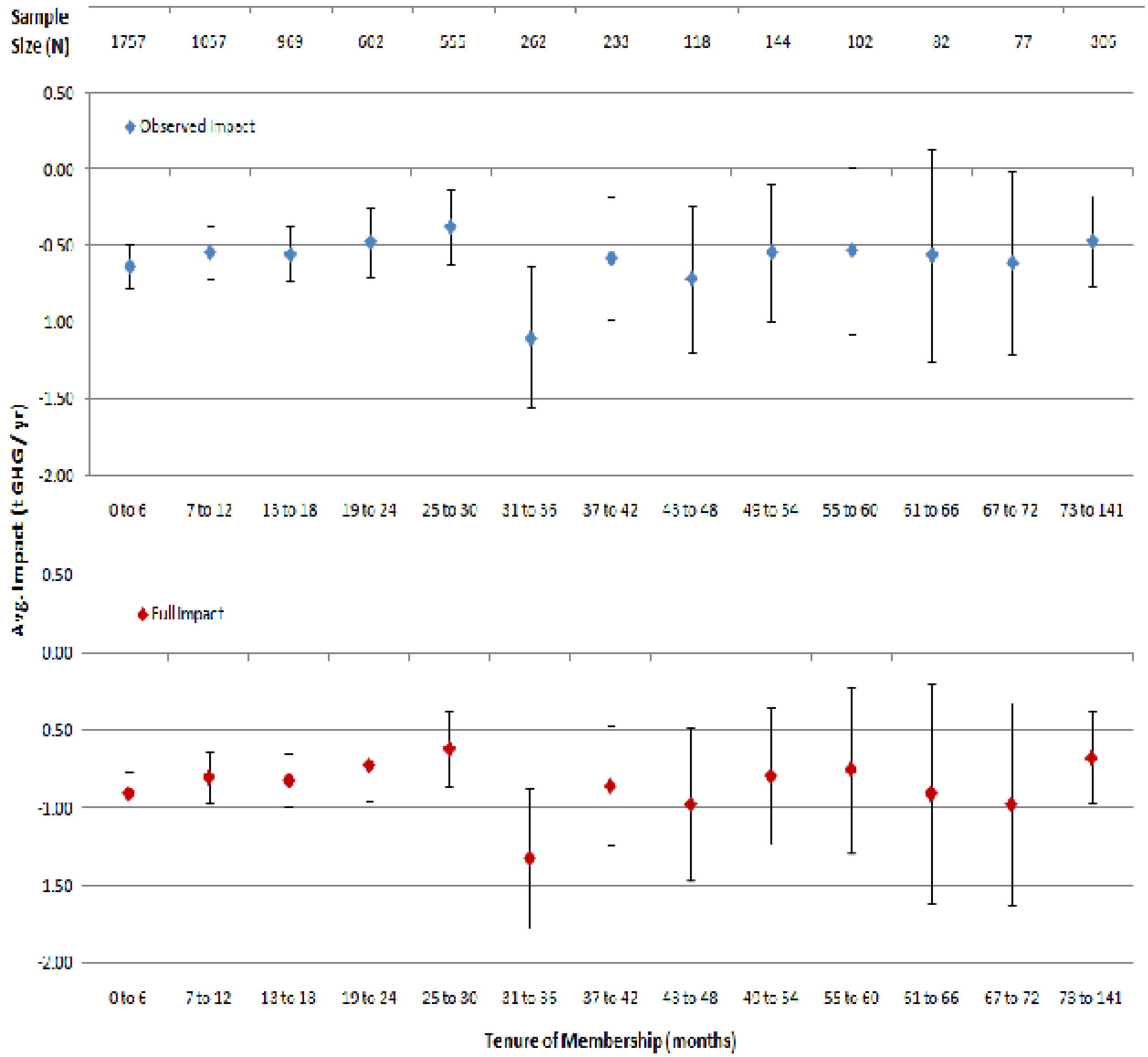


Figure 21 Analysis of Impact by Membership Duration

The subsample numbers at the top illustrate a distribution of the respondents by membership duration. The distribution shows that a majority of respondents to the survey were members of their organization for two years or less. This result is in part expected because the carsharing has grown rapidly in recent years. Thus, the true distribution of the population by membership duration is also weighted toward the years immediately prior to the survey. In addition, there is a natural attrition that occurs with long-term members, as the number of members that joined in any given year can only go down once that year passes. Because the number of enduring members that joined carsharing in 2002 and earlier is small, they are grouped into a one category spanning roughly six years at the right of the figure.

The figure shows that the average of both the observed and full impact is rather stable across the distinct subsamples. The horizontal axis shows the range of months that define the duration of membership for respondents in each subsample. Within each bin, the average observed impact mainly remains within a range of -0.50 to -0.75 t GHG/yr, regardless of the membership duration. Most of these subsamples yield averages that are also statistically significant. The full impact subsamples are always statistically different from zero, while two subsamples of the observed impact are not. These two subsamples contain averages that are in line with the other subsamples, but their confidence intervals expand due to the falling sample size as indicated at the top of the figure. Overall, Figure 21 suggests a stability in the impact of carsharing membership overtime. That is, members that joined six years prior to the survey exhibit a similar average impact to those that joined within a year of the survey. Based on this cross-sectional analysis, once members adapt to the carsharing lifestyle, the reduced emissions that result from this adaptation appear on average to occur year after year while they are members.

CARSHARING IMPACTS BY URBAN DENSITY

The density of an urban environment is highly correlated with the level of service that residents can receive from transportation alternatives to the private vehicle. Public transit services and pedestrian infrastructure are abundant in cities with modest to high density and become sparser with decreasing urban density. Carsharing and urban density interact within a unique multi-objective relationship. Carsharing economically thrives in urban environments in which car ownership is relatively expensive and driving readily competes with public transit and non-motorized daily transportation modes.

While carsharing is most likely to thrive within urban environments in which its services are in high demand, carsharing impacts are potentially greater in low-density urban environments where car ownership is more widespread and annual driving distances are longer. While carsharing has generally risen to prominence within North America’s most cosmopolitan cities, notable opportunities for reducing GHG emissions may exist through the expansion into surrounding suburbs and lower density cities.

Data from the survey can provide a glimpse into how emission impacts correlate with urban density. Respondents provided their home zip code and postal codes as part of their demographic profile. Data on the zip code population density within the U.S. were linked to each respondent. Figure 22 illustrates the average carsharing impact by zip code population density for the observed impact.

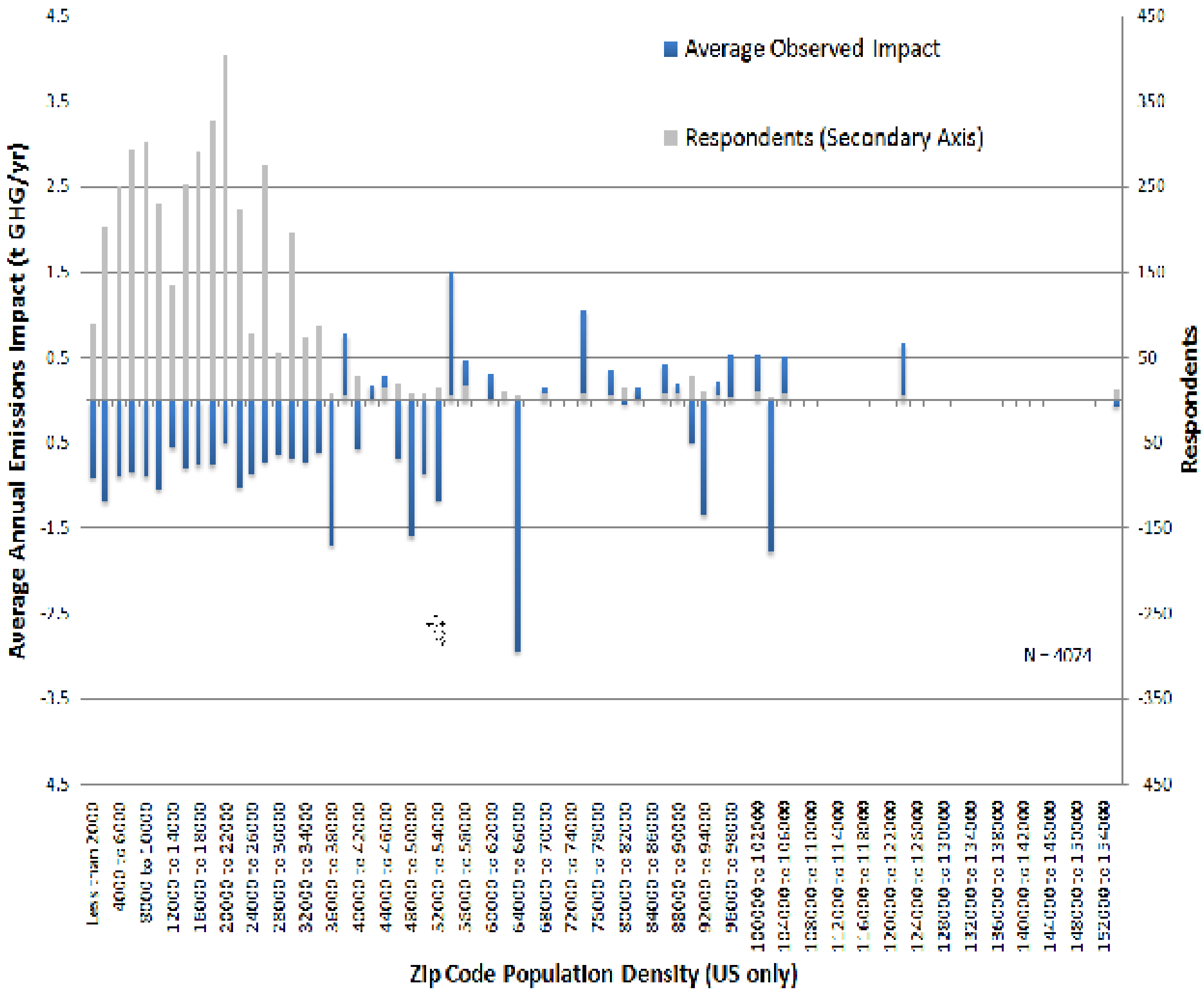


Figure 22 Average Observed Impact by Urban Density (U.S. only)

The data applied in Figure 22 constitutes only American respondents due to data availability. Figure 22 contains two vertical axes to illustrate the trends exhibited by urban density. The left axis describes the average respondent impact within a particular bin of zip code population density. The data show that the average impact is universally negative for densities less than 38,000 people per square mile. As densities increase, the average emission impact becomes more varied. One reason for the increased variance is the smaller sample size within each bin, which is plotted on the secondary axis. The other reason may reflect that higher densities typically constitute regions with lower vehicle ownership and lower driving, meaning that people joining carsharing in higher densities are more likely to increase emissions.

To further illustrate the relationship between density and carsharing impacts, Figure 23 presents a scatter plot of the observed respondent impact and the population density of the zip code in which the respondent resides.

