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Vehicle ownership reduction: A comparison of one-way and two-way carsharing systems

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ABSTRACT

This paper explores how membership in different carsharing service types impacts vehicle ownership. We study the difference between carsharing services offering a one-way (free-floating) service utilizing 2-seaters (Car2go) to a two-way service utilizing a range of vehicles (Modo). By analyzing 3,405 survey responses from carsharing users in Vancouver, we found that users of both Car2go and Modo reported reduced vehicle ownership after joining a carsharing service. However, households differ both in how many cars they owned before they joined carsharing services, and how their membership was associated with further change in car ownership. The average Vancouver household owns 1.56 vehicles. According to this survey's respondents, households joining Car2go report average car ownership rates of 1.08 prior to joining up and 0.98 afterwards. Households joining Modo reduced their ownership from an average of 0.68 to 0.36 vehicles. Furthermore, Modo members were close to five times more likely to reduce car ownership compared to Car2go users. We also found that the two services are used differently. Car2go members are more likely to use the service as a complement to all modes of transportation. Modo members are more likely to use access to carsharing as a substitute for private car ownership. Analysis of expressed preferences in response to termination of access to carsharing indicates that carsharing services have been substituting mobility services previously supplied by private vehicles. The intention to gain a vehicle under the service termination was strongest among users who had both Car2go and Modo memberships. These findings show the two services are not rivals but complements providing different mobility services.

1. Introduction

Carsharing (CS) is a service in which multiple individuals share access to and use of a pool of vehicles. First offered in the late 1940s, it aims to provide affordable access to vehicles (Shaheen et al., 1999). The earliest carsharing services were cooperatives with collective ownership of vehicles. Later, for-profit companies offered their vehicles for rent by users.[1] Carsharing is now available in many urban areas throughout the world; as of the beginning of 2015, there were over 1.5 million users of the service in North America (University of California Berkeley Transportation Sustainability Research Center, 2015). This expansion is supported by users who need affordable mobility and local governments who foresee a range of potential benefits from the service (Millard-Ball et al., 2005). One of these expected benefits is lowering private car ownership, especially in areas where the cost of vehicle ownership is high and alternative modes of transportations are available. Early studies empirically demonstrated this promise, as summarized in Table 1. Note that this table is not meant to cover all previous CS studies but show findings from major studies on two continents leading in CS experience, Europe and North America. The data in the table should be viewed as qualitatively indicative of similar phenomena, but due to a wide range of contexts and lack of standardized methodology, detailed comparisons are inadvisable (de Lorimier and El-Geneidy, 2013). In most cities where CS has been offered, members reduced private vehicle ownership through use of CS vehicles.

Traditionally, CS has been a two-way (round-trip) service in which vehicles are picked up and dropped off at the same location. Most CS services examined in the studies listed up in Table 1 refer to traditional two-way service. However, there is a rapid increase of another service model: one-way CS services (Shaheen et al., 2015). One-way CS services

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[1] This service style can be defined as a type of car rental service. Shaheen et al. claim that this service is short-term car rental service (Shaheen et al., 1999), and this claim is consistent with the definition of carsharing by Carsharing Association (CSA) (Carsharing Association, 2016). CSA also claims that one of the carsharing services' primary objectives is to support multi-modal lifestyle and sustainable environment.

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Table 1
Summary of Reported Vehicle Ownership Reduction among CS users.

Area/Country	Survey year	Target CS (Round-trip or One-way)	Vehicle ownership reduction	Reference
US (Portland)	Around 1999	Round-trip	Among CS survey respondents, 26% of them sold their personal vehicle, and 53% of them forgone purchasing a car.	(Katzev, 2003)
US (San Francisco)	2002	Round-trip	Among CS members, 29.1% of them reduced car ownership, and 67.5% of them foregone the purchase of a vehicle	(Cervero and Tsai, 2004)
US (Philadelphia)	2003	Round-trip	A carsharing vehicle removed an average of 22.8 cars from the roads (10.8 cars removed by vehicle ownership reduction, and 12.0 cars removed by deferring purchase of a car)	(Lane, 2005)
North America (multiple cities)	2004	Round-trip	About 20% of CS users reduced their private car ownership. One carsharing vehicle replaced five to six privately owned cars.	(Millard-Ball et al., 2005)
US (San Francisco)	2005	Round-trip	Among CS survey respondents, 2% of them reduced multiple cars, and 22% of them reduced a car	(Cervero et al., 2007)
North America (multiple cities)	2008	Round-trip	The average vehicle ownership reduced from 0.47 vehicle/household to 0.24 vehicle/household. A carsharing vehicle removed four to six private vehicles from the road.	(Martin et al., 2010)
Canada (Toronto)	2009	Round-trip	29% of CS users gave up a vehicle after becoming a CS member. 55% of CS users forgone purchasing a car as a result of CS participation.	(Engel-Yan and Passmore, 2013)
Europe	Around 2009	Round-trip	CS users who got rid of cars: Belgium: 15.7%, Switzerland: 31.6%, Germany: 16%. CS users who decided against a planned vehicle purchase: Belgium: 35%, Germany: 33%	(Loose, 2010)
US (Ithaca)	2011	Round-trip	A carsharing vehicle reduced roughly 15.3 personal vehicles.	(Stasko et al., 2013)
France (Paris)	2013	One-way (station-based) & Round-trip	23% reduction in the number of private vehicles owned by one-way (station-based) users after their subscription while 67% reduction in the number of private vehicles owned by round-trip users after their subscription.	(6t-bereau de recherché, 2014)
UK (England&Wales excl. London)	2014–15	Round-trip	One carsharing vehicle removed 4 private cars from the road, and differed the purchase of over 9 cars	(Steer Davies Gleave, 2015a)
UK (London)	2014–15	Round-trip	One carsharing vehicle removed 8.6 private cars from the road, and deferred the purchase of 19.8 cars	(Steer Davies Gleave, 2015b)
UK (Scotland)	2014–15	Round-trip	One carsharing vehicle removed 3.5 private cars from the road, and deferred the purchase of 9.3 cars	(Steer Davies Gleave, 2015c)
Canada (Montreal)	2014	Round-trip	Regression models results show that the number of shared vehicles in 500 m radius is negatively correlated with car ownership.	(Klincevicius et al., 2014)
North America (multiple cities)	2014–15	One-way (free-floating)	One carsharing vehicle removed 1–3 private cars from the road, and deferred the purchase of 4–9 cars.	(Martin and Shaheen, 2016)

allow users to return shared vehicles to locations different from the original pick-up locations. In 2014, 24.5% of CS cars were capable of one-way trips, and 26.4% of CS users had access to these services in North America (Shaheen and Cohen, 2015). Some one-way CS services are station based; users can pick stations to return cars (e.g., Car2go service in Toronto, Autolib' in Paris). The other one-way CS services do not even have specific stations; users can drop off cars almost anywhere in the service area often using roadside parking spaces (e.g., Car2go in Vancouver). The majority of one-way CS services use the latter service style, which often called free-floating CS (See for example, Shaheen et al., 2015 for further details about station-based and free-floating CS). In this paper, we examine the impact of CS on vehicle ownership, focusing on potential differences between two-way and free-floating (one-way) CS services.

In free-floating CS services, users are able to check the real-time availability and locations of CS vehicles, and instantly book them via their smartphone or laptop. They can even unlock and lock the car using their smartphone to begin and end the rental. Since the service allows users to make one-way trips, all users need to do is to drive to their destination – so long as that is within the service area. The information of the trip termination is immediately sent to the CS provider, and other CS users now can search and book the car. The introduction of these one-way CS services removed some of the restrictions faced by members of conventional round-trip services. The freedom of operation has been very popular; the first free-floating CS, Car2go, started in 2008 in Ulm, Germany (Shaheen et al., 2015), and it became the largest CS service in the world (Car2go, 2015a) offering its service in over 30 cities in 8 countries (Car2go, 2015b). The growth in this free-floating service is expected to continue (Shaheen and Cohen, 2013).

