THE EVOLUTION OF CARSHARING: HETEROGENEITY IN ADOPTION AND IMPACTS

by

Michiko Namazu

B.E., Kyoto University, 2011
M.E., Kyoto University, 2013

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

in

THE FACULTY OF GRADUATE AND POSTDOCTORAL STUDIES

(Resource Management and Environmental Studies)

THE UNIVERSITY OF BRITISH COLUMBIA
(Vancouver)

March 2017

Abstract

The focus of this thesis lies on understanding how heterogeneity in carshaing (CS) and members at different stages of its adoption in society shape its impacts on Greenhouse Gas (GHG) emissions and car ownership. Past studies have two shortcomings: they do not acknowledge the bias that could arise due to the keen interest of early adopters, and they did not tease out the role of service type in observing outcomes of interest.

The serial studies in this thesis found the potential of CS to reduce GHGs and vehicle dependency. However, this does not mean that CS promises to always provide these benefits to everyone. The positive effects found among early adopters do not guarantee that the same effects would be realized among coming adopters especially because early adopters of CS are atypical of the general public in many individual and household characteristics. This is the one of the two primary findings from this thesis: the dynamics of CS service diffusion. As the adoption stage matures, the usage and roles of CS would be changing hence the effects.

The second primary finding is the importance of heterogeneity between CS services. Two distinct CS services were found to have different impacts in vehicle ownership change, suggesting that the heterogeneities among CS services affect how the services are utilized; hence what kind of effects the CS services bring to society. Policy makers often generalize various CS services as CS; however, the heterogeneities will need a more careful attention and specifically tailored policies in order to ensure CS impacts continue to align with sound urban transport policy.

These dynamic changes will affect how CS services should be maintained. Managing shared properties has been a challenging issue, and this may become even more difficult with more diverse users and CS service models.

Active knowledge sharing and collaborations among stakeholders (policy makers, CS providers, and scholars) may be a kay factor to bring further benefits to all. As CS carries the word of

“sharing”, if these stakeholders could build a better collaborative “sharing” environment, a large part of the potential of CS may be feasible.

Preface

In all four of the following research papers my contributions include: a) identification of research questions, b) research design, c) performance of research activities, d) data analysis and e) manuscript preparation.

Paper I (Chapter 2): *Characterizing the GHG Emission Impacts of Car-sharing*

In this chapter I conducted the literature review, developed travel behaviour scenarios, built a linear emission estimation model, conducted data analysis and wrote the manuscript. Hadi Dowlatabadi and Hisham Zerriffi provided early insights into the paper framing and key concepts. Hadi Dowlatabadi provided comments for revision on several drafts as well. Three anonymous reviewers for *Environmental Research Letters* provided constructive comments on the scope of the work and limitations of findings. The paper was published in 2015 in *Environmental Research Letters* and can be found at http://iopscience.iop.org/article/10.1088/1748-9326/10/12/124017/meta (doi:10.1088/1748-9326/10/12/124017).

Paper II (Chapter 3): *Vehicle ownership reduction: A comparison of one-way and two-way carsharing systems*

In this chapter, I conducted the literature review, developed the paper outline, conducted data analysis and wrote the manuscript. Hadi Dowlatabadi helped with conceptual development, provided valuable insights into the analysis of data and interpretation of findings, and provided comments for revisions. The paper is submitted for jounal publication.

Paper III (Chapter 4): *Is Carsharing for Everyone? Understanding the Diffusion of Carsharing Services*

In this chapter, I conducted the literature review, developed the paper outline, conducted data analysis and wrote the manuscript. Hadi Dowlatabadi contributed to early conceptual development, helped to refine the structure of the paper and clarify findings, and provided comments for several revisions. Hisham Zerriffi contributed to the interpretation of results and provided comments for revisions. Don MacKenzie contributed to the interpretation of statistical results, and provided commends for revisions. The paper has been accepted for oral presentation at Transportation Research Board Annual Meeting 2017 and is in peer review for publication.

Paper IV (Chapter 5): *Nudging for responsible carsharing: Using behavioral economics to change transportation behavior*

In this chapter I conducted the literature review, designed field experiments, conducted the experiments, conducted data analysis and wrote the manuscript. Jiaying Zhao and Hadi Dowlatabadi contributed to the experiment design and data interpretation, and provided comments for revision on several drafts. An editor and three anonymous reviewers for *Transportation* provided constructive comments on the scope of the work and limitations of findings. The paper was published in 2015 in *Transportation* and can be found at http://link.springer.com/article/10.1007/s11116-016-9727-1?view=classic (doi:10.1007/s11116-016-9727-1). This study was conducted with an approval from UBC Behavioural Research Ethics Board (Project title: Inspection before use: examining car-rental user behaviour, UBC BREB Number: H14-03289).

Table of Contents

List of Tables

List of Figures

Acknowledgements

I would like to express my special appreciation and thanks to my supervisor, professor Hadi Dowlatabadi. You have been a tremendous mentor for me. This three and half years of my Ph.D. journey has been an amazing experience thanks to your generous and warm support. Thank you for accepting me who has a totally different background. I know it took a lot of efforts and time for you to lead me to come here. You did not give up on me when I almost gave up on myself. I cannot stop saying this, but thank you so much. I learned a lot from you, and hope to keep learning from you.

I would also like to thank my committee members, professor Hisham Zerriffi and professor Jiaying Zhao for serving as my committee members and support my journey. Thank you very much for being supportive for my projects, and being there whenever I need help.

Another thanks is to my internship supervisor, professor Don MacKenzie for welcoming me to his lab and dedicate his time and effort for me. I am extremely lucky to receive the chance to work with you and your students.

I would also want to thank all of researchers and staffs in local governments, carsharing companies and UBC communities who supported my study. Without your support, my PhD study has never been in this shape. I hope my work is meaningful for you too; my goal is to be a researcher who solve real issues.

Another special thanks is to my friends in Vancouver, Seattle, Japan and other cities and countries. Without your help, I could not come here. Especially for this Ph.D journey, I truly appreciate to be a part of my cohort in RMES. My dearest friend, Ghazal Ebrahimi, you are my friend, supporter, and great mentor. You never know how much you helped me. Thank you so much. I should not forget mentioning Manuel Colombo here too – You two are always there when I face difficulties and feel depressed. It is a miracle that the three from totally different places in the world met in Vancouver, and chat together a lot in English in a Sushi restaurant! Tugce, Jackie, Guillaume, Nick, Liz, and other classmates, words are not enough to express my

appreciation to all of you. Probably it is a good time to learn the western culture that I have been struggling to learn – I promise to give big hugs to all of you!

To my family in Japan; thank you for your encouragement to go through this journey. My mom, who probably have never thought that her fifth kid would go this far from Japan, thank you so much for being supportive for my journey. I know that you never wanted me to leave the country. I hope you are happy to see me completing this journey, and feel proud of your daughter.

Last but not least, I would like to thank my husband, Joshua Dhaliwal. You are the person who know the full picture of my journey. It has been a true adventure (sometime I felt like I am taking the Mummy roller coaster), and you are always there, by my side. You know my joys, excitements, struggles, frustrations, and everything I went through in this journey. I wish I could give you another Ph.D – we came here together. There is no way that I can fully express my appreciation to you. I just hope that I am a good wife for you, and hopefully proud of me (but remember, we achieved this together). I love you so much.

Dedication

To my mother who encouraged me to take this journey, and
To my husband who always be on my side.

献辞

海外で研究するという夢を温かく見守ってくれる母と
いつでも私の味方でいてくれる夫へ。

Chapter 1: Introduction

1.1. Brief Summary of This Thesis

Carsharing (CS), a form of short-term car rental service is on the rise. From 2006 to 2014, membership grew from 0.3 million to 5 million and the fleet serving them grew from 11,000 to over 100,000 (Shaheen & Cohen, 2016). This rise is expected to continue (Le Vine & Polak, 2015; PricewaterhouseCoopers, 2015) partially thanks to integration of technological innovations, such as Global Positioning Systems (GPS), smart phones and online payment technologies (Transportation Research Board, 2016). The rise is also supported by shifts in lifestyle choices, and partially due to the global economic downturn since 2008 making vehicle ownership less affordable (ller, Weikl, Müller, & Bogenberger, 2015; Transportation Research Board, 2016; Zipcar, 2014). Various stakeholders have embraced CS services. City residents have chosen CS as a convenient mobility option (see for example, (Zhou & Kockelman, 2011)), automotive industries consider CS services as a chance to expand their businesses (Firnkorn & Müller, 2011a), and local governments see it as a measure to solve environmental and transportation related issues (see Section 1.2.3 for details).

The literature has treated CS as a homogenous service and treated its early adopters as representative of the general population. My thesis explores four, hitherto neglected, heterogeneities in CS: differences between household trip and mode choice patterns, differences between CS services in car-shedding patterns, differences between household CS membership patterns, and differences between member behaviours. These studies provide a stronger foundation for projecting the future role of CS, its social and environmental impacts.

Findings from these serial studies led to two principal findings: 1) the dynamics of the CS diffusion process and 2) the importance of heterogeneities among CS services. As the rapid rise in membership suggests, CS is no longer at the early adopter stage. As adoption of CS continues to early and late majority, its utilization patterns and impacts will continue to evolve. Looking further ahead, the transportation sector will be undergoing a dramatic transformation with the introduction of autonomous vehicles. CS provides a window on the many factors that will shape their adoption and use. Understanding existing heterogeneities in the adoption and usage of CS services provides critical input for both developing appropriate policies and evolving these policies over time to manage the personal transportation systems of the future.

1.2. The Rise of Carsharing

1.2.1. Brief History of Carsharing

CS started as a way to provide affordable access to a car (Shaheen, Sperling, & Wagner, 1999). The first service of this kind originated in Switzerland in the late 1940s (Le Vine, Lee-Gosselin, Sivakumar, & Polak, 2014a; Shaheen et al., 1999). After this launch, this type of services was rarely reported in any literature until 1970s when some public CS experiments were undertaken and later terminated in Europe (Osborn, 2011). More successful CS experiments started in the late 1980s in multiple European countries; there were approximately 200 CS organizations in 450 cities providing services for 125,000 members (Shaheen et al., 1999). The services eventually expanded to other continents, such as North America and Asia in the late 1990s and 2000s (K. M. N. Habib, Morency, Islam, & Grasset, 2012; Shaheen et al., 1999). Since the launch of the very first successful CS program in North America in 1994 in Quebec, Canada, North American membership in CS has grown rapidly (Figure 1.1 and Figure 1.2).

The role of Information Communication Technologies (ICTs) in this phenomenon is described by Le Vine, Zolfaghari and Polak as well as others (Le Vine, Zolfaghari, & Polak, 2014b; Transportation Research Board, 2016). ICTs lowered CS transaction costs, such as finding, booking, billing and paying for a vehicle (Geradin, 2015; Henten & Windekilde, 2016; Transportation Research Board, 2016). Transaction costs are often classified into three types: *search and information* costs, *bargaining* costs, and *policing and enforcement* costs (Dahlman, 1979). For ICT-based CS platforms, search and information costs, or in other words costs for finding the availability of cars and their pricing systems, are significantly lower than CS platforms that don't use ICTs (Henten & Windekilde, 2016). All CS members need to do in a modern CS platform is to open an app on a smartphone, whereas users in a conventional platform need to talk to CS staff to confirm find and reserve the use of a vehicle. Other high cost transactions such as negotiating prices, and policing and enforcement costs, were also cut by a significant amount thanks to ICT-based platforms. These lowered transaction costs have made modern CS services more convenient, flexible, and affordable.

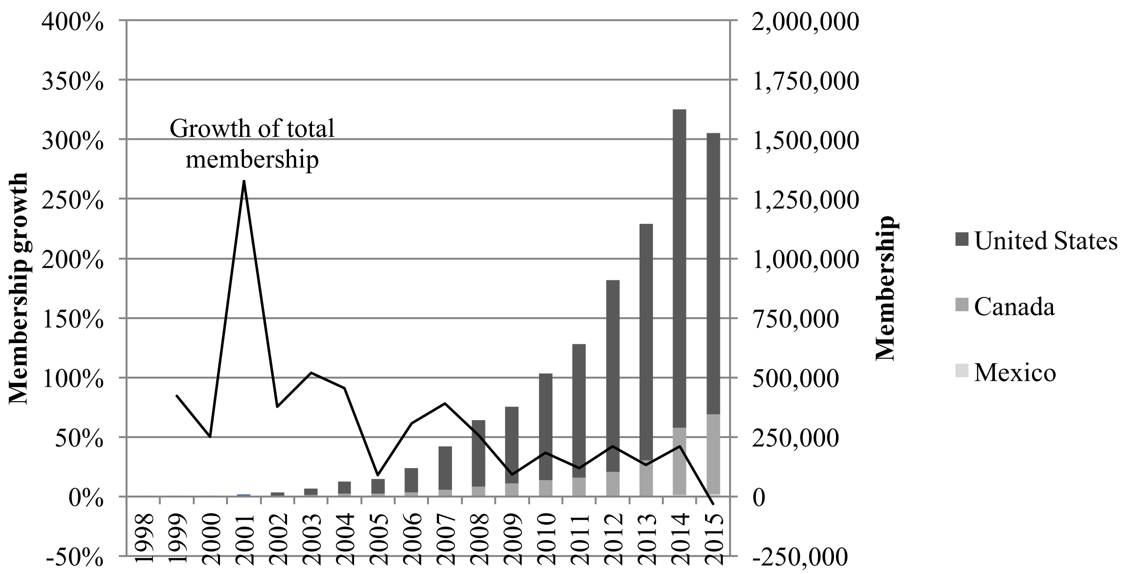

Figure 1.1: Annual growth rate in and total CS membership in North America[1] (Source (Shaheen & Cohen, 2012; 2013b; 2014; University of California Berkeley Transportation Sustainability Research Center, 2015a))

[1] The growth of total CS membership in North America showed a negative growth between 2014 and 2015. This decline was highly likely caused by a membership shrink in the U.S. after the closure of two one-way CS services (University of California Berkeley Transportation Sustainability Research Center, 2015a) in California. Both of the closures were results of disagreement between CS providers and local governments, instead of unpopularity of the services. This issue is discussed in detail in the next section.

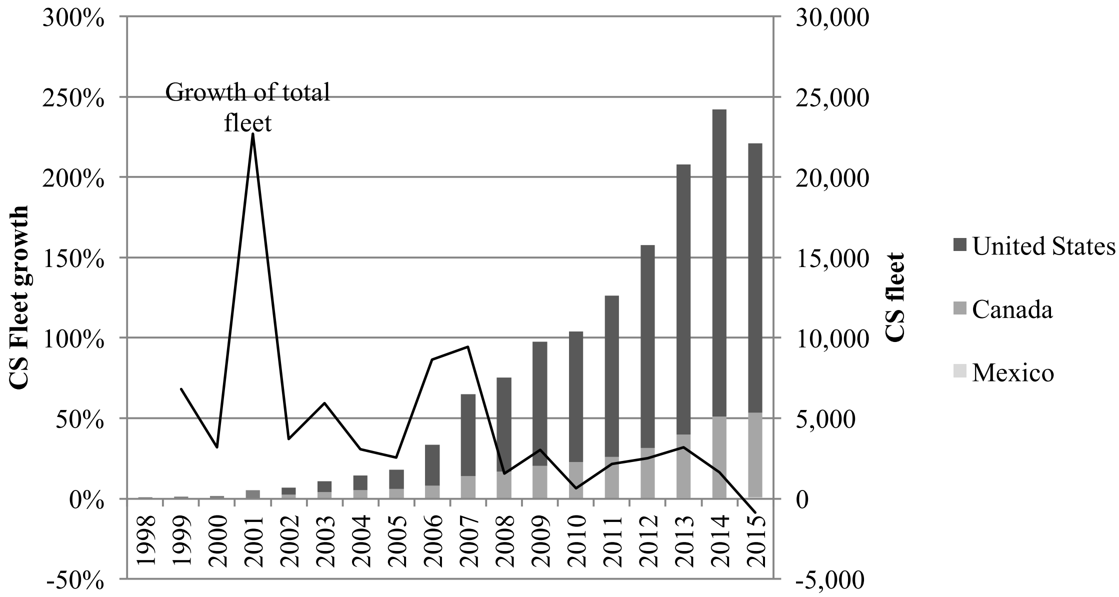

Figure 1.2: Growth of CS fleet in North America[2] (source (Shaheen & Cohen, 2012; 2013b; 2014; University of California Berkeley Transportation Sustainability Research Center, 2015a))

The original CS service style is a round-trip model (Shaheen et al., 1999). The term "round-trip service" here means that members would need to return vehicles to their original starting location. About 30 years after the start of round-trip CS services, one-way CS services (aka, point-to-point CS services) were started in Europe (Shaheen, Chan, & Micheaux, 2015). Unlike round-trip services, one-way CS users do not have to return a vehicle to the original location where they picked up the car; they can select a station to return a vehicle (Station-based one-way CS services). Many attempts were made to provide these one-way CS services since then; however, most of the projects were terminated after the experiment phrase with limited success (Shaheen, Chan, & Micheaux, 2015). In 2008, the capabilities of ICT led to the launch of a new model of service: free-floating one-way CS services. This type of CS service allows users to drop-off vehicles anywhere within a service area as long as they follow local parking regulations. The idea of free-floating CS services has been around for a while, and there were many early trials in different locations (Le Vine, Lee-Gosselin, Sivakumar, & Polak, 2014a; Shaheen, Chan, &

[2] The decline in CS fleet between 2014 and 2015 corresponds to the decline in membership seen in the same period of time. See footnote 1.