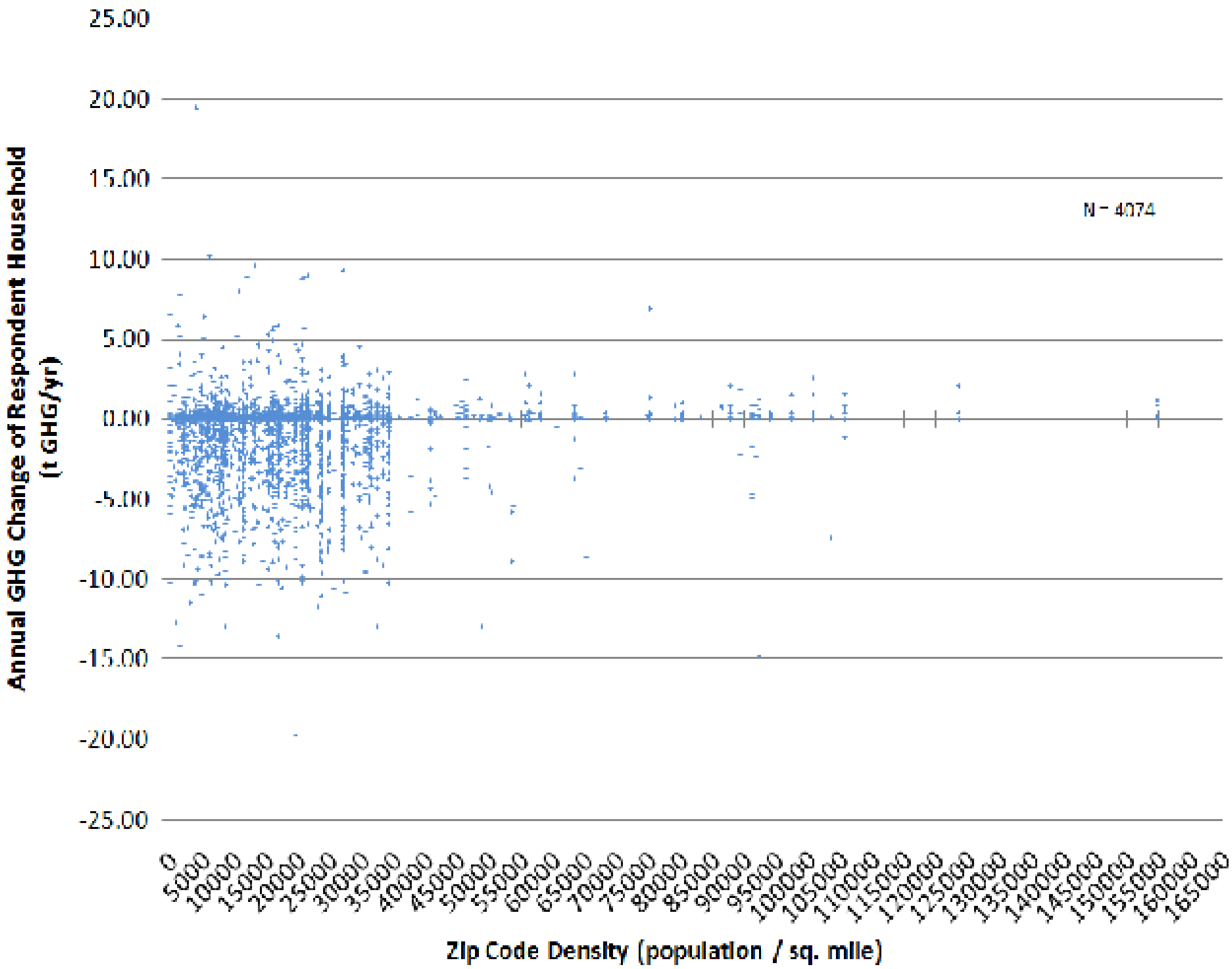


Figure 23 Scatter Plot of Observed Impacts by Urban Density (U.S. only)

The scatter plot more clearly illustrates the variance in responses by urban density. As density increases, the spread of respondents reducing their emissions begins to narrow. Neither figure provides evidence to suggest that carsharing universally increases emissions at higher urban densities. But both Figure 22 and Figure 23 do leave open the possibility that carsharing within ultra-high density cities may not be as effective in reducing emissions as it is in mid-to-lower density cities. The evidence is mixed and limited in scope by the reduced sample size of respondents in higher density areas. What remains clear from the two figures is that carsharing appears to be effective in lowering emissions for urban densities that are smaller than 38,000 people per square mile. At greater densities, the share of the population increasing their emissions rises for many of the urban density bins. While Figure 22 shows a negative average effect at some of the high-density regions, Figure 23 suggests that increased variability may also exist within regions. It is important to keep in mind some of caveats in generating conclusions from Figures 22 and 23. First, the densities described here are localized by zip code, so comparing these densities with an aggregate urban density of a metropolitan region should not be done to draw conclusions. Second, the effectiveness of carsharing in reducing emissions in low-density environments does not translate into economic effectiveness, as carsharing organizations face additional challenges in remaining competitive as an urban environment becomes more auto-oriented.

Third, these data are generated from the empirical experience of carsharing so far, which has traditionally entered urban environments that have good public transit and pedestrian infrastructure, even if the nominal population density is low. There is likely a difference between the carsharing impacts and effectiveness of two regions with similar densities but distinguishable differences in public transit and pedestrian infrastructure quality. Good quality public transit and pedestrian infrastructure have been essential supporting components of carsharing in achieving environmental and economic objectives.

IMPACTS BY ORGANIZATION TYPE AND COUNTRY

The growth of carsharing within North America has occurred primarily under two organizational regimes. Both for-profit and non-profit organizations have grown to achieve sizable membership rosters within their respective markets. As of 2009, non-profit organizations (which include cooperatives in this tally) had more than 50,000 members throughout North America. For-profit organizations hold more than 325,000 members across North America.[37] Because of the distinct business models pursued by the different organization types, a comparative analysis was done to evaluate the degree to which impacts differ by organization type. Tables 10 and 11 illustrate a summary of the average observed and full impacts of respondents by organization type and country.

Table 10 Average Observed Impact by Organization Type and Country

Observed Impact		United States	Canada	Total
Nonprofit	*Mean*	-0.84	-0.54	-0.82
	Confidence Interval	(-0.96, -0.72)	(-0.9, -0.19)	(-0.93, -0.7)
	N	2458	209	2667
Profit	*Mean*	-0.62	-0.18	-0.40
	Confidence Interval	(-0.77, -0.48)	(-0.29, -0.07)	(-0.49, -0.31)
	N	1788	1826	3614
Total	*Mean*	-0.75	-0.22	-0.58
	Confidence Interval	(-0.84, -0.65)	(-0.32, -0.11)	(-0.65, -0.5)
	N	4246	2035	6281

Table 11 Average Full Impact by Organization Type and Country

Full Impact		United States	Canada	Total
Nonprofit	*Mean*	-1.07	-0.73	-1.04
	Confidence Interval	(-1.19, -0.95)	(-1.07, -0.38)	(-1.16, -0.93)
	N	2458	209	2667
Profit	*Mean*	-0.88	-0.49	-0.68
	Confidence Interval	(-1.03, -0.74)	(-0.6, -0.37)	(-0.77, -0.59)
	N	1788	1826	3614
Total	*Mean*	-0.99	-0.51	-0.84
	Confidence Interval	(-1.08, -0.9)	(-0.62, -0.4)	(-0.91, -0.76)
	N	4246	2035	6281

Both Table 10 and Table 11 illustrate the average impacts for distinct members by organization type and by country. The 99% confidence intervals for each average are given immediately below within parentheses, and the sample size for each subpopulation is provided immediately below that.

The most important result exhibited by Table 10 and Table 11 is that all carsharing organizations, when considered in the subgroups defined above, exhibit statistically significant reductions in annual GHG emissions among members. This result is most apparent in the observed impact presented in Table 10. Since none of the 99% confidence intervals overlap zero, all of the means are statistically significant with p-values lower than .005. Across countries, the average reduction in the U.S. appears to be larger than that of Canada. This difference is evident within both for-profit and non-profit organizations. A likely explanation for the difference between the two countries may be rooted in the distinct driving distances of Americans and Canadians. Based on the data collected in this study, Americans joining carsharing drove on average about 1,000 miles more per year than Canadians. Thus, based on this simple analysis, Americans in general have more emissions to eliminate by joining carsharing.

Table 10 also shows that there are some striking differences between the organizations of different types within each country. In both the U.S. and Canada, non-profits empirically exhibit a greater average reduction in GHG benefits than for-profit organizations. While all organization types in all countries are reducing emissions, non-profit organizations appear to be yielding greater benefits on average. The difference between the mean impacts of profits and non-profits is statistically significant in the U.S. and just barely insignificant in Canada.

Table 12 Mean Comparison t-Test of Non-Profit and Profit Organizations Observed Impacts in North America

	t-test for Equality of Means								
	N	Mean	Mean Difference	Std. Error Mean	99% Confidence Interval of the Difference		t	df	Sig. (2-tailed)
					Lower	Upper			
American Nonprofit	2458	-.84	-.22	.07	-.41	-.03	-2.97	4244	.003
American Profit	1788	-.62							
	N	Mean	Mean Difference	Std. Error Mean	99% Confidence Interval of the Difference		t	df	Sig. (2-tailed)
					Lower	Upper			
Canadian Nonprofit	209	-.54	-.37	.14	-.74	.01	-2.56	253.71	.011
Canadian Profit	1826	-.18							

Although the confidence intervals of some means overlap, the probability that the means are different is a function of the joint probability that the true means are at the extreme ends of the distribution defined by the confidence intervals. The t-tests presented in Table 12 show that the difference between the average impacts of profit and non-profit organizations is just barely statistically significant at the 99% level. For Canada, the differences between the two organization types are not significant at the 99% level, but they are significant at the 95% level. The trends and results are essentially the same for the full impact.

Additional insights into the dynamics driving differences between the organization types are evident with an examination of the cumulative emission profile of each organization. Figure 24 illustrates the profile of cumulative emissions for each organization using the same calculation method and set of axes as presented in Figure 9.