Scholars are aware of potential differences between free-floating and conventional round-trip CS services and have pointed to the necessity for such a comparison (Le Vine and Polak, 2015; Shaheen et al., 2015). As far as we are aware of, there is no empirical or quantitative academic studies on vehicle ownership reduction contrasting one-way and two-way CS services. The study done by Wielenski et al. (2015) is the closest one – they compared users of one-way (free-floating) and two-way CS services in Montreal, Canada; however, their analysis is limited to demographics and trip patterns rather than vehicle ownership. The report prepared by 6t-bureau de recherché (2014) also compared the vehicle ownership changes between one-way (station based, not free-floating) and two-way carsharing users; however, they did not conduct any statistical analysis or receive external reviews to verify their methodologies/conclusions. The white paper prepared by Martin and Shaheen (2016) reports the vehicle ownership changes among one-way (free-floating) CS users; however, they only focus on one one-way CS service. Petersen, Zhang and

Darwiche (2017) report on a new model of vehicle ownership that accounts for household access to carsharing. However, their model does not differentiate between different types of carsharing services. Namazu and Dowlatabadi (2016) also presented a study in which association of household characteristics and car-shedding was explored. However, again the focus of the study is not contrasting the two different types of CS services.

In this study, we analyze responses of a CS survey conducted in 2013 targeting CS users in Vancouver, Canada. The survey includes users of both round-trip and one-way CS services. Given the sample size and response rates, we focus on a comparison between a round-trip (Modo) and a free-floating (Car2go) CS services. As noted above, the comparison is not purely contrasting round-trip and one-way services; Modo provides a variety of vehicle types while Car2go only offers a two-seat subcompact.[2] With this in mind, we explore the difference between the two services and develop a statistical estimate of their impact on vehicle ownership.

Section 2 gives details of data used for this study, along with a brief introduction to the study area, the Vancouver region, Canada. Section 3 summarizes the results from several statistical analyses including t-tests and multiple logit regression analyses. The effects of CS on vehicle ownership reduction are quantified here. Section 4 gives the summary and discussion of findings.

2. Data

2.1. Target area: Vancouver

Vancouver is home to Modo, the first CS service in the English-speaking world (Modo the Car Co-op, 2014). Modo[3] was launched in 1997, and currently four CS services provide over 2000 vehicles to their members (Mackie, 2015) in the Metro Vancouver region. The social and economical core of the region is the City of Vancouver, located at the west side of the region. The city's Transportation Panel Survey revealed that 13% of their respondents held CS membership in 2013, and it increased to 20% in 2014 (CH2MHILL, 2015). Given this background, residents of this region, especially the regional core, are expected to be well adapted to CS services. The readers should take care however to contextual the findings here as a reflection of local conditions in Vancouver. While we believe our findings to be relevant to other jurisdictions, they are unlikely to be replicated for three reasons: a) the survey data contrasts a well-established membership based 2-way CS cooperative (Modo) with a more recently established free-floating service (Car2go); b) carsharing membership rates in Vancouver are among the highest in the world and atypical of most other locations; and c) the local transit alternatives and the socio-economics are key factors in mobility and car ownership decisions.

2.2. Metro Vancouver's carsharing survey

Metro Vancouver, comprising 24 local authorities in the region, conducted an online survey targeting CS users in 2013. The survey was part of the first comprehensive study to understand the role of CS in the region (Metro Vancouver, 2014b). The online CS survey comprised 32 questions covering household demographics, CS membership, car ownership, pro-environmental attitudes, etc. (see Metro Vancouver (2014b) for details). The survey was conducted between October 17 and December 2, 2013. Participant recruitment was through the membership lists of the three CS organizations in operation at the time: Modo (Modo the Car Co-op, 2014), Car2go (Car2go, 2014), and Zipcar (Zipcar Canada, 2015). Modo and Car2go distributed the survey hyperlink to their members via e-mail while Zipcar used twitter to provide the hyperlink. Survey respondents could enter into a draw to win one of two gift certificates worth $50. Table 2 provides a brief overview of the three participating CS services (Metro Vancouver, 2014b),[4] and Fig. 1 shows the service area/locations of each CS service in the region.

Table 2
List of CS services in Vancouver (as of Fall (2013), retrieved from The Metro Vancouver Car Share Study Summary Booklet and Technical Summary (Metro Vancouver, 2014b, 2014a)).

	Modo	Zipcar	Car2go
Business type	Co-operative	Private (Avis Budget)	Private (Daimler AG)
Service start year in Vancouver	1997	2007	2011
Service style	Round-trip, various vehicle types	Round-trip, various vehicle types	One-way, two-seater vehicles
Number of vehicles in the region	303 vehicles	128 vehicles	550 vehicles
Membership	7,900	3,337	37,400
Membership fee	Coop membership: Onetime $500 refundable shares purchase and $20 registration fee Casual membership: $5 monthly fee and $20 registration fee	Occasional Driving Plan: $25 one-time non-refundable application fee and $65 annual fee Monthly Driving Plan and Extra Value Plan: $25 one-time non-refundable application fee	$35 one-time registration fee

2.3. Survey response

A total of 3,405 valid responses were collected (estimated response rate for Modo: 1,847/7,031 = 26%, Car2go: 2,363/33,286 = 7% (Metro Vancouver, 2014b)). The following filters were used to establish valid responses: 1) feasibility (i.e., zero household size is invalid), 2) consistency (e.g. a car-free household cannot have purchased a car). In addition, we wanted to exclude the potential conflating effect of home relocation on car ownership and if a respondent stated that home relocation had more than a moderate effect on vehicle ownership we excluded them from the study sample. After these exclusions 3,040 valid responses remained. CS membership possessions of the respondents were summarized in Fig. 2. Given >90% of the respondents was either Car2go or Modo members, we excluded other CS responses and focused on three groups of respondents: Car2go only households, Modo only households, and households with memberships in both Car2go and Modo.

3. Analysis

3.1. Demographics of respondents

The demographics of the three household types (Car2go only, Modo&Car2go and Modo only) are summarized in Table 3.

Due to the voluntary nature of the survey, we are aware of the possibility of sampling bias. Despite the incentive to participate, the wildly different response rates by Modo and Car2go members (4% for Car2go only members and 19% for Modo only members, see Table 7 for details) are an indicator of differential engagement. Since we were not allowed to contact survey invitees, and it is nearly impossible to know the demographics of CS users at the time of survey (2013), there is no feasible approach to characterize any potential sampling bias. Hereafter, we treat the survey results as if unbiased and representative of the CS user

[2] These CS Services also differ along two other dimensions, Modo is a local coop while Car2go is an international for-profit entity.

[3] Formerly known as Cooperative Auto Network (CAN).

[4] A new one-way CS service, Evo, was launched in 2015 with about 300 vehicles (Evo Car Share, 2015).

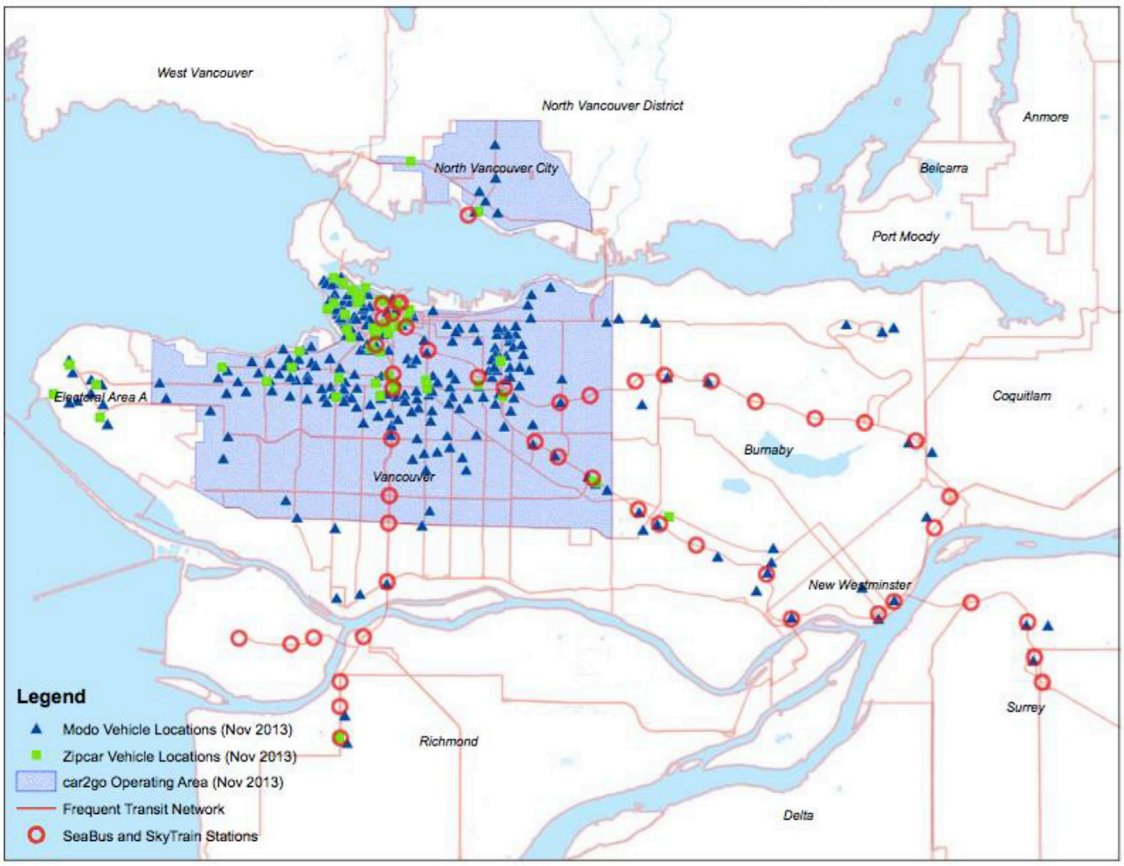

Fig. 1. Map of Vancouver region along with CS service availability (retrieved from (Metro Vancouver, 2014b)).

population. We therefore use a sensitivity analysis of the results to explore the impact of unmeasured bias – see section 3.6.1.