Micheaux, 2015). However, none were practical until the first commercial one-way CS services (Car2go by Daimler AG) started in 2008 in Ulm, Germany by Daimler AG (Le Vine, Lee-Gosselin, Sivakumar, & Polak, 2014a; Shaheen, Chan, & Micheaux, 2015). The success of Car2go was due to multiple factors; however, integration of the smartphone user interface and backend asset management software seems to be crucial to realizing that success. Since the establishment of Car2go, many other one-way CS services have been launched and are accelerating the appeal and adoption of CS (e.g., DriveNow/ReachNow by BMW AG). In 2014, 23% of CS fleets were providing one-way services (including both station-based and free-floating one-way CS services), accounting for 18% of the global memberships (Shaheen & Cohen, 2016).

1.2.2. CS, a Type of Car Rental Services

CS is a type of car rental services. Some advocates of CS and Sharing Economy claim that CS as a part of the Sharing Economy services, which are more pro-social and collaborative style of consumption (Botsman & Rogers, 2011). However, the history of similar activities suggests that this type of car rental services may be branded as "carsharing" due to marketing strategies. Durgee (1995) points out that in the 1990s, the word "borrowing" was preferred over the word "renting", because of "the negative connotation that renting has in certain population segments" (Durgee & Colarelli O'Connor, 1995)(p.91). The same trend could be assumed for the use of the term "sharing" in today's CS services. Originally, the word "sharing" had been used to describe altruistic, pro-social and non-monetary-based giving of goods (Belk, 2010). Belk (2010) also points out that conventional sharing activities are usually seen among family or closed communities, associated with shared responsibilities and ownership. Early CS services may be started as a community-based and more altruistic service. However, modern CS services do not seem to provide conventional sharing services. Current CS services are a type of commercial goods exchange involving a reciprocity mechanism, in particular a monetary return for the usage of these goods, and are rarely associated with shared responsibilities or ownership (Bardhi & Eckhardt, 2012).

Though CS is a type of car rental service in a broader sense, CS still has several unique characteristics:

- Membership requirement: In order to use the service, users must first be a member of the CS service organization.
- Online payment requirement: Payments are done via credit card or other online payment systems.
- Self-service basis: Fewer interactions between CS users and CS organizations or CS car owners are required. For example, no human interaction would be needed to pick-up or drop-off cars.
- Payment per minutes/hours: Users are charged by shorter time units, such as minutes or hours instead of longer terms such as days or weeks. Sometimes additional costs are charged by kilometres.

All CS services discussed in this thesis satisfy the characteristics listed above.

1.2.3. Carsharing and Local Governments

Support from local governments is crucial to the success of CS services[3]. In order to realize a convenient and stable service, a collaboration between CS providers and local governments must be established (Le Vine, Lee-Gosselin, Sivakumar, & Polak, 2014a; Terrien, Maniak, Chen, & Shaheen, 2016). In particular, whether a CS service is able to have privileged access to street parking spaces is a critical factor in its long-term success (Loose, 2010; Millard-Ball, Murray, Schure, Fox, & Burkhardt, 2005), especially for free-floating style CS services. Table 1.1 is a list of incidents related to CS organizations between 2011 and 2016. Two points need to be clarified about the table. Firstly, the list shows reported events, and there are likely unreported cases, such as CS providers and local governments started negotiations but did not reach a point to start any actions. Secondly, the list does not include termination/cutting back of services by merger/absorption of CS providers (e.g. the absorption of PhillyCarShare by Enterprise in 2011 and the purchase of Zipcar by Avis Budget Group in 2013). According to Table 1.1, all of the listed events are related to one-way CS, suggesting the recent growth of the service and the early diffusion stage that one-way CS is placed. In addition, several failures (rows shaded in grey in Table 1.1) stem from insufficient or unsuccessful collaborations between local governments and

[3] There are some CS services which are successful without any direct supports from government (i.e. Autolib in Paris); however these are rare cases and indirect support from local government is highly likely exist.

the CS organization. Two out of three of these operator-regulator discords were in negotiations over parking permits. One case ended in the termination of CS services, and the other case ended in non-adherence to the regulations – this CS company started its service without a proper coordination of efforts with its associated regulating agency. Users may end up being ticketed by a regulator even after following the CS company rules, but the fine would be covered by the company.

Table 1.1: Major CS service delay or terminations between 2011 and 2016. The shaded rows were due to insufficient or unsuccessful collaborations between CS organizations and local governments)

Country	City	Company	Year	Outcome	Reason behind of the incident	Source
France	Lyon	Car2go	2012	Postpone service launch	The launch of car2go service in Lyon was suspended because of name conflict with Car' Go.	(Autoblog, 2012)
UK	London/Birmingham	Car2go	2014	Service termination	According to the car2go website, the reason of service termination is: "We've listened closely to customer feedback and taking the UK's strong culture and tradition of private vehicle ownership into account, we have decided to withdraw from the UK market place".	(Wissenbach & Taylor, 2014)
US	San Francisco	BMW DriveNow	2015	Service termination	900 parking spaces for carsharing vehicles in San Francisco were not available for one-way carsharing services. DriveNow's negotiate with the city was not successful and the service was terminated in November 2015 after 3 years of operation.	(Korosec, 2016)
US	South Bay, Los Angels	Car2go	2015	Service termination	The service area was too small to make the car2go service sustainable. Car2go negotiated with the city to expand the service area; however, the negotiation was unsuccessful. Car2go decided to terminate the service while continue to negotiate with municipalities to re-launch its service with a larger service area.	(Dryden, 2015)
Canada	Toronto	Car2go	2016	Parking rule against city decision	Car2go has negotiated with the city to park car2go vehicles at residential parking areas. After the city rejected the car2go's requests multiple times, car2go gave up on negotiating with the city and started to allow its members to use residential parking without an agreement with the city.	(Cross, 2016)
US	Miami	Car2go	2016	Service termination	Car2go mentions that Florida's rental-car tax makes its business in Miami not sustainable. Cat2go negotiated with the state to Car2go is interested in returning to the city if the tax rule is changed.	(Smiley, 2016)
Denmark	Copenhagen	Car2go	2016	Service termination	The number of registered members did not reach the critical mass to sustain the service.	(W, 2016)

Though some cities are less supportive of CS services, others have established collaborative relationships and actively engaged in expansion of CS services in various neighbourhoods. In these cities, CS is seen part of the solution to critical challenges, such as the reduction of greenhouse gases (GHGs), reducing vehicle dependency, reducing parking shortages, and optimizing their urban space utilization (Millard-Ball et al., 2005). For example, Metro Vancouver, a regional government serving the needs of 24 local municipalities in the Vancouver region of British Columbia, Canada, states that CS is a method to reduce vehicle ownership and environmental impacts in the region (Metro Vancouver, 2013). There are a number of major counties and cities holding similar policies to support CS services to provide an affordable and more sustainable mobility option: including Chicago (Chicago Metropolitan Agency for Planning, 2010), Montreal (Société de Transports de Montréal, 2013), New York (New York City Department of Transportation, 2009), Seattle (Seattle Department of Transportation, 2015), and Washington D.C. (District Department of Transportation, Policy, Planning & Sustainability Administration & Administration, 2014). These local governments' expectations towards CS have been supported by findings from a number of existing studies as explained later; however, these studies have a number of limitations due to their design. Therefore, whether these observed effects would persist as the service systems evolve and diffuse is open to debate. This issue of whether the positive effects of CS reported so far are independent of the evolutionary stages of CS services so far, is explored in detail later in this chapter.

1.3. Problem Statement

As described in the previous section, multiple attempts have made to evaluate the effects of CS, and findings from these studies support the positive effects of CS that local governments expect. Current policies are formulated based on the understanding that CS can help reduce vehicle ownership (Cervero, Golub, & Nee, 2007; Engel-Yan & Passmore, 2013; Loose, 2010; Martin, Shaheen, & Lidicker, 2010; Meijkamp, 1998; Stasko, Buck, & Gao, 2013), vehicle kilometers travelled (VKT) (Cervero et al., 2007; Martin & Shaheen, 2011a; Meijkamp, 1998), and GHG emissions (Loose, 2010; Martin & Shaheen, 2011a; Shaheen & Cohen, 2013a). The shared consensus is that though only a certain amount of CS users actually reduce their vehicle dependency via CS and others do not change or even increase vehicle dependency, the net effect of CS is positive (Firnkorn & Shaheen, 2015; Meijkamp, 1998; Meijkamp & Theunissen, 1996; Steer Davies Gleave, 2014).

However, one issue here is the bias that currently exists in CS users – almost all existing studies have focused on early adopters of CS services. For example, researchers at the University of California Berkeley's Transportation Sustainability Center have published notable and influential works related to the positive effects of CS on societies. According to their studies, CS has helped in cutting GHGs by 0.58 – 0.84 t GHG per year per household in net (Martin & Shaheen, 2011a) and by reducing vehicle ownership from 0.47 to 0.24 vehicles per household (Martin et al., 2010). Similar findings have reported by multiple scholars (Cervero & Tsai, 2004; Engel-Yan & Passmore, 2013; Loose, 2010; Meijkamp, 1998; Millard-Ball et al., 2005; Steer Davies Gleave, 2014; 2015a; 2015b; 2015c). All of these studies are based on surveying existing CS users. Considering the fact that only 12 % of residents have tried CS in San Francisco, where there is a hub of CS studies (Corey, Canapary & Galanis Research, 2016), existing CS users are innovators or early adopters, according to Rogers' diffusion of innovation theory (E. M. Rogers, 2003). The diffusion of innovation theory explains the diffusion process of novel ideas and technologies, and points out the differences in characteristics, demographics, preferences, and usage in each adoption group, namely innovators, early adopters, early majorities, late majorities and laggards (E. M. Rogers, 2003). Assuming that this diffusion theory is applicable to CS services (Firnkorn, 2012), and considering the fact that the membership of CS services is expected to grow for the future (Le Vine & Polak, 2015; PricewaterhouseCoopers, 2015), CS will soon reach or may have already reached the stage of attracting people from the early and late majorities. Therefore, it is highly likely that projecting the effects of CS in the future based on the effects observed among innovators and early adopters is misleading. Moreover, relying on the polices and regulations made in the early stage of CS diffusion may not be the best strategy to maximize the positive effects of CS.

The second issue in existing studies is the lack of coverage of target CS service models. Table 1.2 summaries the variety of CS services and service models. This variety is often neglected in academic research or policymaking. For example, in terms of service styles, there are 2 major classes of conventional services: round-trip and one-way services. Within one-way services, there are two styles of service: a free-floating style where members can drop-off a CS car almost anywhere within the service area, and a station-based style where members must return a CS car to one of many designated parking locations. In terms of business models, there are for-profit models, co-op models, and not-for-profit models. Fleet characteristics are different among CS services too; some offer a variety of vehicle types from compact cars to pick-up trucks, while others offer only one type of car. However, while there are a variety of different CS service styles, almost all CS related studies have not paid sufficient attention to these heterogeneities to consider their impacts. For example, most CS related studies reporting the social and environmental benefits of CS are based on data from conventional round-trip CS models (Table 1.3), while a new yet rapidly growing one-way CS model was left out of the analyses. In 2014, 23% of CS fleets were providing one-way CS services, and accounted for 18% of global CS memberships (Shaheen & Cohen, 2016). While there is no study that has theoretically analyzed the differences between the two CS models, empirical studies show that the usage and user demographics of the two services are quite different (Martin & Shaheen, 2016; Wielinski, Trépanier, & Morency, 2015). Leading scholars in the CS field have alerted a shortage of research considering these perspectives (Le Vine & Polak, 2015; Le Vine, Zolfaghari, & Polak, 2014b). Discussing the effects of CS without properly considering its variation can result in over- and/or under-estimation of effects that CS has already brought, and effects that CS could bring in the future.

Considering these knowledge gaps in existing studies, the focus of this thesis lies on exploring how CS has been used practically in societies so far, and its potential in the future. My thesis consists of four independent and yet interrelated studies: studies of CS's environmental impacts, CS's effect on vehicle ownership reduction, the future diffusion potential of CS, and management of CS vehicles. All of these studies were done within the scope of considering these weaknesses in existing studies, specifically for not considering bias incurred from the adoption stages nor the variety of different CS service styles.

Table 1.2: Types of CS services (All CS services active in the cities listed on Table 1.4 except PitCarz. PitCarz's website did not list sufficient information to be included in this table)

Category	Sub-category		Explanation	Car2go	City Car Share	Comm-uauto	Enter-prise carshare	Evo	Geta-round	Ma-ven	Modo	Turo (Relay Rides)	Reach Now	Zip-car
Service style	Round-trip		Users need to return a CS car to the original location.		X	X	X		X	X	X	X		X
	One-way	Free-floating	Users may drop off CS cars anywhere within service areas as long as they follow local parking rules.	X		X		X					X	
		Station-based	Users may drop off a CS car at a designated parking spot different from the original location.	X*2										X*1
Business model	Not-for-profit		The fundamental goal of the organization is not earning money.		X			X						
	Coop		Members of the coop collectively own and manage cars.								X			
	For-profit	Business to consumer	CS companies own cars and provide members the access to the cars	X		X	X			X			X	X
		Peer to Peer	CS companies provide a platform where owners and users are matched.						X			X		
Organization structure	Independent		Independent of other companies		X	X			X		X	X		
	Subsidiary		Under a parent company	X*4			X*5	X*6		X*7			X*8	X*9
Fleet type	Various		Various cars are offered		X		X		X	X	X	X		X
	Single		Only a few types of cars are offered.	X		X		X					X	
	EV		Mainly electric vehicles are offered.	X*3									X	
Reference				("car2go US," n.d.)	(Carma, n.d.)	(Communauto, n.d.)	(CarShare, n.d.)	(Evo Car Share, n.d.)	(Getaround, n.d.)	(Maven, n.d.)	(Modo the Car Co-op, n.d.)	(Turo, n.d.)	(ReachNow, n.d.)	(Zipcar, n.d.)

*1: Zipcar provides one-way services in some of their service areas
*2: Car2go mainly provides free-floating services, but in some cities they provide station-based services.
*3: Car2go mainly offer gasoline vehicles, but in some cities they offer electric vehicles
*4: Daimler, Auto manufacturer
*5: Enterprise, Car rental company
*6: BCAA, Auto insurance organization
*7: General Motors, Auto manufacturer
*8: BMW, Auto manufacturer
*9: Avis Budget, Car rental company

Table 1.3: List of major CS studies reporting various effects of CS

Study area	Data collection year	Target CS	Reported effects of CS				Reference
			Vehicle ownership	GHG emission	Distance traveled	Mode of transport	
Austria	1994	Round-trip	Yes				(Prettenthaler & Steininger, 1999a)
Leiden (Netherland)	1994	Round-trip	Yes		Yes		(Meijkamp & Theunissen, 1996)
Montreal (Canada)	1996-2008	Round-trip	Yes				(Klincevicius, Morency, & Trépanier, 2014)
Netherland	c. 1997	Round-trip	Yes		Yes	Yes	(Meijkamp, 1998)
San Francisco (USA)	2001	Round-trip	Yes		Yes	Yes	(Cervero, 2003)
Vancouver (Canada)	2001	Round-trip		Yes	Yes		(Government of Canada, New Economy Development Group, 2005)
San Francisco (USA)	2002	Round-trip	Yes	Yes	Yes		(Cervero & Tsai, 2004)
Philadelphia (USA)	2003	Round-trip	Yes		Yes	Yes	(Lane, 2005)
Portland (USA)	c. 2003	Round-trip	Yes			Yes	(Katzev, 2003)
North America	2004	Round-trip	Yes			Yes	(Millard-Ball et al., 2005)
San Francisco (USA)	2005	Round-trip	Yes		Yes	Yes	(Cervero et al., 2007)
Worldwide	2006,08,10	Round-trip		Yes			(Shaheen & Cohen, 2013a)
Japan	2007	Round-trip	Yes			Yes	(Yano, Takayama, Nakao, & Fujii, 2011)
Montreal (Canada)	2008	Round-trip	Yes		Yes		(Sioui, Morency, & Trépanier, 2013)
North America	2008	Round-trip		Yes	Yes		(Martin & Shaheen, 2011a)
North America	2008	Round-trip	Yes				(Martin et al., 2010)
North America	2008	Round-trip				Yes	(Martin & Shaheen, 2011c)
North America	2008	Round-trip	Yes				(Martin & Shaheen, 2011b)
Toronto (Canada)	2008-10	Round-trip			Yes		(Costain, Ardron, & Habib, 2012)
Europe	c. 2009	Probably Round-trip	Yes	Yes	Yes	Yes	(Loose, 2010)
Toronto (Canada)	2009	Round-trip	Yes				(Engel-Yan & Passmore, 2013)
Ulm (Germany)	2009	One-way (stated preference)		Yes			(Firnkorn & Müller, 2011b)
San Francisco (USA)	2009-10	Round-trip	Yes			Yes	(J. ter Schure, Napolitan, & Hutchinson, 2012)
Austin (USA)	c. 2010	Round-trip	Yes		Yes		(Zhou & Kockelman, 2011)
Ithaca (USA)	2011	Round-trip	Yes			Yes	(Stasko et al., 2013)
Korea	2011-12	Round-trip	Yes		Yes		(J. B. Lee, Byun, Lee, & Do, 2014)
Japan	2012	Round-trip		Yes	Yes	Yes	(Transportation Ecology and Mobility Foundation, 2013)
Berlin (Germany)	2012-13	One-way			Yes		(S. Wagner, Brandt, & Neumann, 2014)
Berlin (Germany)	2013	One-way & Round-trip (EV only)	Yes				(Kawgan-Kagan, 2014)
England & Wales (UK)	2013-14	One-way & Round-trip (no distinction)	Yes	Yes	Yes	Yes	(Steer Davies Gleave, 2014)
Montreal (Canada)	2013-14	One-way & Round-trip			Yes	Yes	(Wielinski et al., 2015)
Japan	2014	Round-trip	Yes				(careco car sharing club, 2014)
England & Wales (UK)	2014-15	Round-trip	Yes	Yes	Yes	Yes	(Steer Davies Gleave, 2015a)
London (UK)	2014-15	Round-trip	Yes	Yes	Yes	Yes	(Steer Davies Gleave, 2015b)
Scotland (UK)	2014-15	Round-trip	Yes	Yes	Yes	Yes	(Steer Davies Gleave, 2015c)

1.4. Vancouver: the CS Model City

The majority of the data used for this thesis was collected in the Vancouver region of British Columbia, Canada. There are two main reasons why Vancouver was chosen as a study area: its long history of being involved in CS and its high CS adoption levels.