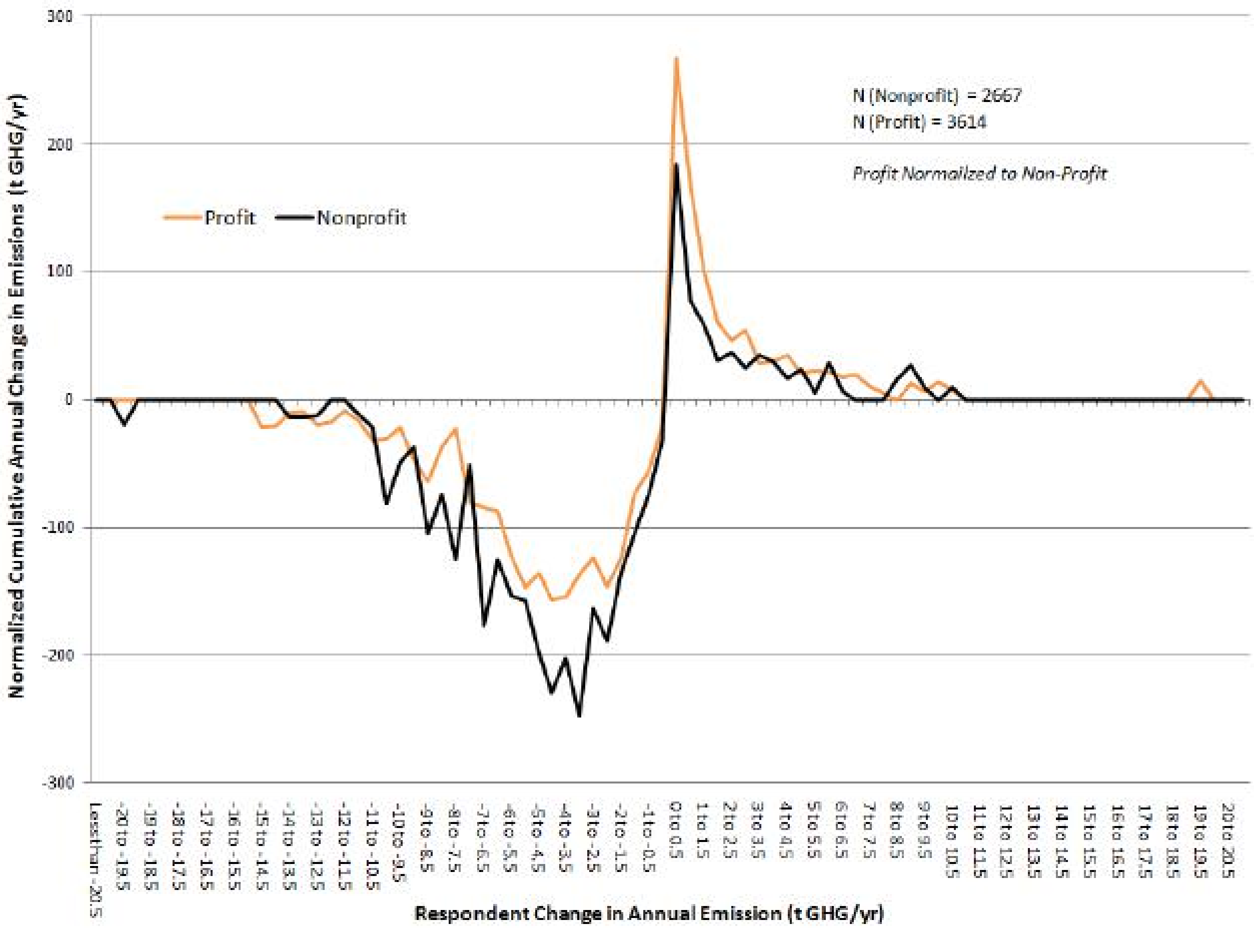


Figure 24 Profile Cumulative Annual Change in GHG Emissions by Respondent by Organization Type (Observed Impact)

The cumulative emissions of respondents of for-profit organizations are normalized to the counts of nonprofit respondents, controlling for the unequal sample sizes. The comparative profiles speak to general trends that drive the difference. The for-profit organizations have comparatively more members increasing their emissions than do the non-profit organizations. In addition, for-profit members reducing their emissions are not generating cumulative reductions as large as the non-profit organizations. The numbers behind these trends are driven in part by a slightly higher share of carless households joining for-profit organizations and slightly higher average driving distances in carsharing vehicles among for-profit carsharing members.

While the data from this survey indicate a distinction in the average impact between profit and non-profit members, there are many possible explanations for the cause. The organizations mainly operate in separate cities, and the markets covered by for-profit operators were generally distinct from the markets surveyed by non-profit operators. Thus, the absence of a direct comparison within the joint cities of operation leaves the cause and magnitude of the difference between the organization types as an open question. Both for-profit and non-profit organizations have membership plans with low fixed costs, but the different rate structures among the organizations offer another potential cause for the distinct effects. The resulting difference in impacts between the organization types is a subject that deserves further exploration. It is not certain that such differences will persist over time. The industry is still in a state of evolution, and the distinct impacts could be a function of a variety of factors that are relevant for this empirical exploration but less relevant in the future.

Even if the difference of emissions impact persists over time, it is uncertain as to whether the results are a reflection of the plans offered by the respective organizations. That is, for-profit organizations may attract a certain type of user that otherwise may not use carsharing. Furthermore, while the average impact of the non-profits is higher, the aggregate impact of for-profit organizations likely outweighs those of non-profits by virtue of membership size. For-profit organizations have been able to expand rapidly and bring carsharing into regions that might not otherwise have well developed carsharing organizations. Overall, the data from this study support that both non-profit and for-profit organizations are reducing emissions, and that non-profit organizations are currently yielding greater reductions in emissions than for-profit organizations on a per member basis. The reasons for this apparent discrepancy remain an open question.

IMPACTS ON VEHICLE HOLDINGS

A reduction in vehicle ownership is one of the more universal results that have been found of previous research on carsharing. As this study focuses on GHG emissions from travel, no GHG factors are ascribed to vehicles shed from carsharing members. Isolating appropriate factors in such accounting is worthy of its own exploration and is outside the scope of this study. But it is important to recognize that vehicle shedding by respondent households is the driving force that is leading to the significant GHG reductions illustrated in the previous sections. Households are reducing their emissions by shedding vehicles that were driven longer distances and relying on carsharing vehicles for a smaller portion of overall travel. For this reason, it is relevant to illustrate the degree which vehicle holdings changed within the final dataset.

The results show that carsharing lowers the total number of vehicles held by members, and this shift is substantial. When changing vehicle holdings, there are four possible actions that a household can take: the household can shed, add, retain, or replace a vehicle. Vehicle replacement involves the shedding and adding of a vehicle within the same household. For instance, in a household that sheds two vehicles and adds one, the added vehicle is counted as a replacement. Similarly, in a household that sheds one vehicle and adds two, one of the added vehicles is a replacement, and the other is an added vehicle. Figure 25 below illustrates the breakdown of the change in vehicle holdings across these four categories, as well as a t-test on the paired sample mean. In addition, a bootstrap simulation of both “before” and “after” means is presented.

Vehicle Change Category	Number of Cars in the Household						Total
	Zero	One	Two	Three	Four	Five or more	
Vehicles Shed	0	1437	486	70	37	16	2046
Vehicles Retained	0	480	340	68	15	19	922
Vehicles Added	219	21	5	1	0	0	246
Vehicles Replaced	0	187	122	19	10	1	339
Net Change (Added+Replaced-Shed)	219	-1229	-359	-50	-27	-15	-1461

Paired Test Variables	Paired Differences t-test							
	Mean	Std. Deviation	Std. Error Mean	99% Confidence Interval of the Difference		t	df	Sig. (2-tailed)
				Lower	Upper			
Vehicles After - Vehicles Before	-0.233	0.559	0.007	-0.251	-0.214	-32.955	6280	0.00

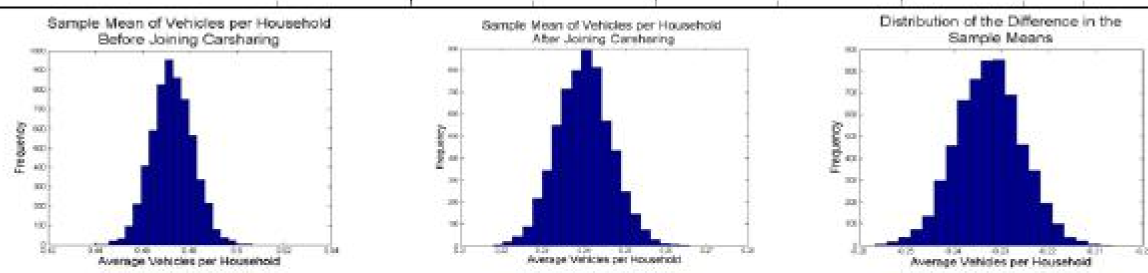


Figure 25 Profile and Statistical Evaluation of the Change in Vehicle Holdings

The columns show the action taken by households that held the stated number of vehicles "before" joining carsharing. Vehicles retained impose no change in the overall vehicle count. The total number of vehicles held by households "before" joining carsharing is the sum of those shed and retained (2,968). This number amounts to just under one vehicle for every two households and reflects that many households that join carsharing are carless. The net change in vehicles is the sum of vehicles added and vehicles replaced (as they are distinct) minus the total number of vehicles shed. This net change across the sample is a reduction of 1,461, resulting in a sample vehicle count "after" joining carsharing of 1,507. Thus, the sample dropped the total number of vehicles by almost 50%. By virtue of its magnitude and the large sample size, this drop is statistically significant ($p<0.01$). The average vehicles per household "before" carsharing is 0.47, and the average vehicles per household "after" carsharing is 0.24. The Canadian average "before" carsharing is 0.31 vehicles per household and 0.13 vehicles per household "after." The U.S. average "before" carsharing is 0.55 vehicles per household and 0.29 vehicles per household "after." Both of these changes are also statistically significant.

A fair number of the households that changed their vehicle holdings owned more than one vehicle. In addition, some households increased their vehicle holdings, while others shed only some of their vehicles. Table 13 below presents a cross-tabulation of household vehicle holdings "before" and "after" joining carsharing and shows how households within the sample transitioned to new vehicle holding states.

Table 13 Transition of Household Vehicle Holding States Among Carsharing Households

Before Joining \ After Joining	Zero	One	Two	Three	Four	Five or more	Total
Zero	3685	182	14	3	0	0	3885 (62%)
One	1250	646	21	0	0	0	1917 (31%)
Two	68	228	112	5	0	0	413 (7%)
Three	7	11	8	19	1	0	46 (1%)
Four	3	2	3	3	2	0	13 (0%)
Five or more	2	1	0	0	1	3	7 (0%)
Total	5016 (80%)	1070 (17%)	158 (3%)	30 (0%)	4 (0%)	3 (0%)	6281

The total column at the far right of Table 13 shows the distribution of households by vehicle holdings "before" joining carsharing. That is, 62% of households joining carsharing owned no vehicle when they joined, while 31% of households owned one vehicle. The bottom row total shows the distribution of households by vehicle holdings "after" joining carsharing. The shift toward carless households is substantial, as they comprise 80% of the "after" sample. Most of this shift is comprised of one-car households becoming carless households. The second largest shift in holdings involves two-car households transitioning into one-car households 4% (n=228). This is followed by two-car households transitioning into carless households 1% (n=68). The diagonal shows households that did not change the number of vehicles owned. Given the large change in vehicles discussed earlier, a paradoxical but accurate observation is that a majority of carsharing households do not change their vehicle holdings. However, this is only true when including carless households, which have no vehicles to shed. Only 12% (n=782) of households that had a vehicle "before" carsharing maintained the same vehicle stock.

Characteristics of Vehicles Added and Shed

The vehicle change illustrates carsharing's impact on aggregate vehicle counts of the sample; however, the vehicle characteristics are not revealed. This section reports on the distribution of key attributes including fuel economy, vehicle age, and miles/kilometers driven on vehicles shed. Figure 26 below presents three graphs that outline fuel economy distributions. Two of these graphs show the fuel economy distribution of vehicles shed and added by carsharing households. The third graph shows the fuel economy distribution of the carsharing vehicles that respondents indicated that they used most often.