A comparison of the three CS user groups and Vancouver statistics reveals that survey respondents are more likely to live in rental housing with fewer family members and own fewer cars prior to joining CS. These are common characteristics among CS users (Steer Davies Gleave, 2015a, 2015b, 2015c; Klincevicius et al., 2014; Loose, 2010; Millard-Ball et al., 2005).

3.2. Vehicle ownership change

In advance to the CS participation, the average number of vehicles owned per household were 1.09, 0.69 and 0.68 for Car2go only, Car2go&Modo, and Modo only groups respectively (Table 4). T-test results shown in Table 4 suggest that households with Car2go only membership owned more vehicles than other households (before joining CS). The results also show a decline in vehicle ownership comparing before and after joining CS services. The reductions were statistically significant for all of the three groups. Note that this result does not confirm the causal relationship between CS participation and vehicle ownership reduction. However, multiple studies have also reported vehicle ownership reduction among CS users (see Table 1) and the average vehicle ownership rate in the Vancouver region has been stable for the latest three census periods (vehicle per household: 1.17 (2001) → 1.14 (2006) → 1.17 (2011) (Metro Vancouver, 2012a, 2015)). In addition, as explained in the previous section, answers from households who stated that home relocation had more than moderate effects on vehicle ownership were excluded in this analysis. Considering these facts, it is highly likely that CS participation and the decline in vehicle ownership have a certain correlation.

Declines in vehicle ownership before and after CS participation are statistically significant for all three groups. Vehicle ownership reduction among Car2go&Modo and Modo users was higher than among Car2go users; the first two reduced ownerships by 35–36% while Car2go only group was only one third that rate at 12% (Fig. 3). This is consistent with the small effect size (d-value) seen in the comparison of vehicle ownership between before and after CS participation among Car2go only group (Car2go: d = 0.12, Car2go&Modo: d = 0.48, Modo: d = 0.51).

3.3. Logit regression analysis

We applied logit regression analysis to quantitatively understand the characteristics of survey respondents who reduced vehicle ownership between before and after CS participation. In order to understand the model fitting level, results of each regression model are shown along with

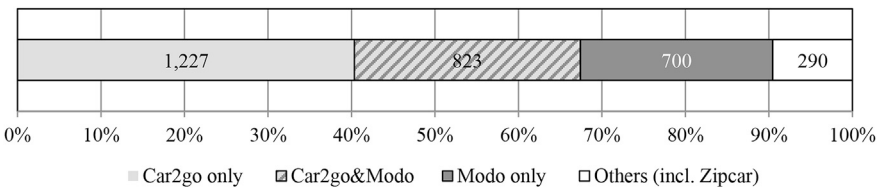

Fig. 2. Survey response.

Table 3
Demographics of respondents.

			Car2go	Modo& Car2go	Modo	Vancouver avg.
Response count by type of membership			1227	700	823	NA
% of responses from City of Vancouver residents			89%	96%	80%	NA
Housing	Living in rental housing		55%	61%	55%	51%[a]
	Bedroom	Bachelor	42%	37%	36%	NA
		1 bedroom	32%	34%	31%	
		2 bedrooms	22%	23%	26%	
		3 or more bedrooms	5%	5%	7%	
	Length of residency in the current house	Less than 1 year	18%	17%	14%	NA
		1 to 2 years	26%	23%	21%	
		3 years or more	56%	60%	65%	
	Household who changed home and/or work location after joining CS		19%	50%	37%	NA
Demo-graphics	Household size	Average	2.25	2.21	2.21	2.28[b]
		% of single households	25%	26%	30%	
		% of households with size 2	46%	46%	41%	
		% of households with size >2	29%	28%	29%	
	Household with children		15%	19%	24%	NA
	Household with elderlies		5%	3%	6%	NA
	Average number of employed family		1.68	1.74	1.52	NA
	Average number of family working outside home		1.56	1.55	1.39	NA
Car Owner-ship	Average vehicle per household (pre CS)		1.08	0.69	0.68	1.56[c]
	Average vehicle per household		0.98	0.35	0.36	NA
	% of zero car households		29%	71%	68%	NA
	Decreased car ownership after CS participation	Total	12%	36%	35%	NA
		Gave up vehicle ownership completely	6%	29%	27%	
		Keep at least one car	6%	7%	8%	
	Increased car ownership after CS participation		2%	4%	4%	NA
CS	Length of membership	Less than 1 year	42%	10%	19%	NA
		1 to 2 years	58%	27%	19%	
		3 years or more	0%	63%	62%	
	Frequency of usage	Very often (>4 times/month)	31%	47%	20%	NA
		Often (>1 time/month)	33%	36%	39%	
		Rarely (<1 time/month)	33%	17%	40%	
		Never	3%	0%	1%	

References.
[a] (Metro Vancouver, 2010).
[b] (Metro Vancouver, 2012b).
[c] (Metro Vancouver, 2015).

Table 4-1
Vehicle ownership change by CS participation (number of vehicle/household).

	Car2go only	Car2go&Modo	Modo only
Before[a]	1.08	0.69	0.68
After[a]	0.98	0.35	0.36
t-test result (Before vs. After)	t(2,451)=2.86, p<0.01, d=0.12	t(1,366)=8.98, p<0.001, d=0.48	t(1,575)=10.29, p<0.001, d=0.51

[a] Before means the number of vehicles owned by a household 12 months prior to joining CS service(s) while After means the number of vehicles currently owned by the household.

Table 4-2
Comparison of avg. vehicle ownership among the three CS membership groups (before CS participation, number of vehicle/household)

	t-test results
Car2go only vs. Car2go&Modo	t(1,656)=10.55, p<0.01, d=0.49
Car2go only vs. Modo only	t(1,989)=11.45, p<0.001, d=0.50
Car2go&Modo vs. Modo only	t(1,449)=0.08, p=0.94, d<0.01

McFadden's Pseudo-R squared values and Receiver Operating Characteristics (ROC) curves. The ROC curves are produced by 100 independent cross-validation tests where randomly selected 75% of the survey data sets are used as a train set and the other 25% are used as a test set.

Since the survey did not ask any questions about respondents' income level, estimated rent index was used to indirectly reflect income level of survey participants. This index was developed based on three independent variables: number of bedrooms, length of residency in the current dwelling,[5] and home municipality. The reported average rent by the number of bedrooms in municipality level was mainly used to estimate rent for each survey respondent, assuming all of them live in rental housings (Canada Mortage and Housing Corporation, 2007, 2008; 2010, 2011; 2012, 2014).

3.3.1. *Vehicle owners who shed cars*

The first regression was conducted to understand the characteristics of vehicle owners who reduced vehicle ownership. The dependent variable is a dummy variable set 1 for respondents who reduced vehicle

[5] British Columbia government limits the maximum increase of rent for people who continue to live in a same dwelling unit. The limit is adjusted every year depending on its economy and social status (Province of British Columbia, 2016). If the reported increase of average rent was higher than the limit, we limited the increase of the rent to the provincial maximum for residents who continue living in the same dwelling.