The CS history in Vancouver started in 1996 when Cooperative Auto Network (CAN, which later changed its name to Modo) was founded in the region (Government of Canada, New Economy Development Group, 2006). CAN was the very first successful CS coop in an English speaking country, and is the second oldest CS service in North America (Government of Canada, New Economy Development Group, 2006). Along with the launch of the service, the city modified regulations to allow CS services to operate in its neighborhoods. One of the regulation arrangements was the introduction of a by-law reducing the parking requirements for buildings that introduced CS services (Government of Canada, New Economy Development Group, 2006). With this by-law, developers are incentivized to substitute multiple parking spaces in a building with a significantly smaller number of spaces designated for CS vehicles. The introduction of this kind of legislation was the very first in the world (Government of Canada, New Economy Development Group, 2006).

Vancouver is not only known for having a long history of CS, but also for its high adoption level of CS. Table 1.4 shows the list of major cities in Canada and the U.S. along with basic statistics and CS data. Vancouver has not only the second highest number of CS cars (2,373 vehicles following 3,757 in New York) but also the highest number of CS cars per 10,000 people (39.3 and the second highest is 22.9 in Washington D.C.). In addition, the Transportation Panel Survey done by City of Vancouver in 2015 revealed that 26% of survey participants were CS members (Ch2m Hill, 2016). This number has steadily increased since the first panel survey took place in 2013 (13%), which increased again in 2014 (20%)(Ch2m Hill, 2015).

To summarize, Vancouver is one of the most advanced CS cities in the world, and can serve as a model for its implementation. Its matured CS environment allows for understanding the dynamics that exist in CS service diffusion. In this thesis, I treat Vancouver as a pioneer of CS and I believe that findings from this thesis are generalizable to other cities, since most are following the adoption path that Vancouver has been through already.

Table 1.4: List of major cities in Canada and U.S. with CS related data. [4][5]

Country	City	Population	Land Area (km2)	Population Density (people/km2)	Vehicle per household	CS	Number of CS cars	CS cars per 10000 people
US	New York	8,175,133	784	10,430	0.6	Car2go, Zipcar, Enterprise Carshare	3,757	4.4
US	Los Angeles	3,792,621	1,214	3,124	1.6	Zipcar,PitCarz	357	0.9
US	Chicago	2,695,598	588	4,582	1.1	Zipcar, Enterprise Carshare, Getaround, Maven	807	3.0
Canada	Toronto	2,615,060	630	4,150	1.1	Car2go, Zipcar, Enterprise Carshare	1,356	5.2
Canada	Montréal	1,649,519	365	4,518	1.0	Car2go, Commuauto	1,867	11.3
US	Philadelphia	1,526,006	347	4,394	1.0	Zipcar, Enterprise Carshare	724	4.6
US	San Jose	945,942	457	2,069	2.0	Zipcar	31	0.3
US	San Francisco	805,235	121	6,633	1.1	Zipcar, Enterprise Carshare, Getaround, City CarShare	1,222	14.3
US	Baltimore	620,961	239	2,598	1.1	Zipcar	234	3.8
US	Boston	617,594	232	2,661	0.9	Zipcar, Enterprise Carshare, Maven	923	14.1
US	Seattle	608,660	217	2,802	1.4	Car2go, Zipcar, Enterprise Carshare	1,391	20.8
Canada	Vancouver	603,502	115	5,248	1.2	Car2go, Zipcar, Modo, Evo	2,373	39.3
US	Washington	601,723	177	3,400	0.9	Car2go, Zipcar, Enterprise Carshare, Getaround, Maven	1,506	22.9
US	Milwauk	594,833	249	2,391	1.3	Zipcar	35	0.6

[4] The selection criteria of the cities listed on Table 1.4 are: 1) over 0.5 millions of city population and 2) over 2,000 people per square km of city population density. Note: All data except data for Vancouver and Montreal are from (Shared-Use Mobility Center, n.d.), data for car2go fleet size for Montreal and Vancouver are from (car2go, 2016a; 2016b; 2016c), data for Montreal carsharing companies are from (Lalonde, 2016), data for Vancouver carsharing companies are from (McLaughlin & Green, 2016) and (Commisso, 2016), data for Vancouver vehicle ownership are from (Metro Vancouver, 2012a; 2015), data for Montreal vehicle ownership are from (La Mobilite des personnes dans la region de Montreal, 2015).

[5] The list is limited to cities in Canada and US. because 1) directly comparing numbers among cities in different continent could be misleading (transportation systems in cities in Europe, Asia and North America are significantly different) and 2) studies summarized in this thesis were done in North America.

1.5. Thesis Structure

The four independent studies that were previously mentioned will be introduced in the following chapters, and each of these studies helps to understand the reasoning behind the two primary findings of this study: 1) the dynamics of the CS diffusion process and 2) the importance of considering the heterogeneities among CS services.

The first chapter is this chapter, offering background information about CS and the goals of this thesis.

Chapter 2 confirms the environmental effects of CS. Though there are some studies reporting the environmental effects of CS already, this study takes a further step to understand the factors affecting the reduction of GHGs. This study confirms that even if future adopters do not reduce VKT, a significant amount of GHGs could be cut by driving CS vehicles instead of private vehicles.

Chapter 3 talks about the vehicle ownership reduction yielded by CS services. This study reveals the heterogeneities existing among CS services. Two services analyzed in the study, Car2go and Modo, are regulated under the same set of laws; however, the two services have different effects on vehicle ownership reduction. These findings suggest that different CS services exist and that each CS model has different effects on societies.

Chapter 4 talks about the diffusion of CS services. By analyzing responses from both CS users and non-CS users living in same buildings, the future diffusion potential of CS and the effective strategies needed to motivate CS participation are confirmed. Moreover, the statistical analysis in this section reveals that early adopters are neither representative of the general public nor do they share demographics or living environments with upcoming adopters.

Chapter 5 explores a way to better manage shared properties. Existing studies and pilot studies confirm that the majority of CS users are not responsible when taking care of CS vehicles. Although an ideal sharing service includes sharing of ownership (Belk, 2010; Botsman & Rogers, 2011), this rarely happens in CS (Bardhi & Eckhardt, 2012; Schaefers, Wittkowski, Benoit nee Moeller, & Ferraro, 2015). With the constant growth in CS membership, and with its huge adoption potential suggested in Chapter 4, managing shared property would be even more difficult. This chapter takes a hint from behavioural economics and explores the possibility to motivate CS users to be more responsible in order to reduce upkeep.

Chapter 6, the last chapter of this thesis briefly summarizes the findings from each chapter, and forms a set of suggestions to better make use of CS services in societies.

Chapter 2: Characterizing the GHG Emission Impacts of Car-sharing[6]

As discussed in Chapter 1, the recent rapid carsharing (CS) expansion has never been feasible without support from local governments. The driving force of their endorsement is the expectation on CS to mitigate the effects of climate change and traffic congestion. This chapter intends to analyze the impacts of CS services on greenhouse gas (GHG) emissions to confirm the validity of those expectations. The novelty of this study is the attention paid to the factors and contexts through which CS impacts are realized. This approach allows for understanding the fundamental causes of CS's environmental benefits and their qualification. Unveiling critical factors affecting CS's environmental contributions would help in examining not only current but also the future potential of CS as a climate change mitigation measure.

2.1. Introduction

The concept of sharing vehicles among multiple users has been practiced for more than three decades (Prettenthaler & Steininger, 1999b); it was invented to provide more affordable access to personal mobility (Shaheen et al., 1999). The popularity of such services has been accelerated by smartphones as platforms for software that facilitates the necessary transaction elements such as: vehicle location, booking and payment for service (Siee, 2014). Many car-sharing platforms allow users the choice of vehicle type as well as pick up locations. Some CS services even provide one-way CS allowing users not to worry about returning the vehicle to the pickup location or being responsible for pay-

---

[6] A version of this chapter has been published as Namazu, M., & Dowlatabadi, H. (2015). Characterizing the GHG emission impacts of carsharing: a case of Vancouver. Environmental Research Letters, 10(12), 1–10. http://doi.org/10.1088/1748-9326/10/12/124017

parking at their destination. A closer examination of the environmental impact of such convenient personal mobility services is the focus of this paper.

Several studies have already examined car-sharing services as a GHG mitigation measure. Martin and Shaheen (Martin & Shaheen, 2011a) and Transportation Ecology and Mobility Foundation (Transportation Ecology and Mobility Foundation, 2013) surveyed members of multiple CS services and calculated emission reduction resulted from CS participation. Firnkorn and Müller (Firnkorn & Müller, 2011b), and Cervero and Tsai (Cervero & Tsai, 2004) focused on one specific CS organization each. While Firnkorn and Müller (Firnkorn & Müller, 2011b) surveyed residents who were interested in CS, Cervero and Tsai (Cervero & Tsai, 2004) conducted multiple surveys throughout four years to analyze the dynamic changes in user behaviour by CS.

The focus of these earlier papers has been on how car sharing leads to a reduction in Vehicle-Kilometers Travelled (VKT) and hence GHG emissions. However, Lane (Lane, 2005) and Katzev (Katzev, 2003) reported issues in VKT reporting; the responses they got were highly likely inaccurate because few drivers actually knew their VKT.

In this paper, we model the impact of CS on GHG emissions through five independent factors beyond VKT reductions. The data used for the model is derived from a travel diary survey in which travel distances were calculated based on trip start and end locations. We use the survey data on trip distances and characteristics of families who are not CS members to construct three clusters of household archetypes. We suspect that household characteristics determine flexibility in utilizing CS. Our scenario-based approach is designed to assess emission reductions as different household types join CS programs.

In this modeling study we consider three factors involving behavioural change:

- *Mode shifting* - higher use of other modes of mobility (public transit, biking and walking);
- *Right sizing* - selecting the appropriate vehicle for the task at hand; and,
- *Trip planning* - aggregation of a number of shorter trips into longer trips.

And two factors arising from fleet composition:

- *Newer cars* - CS fleets are, on average, much newer than owned vehicles. This leads them to benefit from secular improvements in vehicle efficiency;
- *Less macho* - CS fleets, on average, include the more efficient drivetrains offered for each vehicle type in their fleet.

We quantify the effects of each factor and propose future steps to utilize CS as a GHG emission mitigation measure.

In section two we describe the scope of and data used in this study. In section three we explain the scenarios and their rationale. In section four a piecewise-linear emission calculator is introduced to explore the impact of trip aggregation on engine temperature and fuel efficiency. In section five we present results and discuss their implications. In section six we explore the sensitivity of our results to modeling assumptions. We conclude with a summary of findings in section seven.

2.2. Scope and Data

Since vehicle production only accounts for about 10 % of the emissions in the lifecycle of a vehicle (Samaras & Meisterling, 2008), and the majority of the vehicle exhaust gases consists of CO_2 (United States Environmental Protection Agency (US EPA), 2014), we focus on CO_2 emissions due to vehicle operations. Vehicle operations are dependent on household demands for mobility services. Thus, our methodology hinges on patterns of demand for mobility as revealed in detailed travel diary surveys. For this study, we utilized data gathered by Metro Vancouver, the regional authority for the Vancouver region, representing over 21,850 valid surveys from local households reporting their previous day's weekday trips (TransLink, 2013).

We rely on data from Transport Canada (Transport Canada, 2015b) for vehicle composition and fuel efficiency. Unfortunately, fuel efficiencies of the current fleet are only available at the aggregate national level, so our data is not specific to Metro Vancouver. We also used fleet composition and vintage from Modo, a local car cooperative, and vehicle fuel economy statistics (Natural Resources Canada, 2015a) that use the more realistic fuel performance methodology introduced in 2015 (Natural Resources Canada, 2015b; U.S. Department of Energy U.S. Environmental Protection Agency, 2015).

The availability of data on household travel patterns, and characteristics of the fleets of user-owned vehicles and those operated by CS services were the reasons for choosing the Metro Vancouver region. We suspect our findings are replicable wherever the characteristic differences between user-owned and CS fleets are present.

2.3. Scenario Development

For the purpose of this study, we propose three household archetypes: 1) households with children and at least one person working away from home (hereafter referred to as household with children), 2) households without children and at least one person working away from home (referred to as household without children), and 3) households with neither children nor work away from home (referred to as retiree household). The three households were chosen by following the classification used in the Trip Diary Survey administered for Metro Vancouver, Canada (TransLink, 2013).

Trip distances and purposes by household archetypes are presented in Figure 2.1. Mode shares are presented in Figure 2.2. These closely resemble[7] data found in Metro Vancouver's Trip Diary survey for families not utilizing car sharing services (Ipsos Reid, 2012; TransLink, 2013). Our working assumptions are that 1) these households have travel patterns and modes which are no different from that of general public prior to CS

[7] See appendix for the modifications made to the Trip Diary data.

participation, and 2) these households own a single vehicle before participating in CS services[8], and once they become CS members, they use only cars offered by CS services.

The working assumption that households switching to CS are representative of the general public is an over-simplification that we revisit in the sensitivity analysis. The second simplifying assumption can be scaled to reflect actual patterns of access to CS on car ownership and trip characteristics. For example, 80% of people who join Modo[9] sold or donated their cars (Government of Canada, New Economy Development Group, 2006). More recently, Metro Vancouver's CS survey (Metro Vancouver, 2014b) revealed that 28% of households who gained access to CS relinquished their privately owned vehicle, and 70% of them became zero vehicle households, meaning that access to CS fully substituted private car ownership (Namazu & Dowlatabadi, 2016).

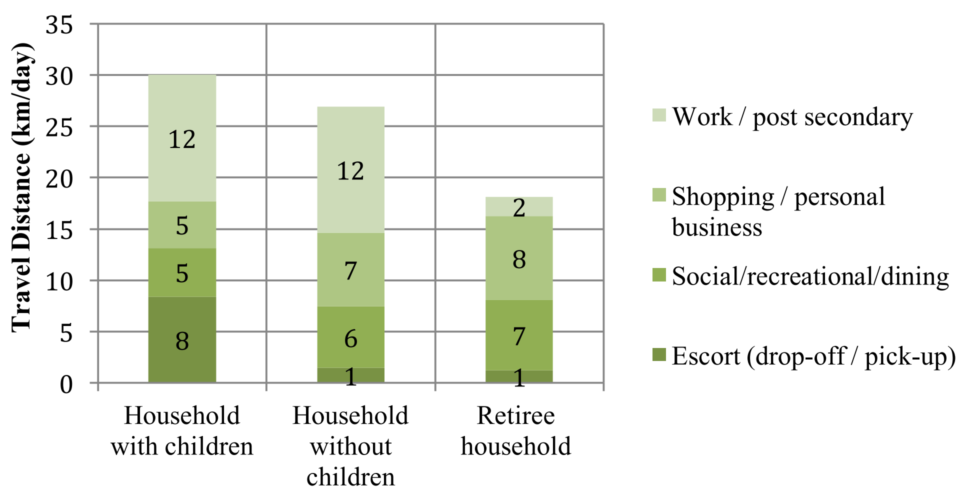

Figure 2.1: Average weekday travel distance by trip purpose (baseline)

[8] The average vehicle ownership rate in the Metro Vancouver region was 1.66 in 2011 (Metro Vancouver, 2015) (Metro Vancouver, 2012c)

[9] Founded in Vancouver in 1997 and previously known as Cooperative Auto Network, CAN.

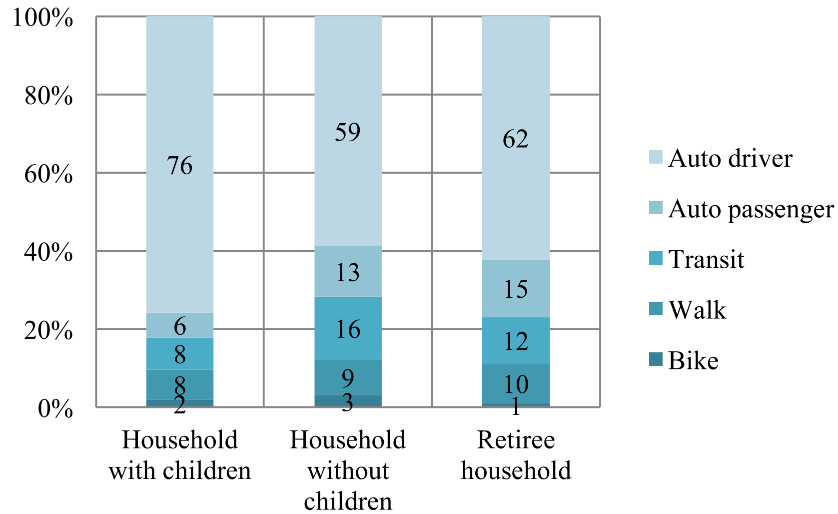

Figure 2.2: Mode of transportation by distance (baseline)

Newer vehicle factor:

Modo owns 340 vehicles (Metro Vancouver, 2014a), and the average age of their fleet is three years (Modo the Car Co-op, 2015a). On the other hand, the average age of privately owned vehicles in British Columbia is 11 years (The Motor Vehicle Sales Authority of British Columbia, 2014)[10]. Given the secular trend to higher fuel efficiency (United States Environmental Protection Agency (US EPA), 2014), this gap in vehicle vintage plays a significant positive role in reducing the GHG emissions from households who use a CS vehicle instead of their own. This *newer vehicle effect* is present whenever CS is used. Thus the other factors impacting GHG such as vehicle optimization and trip planning are additional to the shift in baseline emission that result from the higher efficiency of CS fleets.