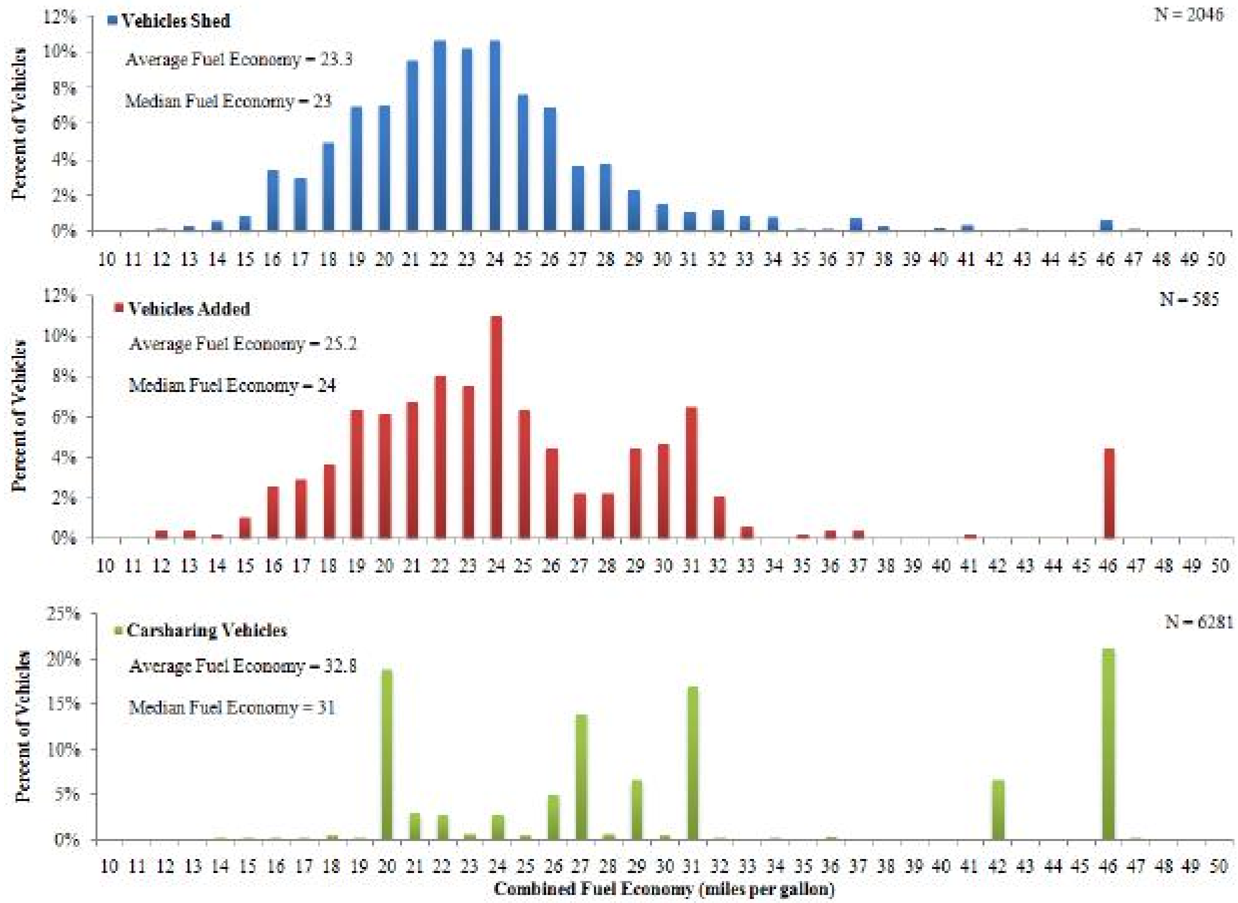


Figure 26 Fuel Economy Distribution of Household Vehicles Shed/Added and Carsharing Vehicles Driven

Figure 26 shows several interesting qualities of the distributions of vehicle fuel economy. For vehicles shed, it is approximately normal with a mean of 23.3 mpg (10.2 L/100km). The distribution of vehicles added (which includes replacement vehicles) is characteristic of concatenated normal distributions with two separate means. The overall mean is 25.2 mpg (9.4 L/km), and the median is 24 mpg (9.9 L/100km). The smaller bell shape to the right indicates a fair share of respondents adding vehicles with a fuel economy of about 30 mpg (7.9 L/100km). Still further to the right is a spike of vehicles at 46 mpg (5.1 L/100km), and this represents acquisitions of the second-generation Toyota Prius. A comparison of these two distributions shows that the autos added are slightly more efficient on average, but there is still a fair share of low fuel economy vehicles added by households. The distribution of carsharing vehicle fuel economy looks very different in shape from the other two. To start, the scales of the percents are different, as three fuel economy values represent nearly 60% of the distribution. Many carsharing organizations offer a diversity of vehicles to members, but the vast majority are highly efficient hybrids, sedans and compact cars. The average fuel economy of carsharing vehicles is 32.8 mpg (7.2 L/100km) with a median of 31 mpg (7.6 L/100km). Hence, the average carsharing vehicle used by the sample overall (U.S. and Canada) is a full 10 mpg (3 L/100km) more efficient than the average vehicle shed by members.

Age and Miles Driven on Vehicles Shed

The data from the survey also allows for an analysis of the miles/kilometers driven on shed vehicles. When considering passenger cars, the average VMT/VKT in 2007 is about 12,300 miles/19,800 kilometers per year in the U.S.[38] In Canada, the average driving distance is about 8,800 miles/14,200 kilometers per year.[39] The vehicles that are removed from the road due to carsharing are typically driven less than average, but some are driven more. The analysis reveals that nearly 75% of all vehicles shed are driven less than 10,000 miles/16,000 kilometers per year. More than 90% of all vehicles shed are driven less than 15,000 miles/24,000 kilometers per year. The average annual distance driven on a vehicle that is shed by a carsharing household is 8,064/13,000 kilometers miles per year, and the median is close to 7,000 miles/11,300 kilometers per year. The average miles driven for vehicles shed by U.S. carsharing members is 8,200 miles/13,200 kilometers per year, and for Canadian vehicles shed the average is 7,700 miles/12,300 kilometers per year. These averages and distributional parameters are consistent with the assumption that carsharing primarily targets lower mileage vehicles. But, it also suggests that carsharing can facilitate some households to give up vehicles that are driven distances that are well above average. The age of shed vehicles is another important factor that influences carsharing's impact on the overall vehicle fleet. Figure 27 below shows the distribution of the production year of vehicles shed by carsharing households.

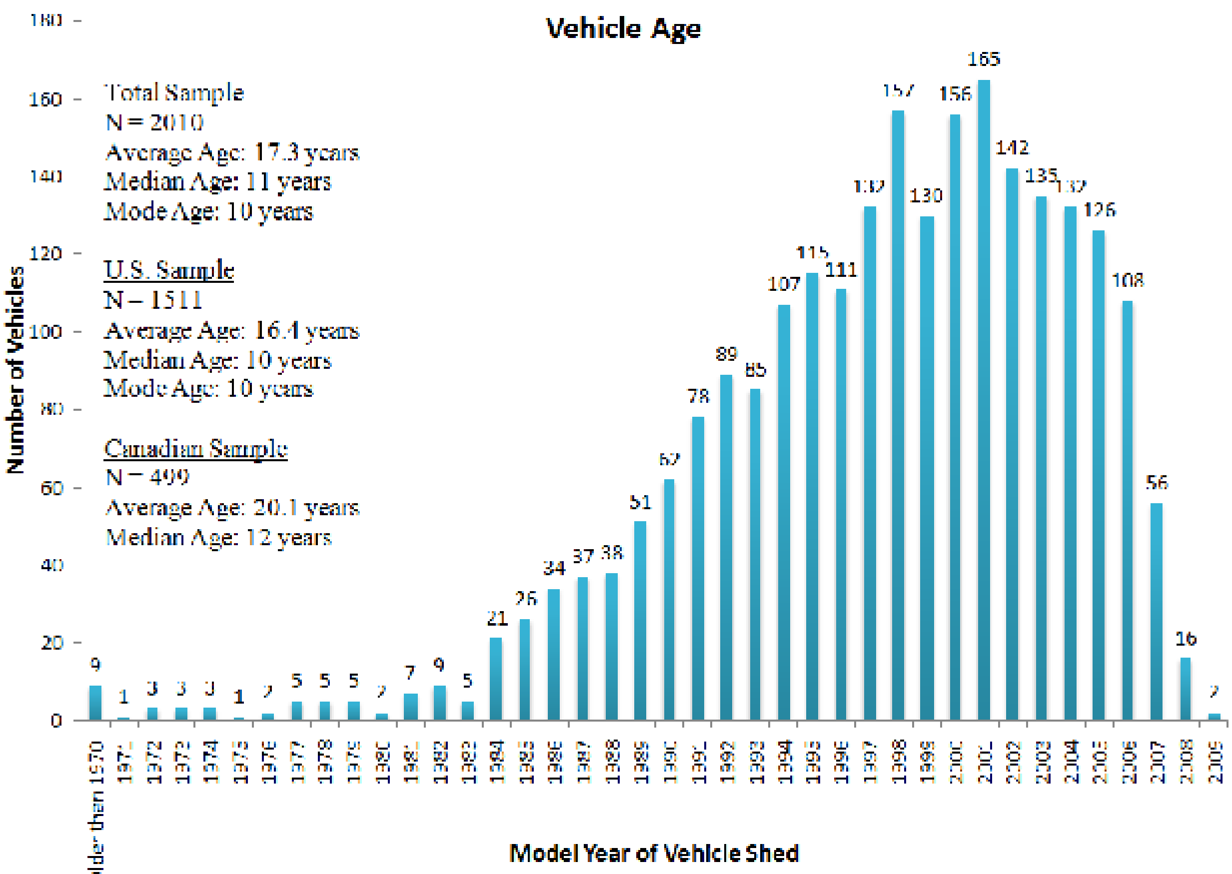


Figure 27 Distribution of Vehicles Shed by Model Year (Vehicle Age)

The shape of the distribution is negatively skewed with the mode at the 1998 model year. Thus, the mode and the median age of the vehicles are 10 and 11 years old, respectively. The average vehicle age is closer to 17 years as a result of the long tail extending back toward very old shed vehicles. In considering the differences between Canada and the U.S., Canadian cars shed were slightly older. Given the unique shape of the distribution, the median age in both cases is more representative of the typical car shed than the average. The sample size of 2,010 is smaller than the total number of vehicles shed because some respondents provided incomplete vehicle information. The distribution shows that the overwhelming majority of vehicles lie between the years of 1984 and 2008, which bounds a normal-shaped distribution. A fair number of the vehicles shed (41%) are younger than ten years old. The range of years within the normal-shaped distribution is well within the typical vehicle lifespan.

THE AGGREGATE IMPACTS OF CARSHARING

The analysis thus far has shown that members of carsharing have reduced their emissions from driving and reduced their vehicle holdings to a degree that is statistically significant. However, until now, the results have presented these impacts in the context of emissions per household or vehicles shed per household. No information thus far has been presented to translate these impacts to the aggregate carsharing industry. To gain insight into this issue, several assumptions must be made.

While the sample of carsharing households is random among active members, several cohorts were excluded from the sample, including college students and business/governmental fleet users that do not use vehicles for non-work trips. The share of these cohorts within the sample is 6% and 2%, respectively. Their exclusion does not imply a zero impact, but the survey design was not appropriate for the analysis of these cohorts. Nevertheless, the sample of these shares within the population is random and thus is applied as an approximation of the population share. However, another cohort that was excluded from the analysis was inactive members. Inactive members constituted a share of approximately 8% of the complete sample. Unfortunately, this share is likely subject to a non-response bias (i.e., inactive carsharing members are less likely to take the survey than active members). Thus, the sample share of 8% is considered closer to a lower bound. In this study, the authors consider inactive members to have a zero impact because they carry on their travel lifestyles irrespective of their carsharing membership. However, it would be a mistake to scale the results of any carsharing sample to an industry level without acknowledging that a share of the industry does not use the service. The uncertainty of the inactive member share, however, can be addressed by illustrating a range of population proportions through a sensitivity analysis. This analysis is done for both aggregate emissions and aggregate vehicles shed.