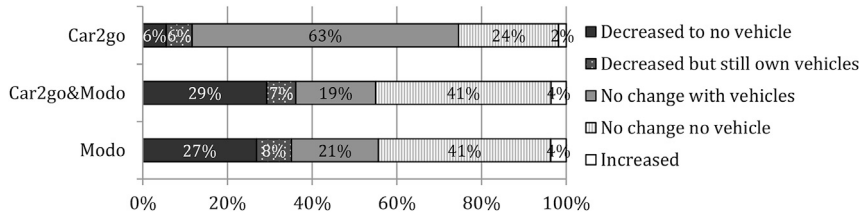

Fig. 3. Vehicle ownership change comparing before and after CS participation.

Table 5
Regression Model 1 and Model 2 (Dependent variable: 1 for respondents who shed cars after CS participation 0 for others).

Category	Sub-category	Model 1			Model 2		
		Est.	P	Odds	Est.	P	Odds
Intercept		−4.54	***	0.01	−4.45	***	0.01
Estimated rent		0.00		1.00	0.00		1.00
Number of bedrooms		0.01		1.02	−0.01		0.99
Living in rental housing		0.52	**	1.69	0.28		1.32
Length of residency in current unit (reference: <1yrs)	1-2 yrs	−0.29		0.75	−0.32		0.72
	3 yrs or more	0.00		1.00	−0.25		0.78
Household size		−0.67	***	0.51	−0.61	***	0.54
Household	with children (<16 yrs old)	0.49		1.64	0.33		1.39
	with elderlies (>64 yrs old)	0.12		1.12	−0.29		0.75
Number of family members work outside of home	−0.46	−0.46	***	0.63	−0.41	**	0.66
Number of vehicles owned (before joining CS)		1.35	***	3.86	1.30	***	3.68
CS membership (reference: Car2go only user)	Modo only user	1.45	***	4.26	1.60	***	4.96
	Modo and Car2go user	1.58	***	4.87	1.67	***	5.31
Length of CS membership (reference: <1 yr)	1-2 yrs	0.30		1.35	0.27		1.31
	3 yrs or more	0.37		1.45	Not applicable		
Frequency of CS use (reference: <1/month)	>4/month	1.07	***	2.91	1.09	***	2.98
	>1/month	1.76	***	5.82	1.71	***	5.54
Regular CS vehicle access location	Within apartment/townhouse complex	0.58		1.79	0.70		2.02
	Street near home	0.37		1.45	0.46		1.58
	Other building/parking facility near home	0.24		1.27	0.36		1.43
	Location close to work or school	−0.13		0.87	0.01		1.01
	Location close to shopping mall	−0.06		0.94	0.15		1.16
	Location close to transit station	0.09		1.09	−0.02		0.98
Trip purpose	Travelling to work	−0.25		0.78	−0.18		0.83
	Travelling to school	0.15		1.16	0.02		1.02
	Shopping and errands	0.78	***	2.17	0.87	***	2.39
	Visiting friends/family	0.35	*	1.41	0.04		1.05
	Going to a restaurant or bar	−0.65	***	0.52	−0.76	***	0.47
	Medical appointments	0.42	*	1.52	0.50	*	1.65
	Recreational activities	0.30		1.35	0.07		1.08
	Vacation trips	0.89	***	2.44	0.66		1.94
Home relocation after joining CS		−0.21		0.81	−0.10		0.91
Reasons to join CS	Free or discounted membership	0.50		1.65	0.51		1.67
	CS is conveniently located in our housing complex	−0.41		0.67	−0.32		0.73
	CS is conveniently located on a street near home	0.48	*	1.62	0.31		1.37
	Additional mobility option	0.00		1.00	0.04		1.04
	Convenient compared to transit	0.02		1.02	0.09		1.09
	Convenient compared to walking	−0.08		0.93	0.42		1.52
	Convenient compared to cycling	1.20	*	3.32	0.95		2.60
	Convenient compared to riding with others (carpooling)	0.15		1.16	0.14		1.15
	Convenient compared to using owned/leased vehicle	0.71	*	2.04	0.13		1.14
	Cost savings compared to owning/leasing a car	1.77	***	5.84	1.95	***	7.01
	Household-owned vehicle stopped working	0.91	*	2.48	0.99		2.68
	Cost savings compared to car rental	0.03		1.03	0.19		1.21
	Cost savings compared to using taxis	0.10		1.11	0.16		1.17
	Reduce pollution and fuel consumption	1.10	***	3.01	0.98	**	2.67
	Free or better parking options	0.01		1.01	0.12		1.13
	The philosophy of sharing	−0.03		0.97	−0.24		0.78
AIC:		1330.30			864.77		
McFadden's Pseudo-R squared:		0.48 (df = 48)			0.43 (df = 47)		

p-value symbols: <0.1 = ., <0.05 = *, <0.01 = **, <0.001 = ***.

ownership and 0 for the others. Respondents who did not own cars at the time of CS participation were excluded from this analysis since they did not have an option to reduce or keep vehicles (n = 1,769, Model 1). Since Car2go service launched in 2011 in Vancouver and the survey was conducted in 2013 (Metro Vancouver, 2014a), the maximum length of membership for Car2go only users is 2 years (Table 3). A supplementary model (Model 2) was built by excluding respondents who had 3 or more years of CS experience to minimize heterogeneities among the three respondent groups (n = 685).

The results of the two logit regression analyses are summarized in Table 5. All VIF (Variance Inflation Factor) values of the independent variables are less than 2. As Table 5 shows, the two models share a general trend. This is consistent with the low explanatory power found for CS membership length in Model 1. Fig. 4 provides the visualization of ROC curves. Overall, both models are moderately (AUC: 0.7–0.9) to highly predictive (AUC: 0.9–1.0) (Vanagas, 2004).

The regression results show that CS membership has one of the strongest effects on predicting respondents who shed cars after joining CS. Respondents who hold Modo membership are close to five times more likely to shed a car compared to Car2go only users (odds ratio: 4.26–4.96, p-value: <0.001) when other variables are normalized. Respondents who hold both Modo and Car2go memberships show an even stronger tendency to reduce vehicle ownership; Modo and Car2go double membership holders are about five times more likely to shed cars compared to Car2go only users (odds ratio: 4.87–5.31, p-value: <0.001).

Rather than the comparison between the two CS services, owning more cars prior to join CS (Odds ratio: 3.68–3.86, p-value: <0.001) and using CS services more frequently (Odds ratio: 2.91–2.98, p-value: <0.001 for members who use the service 4 times a month or more, Odds ratio: 5.54–5.82, p-value: <0.001 for members who use the service once a month or more) show positive correlations with vehicle ownership reduction. While the relationship between vehicle ownership and vehicle shedding (the more cars owned, the more likely a person sheds a car) is somewhat intuitive, the frequency of usage is against our intuition (the frequency of service usage and vehicle shedding are not in a linear relationship). Respondents who use CS once a month or more often had higher odds ratios (5.54–5.82) than respondents who use CS once a week or more (2.91–2.98). This may mean that infrequent drivers are the people who shed cars after joining CS.

The highest negative correlation was estimated for the relationship of household size to vehicle shedding (Odds ratio: 0.51, p-value: <0.001). This implies that as a household size increases from 1 to 2 or 2 to 3, the likelihood that CS will lead to a reduction in vehicle ownership falls by almost one half. We interpret this as an indication of how having many drivers leads to more frequent use of vehicles leading to retention of at least one vehicle.

None of regular CS vehicle access locations are correlated with vehicle shedding in a statistically significant level. Some local governments in the Vancouver region incentivise developers to locate CS vehicles in residential buildings by reducing parking requirement (Metro Vancouver, 2014a). However, the regression results did not confirm the correlation between on-site CS vehicle availability and vehicle ownership. Yet, this survey and analysis are not sufficient to conclude that on-site CS vehicle availability has no effect on vehicle ownership. For instance, Engel-Yan and Passmore (2013) found a correlation between on-site CS availability and vehicle ownership reduction in Toronto, Canada. The Metro Vancouver survey did not ask respondents' home locations; therefore, we do not know what fraction of respondents were living in buildings with on-site CS. Further investigations are required to comprehensively understand the effect of on-site CS vehicles.

As for trip purpose using CS cars, vacation trips (statistically significant for Model 1 only, odds ratio: 2.44, p-value: <0.001), shopping (odds ratio: 2.17–2.39, p-value: <0.001), medical appointments (odds ratio: 1.52–1.65, p-value: <0.05), and visiting friends/family (statistically significant for Model 1 only, odds ratio: 1.41, p-value: <0.05) have positive correlations with vehicle ownership reduction. A strong negative correlation is seen between trips to go to restaurant or bar and vehicle ownership reduction (Odds ratio: 0.47–0.52, p-value: <0.001). Overall, trips that are infrequent or long-distance, or require large storage spaces seem to have positive correlation with vehicle ownership reduction.