[10] Note that this average is based on mathematical calculations. Beyond a certain age, vehicles might be more for leisure than a merely transportation option.

Transportation mode change factor:

Greater use of public transit, walking and biking has often been singled out as the main benefit from implementing CS services (Cervero et al., 2007; Le Vine, Lee-Gosselin, Sivakumar, & Polak, 2014a; Loose, 2010; Meijkamp, 1998). The magnitude of this effect varies depending on user demographics, geographic conditions, and public transit service characteristics (Martin & Shaheen, 2011a). In this study, we assumed that CS participation and the absence of vehicle ownership leads to changes in mode of transport chosen, depending on the nature and distance of trip in question. However, we are not aware of any systematic study of how transportation mode is changed by participation in CS. For the purposes of this study, we relied on informal interviews with CS households, data on travel patterns from the Trip Diary, and other CS reports (Cervero et al., 2007; Martin & Shaheen, 2011a; Metro Vancouver, 2014b; Transportation Ecology and Mobility Foundation, 2013) to develop the trip pattern scenarios. The scenario assumptions for post CS participation are: trips of 1 km or less will be completed by walking; walking and biking will be used twice as frequently as before to complete trips of 1 to 5 km; and, regardless of distance, use of public transit is doubled[11]. In addition, since CS is mainly used for shopping and social trips (Cervero, 2003; Lane, 2005; Namazu & Dowlatabadi, 2016), commuting is also assumed to be completed using public transit alone.

Vehicle optimization factor:

In this study, we reflected vehicle optimization as an aspect of how households would meet their transport needs after switching away from car ownership. In general, car owners purchase vehicles that are too powerful and too large for their daily needs. Vehicle optimization means using a vehicle of sufficient in size and performance to complete a trip with a specific purpose. For example, trips that do not involve large loads

[11] This mode shift might differ among different population (e.g. younger and elderly populations); however, insufficient data kept us from taking into account those insights in this study. This data availability issue is discussed in the conclusion.

can be completed in a sub-compact vehicle, while trips involving large loads would be completed using a light duty truck.

A comparison of the privately owned and CS fleets (see Table 2.2) revealed the latter to have far fewer sport utility vehicles (SUV) and light duty trucks (LDT). The odometer readings from the CS fleets showed that the various cars had roughly equivalent use. This gives us the justification to assert that members of CS services choose the vehicle they use to match their need for that specific trip. In addition, the most prevalent vehicles in the CS fleets of Vancouver are 700 car2go's Smart ForTwo 2-seater sub-compacts (Metro Vancouver, 2014b).

Trip aggregation factor:

Despite the lower barriers for securing CS services today, vehicle availability where and when needed is still inferior to privately owned vehicles. We hypothesize that limited temporal and spatial availability cuts down on ad hoc trips and encourages "trip planning" by users. Trip planning is assumed to involve aggregation of shorter trips into fewer longer trips. This has two effects: a) *shorter distance (SD)* – by combining many trips, the return legs of some trip could be avoided, leading to fewer km travelled,[12] b) *warm start (WS)* – if many trips are combined into sequential short stopover trips, the engine will remain warm. Engines have significantly higher fuel consumption (and emissions) below their operating temperature (cold starts) (Favez, Weilenmann, & Stilli, 2009). In this study, we assumed that households might decide to aggregate half of the trips shorter than 5 km.

A summary of key assumptions about shifts in household trip patterns used in this study is presented in Table 2.1.

[12] For example, when two destinations are combined into one trip, on average, the total distance covered is 30% shorter.

Table 2.1: Summary of scenario assumptions when relying on CS

		Household with children	Household without children	Retiree Household
Mode change	Trips of Less than 1km	The share of walking in travel distance increases from 31% to 100%.	The share of walking in travel distance increases from 23% to 100%.	The share of walking in travel distance increases from 25% to 100%.
	Trips of Less than 5km	The shares of walking, biking, and transit in travel distance increase from 9%, 3%, and 6% to 19%, 6%, and 20%, respectively.	The shares of walking, biking, and transit in travel distance increase from 16%, 5%, and 14% to 32%, 11%, and 30%, respectively.	The shares of walking, biking, and transit in travel distance increase from 18%, 2%, and 5% to 36%, 3%, and 11%, respectively.
	Trips of more than 5km	The share of transit in travel distance increases from 12% to 57%.	The share of transit in travel distance increases from 19% to 65%.	The share of transit in travel distance increases from 20% to 47%.
Vehicle optimization	Commuting	Sub-compact	Sub-compact	Sub-compact
	Escorting	Compact car	Sub-compact	Sub-compact
	Short recreational trips	Compact car	Compact car	Compact car
	Long recreational trips	Station wagon	SUV	Mid-size
	Other	Sub-compact	Sub-compact	Sub-compact
Trip aggregation	Shorter Distance	The half of trips with less than 5 km travel distance is aggregated and overall trip distance is reduced by 30%.		
	Warm Start	The half of trips with less than 5km travel distance is aggregated while travelling the same distances.		
Newer vehicles		Newer vehicles are used in all auto-driving trips. The vehicle efficiency is based on the CS companies' fleets.		

2.4. Emission Calculator

The annual CO_2 emissions for each archetypal household prior to enrollment in CS participation (pre-CS) were calculated using energy efficiency data by vehicle class (Transport Canada, 2015a), emission factors (Natural Resources Canada, 2015a), and the emission data of the public transportation system operating in our case-study region (TransLink, 2012). Since fuel efficiency of a vehicle is dependent of engine temperature (Favez et al., 2009), and about 30% reduction in fuel consumption can be achieved by warming up engines (Favez et al., 2009), we assumed a piece-wise linear efficiency model where fuel efficiency rises as the engine comes into its intended operating temperature. Thus, the fuel efficiency rises from a cold start to the optimal based on cold-start and overall fuel efficiency values reported in Canadian Vehicle Use Study 2014 (Transport Canada, 2015a): vehicle efficiencies were categorized for 9 trip distances (< 1km, 1-5km, 5-10km, 10-15km, 15-20km, 20-30km, 30-50km, 50-100km, and >100km). The same methodology was used for calculation of CO_2 emissions for both the baseline and the CS travel patterns. We used the average energy efficiency of all on-road vehicles by category (Transport Canada, 2015a) for the baseline case while the efficiency data based on the actual vehicle inventories of Modo and car2go were used for the CS scenarios (see Table 2.2).

Table 2.2: Fuel efficiency values used in the calculator

<table>
<tr><th rowspan="2"></th><th colspan="2">Vehicle composition (%)</th><th colspan="2">Fuel efficiency (L/100km)</th></tr>
<tr><th>CS Fleet</th><th>Canada</th><th>CS Fleet</th><th>Canada</th></tr>
<tr><td>Data source</td><td>Modo</td><td>Canadian Vehicle Survey 2009</td><td>Modo + Fuel Consumption Guide 2014</td><td>Canadian Vehicle Use Study 2014</td></tr>
<tr><td>Sub compact</td><td>NA*</td><td rowspan="4">55</td><td>7</td><td rowspan="4">9.7</td></tr>
<tr><td>Compact</td><td>44</td><td>8.7</td></tr>
<tr><td>Mid-size</td><td>19</td><td>8.8</td></tr>
<tr><td>Full size</td><td>1</td><td>5.5 (hybrid)</td></tr>
<tr><td>SUV</td><td>6</td><td>13</td><td>12</td><td rowspan="2">12.6</td></tr>
<tr><td>Station Wagon</td><td>16</td><td>3</td><td>9.4</td></tr>
<tr><td>Pickup truck</td><td>3</td><td>13</td><td>13.2</td><td rowspan="2">16.3</td></tr>
<tr><td>Van</td><td>11</td><td>16</td><td>13.7</td></tr>
<tr><td>Average</td><td>NA</td><td>NA</td><td>9.7**</td><td>12.2***</td></tr>
</table>

* Modo does not provide any sub compact cars; however, car2go provides more than 700 Smartfortwo vehicles in Vancouver
** This averaged vehicle efficiency was used to calculate baseline emissions
*** This averaged vehicle efficiency was used to calculate post-CS emissions except vehicle optimization case, in which different vehicle types were assumed depending on trip purpose

2.5. Result & Analysis

CO_2 emissions before and after participation in CS are shown in Figure 2.3. Note that newer vehicle effects are present for all cases except pre-CS. The emission reduction effects by using newer vehicles vary depending on other factors at work especially mode change where use of other modes renders the fleet effect to be much smaller.

Overall, households with children had both the highest emission baseline and the largest emission reduction potential in absolute terms through CS. In terms of emission reduction ratio compared to baseline, households without children had the highest reduction potential (55% reduction of emission when all five factors are active). All household archetypes showed the same pattern of emission reductions from the five factors considered here. The quantitative emission reduction effects by CS can be summarized as falling into two categories. Using CS services without changing transportation modes, reduces emissions by 19-20% due to the newer fleet; and a further 16-19% due to vehicle optimization. Trip aggregation using the newer fleet delivers another 2-8% GHG reduction. Trip aggregation to ensure warm starts delivers a marginal 1% reduction in GHG emissions[13]. If, on the other hand, households were to use the new fleet and rely more on other transportation modes (as specified in Table 2.1), a 42%-54% reduction in emissions can be realized. When all factors are considered, the maximum emission reduction potential of CS is expected to be in the range of 48% to 55%.

[13] The impact of warm restarts is far more significant for criteria pollutants.

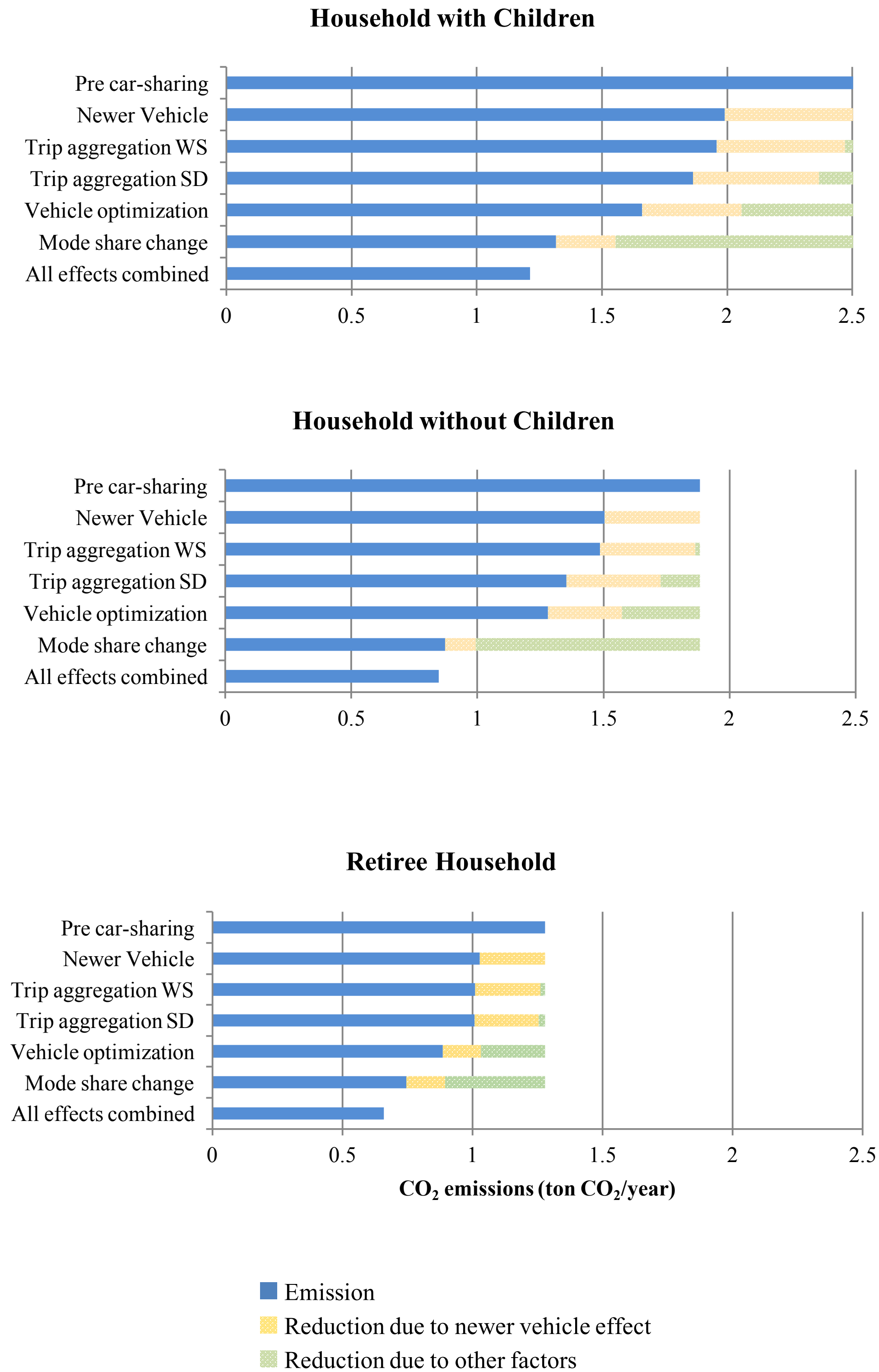

Figure 2.3: Modeled CO_2 emissions by scenario and household

The effect of transportation mode change was the largest of the five factors considered here, and accounted for total 42% to 54% of reduction depending on the type of the household (including newer vehicle effect). However, it is important to recognize the assumptions leading to this outcome. We assumed that households would switch to public transit for commuting, but this is possible only if they have access to desirable public transportation services. Vancouver is a city well regarded in North America for its public transportation services; however, currently, one-third of the jobs in the Metro region are located beyond normal walking distance from its frequent transit network (Mayors' Council on Regional Transportation, 2014).

While realizing full effects of the transportation mode change requires a huge investment in infrastructure, vehicle optimization only requires a CS membership with vehicles at convenient pickup locations. CS is financed by users and municipal governments help their adoption through convenient parking areas. Emission reductions due to vehicle optimization consist of two independent effects: effects caused by using newer vehicles and effects resulting from using right-sized vehicles. Combining the two effects leads to a privately funded GHG reductions of 31-34%.

2.6. Sensitivity Analysis

We conducted two types of sensitivity analysis to confirm the robustness of the model: 1) modifying fuel efficiency of pre-CS vehicles, and 2) modifying travel pattern prior to the CS participation. For simplicity's sake, we focused on the household without children because 1) there was a consistent emission reduction trend among the three household types, and 2) existing studies confirmed that the majority of CS users were younger professionals without children (Cervero, 2003; Cervero & Tsai, 2004; Lane, 2005; Loose, 2010; Millard-Ball et al., 2005).

Table 2.3 shows the CO_2 emissions by assuming different fuel efficiencies. The original assumption of the efficiency was 12.2 L/100km, equal to the average Canadian vehicle

(Transport Canada, 2015b)[14]. CS members motivated by environmental concerns are likely to be using a more efficient personal vehicle. A study covering 11 CS organizations in North America reported that the average fuel efficiency of vehicles shed by CS participation was 10.1 L/100km (Martin et al., 2010). By applying this number, the emission reduction effects by mode share change and vehicle optimization effect would be 45% and 19%, which are 9% and 13% lower than the baseline calculation respectively. For those motivated to join CS for economic grounds, it is likely that their current vehicle is older and less fuel efficient than the fleet average (Miller, Davis, & Reed, 2002). This would result in a higher emission reduction potential by CS as shown in Table 2.3.

Table 2.3: Sensitivity of emission reductions to the fuel efficiency of vehicle shed

		Emission reduction (%) due to				
		Mode share change*	Vehicle optimization*	Trip aggregation SD*	Trip aggregation WS*	Newer Vehicle
Assumed fuel efficiency of vehicle shed (L/100km)	8.0	30.6	-2.0**	-17.9**	-18.5**	-19.9**
	9.0	38.0	8.9	-5.3**	-5.8**	-7.1**
	10.0	44.0	17.7	4.9	4.4	3.3
	11.0	48.9	25.0	13.2	12.8	11.8
	12.0	53.1	31.1	20.3	19.9	18.9
	13.0	56.6	36.2	26.2	25.9	25.0
	14.0	59.6	40.7	31.4	31.1	30.2
	15.0	62.2	44.5	35.9	35.6	34.8
	16.0	64.6	47.9	39.8	39.5	38.8
Originally assumed fuel efficiency of vehicle shed (L/100km)	12.2	53.7	32.0	21.4	21.0	20.1

* Newer vehicle effect is included

** Negative values mean an increase of emissions

[14] Canadian average fuel efficiencies of passenger car, minivan, pick-up truck, and SUV were 9.7, 13.6, 16.4 and 12.9 L/100km (Transport Canada, 2015b).

The second sensitivity analysis was conducted in order to see the relationship between travel pattern and emission reduction by CS. A hypothesis assumed here is that households who join CS and shed their cars have different travel patterns compared to the general public. Unfortunately, as far as we are aware, there is no quantitative report comparing travel patterns of households who join CS and do not. However, multiple studies and reports confirmed that most trips done by CS cars were non-commuting trips (Cervero, 2003; Cervero et al., 2007; Millard-Ball et al., 2005; Nakao, 2011; Stasko et al., 2013; Transportation Ecology and Mobility Foundation, 2013), showing a possibility that commuting trips were originally done by non-car trips, such as public transit. In this sensitivity analysis, we re-allocated commuting trips that were originally assumed to be done by cars to public transit. Table 2.4 shows the results. The more reallocation, the less emission reduction effects are expected. Note that trip aggregation effects were excluded because of their marginal emission reduction potential. When all commuting trips were reallocated to transit, the emission reduction effects range between 15 and 33%.