Aggregate Emissions Impact of Carsharing

To compute the aggregate emission impact, we apply the average emission impact calculated in this report to the aggregate member population in the carsharing industry. The result is a range of annual emission reductions that are derived from the activities of the industry. As of mid-2009, the carsharing industry had 378,000 members within North America.

However, as this population includes college members, business users and inactive members, the active member population using the neighborhood model is smaller. To scale the population to the number of active members, the population total is reduced by the 6% of college members and 2% of strictly business members (a total of 8%) down to 347,390 members using the neighborhood carsharing model. In addition, some households contain more than one member. As discussed earlier, the unit of analysis in this study is the respondent household, and questions were inserted to remove duplicate respondents from different members within the same households. In the search for duplicate responses, the survey asked questions about joint membership. The survey found that 81% of the 6,281 respondents were the sole carsharing members within the household. The remaining 19% of respondents were members living in households with someone else who was also a carsharing member. The share of respondents with more than two members per household was negligible. This membership balance implies that about 19% of the population has two carsharing members within one household. Thus, translating the 347,390 carsharing members to carsharing households is computed as (347390 (.81) + 347390 (.19)/2), which roughly equals 314,390 households using carsharing.

The final adjustment to this aggregate number involves the share of households that contain inactive members. This adjustment requires a range of ratios rather than a set ratio because it is possible that the share of inactive members is subject to a downward sampling bias in the survey. From the sample collected in this study, the share of inactive members is found to be at least 8%, but it is likely higher across the industry. Thus, the sensitivity analysis of aggregate impacts provides a range of inactive member proportions across the industry. Once the inactive members are removed from the aggregate household population, the average impact factors can be applied to determine an estimate of the aggregate annual impact of carsharing. Table 14 illustrates the results of this sensitivity analysis on the aggregate impacts of carsharing.

Table 14 Sensitivity of Aggregate Carsharing Emissions Impacts

Inactive Share	Active Carsharing Household Population	Observed Impact Total Annual Emissions (t GHG / yr)	Full Impact Total Annual Emissions (t GHG / yr)
0%	314,390	-182,000	-264,000
5%	298,671	-173,000	-251,000
10%	282,951	-164,000	-238,000
15%	267,232	-155,000	-224,000
20%	251,512	-146,000	-211,000
25%	235,793	-137,000	-198,000
30%	220,073	-128,000	-185,000
35%	204,354	-119,000	-172,000
40%	188,634	-109,000	-158,000
45%	172,915	-100,000	-145,000
50%	157,195	-91,000	-132,000

Table 14 shows a range of annual impacts that result from carsharing. The results vary depending on the proportion of households that actively use carsharing. The true share is not known. Based on the authors' knowledge of the current industry, the proportion of inactive members may fall within a generous range of 15% to 40% of total industry membership. But this range could change over time depending on the balance of membership plans within the industry. Plans that have very low or no fixed costs could increase the share of inactive members. In addition, individual organizations may have proportions that are outside this range. Table 15 shows estimates for both the observed and full annual emissions impact. Based on the observed impact, carsharing reduces between 110,000 to 155,000 metric tons of GHGs per year, when strictly evaluating observable emission changes. When considering the full impact, carsharing prevents between 160,000 to 225,000 metric tons of GHG emissions per year. The authors consider the full impact to be more representative of the true impact of carsharing because it includes emissions that would have occurred in the absence of carsharing as well as emissions that were reduced.

Aggregate Vehicle Holding Impact of Carsharing

As of mid-2009, carsharing organizations had deployed 9,818 vehicles throughout their networks in North America. As shown earlier, 1,461 vehicles were shed across 6,281 households. We can apply a similar methodology as defined above using the ratio 1,461:6,281 (.23) as the number of vehicles shed per household within the sample. However, the population is adjusted in the same manner as with the aggregate emission calculation. We consider an adjusted population of 314,000 households using carsharing in North America. The analysis here presents vehicles shed per carsharing vehicle as well as an estimate of vehicles avoided due to carsharing. The vehicles avoided are derived in the same manner as the avoided emissions from the full impact. Respondents that indicated that they maybe, probably, or definitely would buy a car in the absence of carsharing were considered, and this amounted to roughly 25% of the total sample. Only the responses of households that did not shed a vehicle were considered for this estimate (due to double counting otherwise). As before, inactive households introduce the same spectrum of uncertainty into the active carsharing population.

Table 15 illustrates a similar analysis as presented in Table 14. Alongside the estimate of the active household population, Table 15 includes an estimate of the vehicles shed per carsharing vehicle. In addition, the vehicles avoided, which are the vehicles that could have been acquired in the absence of carsharing are presented in the fifth column. Finally, the far right column considers both vehicles shed and avoided to calculate the total number of vehicles removed per carsharing vehicle.

Table 15 Sensitivity Analysis of Industrywide Carsharing Impacts on Vehicle Holdings

Inactive Share	Active Carsharing Household Population	Total Vehicles Shed	Vehicles Shed Per Carsharing Vehicle	Vehicles Avoided	Total Vehicles Removed Per Carsharing Vehicle
0%	314,390	73,129	7.4	78,598	15.5
5%	298,671	69,473	7.1	74,668	14.7
10%	282,951	65,816	6.7	70,738	13.9
15%	267,232	62,160	6.3	66,808	13.1
20%	251,512	58,503	6.0	62,878	12.4
25%	235,793	54,847	5.6	58,948	11.6
30%	220,073	51,190	5.2	55,018	10.8
35%	204,354	47,534	4.8	51,088	10.0
40%	188,634	43,877	4.5	47,159	9.3
45%	172,915	40,221	4.1	43,229	8.5
50%	157,195	36,565	3.7	39,299	7.7

As in Table 15, the left column describes the assumed percentage of inactive members. The top row shows carsharing's impact on total vehicles shed assuming that all remaining households are active. The table illustrates the estimated total number of vehicles shed with each assumption. The fourth column to the right shows the vehicles shed per carsharing vehicle, which is the total divided by 9,818. This result suggests that between five to six vehicles were shed per carsharing vehicle. The vehicles avoided as a result of carsharing are computed separately. This 25% sample share consists of respondents that did not shed any vehicles but also did not purchase any vehicles due to carsharing. When vehicle purchases avoided are considered in conjunction with vehicles shed, these estimates suggest that for the existing membership base of mid-2009, carsharing has removed between 90,000 to 130,000 vehicles from the road. Given the number of vehicles deployed, this implies a removal of 9 to 13 personal cars for each carsharing vehicle. This is estimate consistent with previous carsharing literature.[40]

CONCLUSIONS AND POLICY IMPLICATIONS

The results from this study strongly suggest that carsharing is reducing net annual GHG emissions in North America. The data represent a cross-section of all major carsharing organizations across North America, and the sample is large enough to show statistically significant impacts across a variety of assumptions and conditions. The reduction in emissions brought by carsharing is not the result of all members, or even a majority of members, reducing their emissions. Rather, it is derived from the balance of the distribution of changes across all members that are increasing and decreasing emissions. The number of carless households increasing their emissions is comparatively large, constituting more than half of the respondents in both of the evaluated metrics. The degree to which these households are increasing emissions as a result of carsharing is small on an individual basis and large collectively. However, the overall reduction of emissions is driven by the remaining respondents who are reducing their emissions by larger individual amounts that, when taken together, more than compensate for the incremental increases of the majority. Carsharing apparently facilitates members to collectively converge to a shared-vehicle, low-mileage lifestyle. Carless households converge to this lifestyle by increasing emissions, and car holding households converge by decreasing emissions. The magnitude of the collective decrease outweighs the magnitude of the collective increase.

It is important to recognize that the magnitude of GHG reductions attributable to carsharing depends on how the impact is measured. In this study, two metrics were established: the observed impact and the full impact. The observed impact is a lower bound on the true impact of carsharing. It constitutes the change in emissions that can be “seen” by behavioral shifts. An augmentation of the observed impact is the full impact, which includes an estimate of emissions that would have occurred had carsharing not existed. Because the full impact is and always will be an estimate of a hypothetical alternative behavior, it naturally exhibits a higher degree of measurement uncertainty. Because the avoided impacts of carsharing are real impacts, future studies should also aim to consider the emissions that would have occurred in the absence of carsharing as closer to the true impact. In this study, consideration of the avoided emissions shifted 1,135 respondents (18%) that had positive emissions under the observed impact to having negative emissions with the full impact. For these reasons, future carsharing studies should continue to consider both types of impact.

This study contributes to mounting evidence that carsharing is lowering GHG emissions by providing people with automotive access on an as-needed basis. The scope of the emission impacts is travel based. The results and scope of the study have important implications for policy design. Carsharing systems provide environmental benefits. However, caution regarding the caveats of this study in any policy design and emission crediting is necessary. It is clear from the data collected that not all members reduce emissions. More importantly, not all members of carsharing organizations are active members. Carsharing organizations contain some number of inactive or casual members. These members use carsharing very infrequently and are only members for occasional events and emergencies. Carsharing provides a supplement to their lifestyle, but it does not influence or facilitate it in a major way. Were carsharing to disappear, very little would change in the lives of this casual cohort. For this reason, we avoid a blanket application of the average emission factors to carsharing membership numbers. Instead, cohorts should be identified on an organization-by-organization basis. The importance of inactive membership is likely to be dynamic across organizations and time as an organization can increase casual members by initiating a zero fixed cost membership plan. The diversity of impacts by member (and member type), region, and organization type suggests that credits for carsharing impacts should be certifiable. Certifying the balance of membership that is reducing emissions would be a productive mechanism to ensure that carsharing growth continues to facilitate emission reductions. Carsharing organizations could implement such a certification process by establishing an intake and annual follow-up survey of its members that asks the appropriate questions needed to establish and track changes in GHG emissions. Many organizations already survey their members on a regular basis to evaluate customer needs and satisfaction.

The empirical analysis of this study presents robust evidence that carsharing is reducing GHG emissions. The largest impacts from carsharing may indeed lie in the years ahead. As North America contains a natural limit to the number of carless households, expansion of carsharing into smaller cities and lower density suburbs may offer even greater emission reductions, if coupled with increases in public transit and pedestrian provisions. These environments will inevitably be more challenging for carsharing to thrive economically, as these environments typically lack the infrastructure that has allowed carsharing to succeed. Nevertheless, the results of this study show that North American carsharing has provided: (1) mobility to thousands of carless households with some increase in emissions and (2) a mobility alternative to urban households that can adapt to a less auto-intensive lifestyle. The net effect of these two trends is an overall reduction in annual emissions. Future studies should continue to evaluate these trends, as they will likely evolve. Based on these results, as long as carsharing continues to thrive economically, its benefits are likely to persist and grow, as more carholding households find carsharing to be an established and stable option for meeting automotive travel needs within North America cities.

APPENDIX: SURVEY SAMPLE

Note: Sample does not show survey branching. This sample applies to the survey given to members within the United States. The survey given to Canadians was exactly the same, with a substitution of the appropriate units and organizations.

Thank you for taking this survey about your carsharing use. Your responses will help the transportation research community better understand how carsharing interacts with your personal travel needs and lifestyle. All of your responses will remain confidential. If you have any questions about the survey, feel free to respond to the email: survey@tsrc.berkeley.edu. This email is also listed at the bottom of each page and will be checked frequently during the operation of this survey. The survey should take between 10 to 15 minutes to complete. Thank you again for your participation. First, we would like to ask you some questions about your carsharing membership and why you joined.