The highest odds ratio among all independent variables is seen in a motivation to join CS: cost savings compared to owning/leasing a car (odds ratio: 5.84–7.01, p-value: <0.001). A motivation to reduce pollution and fuel consumption had a positive correlation as well (odds ratio: 2.67–3.01, p-value: <0.01). Respondents with high financial and environmental sensitivities are more likely to reduce vehicle ownership.

3.4. Vehicle owners who give in vehicle ownership

865 respondents reported vehicle ownership reduction. They can be divided into two groups: those who gave up all vehicle ownership, and those who gave up some but not all of their cars. Regression Model 3 was built to understand the differences between these two groups. In this model, the dependent variable has value 1 for respondents who became zero-vehicle households, and 0 for those who kept at least one car.

Table 6 summarizes Model 3. All VIF values of the independent

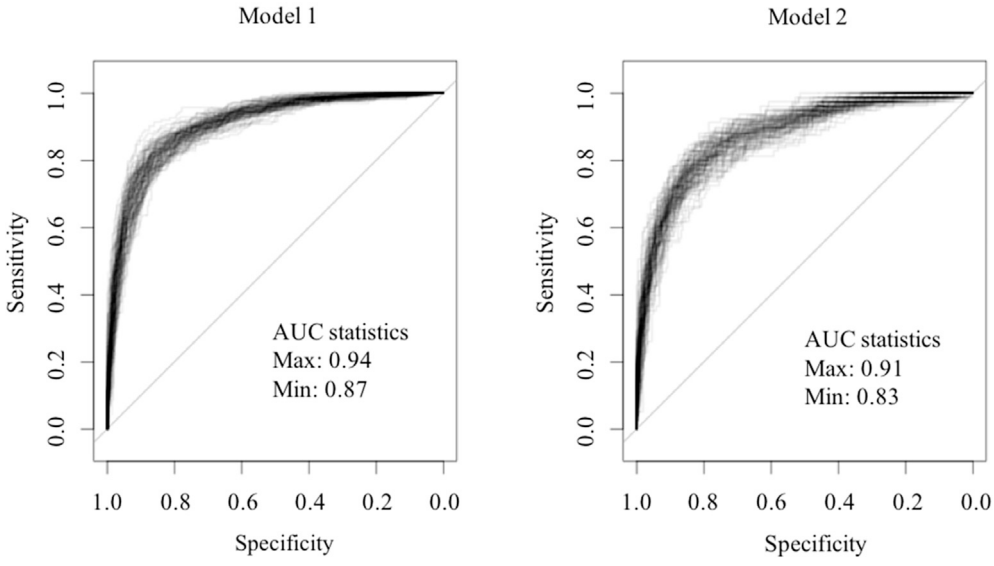

Fig. 4. ROC Curves (model 1 and model 2).

variables are less than 2. Fig. 5 shows the ROC curves of 100 random trials (train set: test set = 75:25). The predictability of Model 3 is moderate but lower than that of Model 1 and 2.

According to Table 6, when compared to the others, those who give up all vehicle ownership are more likely to: be living in rental housing (odds: 3.09, p-value: <0.001), have children (odds: 2.80, p-value: <0.5), have a smaller household size (household size, odds: 0.25, p-value: <0.001), and have a high environmental awareness (reduce pollution and fuel consumption, odds: 2.81, p-value: <0.5). In addition, these households are more likely to use both Modo and Car2go (odds: 2.72, p-value: <0.01), and use the services every month to every 2 weeks (odds: 3.04, p-value: <0.01). The purposes of trips using CS cars are likely for vacation trips (odds: 4.06, p-value: <0.001), shopping (odds: 3.73, p-value: <0.001), and recreational activities (odds: 2.45, p-value: <0.001), and rarely for going to a restaurant or bar (odds: 0.33, p-value: <0.001).

3.5. Alternative to CS

The survey asked questions about households' decisions in case CS programs were discontinued permanently (Fig. 6). Among Car2go only users, the CS service was used as an alternative of using transit (57%), pre-owned private car (46%) and taxi (44%). Given the relatively high vehicle ownership rate among this group of CS users (0.98 vehicle per household) and the small effect on vehicle ownership change (Table 5), Car2go service is less likely to substitute private car ownership but complement multi-modal travels of households who do not need additional access to private vehicles. Among Modo only and Car2go&Modo users, CS services were used as the alternative to own private car (43–52%), to use transit (41–55%) and taxi (32–44%). Since close to 70% of these users did not own cars, the termination of the services is likely to lead them to increase vehicle ownership.

Fig. 7 summarizes stated preference for buying/leasing additional cars if CS programs ceased. The likelihood of buying/leasing additional cars was higher among those who had reduced vehicle ownership, when compared who had not. Among those who reduced vehicles owned, over 55% stated they would increase vehicle ownership if CS services ceased, regardless of their CS provider (Fig. 7) – supporting the conclusion that CS is a substitute for car ownership for the majority of those who had reduced vehicle ownership after participating CS. Among those who did not change vehicle ownership, 30–49% stated that they would buy/lease additional cars if CS services ceased. This suggests that CS services may positively influence these households to forgo the purchase of vehicles. However, the responses were not sufficient for us to differentiate users who were motivated to gain vehicle ownership by joining CS from others who had an intention to have/add vehicles in prior to joining CS. For example, for some CS can satisfy their mobility demand and help them forgo buying a car. For others, CS may stimulate them to use cars more often. Both households would purchase cars under the termination of CS services; in the first case, CS works as a substitute for private cars while in the latter case, CS works as a gateway to vehicle ownership.

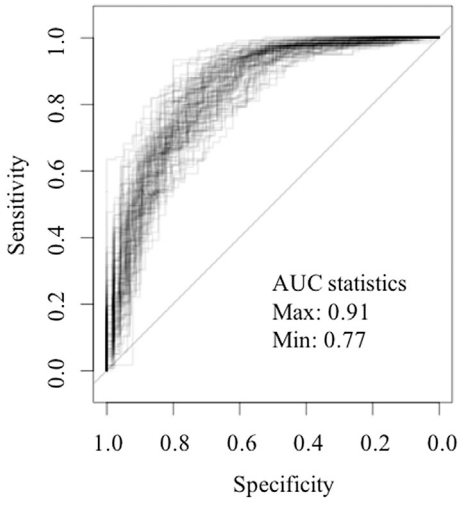

Fig. 5. ROC curve (Model 3).

The highest likelihood to purchase/lease cars under the termination of CS programs was found among households with membership in both Modo and Car2go. The combined features of these CS services delivered a more complete substitute for private vehicles. However, we need to be cautious about causality; for households who originally had mobility demand, CS could work as substitute for private vehicle ownership. On the other hand, for households who did not have mobility demand in the beginning, CS could work as a motivator of vehicle ownership. Further investigation is needed to understand the actual role of CS on mobility demand.

3.6. Vehicle reduced in the region

We calculated the number of private vehicles reduced by CS in the Vancouver region using the numbers found from the survey. Note that this calculation presumes that there is no selection bias, in other words, we assume that CS users who joined the survey were representatives of the whole CS users in the region. The robustness of the results based on this assumption is discussed later with a sensitivity analysis.