Table 2.4: Sensitivity of emission reductions by commuting trip reallocations
(% emission reduction)

	Reallocation of commuting from cars to transit[15]					
	0%	20%	40%	60%	80%	100%
Newer vehicle	20.1	19.4	18.6	17.6	16.5	15.2
Vehicle optimization (incl. newer vehicle effect)	32.0	30.0	27.6	24.8	21.6	17.7
Mode share change (incl. newer vehicle effect)	53.7	50.6	47.1	43.0	38.2	32.6

[15] For example, 30% of reallocation means 30% of commuting trips originally done by auto-driver are done by transit alternatively. 0% reallocation means no reallocation, equal to the original assumptions.

2.7. Conclusion

In this study, we explored the GHG emissions of different household archetypes switching to CS. The study characterized and quantified five contributing factors to a change in GHG emissions: mode shift, newer fleet, right sizing, more efficient drivetrains and trip aggregation. The first three factors led to significant reductions in GHG emissions regardless of the household archetype (42-54%, 19-20%, 31-34%, respectively). Transportation mode change had the highest emission reduction potential; 42-54% reduction of CO_2. The GHG mitigation effects compared to baseline in relative term were highest for households working away from home and without children, and lowest for households working at home (or retired) and without children. The highest impact group is the most likely to adopt CS as their daily routines can be accommodated to being without a personal vehicle. However high GHG reductions are conditional on the provisioning of an attractive public transportation option. Since many households do not have access to such public transportation services, it is unrealistic to assume all households with external employment shift from cars to public transit to commute to work.

CS advocates have emphasized the GHG savings arising from the increased use of public transit when users forego their personal vehicles for CS. Here, we have shown that regardless of mode shifts, access to a newer and optimized fleet of vehicles through CS leads to more than 1/3 GHG reductions without any mode shift. This effect may be more compatible with personal preferences that prefer private transport and does not entail large public outlays to expand and maintain public transit. Public policies that support CS through minimally impactful measures such as special parking arrangements, are critical in expanding CS services (Shaheen & Cohen, 2013a). Our findings emphasize the environmental benefits of increased effort to enhancing access and use of CS at little or no cost to the public purse.

We close with limitations of this study and suggestions for future research. First, the scenarios used for this study were not based on actual data on how CS impacts trip mode choices and patterns. Second, we assumed that households who join CS and shed their cars, are no different from general public. The sensitivity analyses show how the GHG savings are affected when this assumption is relaxed. Third, those who choose to abandon their private cars when joining a CS service for economic reasons, may not continue to eschew private car ownership as their circumstances change. More detailed longitudinal data are needed to assess the population-wide long-term effects of CS on car ownership, travel patterns and GHG emissions. Fourth, we focused on households owning private cars, which are expected to be the standard household archetypes in this region. However, the environmental impact caused by households who gain access to cars through CS needs to be examined to develop a full picture of the effects of CS. Fifth, while this paper is focused on GHG emissions; many other environmental effects should also be studied – most notably emissions of criteria pollutants and noise. Finally, casual observation suggests that actual driving behaviour of per-minute CS drivers may be more aggressive than the average. This may be motivated by operators' desire to minimize rental payments, but its impacts on fuel efficiency, safety and collision rates need to be assessed.

CS is relatively new and many private companies are entering this market (Shaheen & Cohen, 2014). We believe that developing an appropriate data sharing platform open to analysis for public interest purposes is an important step towards development of evidence-based public policies to maximize the benefits from CS services.

2.8. Acknowledgements

We would like to thank Milind Kandlikar and Hisham Zerrifi at the University of British Columbia for their careful review and suggestion of how to improve this paper. We also greatly appreciate data and support from Karen New at Modo, Aaron Ludmer at Transport Canada, and Klaas-Pieter Marinesse at Moovel. M. Namazu is grateful for support from the Takenaka Scholarship Foundation from Japan. This project was also supported by Carnegie Mellon's Climate and Energy Decision Making Center (CEDM) under a subcontract from the US National Science Foundation (SES-0949710).

Chapter 3: Vehicle Ownership Reduction: A Comparison of One-way and Two-way Carsharing Systems[16]

Chapter 2 confirmed the potential of carsharing (CS) to cut greenhouse gases. Chapter 3 aims to explore another potential of CS, namely the potential to reduce vehicle ownership. Multiple case studies have reported vehicle ownership reduction among CS users. However, as identified in Chapter 1, all of these studies are solely based on observing round-trip CS users. This study contrasts the vehicle ownership reduction rates among users of two CS services; Modo, a round-trip CS service and Car2go, a one-way CS service.

3.1. 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 CS services were cooperatives with collective ownership of vehicles. Later, for-profit companies offered their vehicles for rent by users[17]. CS 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, 2015a). 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. Early studies empirically demonstrated this promise, as summarized in Table 3.1.

---

[16] A version of this chapter has been submitted for publication: Namazu, M., & Dowlatabadi, H. (in review). Vehicle ownership reduction: A comparison of one-way and two-way. *Transport Policy*.

[17] 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.

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 & El-Geneidy, 2013). In most cities where CS has been offered, members reduced private vehicle ownership through use of CS vehicles.

Table 3.1: 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 & 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 & 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)
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 500m radius is negatively correlated with car ownership.	(Klincevicius et al., 2014)
North America (multiple cities)	2014-15	One-way	One carsharing vehicle removed 1-3 private cars from the road, and deferred the purchase of 4-9 cars.	(Martin & Shaheen, 2016)

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 3.1 refer to traditional two-way service. However, there is a rapid increase of another service model: one-way CS services (Shaheen, Chan, & Micheaux, 2015). One-way CS services 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 & Cohen, 2014). Some one-way CS services are station based; users can pick stations to return cars (e.g., Car2go service in Toronto). 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. 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 instantaneously. 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, Chan, & Micheaux, 2015), and it became the largest CS service in the world (car2go, 2015a) offering its service in over 30 cities in 8 countries (car2go, 2015c). The growth in this free-floating service is expected to continue (Shaheen & Cohen, 2013a).

The question explored in this paper is the effect of these free-floating CS services on private vehicle ownership. 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 & Polak, 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 and two-way CS services in Montreal, Canada; however, their analysis is limited to demographics and trip patterns rather than vehicle ownership. The white paper prepared by Martin and Shaheen (Martin et. al, 2016) reports the vehicle ownership changes among one-way 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 CS. However, their model does not differentiate between different types of CS 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 sub-compact[18]. With this in mind, we explore the difference between the two services and develop a statistical estimate of their impact on vehicle ownership.

Section 3.2 gives details of data used for this study, along with a brief introduction to the study area, the Vancouver region, Canada. Section 3.3 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 3.4 gives the summary and discussion of findings.

---

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

3.2. Data

3.2.1. Target Area: Vancouver

Vancouver is home to Modo, the first CS service in the English-speaking world (Modo the Car Co-op, 2014). Modo[19] was launched in 1997, and currently four CS services provide over 2,000 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 (Ch2m Hill, 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) CS 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.

3.2.2. 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, 2014a; 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, 2014a), 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 3.2 provides a brief overview of the three participating CS services (Metro

---

[19] Formerly known as Cooperative Auto Network (CAN)

Vancouver, 2014b)[20], and Figure 3.1 shows the service area/locations of each CS service in the region.

Table 3.2: 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, 2014a; 2014b))

	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

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

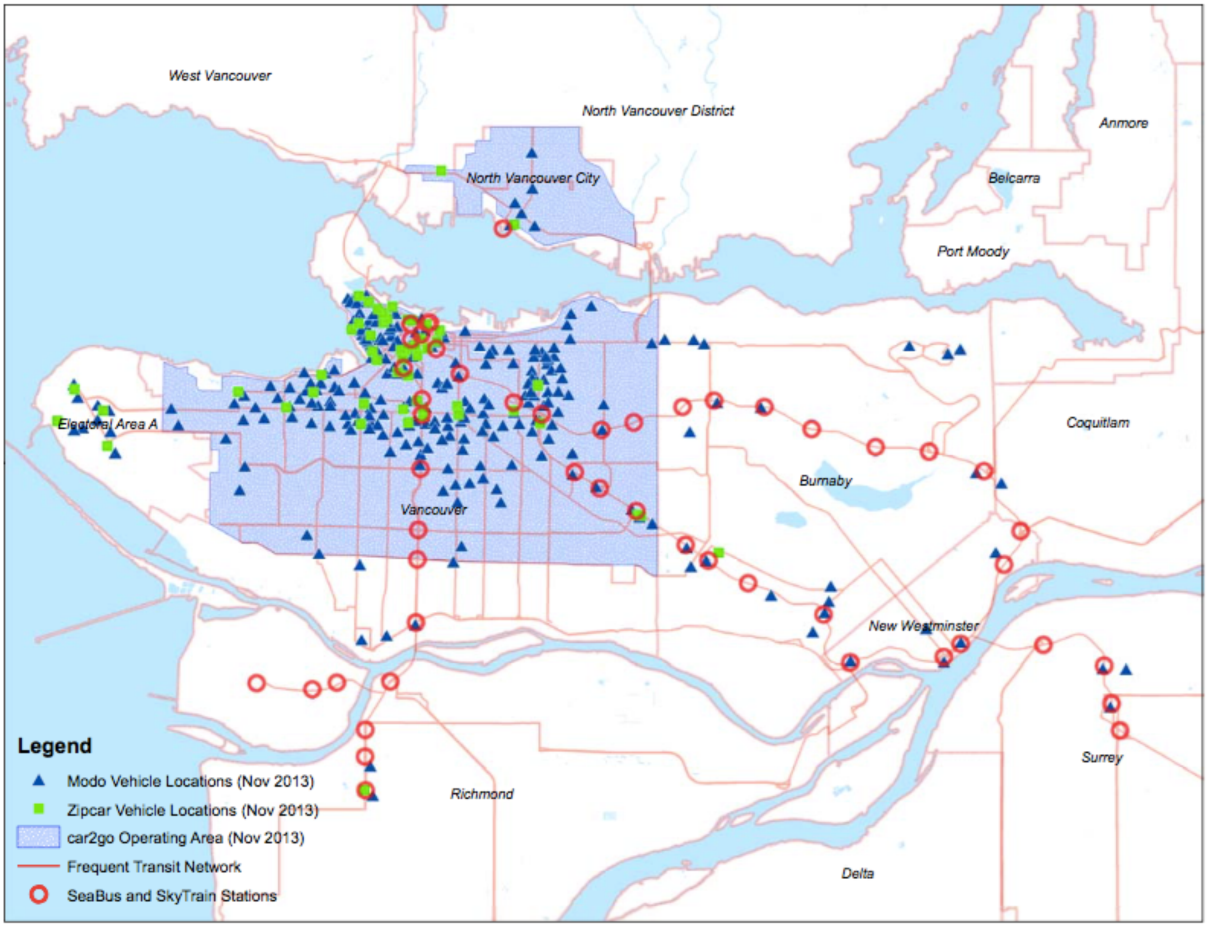

Figure 3.1: Map of Vancouver region along with CS service availability (retrieved from (Metro Vancouver, 2014b))

3.2.3. Survey Response

A total of 3,405 valid responses were collected. 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 Figure 3.2. 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.

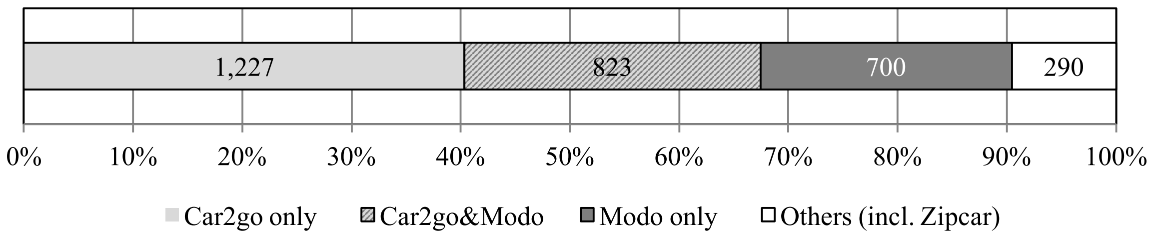

Figure 3.2: Survey response

3.3. Analysis

3.3.1. Demographics of Respondents

The demographics of the three household types (Car2go only, Modo&Car2go and Modo only) are summarized in Table 3.3.

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 3.7 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 population. We therefore use a sensitivity analysis of the results to explore the impact of unmeasured bias – see section 3.4.1.

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., Loose, 2010; Millard-Ball et al., 2005).

Table 3.3: 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%*
	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	Average household size		2.25	2.21	2.21	2.28**
	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 ownership	Average vehicle per household (pre CS)		1.08	0.69	0.68	1.56**
	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:
* (Metro Vancouver, 2010)
** (Metro Vancouver, 2012d)
*** (Metro Vancouver, 2015)

3.3.2. 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

3.4). T-test results shown in Table 3.4 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 3.1) 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% (Figure 3.3). 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).

Table 3.4: Vehicle ownership change by CS participation (number of vehicle/household)

	Car2go only	Car2go&Modo	Modo
Before*	1.08	0.69	0.68
After*	0.98	0.35	0.36
t-test (Before vs. After)	t (2451) = 2.86, p<0.01, d = 0.12	t (1366) = 8.98, p<0.001, d = 0.48	t (1575) = 10.29, p <0.001, d = 0.51
t-test (Car2go vs Car2go&Modo, Before)	t(1656)=10.55, p<0.001, d=0.49		
t-test (Car2go&Modo vs Modo, Before)		t(1449)=0.08, p=0.94, d<0.01	
t-test (Car2go vs Modo, Before)	t(1989) = 11.45, p<0.001, d = 0.50		t(1989) = 11.45, p<0.001, d = 0.50

* 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.

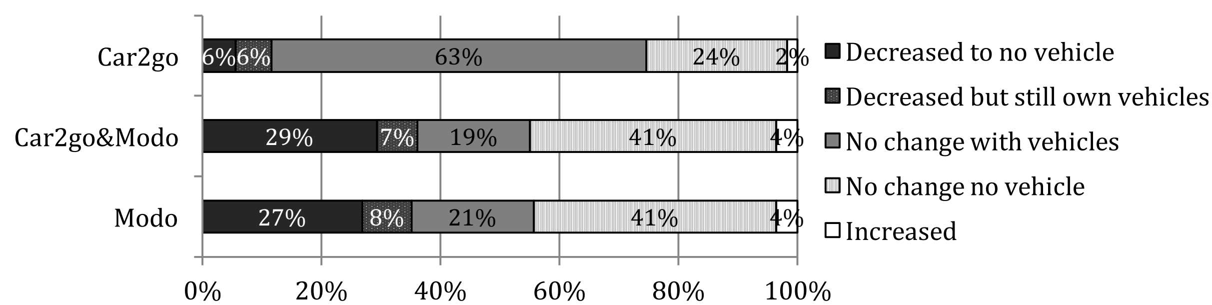

Figure 3.3: Vehicle ownership change comparing before and after CS participation

3.3.3. 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 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[21], 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).

3.3.3.1. 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 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 3.3). 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 3.5. All VIF (Variance Inflation Factor) values of the independent variables are less than 2. As Table 3.5 shows, the two models share a general trend. This is consistent with the low explanatory power found for CS membership length in Model 1. Figure 3.4 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-

[21] 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.

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.

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.

Table 3.5: Regression Model 1 and Model 2

(Dependent variable: 1 for respondents who shed cars after CS participation 0 for others)

		Model 1			Model 2		
Category	Sub-category	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	***	0.63	-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

	Model 1	Model 2
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=***

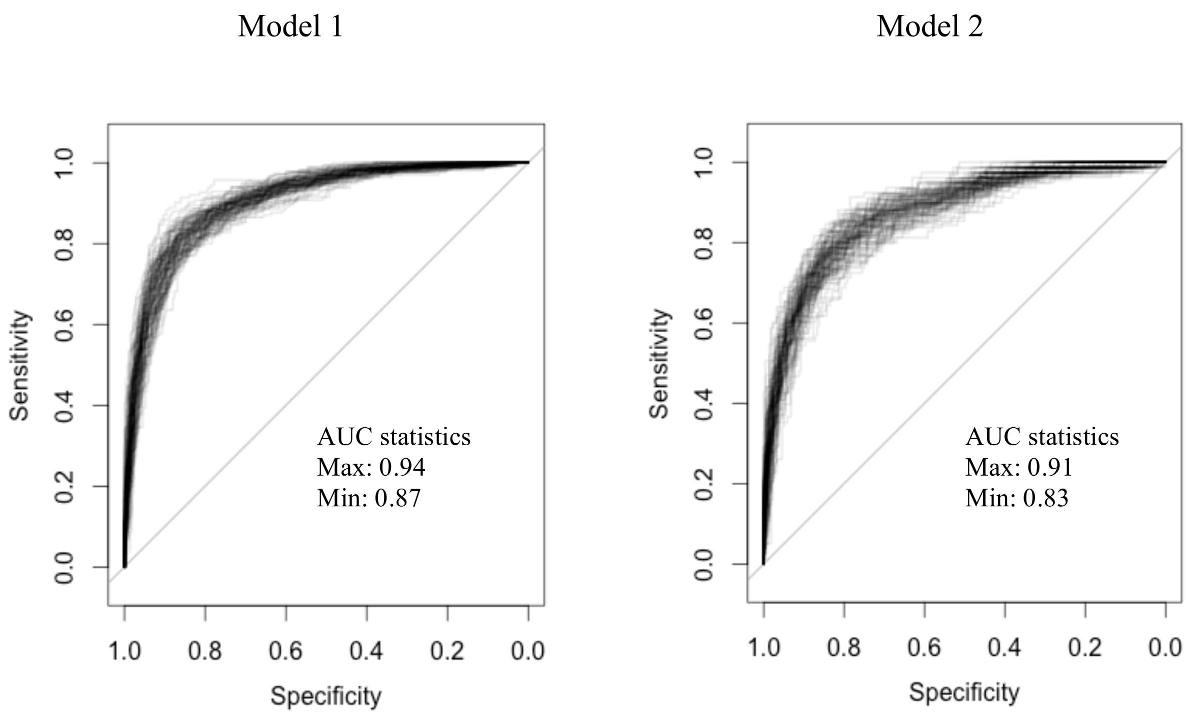

Figure 3.4: ROC curves (Model 1 and Model 2)

3.3.3.2. 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 3.6 summarizes Model 3. All VIF values of the independent variables are less than 2. Figure 3.5 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 3.6, 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 be for going to a restaurant or bar (odds: 0.33, p-value: <0.001).