When did you join your carsharing organization? Please select the year.

1. 1997 or earlier
2. 1998
3. 1999
4. 2000
5. 2001
6. 2002
7. 2003
8. 2004
9. 2005
10. 2006
11. 2007
12. 2008

Please select the month of that year in which you joined.

1. January
2. February
3. March
4. April
5. May
6. June
7. July
8. August
9. September
10. October
11. November
12. December

Which organization are you a member of? (If you are a member of more than one, please pick the one you use most)

1. Austin CarShare

2. Community Car Share of Bellingham
3. Boulder Carshare
4. City CarShare
5. CityWheels
6. Community Car
7. Hour Car
8. IGo
9. PhillyCarShare
10. Roaring Fork Valley Vehicles
11. Zipcar

To which plan do you subscribe at Austin Carshare?
1. Freedom Plan
2. Limited Plan
3. Other, please specify: ____

To which plan do you subscribe at Community Car Share of Bellingham?
1. Destination Plan
2. Occasional Use Plan
3. Standard Rate Plan
4. Truck Only Plan
5. Corporate Account
6. Other. please specify: ____

To which plan do you subscribe at City Carshare?
1. ShareLocal
2. SharePlus
3. Business Membership
4. City College of San Francisco
5. UC Berkeley
6. UC San Francisco
7. Kaiser Permanente of San Francisco
8. Bay Area Wilderness Training Plan
9. Other, please specify: ____

To which plan do you subscribe at CityWheels?
1. Value Plan
2. Standard Plan
3. Business Membership
4. Other, please specify: ____

To which plan do you subscribe at Community Car?
1. Smart Freedom
2. Smart Plus
3. Smart Basic
4. Motion 4
5. Motion 15

6. Motion 35
7. Motion 6
8. Motion 20
9. Motion 40
10. Eagle Heights
11. Pay As You Drive
12. Smart Freedom (through business or non-profit)
13. Smart Plus (through business or non-profit)
14. Smart Advantage (through business or non-profit)
15. Smart Essential (through business or non-profit)
16. Other, please specify: ____

To which plan do you subscribe at HourCar?
1. Standard GO-Plan
2. Value GO-Plan
3. Thrifty Miles GO-Plan
4. Smart 5
5. Smart 8
6. Smart 11
7. Smart 14
8. Silver
9. Gold
10. Platinum
11. Other, please specify: ____

To which plan do you subscribe at IGo?
1. GO Standard
2. GO Standard Plus
3. GO Budget
4. GO Anytime
5. GO Bronze
6. GO Silver
7. GO Gold
8. GO Platinum
9. GO Diamond
10. Other, please specify: ____

To which plan do you subscribe at PhillyCarShare?
1. Basic Freedom
2. Advantage
3. Business
4. Green Business (10+ employees)
5. University of Pennsylvania
6. Other, please specify: ____

To which plan do you subscribe at Roaring Fork Valley Vehicles? (Please check all that apply)

1. Personal Account
2. Corporate Account
3. Other, please specify: ____

To which plan do you subscribe at Zipcar?

1. Extra Value Plan 50 (EVP 50)
2. Extra Value Plan 75 (EVP 75)
3. Extra Value Plan 125 (EVP 125)
4. Extra Value Plan 250 (EVP 250)
5. Occasional Driving Plan
6. z2b (through a company)
7. z2b (through an apartment building)
8. Other, please specify: ____

Are you member of more than one carsharing organization? If so please indicate any other carsharing organizations of which you are a member.Please do not consider joint-use agreements as multi-memberships. Only consider organizations to which you pay bills.

1. No, I am only a member of the organization I just indicated.
2. Austin CarShare
3. Community Car Share of Bellingham
4. Boulder Carshare
5. City CarShare
6. CityWheels
7. Community Car
8. Hour Car
9. IGo
10. PhillyCarShare
11. Roaring Fork Valley Vehicles
12. Zipcar

I am a member of an organziation not listed here: ______________________________ __________

Please select the statement that best characterizes the household circumstances under which you joined carsharing.

1. My household did not have a car, but joined carsharing to gain additional personal freedom.
2. My household did not have a car, but changes in life required a car and I joined carsharing instead.
3. I am in college, and I joined carsharing to gain access to a vehicle while in college.
4. A car of mine stopped working, and instead of replacing it I joined carsharing.
5. Owned at least one car, but needed an additional car for greater flexibility, and joined carsharing instead of acquiring an additional car.
6. Owned one car, but I joined carsharing and got rid of the car.

7. Owned more than one car. Got rid of at least one car and joined carsharing.
8. My employer joined carsharing, and I joined through my employer.
9. I live in an apartment building with a designated carsharing vehicle, and I joined through its membership arrangement.
10. I joined carsharing for reasons other than those listed above. Please explain:

Because you are a member through your employer, we have a few questions about your specific membership.

How would you characterize your employer?
1. Private Sector Employer
2. Municipal Employer
3. State or Federal Employer
4. University Employer
5. Other

Do you use carsharing for trips outside of work?
1. Although I am a member through my employer, I have not used my carsharing membership.
2. No, I only use it for work related trips.
3. Yes, I use carsharing for both work-related and non-work related travel.
4. Actually, I only use carsharing for non-work related travel.

Next, we would like to learn more about your vehicle ownership and driving patterns BEFORE you joined carsharing.

How many vehicles did your household own or lease BEFORE you joined carsharing?

	Zero	One	Two	Three	Four	Five	More than Five
Vehicles owned BEFORE joining carsharing	☐	☐	☐	☐	☐	☐	☐

In the following question, we ask you to estimate the miles that vehicles within your household were driven prior to joining carsharing.

If you do not know the annual miles of a vehicle off the top of your head, you can compute a rough estimate.Everyone has different driving habits, but most people can break down driving needs into two trip types, (1) driving to work (for those who commuted by car), and (2) driving everywhere else. To help you with computing annual miles, start with the round trip distance a vehicle was driven during a typical work day, then multiply that by the number of days per week the vehicle is taken to work (usually 3 to 5). Now you have commuting miles per week. You can multiply that by the number of weeks per year that you went to work at that location. Non-work miles are much more variable over a year. These are the miles driven around town for errands as well as out of town trips over the year BEFORE you joined carsharing. Add this non-work estimate to the commuting miles. The sum is your total annual miles for that vehicle. Alternatively, if the annual miles driven on a vehicle is something that you happen to know, feel free to just enter that estimate. Please list the make, model, and year of any vehicles your household owned or leased BEFORE joining carsharing. If you had more than five, please list the five most frequently driven.For each vehicle, please give your best estimate as to the ANNUAL MILES it was driven DURING THE YEAR BEFORE you joined carsharing. In answering this question, please consider the driving of ALL members of your household.

	Make (e.g., Honda)	Model (e.g., Civic)	Year	Annual Miles Driven BEFORE Carsharing
Vehicle #1 (Vehicle you drove most)				
Vehicle #2				
Vehicle #3				
Vehicle #4				
Vehicle #5				

Now, we would like to learn more about your CURRENT vehicle ownership and driving patterns.

How many vehicles does your household own or lease CURRENTLY?

	Zero	One	Two	Three	Four	Five	More than Five
Vehicles owned CURRENTLY	☐	☐	☐	☐	☐	☐	☐

In the following question, we ask you to estimate the miles that vehicles within your household are CURRENTLY DRIVEN.The following text discusses how to compute a rough estimate for annual miles for each vehicle.

If you have read this text in a previous question, it is the same as before. Everyone has different driving habits, but most people can break down driving needs into two trip types, (1) driving to work (for those who commute by car), and (2) driving everywhere else. To help you with computing annual miles, start with the round trip distance a vehicle is driven during a typical work day, then multiply that by the number of days per week the vehicle is taken to work (usually 3 to 5). Now you have commuting miles per week. You can multiply that by the number of weeks per year that you go to work at that location. Non-work miles are much more variable over a year. These are the miles driven around town for errands as well as out of town trips over the CURRENT year. Add this non-work estimate to the commuting miles. The sum is your total annual miles for that vehicle. Alternatively, if the annual miles driven on a vehicle is something that you happen to know, feel free to just enter that estimate.

Please list the make, model, and year of any vehicles your household CURRENTLY owns or leases. If you have more than five vehicles, please list the five most driven.For each vehicle, please give your best estimate as to the ANNUAL MILES that the vehicle is CURRENTLY driven within your household.

	Make (e.g., Honda)	Model (e.g., Civic)	Year	Annual Miles Driven CURRENTLY
Vehicle #1 (Vehicle you drive most)				
Vehicle #2				
Vehicle #3				
Vehicle #4				
Vehicle #5				

Next, we have a few questions about how you use your carsharing account

How many people are jointly listed on your carsharing account (including yourself)? (If you are part of a business account, then select the only number of people within your household that are members of that account)

1. One
2. Two
3. Three
4. Four
5. Five
6. More than five

Do you consider yourself to be the primary user of the carsharing account (using it the majority of the time)?

1. Yes, I am the primary user of the carsharing account.
2. No, someone else on the account is the predominant user.
3. No single member of the account would be considered the predominant user.

Do you and the other account holders all live at the same address?

1. Yes, were all in the same household
2. Some are at the same address and others are not
3. No, we live at different addresses

Help us match responses from joint accounts.

Please enter the last 3 digits of your home (landline) telephone number.This will help us match responses from other members of your household if they take the survey. We cannot identify or contact you from just the last three digits of your phone number. If you do not have a landline or do not wish to respond to this question, just indicate that below: As an example, if your landline phone number was 555-510-4936, then you would enter 936.

1. The last THREE digits of my household's most frequently used landline telephone number are:
2. My household does not have a landline.
3. The last 3 digits are:

For all people on your account, how many total miles would you estimate are driven in carsharing vehicles during a typical month? (If you have a membership invoice handy, it might be helpful to refer to that if it gives miles, otherwise your best guess is appreciated.)

Miles per month_____________

How many total miles would you estimate that you PERSONALLY drive in carsharing vehicles during a typical month? (If you have a membership invoice handy, it might be helpful to refer to that if it gives miles, otherwise your best guess is appreciated.)

Miles per month_____________

For all people on your account (or if its just you), approximately how many reservations per month are made for carsharing vehicles?

Reservations per month_____________

During a typical work week, how many days a week would you commute to work or school by car BEFORE JOINING carsharing, and how many days a week do you commute by car CURRENTLY?

	0 Days / Week	1 Day / Week	2 Days / Week	3 Days / Week	4 Days / Week	5 Days / Week	6 Days / Week	7 Days / Week
BEFORE	☐	☐	☐	☐	☐	☐	☐	☐
CURRENTLY	☐	☐	☐	☐	☐	☐	☐	☐

Can you provide the VEHICLE MODEL NAME of the carsharing vehicle that you use most frequently? (i.e., Civic, Prius, Yaris, Civic Hybrid, Element, etc.)
1. No, I really don't know the specific model name.
2. Yes, the carsharing VEHICLE MODEL that I use most often is: ___________________
____

Instead, can you provide the VEHICLE TYPE of the carsharing vehicle that you use most frequently? (i.e., 4-door sedan, 4-door sedan hybrid, small sports utility vehicle (SUV), cross-over vehicle, pick-up truck, etc.)