The rate of vehicle ownership reduction in each CS group is calculated as:

$$\overline{\boldsymbol{Pr_i}} = \overline{\boldsymbol{Vr_i}} \Big/ \overline{\boldsymbol{S_i}} \tag{1}$$

Where $\overline{Pr_i}$ is probability of vehicle ownership reduction among CS service i users, $\overline{Vr_i}$ is number of reduced vehicles in CS service i, and $\overline{S_i}$ is number of responses (sample size) from CS service i users. Similarly, the rate of forgoing vehicle purchase in each CS group is calculated as:

$$\overline{\boldsymbol{Pf}_i} = \overline{\boldsymbol{Vf}_i} \Big/ \overline{\boldsymbol{S_i}} \tag{2}$$

Where $\overline{Pf_i}$ is probability of forgoing vehicle purchase among CS service i users, and $\overline{Vf_i}$ is number of forgone vehicles in CS service i. Assuming that these rates ($\overline{Pr_i}$ and $\overline{Pf_i}$) are applicable to not only surveyed CS users but also non-surveyed CS users, the number of cars shed by CS in the Vancouver region can be calculated as:

$$\boldsymbol{Vr_i} = \overline{\boldsymbol{Pr_i}} \cdot \boldsymbol{Nc_i} \tag{3}$$

Where Vr_i is the number of vehicles reduced by CS service i in the entire region, and Nc_i is the number of users of CS service i in the region. Similarly, the number of vehicles that were not purchased because of CS in this region, in other words, the number of vehicles that will be added in case of CS service termination, is calculated as:

$$\boldsymbol{Vf}_i = \overline{\boldsymbol{Pf}_i} \cdot \boldsymbol{Nc_i} \tag{4}$$

Where Vf_i is the number of vehicles that were forgone purchase because of CS service i. Given the number of CS vehicles in each service, cars shed by per CS vehicle and cars added per CS vehicle in case of CS service termination can be calculated as:

$$\boldsymbol{Vr_i^p} = \boldsymbol{Vr}_i / \boldsymbol{Nv_i} \tag{5}$$

$$\boldsymbol{Vf_i^p} = \boldsymbol{Vf}_i / \boldsymbol{Nv_i} \tag{6}$$

Where Vr_i^p is the number of vehicles shed by each CS vehicle in service i, Nv_i is the number of shared vehicles in CS service i, and Vf_i^p is the number of vehicles added by each CS vehicle in case of service termination.

At the time of the survey, Car2go had 37,400 users and Modo had

Table 6
Regression model 3 (Dependent variable: Among respondents who shed cars, 1 for respondents who gave up vehicle ownership completely, 0 for the others).

Category	Sub-category	Est.	Pr(>|z|)		Odds
Intercept		−0.02	0.99		0.98
Estimated rent		0.00	0.83		1.00
Number of bedrooms		0.24	0.31		1.27
Living in rental housing		1.13	0.00	***	3.09
Length of residency in current unit (reference: <1yrs)	1-2 yrs	0.22	0.61		1.25
	3 yrs or more	0.29	0.48		1.34
Household size		−1.40	0.00	***	0.25
Household	with children (<16 yrs old)	1.03	0.02	*	2.80
	with elderlies (>64 yrs old)	0.18	0.73		1.20
Number of family members work outside of home	−0.31	−0.31	0.10		0.74
Number of vehicles owned (before joining CS)					
CS membership (reference: Car2go only user)	Modo only user	−0.04	0.92		0.96
	Modo and Car2go user	1.00	0.01	**	2.72
Length of CS membership (reference: <1 yr)	1-2 yrs	0.29	0.43		1.33
	3 yrs or more	0.32	0.44		1.38
Frequency of CS use (reference: <1/month)	>4/month	0.40	0.24		1.50
	>1/month	1.11	0.00	**	3.04
Regular CS vehicle access location	Within apartment/townhouse complex	0.68	0.37		1.98
	Street near home	0.24	0.55		1.28
	Other building/parking facility near home	−0.25	0.45		0.78
	Location close to work or school	−0.18	0.57		0.83
	Location close to shopping mall	0.39	0.51		1.48
	Location close to transit station	0.17	0.60		1.18
Trip purpose	Travelling to work	−0.46	0.14		0.63
	Travelling to school	0.29	0.62		1.34
	Shopping and errands	1.32	0.00	***	3.73
	Visiting friends/family	0.34	0.20		1.41
	Going to a restaurant or bar	−1.11	0.00	***	0.33
	Medical appointments	0.15	0.60		1.16
	Recreational activities	0.90	0.00	***	2.45
	Vacation trips	1.40	0.00	***	4.06
Home relocation after joining CS		−0.02	0.96		0.98
Reasons to join CS	Free or discounted membership	0.31	0.54		1.36
	CS is conveniently located in our housing complex	0.44	0.52		1.55
	CS vehicle is conveniently located on a street near home	0.45	0.27		1.56
	Additional mobility option	0.35	0.43		1.41
	Convenient compared to transit	−0.10	0.80		0.90
	Convenient compared to walking	0.85	0.46		2.34
	Convenient compared to cycling	−1.58	0.09		0.21
	Convenient compared to riding with others (carpooling))	−0.72	0.32		0.48
	Convenient compared to using owned/leased vehicle	0.32	0.51		1.37
	Cost savings compared to owning/leasing a car	0.05	0.90		1.05
	Household-owned vehicle stopped working	−0.06	0.91		0.94
	Cost savings compared to car rental	0.10	0.85		1.11
	Cost savings compared to using taxis	−0.32	0.51		0.72
	Reduce pollution and fuel consumption	1.03	0.02	*	2.81
	Free or better parking options	−0.20	0.69		0.82
	The philosophy of sharing	0.74	0.11		2.09
AIC:	563.07				
McFadden's Pseudo-R squared:	0.42 (df = 47)				

p-value symbols: <0.1 = ., <0.05 = *, <0.01 = **, <0.001 = ***.

7,900 users (Metro Vancouver, 2014b). Unfortunately, the number of households who had both Car2go and Modo is unknown. Among the survey respondents, 46% of Modo members had Car2go membership. Assuming that this number is applicable to all Modo members, the numbers of each group can be estimated at Car2go only (33,766), Car2go&Modo (3,634) and Modo only (4,266). The result of calculations using equations (1-6) is summarized in Table 7.

Assuming a representative sample of survey respondents, we estimate cars removed by each CS service: 3,385 for Car2go only, and 1,204 for Car2go&Modo, and 1,374 for Modo only. Potential increases of cars under the termination of CS services are 10,953 by Car2go only users, 2,092 by Car2go&Modo users, and 2,068 by Modo only users. Note that this increase is not equal to the number of forgone car purchases by CS users. Intention to purchase a car could be a dependent of CS experience, for example, by joining CS, car-free households might learn the convenience and necessity to have access to cars, or households with car ownership may realize the benefits of less car-dependent lifestyle.

The results in Table 7 show that Car2go only users reduced the largest

Table 7
Vehicle reduction by CS in the region.

		Car2go only	Car2go & Modo	Modo only
Survey results	Cars shed by CS ($\overline{Vr_i}$)	123	232	265
	Households who definitely or likely buy/lease cars under CS service termination ($\overline{Vf_i}$)	398	403	399
	Survey response ($\overline{S_i}$)	1,227	700	823
	Response rate	0.04	0.19	0.19
Calculated coefficient	Cars shed per response ($\overline{Pr_i}$)	0.10	0.33	0.32
	Cars added per response under CS service termination[a] ($\overline{Pf_i}$)	0.32	0.58	0.48
CS data	Number of CS users	Car2go: 37,400, Modo: 7,900		
	Assumed number of CS users (N_i)	33,766	3,634	4,266
	Number of CS cars	550	550 + 303 = 853	303
Calculated value	Cars shed by CS (Vr_i)	3,385	1,204	1,374
	Cars shed per CS vehicle in service (Vr_i^p)	6	1	5
	Cars added under CS service termination (Vf_i)	10,953	2,092	2,068
	Cars added per one CS vehicle under CS service termination (Vf_i^p)	20	2	7

[a] Assuming that a household who increase vehicle ownership lease/purchase a single car.

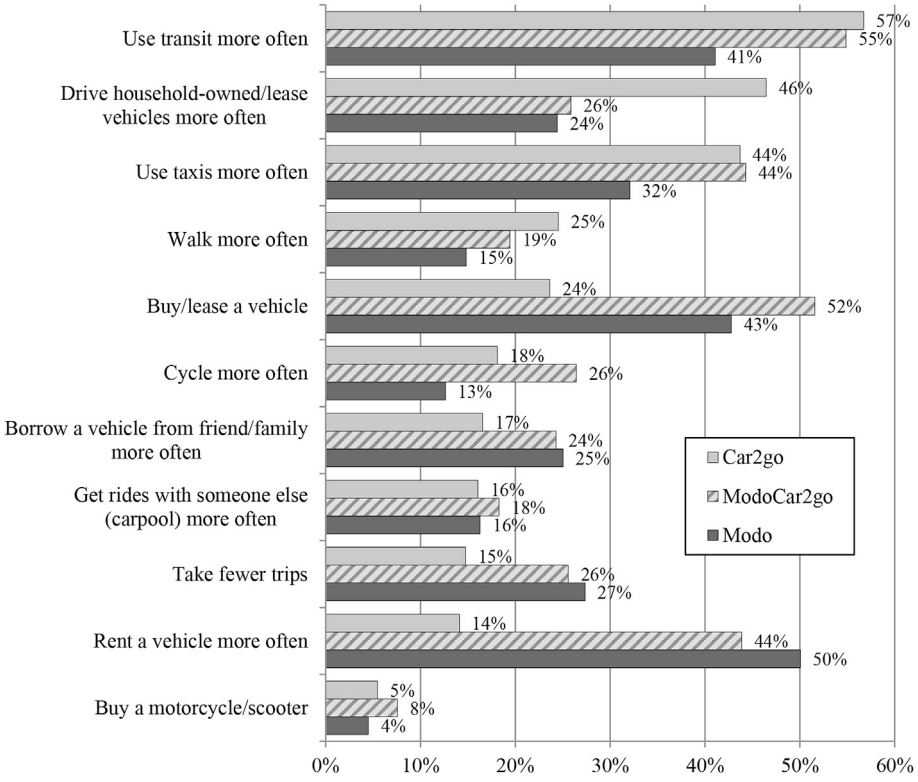

Fig. 6. If CS programs were discontinued permanently, would your household?