Table 3.6: 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	0.10	.	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=***

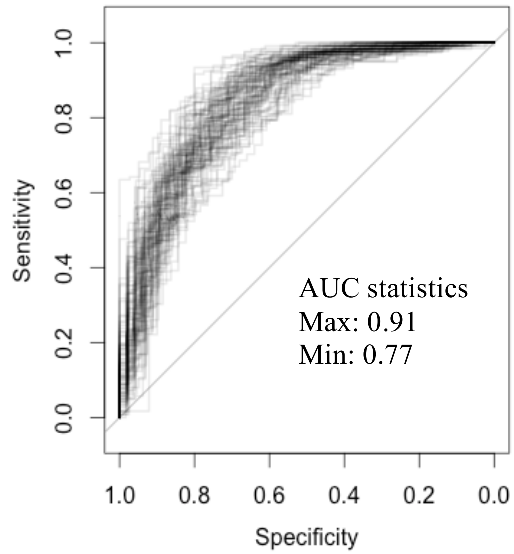

Figure 3.5: ROC curve (Model 3)

3.3.4. Alternative to CS

The survey asked questions about households' decisions in case CS programs were discontinued permanently (Figure 3.6). 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 3.5), 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.

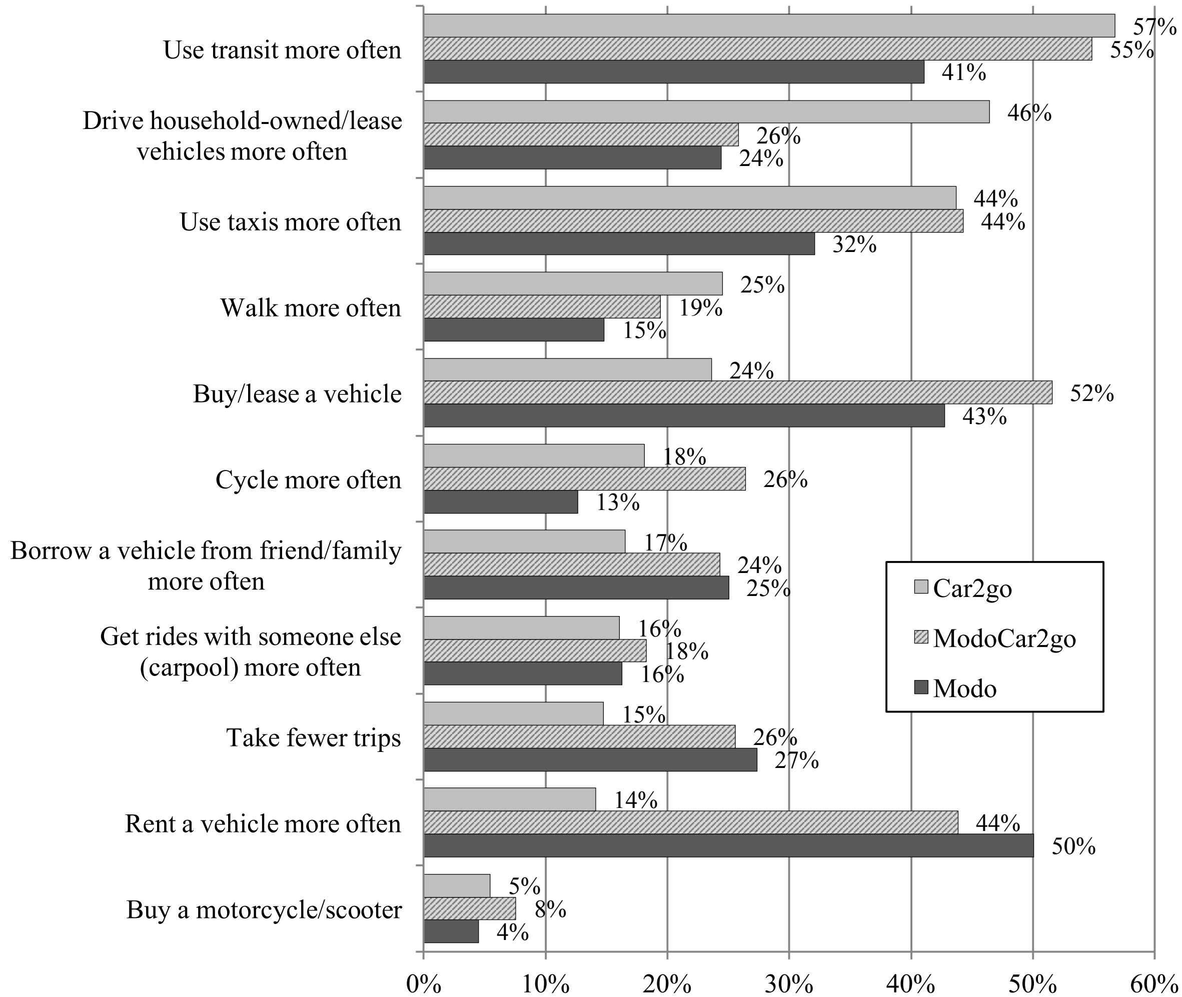

Figure 3.6: If CS programs were discontinued permanently, would your household?

Figure 3.7 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 (Figure 3.7) – 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.

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.

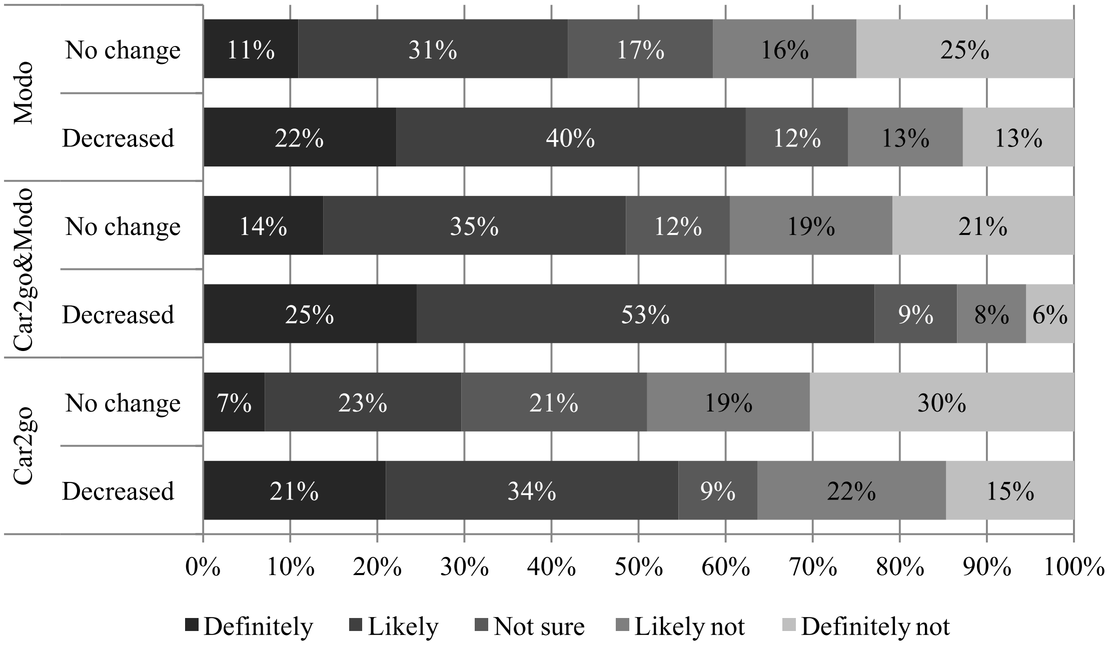

Figure 3.7: Likelihood of buying/leasing additional vehicles under the termination of CS programs (Because of small sample size, households who increased vehicle ownership were excluded)

3.4. 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:

$$\overline{Pr_i} = \overline{Vr_i}/\overline{S_i} \quad (1)$$

Where $\overline{Pr_\iota}$ is probability of vehicle ownership reduction among CS service i users, $\overline{Vr_\iota}$ is number of reduced vehicles in CS service i, and $\overline{S_\iota}$ 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:

$$\overline{\boldsymbol{Pf_\iota}} = \overline{\boldsymbol{Vf_\iota}}/\overline{\boldsymbol{S_\iota}} \tag{2}$$

Where $\overline{Pf_\iota}$ is probability of forgoing vehicle purchase among CS service i users, and $\overline{Vf_\iota}$ is number of forgone vehicles in CS service i. Assuming that these rates ($\overline{Pr_\iota}$ and $\overline{Pf_\iota}$) 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:

$$\boldsymbol{Vr_i} = \overline{\boldsymbol{Pr_\iota}} \cdot \boldsymbol{Nc_i} \tag{1}$$

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:

$$\boldsymbol{Vf_i} = \overline{\boldsymbol{Pf_\iota}} \cdot \boldsymbol{Nc_i} \tag{2}$$

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:

$$\boldsymbol{Vr_i^p} = \boldsymbol{Vr_i}/\boldsymbol{Nv_i} \tag{3}$$

$$\boldsymbol{Vf_i^p} = \boldsymbol{Vf_i}/\boldsymbol{Nv_i} \tag{4}$$

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 7,900 users (Metro Vancouver, 2014a). 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 equation (1)-(6) is summarized in Table 3.7.

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.

Table 3.7: 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* ($\overline{Pf_i}$)	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

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

The results in Table 3.7 show that Car2go only users reduced the largest 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.

3.4.1. Sensitivity Analysis

As pointed out in the beginning of Section 3.3, 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 users 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 3.7 reflect CS user population that are reported by CS providers; in other words, the numbers on Table 3.7 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.

Figure 3.8 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, 2016) . 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, a sampling bias is likely to exist, while the most of Modo users are active members. Since the survey response rate was 19% for Modo only users (Table 3.7), the survey participants represent minimum 19% of the whole Modo users, but not likely 100% of the whole population.

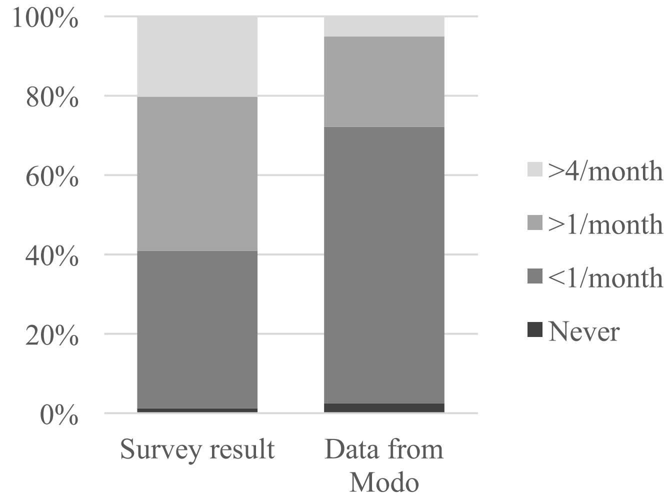

Figure 3.8: Distribution of frequency of service use among Modo users (Modo, 2016)

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. Considering that 550 vehicles were available (Table 3.2), 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 3.3). Considering the number of Car2go only users estimated in Table 3.7, the number of trips made at the time of survey was estimated as 1,016,966 trips, 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 3.7), 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, the equation (1) is altered to

$$\overline{Pr_i} = (\overline{Vr_i}/\overline{S_i}) \cdot SMP_i$$

$$(0.04 \leq SMP_{Car2go} \leq 1.00, 0.19 \leq SMP_{Modo} \leq 1.00) \quad (1')$$

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, $\overline{S_i}$ 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 $0.04 \leq SMP_{Car2go} \leq 1.00$, SMP_{Modo}: mean=(1+0.19)/2=0.60 , SD=0.06, satisfying $0.19 \leq SMP_{Modo} \leq 1.00$). When SMP_i is equal to 1.00, there is no sampling bias 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:

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

$$(0.5 \leq ACT_{Car2go} \leq 1, ACT_{Modo} = 1.00) \quad (3')$$

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 (Figure 3.8). 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 3.2, 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. 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 $0.5 \leq ACT_{Car2go} \leq 1$).

Figure 3.9 and Figure 3.10 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 Figure 3.9, 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.

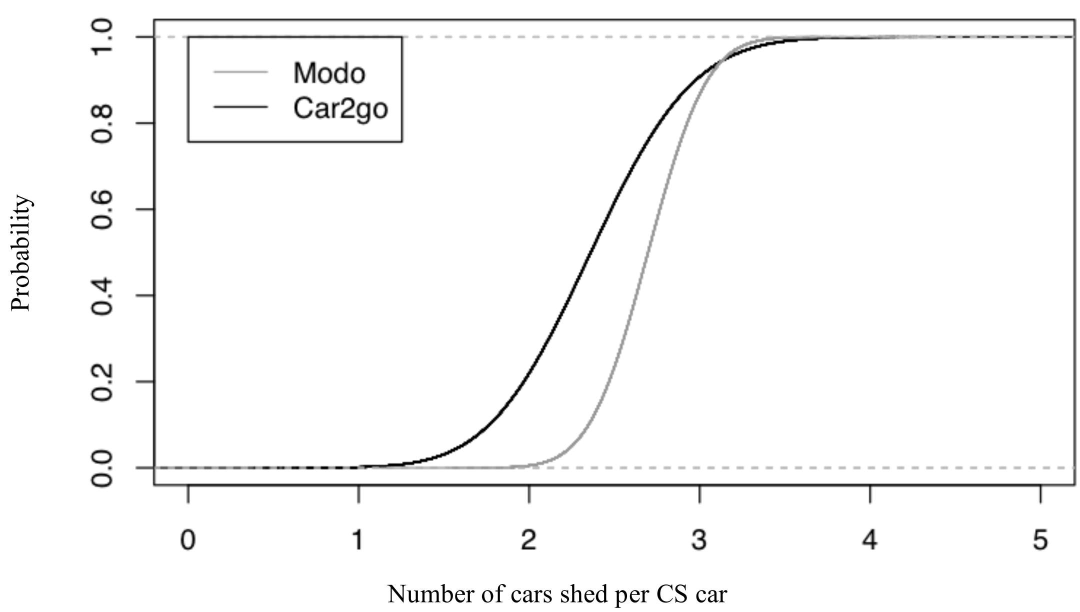

Figure 3.9: Cumulative density of number of cars shed per vehicle in Car2go or Modo fleet based on the 2013 Metro Vancouver survey.

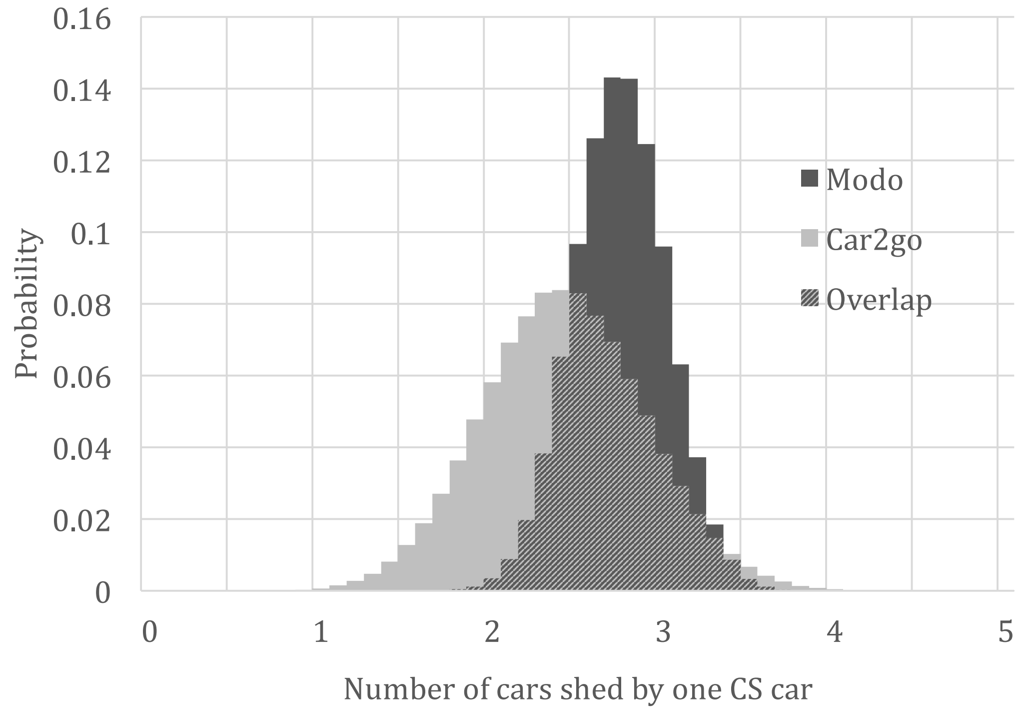

Figure 3.10: Probability density of number of cars shed per vehicle in Car2go or Modo fleet based on the 2013 Metro Vancouver survey

3.5. 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 3.1), 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 3.5). 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.