1. 2-door microcar (Mercedes-Benz Smart)
2. 2-door car
3. 4-door sedan
4. Luxury sedan
5. 4-door sedan hybrid
6. Hatchback (or liftback)
7. Wagon
8. Cross-over
9. Small SUV
10. Regular SUV
11. Minivan
12. Pick-up truck
13. Other, please specify

Now we have a few questions pertaining to your use of other transportation modes BEFORE and AFTER you joined carsharing. As best you can, estimate the HOURS TRAVELED and ROUND TRIPS TAKEN by the modes listed. After this, were nearly finished with questions about travel behavior.

BEFORE JOINING CARSHARING, approximately how many HOURS PER WEEK and ROUND TRIPS were you traveling by each of the following travel modes? Please complete the information to your best recollection and leave any modes or time periods that you did not use blank.

	Average Hours / week	Round Trips / week
Rail Transit		
Bus Transit		
Walking (for travel)		
Bicycling (for travel)		
Carpool (commute)		
Ferry		

Now please consider the same question for how you CURRENTLY travel.Please complete the information to your best recollection and leave any modes or time periods that you did not use blank.

	Average Hours / week	Round Trips / week
Rail Transit		
Bus Transit		
Walking (for travel)		
Bicycling (for travel)		
Carpool (commute)		
Ferry		

For the following questions, please consider your annual local taxi usage (if any) during the year BEFORE you joined carsharing and CURRENTLY.

To best of your ability, please estimate your annual miles traveled in taxis locally (within your city) during the year BEFORE you joined carsharing.
1. Taxis were NOT a part of my local transportation needs before joining carsharing.
2. I cannot recall my taxi usage back then.

Annual miles I traveled in taxis: _______

Similarly, please estimate your CURRENT annual miles traveled locally in taxis (within your city).
1. Taxis are NOT a part of my local transportation needs currently.
2. I do not know.
3. Annual miles I currently travel in taxis:

Do you occassionaly rent cars (from Avis, Hertz, etc) while at home to take trips that would otherwise be more expensive or inconvenient with a carsharing vehicle?
1. No, not really.
2. Yes, most every year I rent a car or SUV locally at least once.

On average, how many miles per year do you think you put on rental cars that are rented locally? (Your best guess is appreciated.)
1. 100
2. 200
3. 300
4. 400
5. 500
6. 600
7. 700
8. 800
9. 900
10. 1000
11. 1200
12. 1400
13. 1600
14. 1800
15. 2000
16. 3000
17. 4000
18. 5000
19. Other, please type to the right

Can you recall the annual miles that you put on vehicles rented locally (from Avis, Hertz, Enterprise, etc.) during the year BEFORE you joined carsharing?
1. No, I cannot recall that mileage.
2. I did NOT rent vehicles locally prior to joining carsharing.

3. Yes, the annual miles I put on locally rented vehicles during that year was roughly:
The next set of questions pertain to how carsharing has fit into your lifestyle.

Consider the frequency with which you visit the following Point of Departure (POD) locations to access a carsharing vehicle. The locations are listed as general categories.To the nearest 10 percent (i.e., 30, 40, etc.), please indicate the percent of time you access a carsharing vehicle at the following location types. Please make sure that your answers add up to 100. (You can leave irrelevant categories blank.)
1. POD that is near your home __________
2. POD that is near or at your work __________
3. POD that is near a rail or transit station not close to home or work __________
4. POD that is in some other location __________

If carsharing suddenly disappeared from my region, I would:
1. Definitely buy a car
2. Probably buy a car
3. Maybe buy a car
4. Probably not buy a car
5. Definitely not buy a car

How many cars do you think your household would have to acquire?
1. 0
2. 1
3. 2
4. 3
5. 4
6. 5

In total, how many miles (annually), do you think you would put on these vehicles if you had to use them instead of carsharing? (Your best estimate is fine)
1. 0–1000 miles
2. 1000–2000 miles
3. 2000–3000 miles
4. 3000–4000 miles
5. 4000–5000 miles
6. 5000–7500 miles
7. 7500–10000 miles
8. 10000–15000 miles
9. 15000–20000 miles
10. More than 20000 miles
11. I do not know

Have you moved your home or work location since joining carsharing?
1. No
2. Yes, I changed my home location
3. Yes, I changed my work location
4. Yes, I changed both my home and work location

What would you say has contributed more to your overall change in driving? The move (of home or work) OR the availability of carsharing?

1. Mostly carsharing
2. More carsharing than the move
3. Equally the move and carsharing
4. More the move than carsharing
5. Mostly the move

The following questions aim to get a sense of your reaction to the rise in gasoline prices during 2008 and how it affected your use of carsharing.

Overall, how do you feel about the recent (in 2008) rise in fuel prices? (Please select the response that best describes your sentiments.)

1. Overall, it's good for the country, although I am NOT impacted significantly.
2. Overall, it's good for the country, but I am mildly impacted.
3. Overall, it's good for the country, even though I have been significantly impacted.
4. Overall, it's bad for the country, although I am NOT impacted directly.
5. Overall, it's bad for the country, and I have been mildly impacted.
6. Overall, it's bad for the country, and I have been significantly impacted.

To what extent has the recent (in 2008) rise in gasoline prices impacted how you travel today (since joining carsharing)?

1. The recent rise in gasoline prices has NOT altered how I travel at all.
2. The recent rise in gasoline prices has caused me to travel somewhat less (fewer trips).
3. The recent rise in gasoline prices has caused me to travel somewhat differently (shifting toward other modes).
4. The recent rise in gasoline prices has caused me to reduce my travel AND change how I travel (both fewer trips and different modes).

To what extent has the recent (in 2008) rise in gasoline prices impacted how you use carsharing today (since joining carsharing)?

1. The recent rise in gasoline prices has caused my use of carsharing to go UP.
2. The recent rise in gasoline prices has caused my use of carsharing to go DOWN.
3. The recent rise in gasoline prices has NOT BEEN A FACTOR influencing my use of carsharing.

Please select the statement that best describes your feelings about gasoline prices.

1. High gasoline prices are a significant personal financial concern.
2. High gasoline prices are a moderate personal financial concern.
3. High gasoline prices are occasionally a personal financial concern.
4. High gasoline prices are not currently a personal financial concern.

I have actively changed my travel patterns specifically in order to lower the carbon footprint of my transportation activity.

1. Strongly Agree
2. Agree

3. Disagree
4. Strongly Disagree
5. Dont Know

Now we're nearly finished. Our final questions pertain to demographics followed by a few questions on general location.

Please indicate your gender.

1. Male
2. Female

In what year were you born? Year of birth:__________

What is your highest level of education?
1. Grade School
2. Graduated High School
3. Some College
4. Associate's Degree
5. Bachelor's Degree
6. Master's Degree (M.S., M.A., M.B.A.)
7. Juris Doctorate Degree (JD)
8. Doctorate (Ph.D., Ed.D., etc.)
9. Other

Please indicate the number of household members (including yourself) that fall into the different age groups listed below.

	Number of People in Age Group
0–5	
6–15	
16–18	
19–23	
24–30	
31–35	
36–40	
41–45	
46–50	
51–55	
56–60	
61– 65	
66–74	
75 and older	

What was your household's 2007 pre-tax income?

1. Under $10,000
2. $10,000–$20,000
3. $20,000–$30,000
4. $30,000–$40,000
5. $40,000–$50,000
6. $50,000–$60,000
7. $60,000–$70,000
8. $70,000–$80,000
9. $80,000–$90,000
10. $90,000–$100,000
11. $100,000–$110,000
12. $110,000–$120,000
13. $120,000–$130,000
14. $130,000–$140,000
15. $140,000–$150,000
16. More than $150,000
17. Decline to Respond

Finally, we would like to finish by asking you a few brief questions about your general home and work location. Any information that you can offer will help us in better understanding the travel patterns of carsharing users. When you're finished, you can choose to participate in a raffle for a $100 credit to your carsharing account. You can choose to participate on the following page, and if you do, well ask for some basic contact information. Thank you for your participation!

What is your zip code?

Could you provide us with the city, state, and a pair of cross streets near your home location? For example, Strawberry St., Grove Ave., Richmond, VA, would be a sufficient format of response. This is an intersection, and it does NOT have to be adjacent or exceptionally close to your home location. Anything within one quarter mile would be helpful.

Cross Street #1:

Cross Street #2:

City, State (e.g. Richmond, VA):

Could you provide us with the city and a pair of cross streets near your most frequently visited work location in a format similar to that above? Again, it does not have to be adjacent to your work location, as anything within one-quarter mile would be helpful. If you are retired, feel free to write "Retired." If you are currently not working, raising children, or work exclusively from home, feel free to write "Same as home" in any one of the boxes.

Cross Street #1:

Cross Street #2:

City, State (e.g. Richmond, VA):

If you have any suggestions or comments for your carsharing organization, you can submit them on this page. You are welcome to participate in the raffle for a $100 credit to your carsharing account. If you elect not to participate, your results will be automatically submitted when you select No on the last question and press the “Continue” button. Again, thank you for your time and participation.

Is there anything about your carsharing organization that you would like to see improved? Do you have any suggestions for your carsharing organization? Please say as much or as little as you would like. Your answers will be sent to your organization, but they will not be tied to your identity.

Suggestions or Comments:

Do you wish to participate in the raffle for a $100 credit to your carsharing account?
1. Sure, I can provide basic contact information, and then submit my results.
2. No, thanks. Simply submit my results now.

Please provide the following information to participate in a drawing for a $100 credit to your carsharing account.
Name: ________________________________
Email: ________________________________

Thank you very much for your time in completing this survey! You are now entered into the drawing for a $100 credit to your carsharing account. At least one person from each participating organization will be a winner.

Next, we have a few questions about how you use your carsharing account

1. Cross-over
2. Small SUV
3. Regular SUV
4. Minivan
5. Pick-up truck
6. Other, please specify

Now we have a few questions pertaining to your use of other transportation modes BEFORE and AFTER you joined carsharing. As best you can, estimate the HOURS TRAVELED and ROUND TRIPS TAKEN by the modes listed. After this, were nearly finished with questions about travel behavior.

BEFORE JOINING CARSHARING, approximately how many HOURS PER WEEK and ROUND TRIPS were you traveling by each of the following travel modes? Please complete the information to your best recollection and leave any modes or time periods that you did not use blank.

	Average Hours / week	Round Trips / week
Rail Transit		
Bus Transit		
Walking (for travel)		
Bicycling (for travel)		
Carpool (commute)		
Ferry		

Now please consider the same question for how you CURRENTLY travel.Please complete the information to your best recollection and leave any modes or time periods that you did not use blank.

	Average Hours / week	Round Trips / week
Rail Transit		
Bus Transit		
Walking (for travel)		
Bicycling (for travel)		
Carpool (commute)		
Ferry		

For the following questions, please consider your annual local taxi usage (if any) during the year BEFORE you joined carsharing and CURRENTLY.

To best of your ability, please estimate your annual miles traveled in taxis locally (within your city) during the year BEFORE you joined carsharing.

1. Taxis were NOT a part of my local transportation needs before joining carsharing.
2. I cannot recall my taxi usage back then.
3. Annual miles I traveled in taxis:

Similarly, please estimate your CURRENT annual miles traveled locally in taxis (within your city).

1. Taxis are NOT a part of my local transportation needs currently.
2. I do not know.
3. Annual miles I currently travel in taxis:

Do you occassionaly rent cars (from Avis, Hertz, etc) while at home to take trips that would otherwise be more expensive or inconvenient with a carsharing vehicle?