number of cars (3,385). Also, each Car2go vehicle reduced 6 cars while one Modo vehicle reduced 5 cars. However, this number is highly likely the response of a system out of equilibrium. 2013 was the third year of operations for Car2go– the early adopters of Car2go. Meanwhile, Modo was in its 16th year of operation, a mature system. We suspect that early adopters are those for whom CS offers the greatest impact. Further research is needed to characterize the returns to introduction of additional CS vehicles as the general population join up.

3.6.1. *Sensitivity analysis*

As pointed out in the beginning of Section 3, the survey responses are likely to be biased. There is a high possibility that the survey participants are skewed towards CS users who are active and/or interested in the survey objectives (e.g., positive social impacts of CS services, see Sioui et al. (2013) for example). Moreover, the numbers shown on Table 7 reflect CS user population that are reported by CS providers; in other words, the numbers on Table 7 assume that all registered CS membership holders are active users. In order to understand the significance of these bias and assumption, we conducted a sensitivity analysis assuming different levels of sampling bias and active CS member rate. Since we lack data of users who use both Car2go and Modo, this analysis focuses on the other two groups, Car2go only and Modo only groups.

Fig. 8 shows the distribution of frequent service users among Modo membership holders. The left bar shows the distribution among the survey participants (Modo only users), while the right bar shows the distribution among the whole population of Modo membership holders (Modo the Car Co-op, 2016).[6] The rates of frequent users (“>4/month” and “>1/month”) are higher among the survey respondents, while a small difference is seen in the rate of inactive (“Never”) users (1.2% vs. 2.6% for the survey participants and Modo data, respectively). Therefore,

[6] The data is shared by Modo, and is based on the service usage recorded during the period between 2014 and 2016. The survey data used for the earlier analyses were collected in 2013. Because of Modo's over 15 years of service history, we believe that the service has been matured enough and there is little difference in user characteristics between 2013 and 2016.

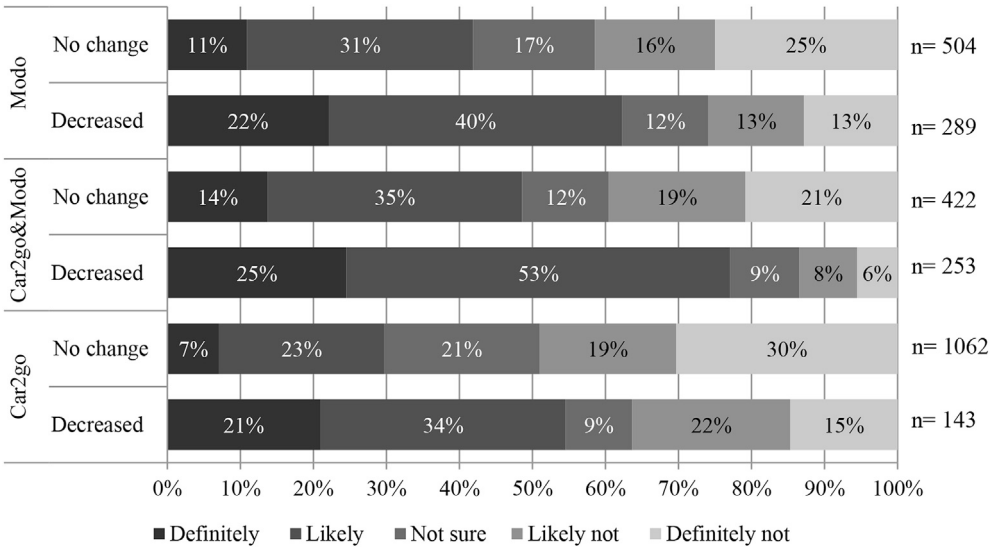

Fig. 7. Likelihood of buying/leasing additional vehicles under the termination of CS programs (Because of small sample size, households who increased vehicle ownership were excluded).

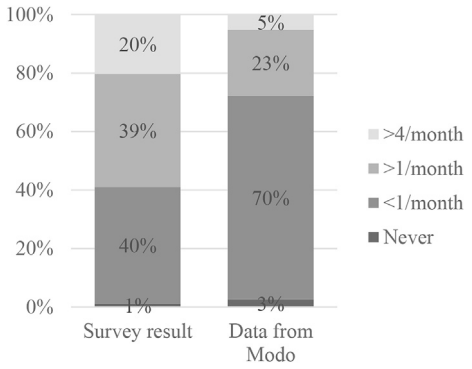

Fig. 8. Distribution of frequency of service use among Modo users (Modo the Car Co-op, 2016).

a sampling bias is likely to exist, while most Modo users are active members. Since the survey response rate was 19% for Modo only users (Table 7), the survey participants represent minimum 19% of the whole Modo users, but not likely 100% of the whole population.

The actual distribution of the frequency of Car2go use is unknown. However, we were able to assume the average number of daily trips per car2go vehicle: 3.3 trips per day.[7] Considering that 550 vehicles were available (Table 2), 662,475 trips were made annually at the time of survey. On the other hand, the distribution of frequent users among the survey participants was; 31% of the survey participants used the service more often than four times per month, 33% used more than once a month, another 33% used less than once a month, and the rest of 3% had never used the service (Table 3). Considering the number of Car2go only users estimated in Table 7, the number of trips made at the time of survey was estimated as 1,016,966 trips,[8] which is 56% larger than the number calculated based on the average vehicle usage data. Moreover, this number, 1,016,966 trips, does not include trips made by people who have both Car2go and Modo memberships. Therefore, the survey participants are highly likely overrepresented by frequent and active service users. Since the response rate of Car2go users was 4% (Table 7), the survey participants at least represented 4% of the whole Car2go population, but not likely to represent somewhere close to 100%.

Considering these arguments, in this sensitivity analysis, equation (1) is altered to

$$\overline{\boldsymbol{Pr_i}} = \left(\overline{\boldsymbol{Vr_i}} \Big/ \overline{\boldsymbol{S_i}}\right) \cdot \boldsymbol{SMP_i}$$

$$\left(0.04 \le \boldsymbol{SMP_{Car2go}} \le 1.00, 0.19 \le \boldsymbol{SMP_{Modo}} \le 1.00\right) \quad (7)$$

Where $\overline{Pr_i}$ is probability of vehicle ownership reduction among CS service i users, $\overline{Vr_i}$ is number of reduced vehicles in CS service i, $\overline{S_i}$ is number of responses (sample size) from CS service i users, and SMP_i is a random sampling bias variable of CS service i users. The sampling biases were assumed to follow normal distributions (SMP_{Car2go}: mean=(1 + 0.04)/2 = 0.52, SD = 0.1, satisfying $0.04 \le SMP_{Car2go} \le 1.00$, SMP_{Modo}: mean=(1 + 0.19)/2 = 0.60, SD = 0.06, satisfying $0.19 \le SMP_{Modo} \le 1.00$). When SMP_i is equal to 1.00, there is no sampling biases between the survey participants and the whole population of service users.

Similarly, equation (3) calculating the number of cars shed by CS in the Vancouver region is altered to:

$$\boldsymbol{Vr_i} = \overline{\boldsymbol{Pr_i}} \cdot \boldsymbol{Nc_i} \cdot \boldsymbol{ACT_i}$$

$$\left(0.50 \le \boldsymbol{ACT_{Car2go}} \le 1.00, \boldsymbol{ACT_{Modo}} = 1.00\right) \quad (8)$$

Where Vr_i is the number of vehicles reduced by CS service i in the entire region, Nc_i is the number of entire users of CS service i in the region, and ACT_i is a randomly chosen active membership rate of CS service i users. ACT_{Modo} was set to 1.00 because over 97% of Modo membership holders were active users (Fig. 8). When comparing Car2go and Modo, the difference in fee structures for the two services are likely to lead to different levels of participation by members. As noted in Table 2, Car2go does not levy an annual fee, while Modo imposes a $5/month membership fee or $500 refundable share purchase. Sometimes Car2go even forgoes their nominal fee for membership registrations. This lowers the barrier to membership, and Car2go membership are more likely to have it as a low cost additional option for personal transportation that is rarely exercised. Therefore, assuming a lower value of active membership rate for Car2go only users is likely to reflect the actual condition.