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 3.5). The double membership is especially prominent for respondents who gave up vehicle ownership completely and became zero-vehicle households (see Table 3.6). 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; CS users have distinct demographics and lifestyles compared to the general public (Namazu, MacKenzie, Zerriffi, and Dowlatabadi, submitted). 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.

3.6. Acknowledgements

We would like to acknowledge support from Metro Vancouver for this study. We especially appreciate generous input from Raymond Kan. We are thankful for the insightful statistical support from Prof. John Petkau and Mr. Eric Shing Fu, at the University of British Columbia Department of Statistics. We are grateful for support from the Takenaka Scholarship Foundation from Japan and additional funding from Carnegie Mellon's Climate and Energy Decision Making Center (CEDM) under a subcontract from the US National Science Foundation (SES-0949710). We are grateful for support from the Canada Research Chairs.

Chapter 4: Is Carsharing for Everyone? Understanding the Diffusion of Carsharing Services[22]

Chapter 2 and 3 showed the positive potential of carsharing (CS) as a method to reduce greenhouse gases (GHGs) and vehicle dependency. These benefits could be multiplied when more people start using the service. However, assuming future benefits based solely on observed results demands careful attention to ensure the accuracy of any outcomes; especially when biases are expected to exist. For example, only a fraction of the whole population has adopted CS, and these early adopters may be quite unique when compared to the others. Examining effects that CS has brought is important; however, exploring the effects that CS will bring in the future is potentially even more important. This chapter seeks to determine the possibility for CS to be accepted by more people in the future, and also examine the characteristics of the late adopters of CS. How these late adopters of CS utilize the service would be a key to determine the actual effect of CS to larger societies.

4.1. Introduction

Private cars are, on average, only used for 5% of their life (Knack, 2005). Carsharing (CS) offers an alternative where multiple individuals can access a fleet of cars for their private use. Shared cars have much higher utilization rates reducing lifecycle environmental impacts of cars. In 2014, there were close to 5 million CS members and over 0.1 million shared cars globally (Shaheen & Cohen, 2016).

Local governments have supported expansion of CS based on a range of expected benefits to society. In its development strategy, City of Vancouver, Canada lists CS as a method to realize sustainable transportation systems and to build a multi-modal city (City of Vancouver, 2012).

[22] A version of this chapter has been submitted for publication: Namazu, M., MacKenzie, D., Zerriffi, H., & Dowlatabadi, H. (in review). Is Carsharing for Everyone? Understanding the Diffusion of Carsharing Services. *Transport Policy*, 1–19.

Other cities place their interest on the possibility of CS to make more parking spaces available and help in reducing vehicle kilometre travelled (VKT) (Schreier, Becker, & Heller, 2016).

A number of studies have shown CS benefits, e.g., lowering the frequency of car use (Meijkamp, 1998); overall reductions in VKT (Firnkorn & Shaheen, 2015; Meijkamp, 1998); and, giving up car ownership (Cervero et al., 2007; Engel-Yan & Passmore, 2013; Katzev, 2003; Millard-Ball et al., 2005). In addition to these reductions in car use by CS, the supply of a variety of cars, which are often newer and more fuel efficient compared to typical private cars (Steer Davies Gleave, 2015a; 2015c), via CS platforms can motivate the optimization of vehicle size and features depending on trip purposes. As a result, CS users can cut transportation related carbon dioxide emissions up to 45-55% per household (Namazu & Dowlatabadi, 2015a).

The focus of this study is on how outcomes may evolve with adoption of CS by the broader population. Existing studies are almost exclusively based on surveys of current CS users, and CS is yet in the first stage of technology diffusion. According to Rogers' technology diffusion theory (E. M. Rogers, 2003) there are five stages of technology adoption: Innovators, Early Adopters, Early Majority, Late Majority and Laggards. A technology takes off at the transition between Early Adopters and Early Majority. This is usually set arbitrarily at 10% of the population eventually adopting a technology. At the time of the survey roughly 10% of the population of the study region (Vancouver, Canada) were members of CS services. A key question motivating our study is whether these early adopters are similar to the broader public and outcomes associated with their adoption of CS can be generalized as CS membership rolls grow. In particular, early adopters may be especially well disposed to changing their private transportation choices, or financially forced into shedding car ownership. Earlier studies have found that early CS adopters can be characterized as being younger, non-vehicle owners, more highly educated, more likely to live in urban centres and less likely to have children than the general population (Government of Canada, New Economy Development Group, 2006; Loose, 2010; Prettenthaler & Steininger, 1999b).

If future adopters have different characteristics than early adopters, extrapolation of outcomes based on studies of early adopters is likely to lead to biased expectations. In other words, further expansion of CS may fail to generate similar patterns of benefits for society. This study has two objectives: a) examining whether early CS adopters are atypical of the general public and b) understanding characteristics and limits to further adoption of CS and the implications of these on outcomes associated CS. To the best of our knowledge, this is the first study of its kind.

This paper consists of five sections. Section two describes the survey context, data and methods. Section three presents results of statistical analyses to understand differences in characteristics among CS adoption groups (Early Adopters, Followers, and Non-adopters). The fourth section shows the characteristics of future adopters and least likely adopters in detail, exploring how the Majority can be motivated to join CS, and the reasons why a significant portion of the population (25%) may never adopt CS. The fifth section provides a discussion and summary of findings and their policy implications for local governments.

4.2. Methodology

4.2.1. Study Area

The study area is the Vancouver Metropolitan region in British Columbia, Canada. The municipality with the highest population density and best public transit in this region is the city of Vancouver. The city has one of the highest CS adoption rates in the world; in 2015, 26% of its population was a member of one or more of four CS services available locally (Ch2m Hill, 2016).

4.2.2. The Survey

Metro Vancouver is a political body and service provider to 24 local municipalities in the region including the city of Vancouver. In the fall of 2013, Metro Vancouver used a survey of 20 questions to understand the role of CS in the region. At the time, the region was served by three CS systems as summarized in Table 4.1.[23]

---

[23] Evo, a new free-floating CS, was introduced after the survey used in this study.

Table 4.1: CS services in Vancouver (2013)

	Modo	Zipcar	car2go
Service style	Two-way	Two-way	One-way (Mainly free-floating)
Start year	1997	2007	2011
Locations and Vehicles	303 vehicles, 245 locations	128 vehicles, 53 locations	550 vehicles, no fixed locations
Operating Areas	Vehicles located in Vancouver, UBC, City of North Vancouver, West Vancouver, Richmond, Burnaby, New Westminster, Coquitlam, Surrey	Vehicles located in Vancouver, UBC, City of North Vancouver, Richmond, SFU Burnaby	Most of Vancouver, UBC, City of North Vancouver, parts of District of North Vancouver, Kwantlen University campuses in Richmond, Surrey, and Langley City
Membership	7,897 individual drivers; 1,667 business-only drivers	Not disclosed	55,000
Individual Membership Fees	Co-op membership: One-time $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

We used the data from this survey to compare the characteristics of CS adopters and non-adopters. This survey was the first with a focus on CS services in the region (Metro Vancouver, 2014b). 110 apartment complexes in Metro Vancouver were targeted for the survey. They were selected on the basis of two criteria: being located within 800m of a two-way CS station; and, being built between 2006 and 2008. All residents of these apartment buildings were invited to participate in the on-line survey by mail (Metro Vancouver, 2014b) [24]. Figure 4.1 shows the locations of the buildings along with survey responses. 2,054 responses were collected with a calculated response rate of 12.8% (Metro Vancouver, 2014b) .[25]

[24] An opportunity to win one of two $50 worth gift cards was given to survey respondents as an incentive.

[25] Unfortunately, a technical glitch in data collection led to no data being collected about the number of family members aged between 55 and 64.

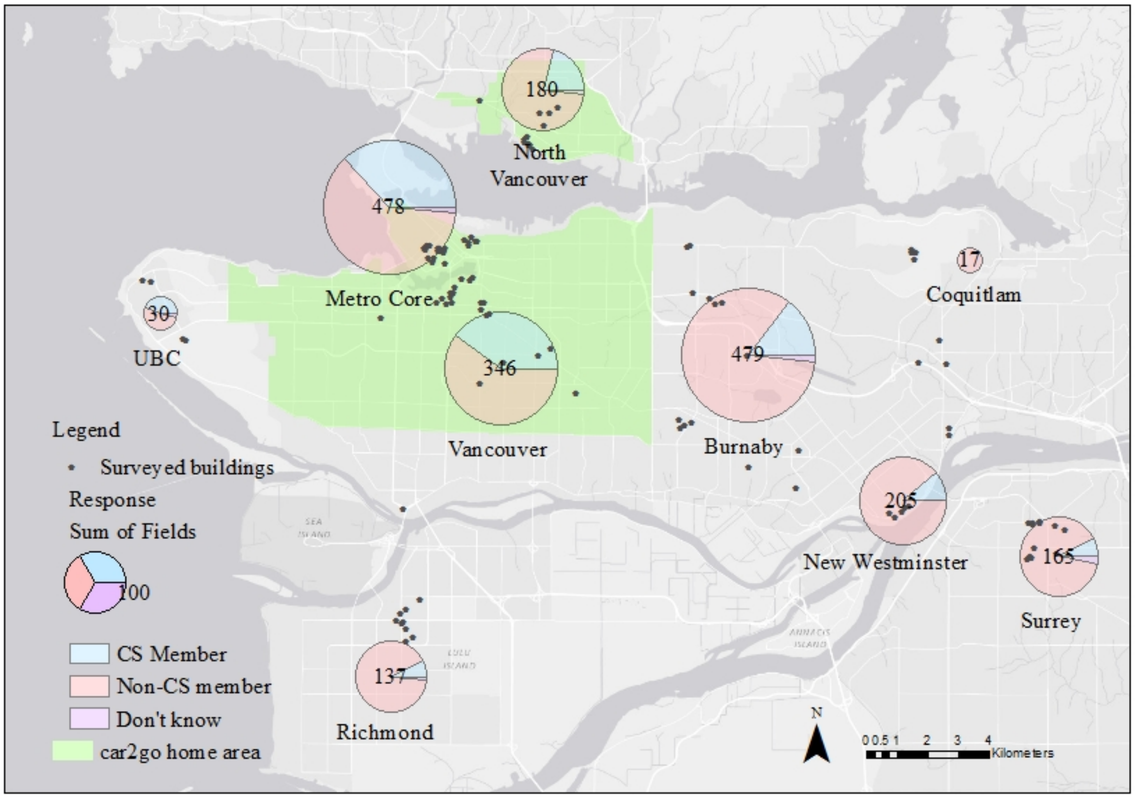

Figure 4.1: Surveyed buildings and survey response
(All the buildings in the survey were within 800 m of a 2-way car service. In addition, we have shaded the region being served by car2go, a free-floating CS service in the region.)

About 40% of the respondents to this targeted survey are residents of the City of Vancouver (Metro core and Vancouver in Figure 4.1). The average number of vehicles per household among these respondents was 1.06 while the Metro Vancouver average in 2011 was 1.66 (Metro Vancouver, 2012b; 2015). Among respondents 23% had one or more CS memberships. By comparison, the City of Vancouver reports, 13% of its residents were CS users in 2013 (Ch2m Hill, 2015). CS membership continues to expand in the region and had doubled by 2015. We suspect the low vehicle ownership rate and high membership in CS among survey participants may be an artifact of the sample design.

4.3. Heterogeneities among CS Adaptation Groups

4.3.1. Grouping

Depending on their actual and expected CS adoption, respondents were classified into three groups: Early Adopters, Followers, and Non-adopters. This classification is modified from the original since Rogers' theory (14) applies to the final population that eventually adopt a technology. In our case, the surveyed population contains a subgroup that self-identify as having mobility needs that cannot be met through CS. Early Adopters are already members of CS services. Followers do not have a CS membership, but identified at least one approach that may persuade them to join a CS program (e.g., more cars, lower fees). Non-adopters do not have a CS membership and declared that there was no way to encourage them to join. Respondents who are inactive CS members and/or cancelled their membership prior to the survey were excluded from analysis (8 responses).

Table 4.2 displays a summary of household and other characteristics for each CS adoption category. Roughly a quarter are Early Adopters, half are Followers and the remainder Non-adopters. As expected, vehicle ownership was lower among Early Adopters[26] replicating findings of earlier studies (Cervero et al., 2007; Engel-Yan & Passmore, 2013; Katzev, 2003; Millard-Ball et al., 2005).

[26] Results of one-way ANOVA (p<0.01) and Tukey's Honest Significant Difference (Early Adopters vs. Non-adopters: p<0.01, Early Adopters vs. Followers: p<0.01, Followers vs. Non-adopters: p=0.03) reject the null hypothesis of no difference in means in any pairs of the three adoption groups.

Table 4.2: Grouping results

Criteria			EA	Followers	Non-Adopters
			Households with at least one CS membership	Households without CS membership + open to joining CS	Households without CS membership + unlikely to join CS
Response			478	1019	514
CS	Holding CS membership		100%	0%	0%
	Living in buildings with on-site CS		30%	18%	18%
Demographics	Average number of bedrooms		1.48	1.63	1.7
	Living with children (<=15)		12%	14%	12%
	Living with elderlies (>65)		2%	6%	12%
Housing	Living in rental housings		40%	31%	25%
	Length of residency	<1yr	21%	21%	13%
		1-2yrs	36%	31%	27%
		>2yrs	43%	48%	60%
Vehicle ownership	Average number of vehicles per household		0.82	1.10	1.19
	Top 3 amenities near home which help giving up/postponing vehicle ownership	1	Availability of car share vehicles (47%)	Frequent and direct transit service (52%)	None (68%)
		2	Frequent and direct transit service (47%)	Availability of car share vehicles (34%)	Frequent and direct transit service (21%)
		3	Shops and services like grocery stores, daycare, restaurants (31%)	Shops and services like grocery stores, daycare, restaurants (33%)	Shops and services like grocery stores, daycare, restaurants (12%)
	Top 3 amenities near work which help giving up/postponing vehicle ownership	1	Frequent and direct transit service (46%)	Frequent and direct transit service (51%)	None (71%)
		2	Availability of car share vehicles (36%)	None (32%)	Frequent and direct transit service (22%)
		3	None (32%)	Availability of car share vehicles (25%)	Shops and services like grocery stores, daycare, restaurants (4%)

4.3.2. Multinomial Mixed Logistic Regression Analysis

We used data on household characteristics and dwelling amenities to detect differences between Early Adopters and others. Since the response variable was the adoption groups (a three-category discrete variable), multinomial logistic regression was applied with Followers as a reference category. A hierarchical structure in groups is expected; however, the evidence of non-proportional odds was found, hence a multinomial logistic regression model was employed instead of an ordered logistic regression model. As the responses were collected from 110 buildings each of which could have unobserved features that potentially impact survey responses, we used a multinomial mixed logistic regression model, which allows separation and quantification of individual and building level effects.

Table 4.3 shows the variables used to estimate the model. Amenities near each building were identified and characterized using the Yelp API and ArcGIS software. Three distance thresholds (400m, 800m and 1,200m) were used to quantify ease of accessibility to these facilities.

Table 4.3 Variables considered in the regression

Type	Variable explanation
Dwelling	Number of bedrooms
	Length of residency at the current dwelling unit
	Living in rental housings
	Estimated rent (100CAD/month)[27]
Household demographics	Number of employed family members
	Number of family members working outside home
	Living with children (<16)
	Living with elderlies (>64)
Car ownership	Number of cars owned
CS related	Living in buildings with on-site CS
Transit	Quality of transit near home[28]
Amenities near home (400m, 800m, 1200m distance[29])	Number and distance category of CS locations nearby
	Number and distance category of bus stops nearby
	Number and distance category of Skytrain[30] stations nearby
	Number and distance category of grocery stores nearby
	Number and distance category of restaurants nearby

Table 4.4 shows the results of the multinomial mixed logistic regression. Variables listed in Table 4.3 but missing in Table 4.4 were variables excluded in the step-wise regression model

[27] This variable shows estimated rent of the unit. The rent was estimated based on average rent in the neighbourhood (Canada Mortage and Housing Corporation, 2010) (Canada Mortage and Housing Corporation, 2011) (Canada Mortage and Housing Corporation, 2012), move-in year, and maximum allowance for annual rent increase regulated by the B.C. government (Province of British Columbia, 2016).

[28] This variable is the answers to a qualitative survey question: "How would you describe the quality of transit near your home?"

[29] 400m is often used as a standard distance that people are willing to walk to take a bus. Since further distances could be walked for rapid transit systems, the three levels of distances are considered in this study.

[30] Skytrain is the automated driverless light rapid transit systems running in the Vancouver region.

because of lower explanatory power and/or in order to avoid multicollinearities. Table 4.5 shows the accuracy of the model prediction.

Table 4.4 Result of multinomial mixed logistic regression
(Odds ratio with P-value, reference = Followers)

	Early Adopters				Non-adopters			
	Coef.	S.E.	Odds	Sig.	Coef.	S.E.	Odds	Sig.
Intercept	-3.14	0.48	0.04	**	-1.30	0.41	0.27	**
Number of Bedrooms	-0.79	0.26	0.45	**	0.47	0.19	1.59	*
Living in rental housings	0.40	0.22	1.49	†	-0.35	0.21	0.71	†
Number of employed family members	0.43	0.16	1.53	**	-0.22	0.14	0.81	
Number of owned cars	-0.93	0.19	0.40	**	0.34	0.17	1.41	*
Living in buildings with on-site CS	0.51	0.32	1.66		0.59	0.27	1.80	*
Estimated rent	0.26	0.04	1.30	**	-0.02	0.03	-0.51	

**: $p < 0.01$, *: $p < 0.05$, †: $p < 0.1$

Table 4.5 Prediction accuracy of the regression model (%)

		Predicted		
		Early Adopters	Followers	Non-adopters
Observed	Early Adopters	53.5	44.1	2.4
	Followers	11.0	83.3	5.6
	Non-adopters	7.8	83.8	8.4

Based on the results from the regression analysis, when compared to Followers, Early Adopters tend to:

- live in more expensive rental housing with fewer bedrooms
- have more employed family members
- own fewer cars

On the other hand, when compared to Followers, Non-adopters tend to:

- live in owner-occupied housing with more bedrooms
- own more cars

- live in buildings with on-site CS

Also, CS membership status is less affected by:

- Availability of facilities near home (e.g. grocery stores, bus/Skytrain stations, restaurants)
- Presence of children

In addition to these findings, Table 4.5 shows low prediction accuracy for Non-adopters. Most of Non-adopters are predicted as Followers by the model, meaning that Non-adopters and Followers share many characteristics. This finding also suggests that survey questions fail to capture factors that lead respondents to self-identify into different groups. We turn to qualitative responses to understand these differences in section 4.