1. No, not really.
2. Yes, most every year I rent a car or SUV locally at least once.

On average, how many miles per year do you think you put on rental cars that are rented locally? (Your best guess is appreciated.)

1. 100
2. 200
3. 300
4. 400
5. 500
6. 600
7. 700
8. 800
9. 900
10. 1000
11. 1200
12. 1400
13. 1600
14. 1800
15. 2000
16. 3000
17. 4000
18. 5000
19. Other, please type to the right

Can you recall the annual miles that you put on vehicles rented locally (from Avis, Hertz, Enterprise, etc.) during the year BEFORE you joined carsharing?

1. No, I cannot recall that mileage.
2. I did NOT rent vehicles locally prior to joining carsharing.
3. Yes, the annual miles I put on locally rented vehicles during that year was roughly:

The next set of questions pertain to how carsharing has fit into your lifestyle.

Consider the frequency with which you visit the following Point of Departure (POD) locations to access a carsharing vehicle. The locations are listed as general categories.To the nearest 10 percent (i.e., 30, 40, etc.), please indicate the percent of time you access a carsharing vehicle at the following location types. Please make sure that your answers add up to 100. (You can leave irrelevant categories blank.)

- POD that is near your home __________
- POD that is near or at your work __________
- POD that is near a rail or transit station not close to home or work __________
- POD that is in some other location __________

If carsharing suddenly disappeared from my region, I would:

1. Definitely buy a car
2. Probably buy a car
3. Maybe buy a car
4. Probably not buy a car
5. Definitely not buy a car

How many cars do you think your household would have to acquire?

1. 0
2. 1
3. 2
4. 3
5. 4
6. 5

In total, how many miles (annually), do you think you would put on these vehicles if you had to use them instead of carsharing? (Your best estimate is fine)

1. 0 – 1000 miles
2. 1000 – 2000 miles
3. 2000 – 3000 miles
4. 3000 – 4000 miles
5. 4000 – 5000 miles
6. 5000 – 7500 miles

7. 7500 – 10000 miles
8. 10000 – 15000 miles
9. 15000 – 20000 miles
10. More than 20000 miles
11. I do not know

Have you moved your home or work location since joining carsharing?

1. No
2. Yes, I changed my home location
3. Yes, I changed my work location
4. Yes, I changed both my home and work location

What would you say has contributed more to your overall change in driving? The move (of home or work) OR the availability of carsharing?

1. Mostly carsharing
2. More carsharing than the move
3. Equally the move and carsharing
4. More the move than carsharing
5. Mostly the move

The following questions aim to get a sense of your reaction to the rise in gasoline prices during 2008 and how it affected your use of carsharing.

Overall, how do you feel about the recent (in 2008) rise in fuel prices? (Please select the response that best describes your sentiments.)

1. Overall, it's good for the country, although I am NOT impacted significantly.
2. Overall, it's good for the country, but I am mildly impacted.
3. Overall, it's good for the country, even though I have been significantly impacted.
4. Overall, it's bad for the country, although I am NOT impacted directly.
5. Overall, it's bad for the country, and I have been mildly impacted.

6. Overall, it's bad for the country, and I have been significantly impacted.

To what extent has the recent (in 2008) rise in gasoline prices impacted how you travel today (since joining carsharing)?

1. The recent rise in gasoline prices has NOT altered how I travel at all.
2. The recent rise in gasoline prices has caused me to travel somewhat less (fewer trips).
3. The recent rise in gasoline prices has caused me to travel somewhat differently (shifting toward other modes).
4. The recent rise in gasoline prices has caused me to reduce my travel AND change how I travel (both fewer trips and different modes).

To what extent has the recent (in 2008) rise in gasoline prices impacted how you use carsharing today (since joining carsharing)?

1. The recent rise in gasoline prices has caused my use of carsharing to go UP.
2. The recent rise in gasoline prices has caused my use of carsharing to go DOWN.
3. The recent rise in gasoline prices has NOT BEEN A FACTOR influencing my use of carsharing.

Please select the statement that best describes your feelings about gasoline prices.

1. High gasoline prices are a significant personal financial concern.
2. High gasoline prices are a moderate personal financial concern.
3. High gasoline prices are occasionally a personal financial concern.
4. High gasoline prices are not currently a personal financial concern.

I have actively changed my travel patterns specifically in order to lower the carbon footprint of my transportation activity.

1. Strongly Agree
2. Agree
3. Disagree
4. Strongly Disagree

5. Dont Know

Now, we would like to learn more about your CURRENT vehicle ownership and driving patterns.

Now many vehicles does your household own or lease CURRENTLY?

	Zero	One	Two	Three	Four	Five	More than Five
Vehicles owned CURRENTLY	☐	☐	☐	☐	☐	☐	☐

Now we're nearly finished. Our final questions pertain to demographics followed by a few questions on general location.

Please indicate your gender.

1. Male
2. Female

In what year were you born?

Year of birth:_______

What is your highest level of education?

1. Grade School
2. Graduated High School
3. Some College
4. Associate's Degree
5. Bachelor's Degree
6. Master's Degree (MS, MA, MBA)

7. Juris Doctorate Degree (JD)
8. Doctorate (PhD, EdD, etc.)
9. Other

Please indicate the number of household members (including yourself) that fall into the different age groups listed below.

	Number of People in Age Group
0 - 5	
6 - 15	
16 - 18	
19 - 23	
24 – 30	
31 - 35	
36 - 40	
41 - 45	
46 - 50	
51 - 55	
56 - 60	
61 - 65	
66 - 74	
75 and older	

What was your household's 2007 pre-tax income?

1. Under $10,000
2. $10,000 - $20,000
3. $20,000 - $30,000
4. $30,000 - $40,000
5. $40,000 - $50,000
6. $50,000 - $60,000
7. $60,000 - $70,000
8. $70,000 - $80,000
9. $80,000 - $90,000

10. $90,000 - $100,000
11. $100,000 - $110,000
12. $110,000 - $120,000
13. $120,000 - $130,000
14. $130,000 - $140,000
15. $140,000 - $150,000
16. More than $150,000
17. Decline to Respond

Finally, we would like to finish by asking you a few brief questions about your general home and work location. Any information that you can offer will help us in better understanding the travel patterns of carsharing users. When you're finished, you can choose to participate in a raffle for a $100 credit to your carsharing account. You can choose to participate on the following page, and if you do, well ask for some basic contact information. Thank you for your participation!

What is your zip code?

Could you provide us with the city, state, and a pair of cross streets near your home location? For example, Strawberry St., Grove Ave., Richmond, VA, would be a sufficient format of response. This is an intersection, and it does NOT have to be adjacent or exceptionally close to your home location. Anything within one quarter mile would be helpful.

Cross Street #1:

Cross Street #2:

City, State (e.g. Richmond, VA):

Could you provide us with the city and a pair of cross streets near your most frequently visited work location in a format similar to that above? Again, it does not have to be adjacent to your work location, as anything within one-quarter mile would be helpful.If you are retired, feel free to write “Retired.” If you are currently not working, raising children, or work exclusively from home, feel free to write “Same as home” in any one of the boxes.

Cross Street #1:

Cross Street #2:

City, State (e.g. Richmond, VA):

If you have any suggestions or comments for your carsharing organization, you can submit them on this page. You are welcome to participate in the raffle for a $100 credit to your carsharing account. If you elect not to participate, your results will be automatically submitted when you select No on the last question and press the "Continue" button. Again, thank you for your time and participation.

Is there anything about your carsharing organization that you would like to see improved? Do you have any suggestions for your carsharing organization? Please say as much or as little as you would like. Your answers will be sent to your organization, but they will not be tied to your identity.

Suggestions or Comments:

Do you wish to participate in the raffle for a $100 credit to your carsharing account?

1. Sure, I can provide basic contact information, and then submit my results.
2. No, thanks. Simply submit my results now.

Please provide the following information to participate in a drawing for a $100 credit to your carsharing account.

Name

Email

Thank you very much for your time in completing this survey! You are now entered into the drawing for a $100 credit to your carsharing account. At least one person from each participating organization will be a winner.

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4. Shaheen, Cohen and Roberts; Shaheen, Cohen and Chung.

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12. Katzev, 1999.

13. Shaheen and Cohen; Susan Shaheen, Daniel Sperling, and Conrad Wagner, "Carsharing in Europe and North America: Past, Present, and Future," *Transportation Quarterly*, Summer 1998: 35–52.

14. Roberto Cervero, "City CarShare: First-Year Travel Demand Impacts," *Transportation Research Record: Journal of the Transportation Research Board, No. 1839*, Transportation Research Board of the National Academies, Washington DC, 2003: 159–166.

15. Ibid.

16. Lane.

17. Cervero, Golub, and Nee; Cervero and Tsai.

18. Cervero, Golub, and Nee.

19. Ibid.

20. Ibid.

21. As a quick aside, the reader may wonder how a carsharing household might satisfy 2,000 miles of private vehicle mobility with 1,000 miles of carsharing mobility. The reason is that some trips that would have occurred in a private vehicle were it available, might now be substituted with transit, biking, and walking. In addition, fewer total trips may be taken because the marginal cost of travel is higher with carsharing and thus less essential travel is forgone.

22. Blacksburg Transit Agency, "Bus Facts," http://www.btransit.org/cms.php/kids/bus_facts.html, accessed December 1, 2009.

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24. EPA, 2005(b)

25. Ibid.

26. Environmental Protection Agency Office of Civil Enforcement, "Many Small Highway and Off-Road Motorcycle Imports Fail to Meet EPA Standards," Enforcement Alert, EPA

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28. ICF Consulting, “Update of Methane and Nitrous Oxide Emission Factors for On-Highway Vehicles,” prepared for the U.S. Environmental Protection Agency, technical report EPA 420-P-04-016, Washington DC, 2004; Environmental Protection Agency, “Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2007,” U.S. Environmental Protection Agency, Washington DC, 2009.

29. There are plausible scenarios in which a carsharing membership by an inactive user does have an impact on GHG emissions. For example, in the absence of the back-up option provided by carsharing, a household finds it requires the security of an automobile and thus purchases a car. Hence carsharing is preventing this car from being acquired and the subsequent emissions from happening. While a plausible scenario, the inclusion of inactive members presented more complications than benefits. Because carsharing does not play a significant role in their lifestyle, the authors consider the impact that carsharing has on their emissions to be zero.

30. See “Appendix” for the exact survey question used.

31. Federal Highway Administration, Highway Statistics 2007, Table VM1, FHWA, U.S. Department of Transportation, Washington DC, 2008; Transport Canada, Transportation in Canada 2008: Addendum, Table RO4, Transport Canada, Ottawa, ON, 2008.

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36. Cervero, Golub, and Nee.

37. Shaheen, Cohen, and Chung.

38. FHA, 2008.

39. Transport Canada, 2008.

40. Shaheen and Cohen.

ABBREVIATIONS AND ACRONYMS

CH_4	Methane
CLT	Central Limit Theorem
GHG	Greenhouse Gases
EPA	U.S. Environmental Protection Agency
HFC	Hydrofluorocarbons
N_2O	Nitrous Oxide
POD	Point of Departure
PVMT	Personal Vehicle Miles Traveled
t	Metric Ton
VKT	Vehicle Kilometers Traveled
VMT	Vehicle Miles Traveled

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