[7] Car2go reported that over 825,000 Car2go trips had been made by February 2013 since its service launch in Vancouver (June 2011)(Crowe, 2013). Assuming that the average number of fleet active during the service period was 388 (considering the service had 225 cars at the time of launch and increased to 550 at the time of the survey in 2013), one average Car2go car had about 3.3 trips per day.

[8] The survey provided four options to answer the frequency of service usage: very often (more than 4 times per month), often (more than once a month), rarely (less than once a month) and never. In order to estimate the total number of trips, we assumed that "very often" as 5 times per month, "often" as 2 times/month, "rarely" as once a month, and "never" as zero.

Unfortunately, there is no relevant data available to systematically assume the active membership rate. Therefore, for simplification sake, ACT_{Car2go} was assumed to follow a normal distribution with mean of 0.75 and SD of 0.04 (satisfying $0.5 \leq ACT_{Car2go} \leq 1$).

Fig. 9 and Fig. 10 summarize the results of the Monte Carlo simulation as a Cumulative Distribution Function (CDF) and a Probability Distribution Function (PDF)(showed as histograms). The simulation was conducted for 500,000 times. Both of the figures show that levels of sampling bias and active membership rates significantly affect the number of cars shed by one CS vehicle. In Fig. 9, the two curves cross at the probability of 0.94 and the number of cars shed per CS car of 3.13, meaning that with 94% of probability, one Modo car shed more cars than one Car2go car.

These are result of a very preliminary sensitivity analysis. Unless the information of CS usage and people who were invited to the survey become available, detailed sensitivity analyses are unlikely to be feasible.

4. Summary and discussion

This paper explores the relationship between membership in CS services and vehicle ownership. We studied the difference between CS services offering a one-way (free-floating) service utilizing a fleet of subcompact 2-seaters (Car2go) to a two-way service utilizing a range of vehicles suitable for a variety of trip purposes (Modo).

By analyzing the results of a survey directed at CS members in Vancouver, we found that both Car2go and Modo users reported reduced vehicle ownership after joining CS. The reductions were statistically significant for all user groups in the study. Although the survey data is not sufficient to conclude the causal relationship between CS participation and vehicle ownership reduction, considering the facts that vehicle ownership in the region has been stable during these 15 years (Metro Vancouver, 2012a, 2015) and vehicle ownership reduction among CS users have been repeatedly reported (see Table 1), it is highly likely that CS participation and vehicle ownership reduction have a certain correlation.

The reported vehicle reduction was smallest for respondents who were only members of Car2go. In this group, 12% reduced vehicle ownership while in the other two groups (Modo and Modo&Car2go users) over 35% reduced vehicle ownership. The result of the logit regression analysis quantitatively substantiated this difference between Car2go and Modo users. Respondents with Modo membership were roughly five times more likely to reduce car ownership compared to users who were only members of Car2go (see Table 5). Following the financial motivation to join CS and frequent use of CS cars, membership in Modo was the third largest factor explaining vehicle ownership reduction.

By analyzing what respondents would do should CS services be terminated, we found that Car2go and Modo are likely to be used differently. Car2go users utilize the service as a complement to other modes of transportation including: taking transit, using pre-owned private cars, and taking taxis. In other words, Car2go is an additional option to make their multi-modal travels easier and more convenient. In contrast, Modo is more likely to be used as a substitute for private car ownership. Under the termination of CS programs, 50% of Modo users will rent a vehicle more often, and over 40% will buy/lease a vehicle.

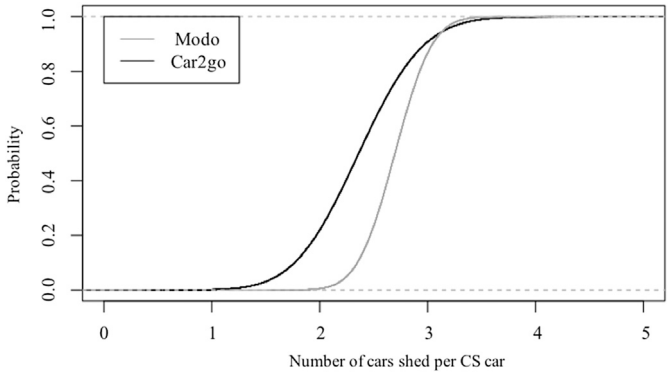

Fig. 9. Cumulative density of number of cars shed per vehicle in Car2go or Modo fleet based on the 2013 Metro Vancouver survey.

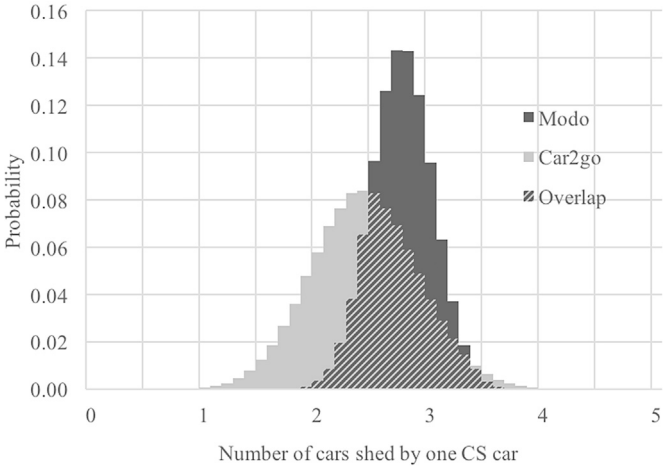

Fig. 10. Probability density of number of cars shed per vehicle in Car2go or Modo fleet based on the 2013 Metro Vancouver survey.

In terms of reported intention to buy/lease a vehicle in case of CS program termination, CS users who reduced vehicle ownership showed stronger likelihoods to buy/lease a vehicle. This suggests that for users who reduced vehicle ownership, CS services have been substituting mobility services previously supplied by private vehicles. The intention to gain a vehicle under the termination of CS programs was strongest among users who had both memberships of Car2go and Modo. We consider this is because Car2go and Modo are not simple rivals as CS services but complements providing difference mobility services. A possible scenario is that Modo substitutes private vehicle ownership, and Car2go eases a lifestyle with restricted access to private vehicles.

This scenario is consistent with the findings from regression models. Respondents who hold memberships of both Modo and Car2go had higher likelihood to shed cars compared to both Car2go only and Modo only users (see Table 5). The double membership is especially prominent for respondents who gave up vehicle ownership completely and became zero-vehicle households (see Table 6). These findings again suggest the possibility of the two services as compliments, and that utilizing the two service simultaneously may benefit to reduce the vehicle dependency.

Our analyses show that Car2go and Modo have different roles in mobility provision. Modo has a stronger correlation with reduced vehicle ownership. We do not conclude that these differences are caused only by one-way and round-trip service styles. We believe that the difference in the service style (one-way vs. round-trip) is a key factor leading to the difference in vehicle ownership reduction; however, we also acknowledge that other factors, especially available vehicle size and functions may be important. Further analyses are required to explore this question, preferably by comparing two one-way and round-trip CS services sharing common vehicle offerings and other attributes such as membership fees.

This study employed data solely from the Vancouver region in Canada; however, the methodology is applicable to other regions and countries. By applying the same methodology on other data sets, a more comprehensive picture of CS's effects on society could be revealed.

We caution the reader about the various limitations of this study. The survey respondents are unlikely to be representative of all CS members. At the time of the survey, Car2go was relatively new to the region. Early adopters are likely to have been those who were more prepared to shed vehicle ownership. More than 90% of the respondents were from the City of Vancouver, a dense urban core where a quarter of the greater metropolitan region's population reside. This sub-population is unlikely to be

representative of the whole; carsharing users have distinct demographics and lifestyles compared to the general public (Namazu et al.). Findings from this study should not be generalized to the general public without careful considerations. Finally, as CS matures we will be in a better position to estimate its long-term impact on private vehicle ownership.

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