Overall, Early Adopters are more distinctive than the rest of the respondents. They were more likely to be at an early stage of forming an independent household.

In our analysis, presence of elderly household members was not selected as an explanatory variable. However, we know that Early Adopters, on average, were far less likely to live with elderly family members – see Table 4.2. We suspect the high correlation between resident elderly and home ownership is why this feature of the household was not highlighted. 90% of households with elderlies owned their home, while only 40% of households without elderlies were owner-occupied. The exclusion of the length of residency in the model can be explained in the same way. Two-thirds of respondents living at their current address for less than one year were renters. Renter percentage falls to 21% for residence in the same location for longer than three years. Therefore, Early Adopters are more likely to live in rental housings, as well as live with fewer elderlies in the current unit for a shorter period of time. It should also be noted that given double digit housing cost increases for nearly a decade and rent control, those living in the same dwelling for longer were facing significantly lower housing costs.

Findings presented here are consistent with results from a previous study on the effect of CS on vehicle ownership showing that moving households may have triggered car-shedding (Namazu & Dowlatabadi, n.d.). As the estimated rent positively correlated with CS membership, we suspect high housing costs in and around Metro Vancouver are contributing to a household budget crunch that cannot simultaneously sustain housing and private car ownership. CS could be less a choice than a forced decision among Early Adopters. Available data and this analysis are ill-equipped to answer whether Early Adopters' use of CS crystallizes into a preference that survives changing household circumstances. Longitudinal surveys, such as a panel study or cross-comparisons with cities that have more affordable housing are required to explore this critical question.

All buildings in this survey were located in areas with many facilities nearby, and easy access to transit services. More specifically, all buildings had at least one bus stop within 800-meters, and 93% of the buildings had at least one grocery store within 800-meters. Thus, building level amenities except the availability of on-site CS had no or weak explanatory power. Even for the availability of on-site CS, the correlation with CS membership was not statistically significant (p =0.11). This points to the possible need to conduct a follow-up survey targeting residential settings with different neighbourhood level amenities as another potential differentiator of CS adoption and use patterns.

4.4. Future CS Adopters

The previous section provided a quantitative assessment of differences between Early Adopters of CS and others. In this section, we delve beyond the quantitative analysis and try to understand Followers and Non-adopters.

4.4.1. Non-adopters

Non-adopters were those who stated that they could not be motivated to join CS in any way. Unfortunately, the survey questions did not explore the reasons for this directly. One measure of their differential reliance on a personal vehicle is their high level of car ownership (over 90% of Non-adopters were vehicle owners[31]). While there is no direct evidence regarding reasons for not joining CS, there is evidence about how Non-adopters rely on their vehicles. When asked if the addition of any particular amenity near home or work would help them give up their car nearly 68% said no (71% said no to near work)(Table 4.2). The majority of Non-adopters provided reasons why nothing could help them in shedding car ownership. We coded their verbal reasoning based on keywords and concepts and present these here.

Figure 4.2 shows the coding results. Based on the keywords and their frequency of appearance, we came up with four categories of car usage among Non-adopters: Cars for weekend trips, Cars for work, Car enthusiasts, and Cars for transporting people/animals/materials. Table 4.6 shows the detailed characteristics of each category along with some quotations from respondents' comments. These categories are not mutually exclusive – some respondents belong to many simultaneously.

[31] The percentages of car owners in each adoption group are 71%, 87%, and 93% for Early Adopters, Followers, and Non-adopters, respectively. Chi-square test results suggest a relationship between vehicle ownership and adoption groups (Early Adopters vs. Non-adopters: $p<0.01$, Early Adopters vs. Followers: $p<0.01$, Followers vs. Non-adopters: $p<0.01$)

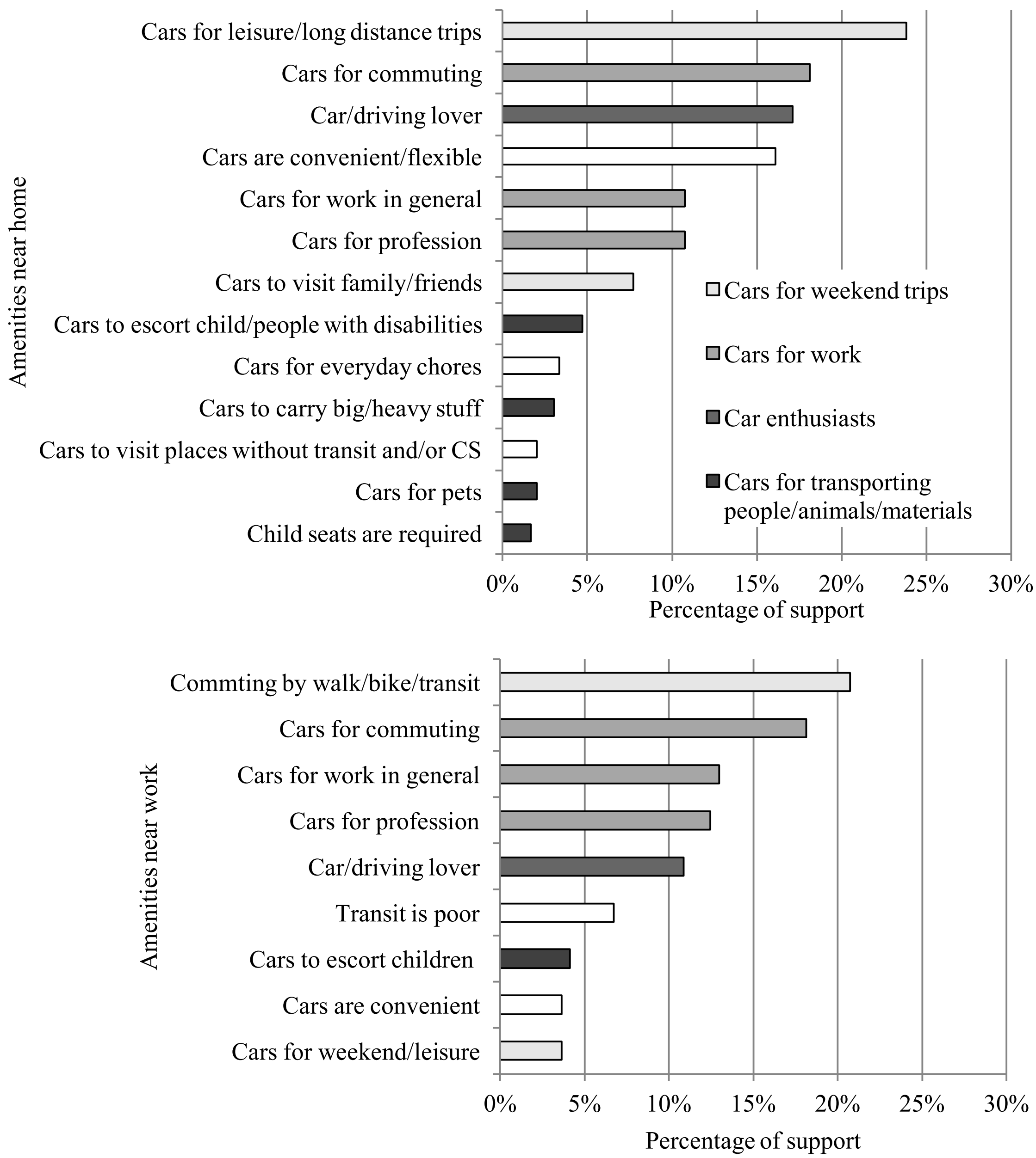

Figure 4.2 Reasons why amenities near home/work do not help giving up cars for Non-adopters

Table 4.6 Five categories in Non-adopters

Sub-group	Characteristics	
Cars for weekend trips	Explanation	Already practicing lifestyle with multi-modal transportation, and using cars only for weekend trips.
	Reasons why CS doesn't work for them	Because the main purpose of owning a car is to take long-distance trips, and owning a car is a better option than using CS services for such trips.
	Excerpt of reasons why no amenities near home/work help giving up cars	*"We do not use the car for commuting. One of us walks or transits to work, the other cycles. The car is used to go to the country, for travelling, and errands that involve large or heavy parcels "*
		"Although I live beside a sky train station and use it regularly to get to work in downtown Vancouver, my family members are scattered throughout the Lower Mainland and other parts of this province. Consequently, I will not give up my vehicle "
Cars for work	Explanation	Using cars for commuting and/or their jobs.
	Reasons why CS doesn't work for them	Because CS is not convenient for commuting, carrying job-related tools or frequent use. Round-trip CS requires users to return cars to the original locations to finish trips, and one-way CS does not offer over 30min in-advance vehicle reservation hence vehicle availability is always uncertain.
	Excerpt of reasons why no amenities near home/work help giving up cars	*"My husband works off Marine in industrial areas where there is no feasible transit so a car is a necessity."*
		"We work in film and have a different location to go to almost every other day. ex could be downtown one day then langley or maple ridge the other. Work extra ordinary long hrs to much to take transit adds way too much time to a already long day."
		"I'm a contractor, I need my truck for work. Can't fit a bunch of lumber, tools and what not in a smart car or take on the bus..."
Car enthusiasts	Explanation	Car/driving lovers. Emotional attachments to cars/driving.
	Reasons why CS doesn't work for them	Because CS service does not satisfy their need, which is more than a simple mobility that transports things from point A to point B.
	Excerpt of reasons why no amenities near home/work help giving up cars	*"I am not getting rid of my car ! I do not care what you offer me."*
		"too old but not yet old enough to give up my car"
		"I wouldnot be willing to give up my vehicle under any circumstances."
Cars for transporting people/materials	Explanation	Having a demand to transport people and/or materials. These people and materials to be transported often require special equipment
	Reasons why CS doesn't work for them	Because it is difficult if not possible for them to receive the required mobility service from CS.
	Excerpt of reasons why no amenities near home/work help giving up cars	*"Transit service inconvenient for times/places I need to go. Need my own vehicle to take care of disabled individuals who need rides to doctors in and out of Vancouver Broadway area, UBC, Burnaby Hospital and I frequently go out to Abbotsford to care give for an elderly lady. None of my clients could access transit due to their injuries or orientation issues."*
		"We also have a one year old child; her safety is a priority and her child seat is installed in our car and has been approved by the local fire department. For us, the convenience of having a car is paramount. Time is limited when you have young children, things take 2-3 times longer. Having to seek out a car, carry my car seat with me, and a baby, and a stroller, etc. does not make any sense. I do not have the time to take public transit to places like Superstore."

Roughly a quarter of respondents, and a third of the respondents without a CS membership belonged to this Non-adopter group. Respondents typically offered multiple reasons for why there is no effective way to encourage them to substitute car ownership with other modes of transportation. By exploring the meaning of vehicle ownership for people in this group, we found multiple reasons why CS could not meet their mobility needs.

Beyond car enthusiasts who self-identify with owning cars, Non-adopters are not averse to reducing vehicle dependency. However doing so involves provision of CS service features that are currently inconsistent with efficient use of the CS fleet – e.g., booking one-way cars long in advance of use.

4.4.2. Followers

Followers may become CS members if some improvements in the service are made. Out of total 2,011 valid survey responses, 1,019 responses belonged to this group. Within this group, 4.9% had considered joining CS in the 12 months prior to the survey.

33% of Followers stated that should they adopt CS, it would help them reduce vehicle ownership. This number is higher than the percentage of active CS users who shed their cars, reported by other scholars (20-29%, (Cervero et al., 2007; Cervero & Tsai, 2004; Engel-Yan & Passmore, 2013; Katzev, 2003; Millard-Ball et al., 2005; Namazu & Dowlatabadi, 2015b)). This result reflects the well documented bias between stated and revealed preferences (Loomis, 2011; Wardman, 1988), and cannot be used to project the consequence of Followers joining CS.

If Followers are interested in joining CS, how could they be motivated to join up? Figure 4.3 shows amenities and improvements that encourage Followers to sign up. Followers are divided into three groups in the figure: vehicle owners who may reduce vehicles after membership in CS, vehicle owners who will not reduce vehicles, and non-vehicle owners.

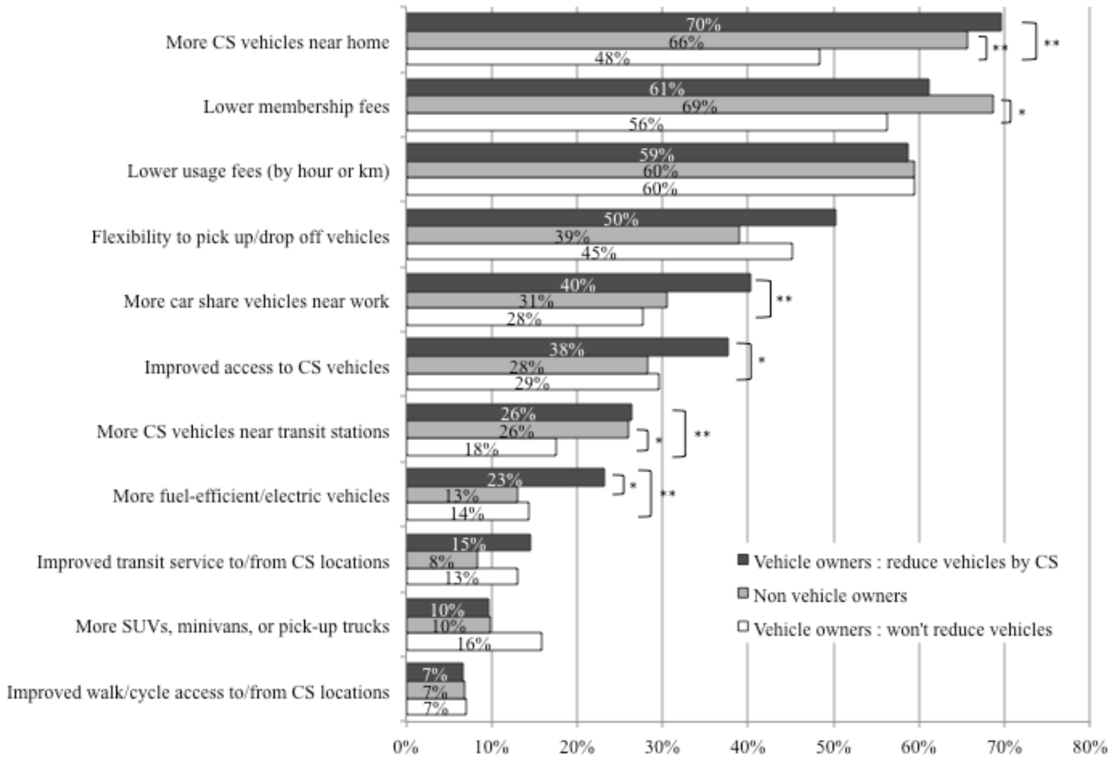

Figure 4.3: What amenities/improvements would motivate you to join CS?
(Answers by Followers, chi-square test results: $p<0.01$:**, $p<0.05$:*)

The top three amenities/improvements leading to further CS recruitments are the same for all three groups:

- Availability of CS vehicles near home
- Lowering membership fees
- Lowering usage fees

The relative importance of these varies among the three Follower sub-groups. In order to attract potential adopters who may substitute CS for private cars, increasing CS vehicle supply near home is the key. Lowering financial barriers would motivate CS participation in general, but this approach is more likely to attract people who use CS as an additional mobility, not substitutes for private cars. Lowering initial investment would be most attractive to non-vehicle owners. In this case, CS might work as a gateway for vehicle ownership, in which non-vehicle owners experience the convenience of using vehicles.

The survey asked about willingness to walk to CS locations, and the mode of transportation to access CS locations. 20% of Followers answered that they are willing to walk up to 2 minutes, and another 48% said up to 5 minutes, with the remainder willing to walk 10-15 minutes. These results point to close proximity of CS being a significant factor in attracting membership among Followers (Figure 4.3). Therefore, CS providers should seek to increase vehicle availability within a 5-minute walk (about 400m) of new work or housing projects.

Figure 4.4 shows the modes of transportation that are (will be) used to access CS cars. The bars in light grey are results from Followers showing how they expect to access CS cars if they join the service. On the other hand, the bars in dark grey are results from CS users[32], who are already using the service in the region. Multiple answers were allowed in this question. Walking was the major mode of transportation for existing CS users. Followers (i.e. potential CS users) also indicated a strong intention to walk to CS vehicles (though smaller than for existing users). However, they expressed much stronger intention to use public transit to access CS cars than is manifested in existing CS users, only a small number of whom actually use public transit to access cars. If Followers are a distinct group from existing users and act as they reported, providing CS locations close to public transit stations may be a unique approach to attract Followers. However, the issue of stated preference needs to be addressed here as well. As Figure 4.4 shows, only a small number of current CS users use transit to access to CS cars.

[32] The question of mode of transportation to access CS cars was only asked of Followers in the survey. However, the exact same question was asked of CS users in a parallel survey, conducted in the same period of time in the same region (Metro Vancouver, 2014b). The dark grey bars show the results from this parallel survey.

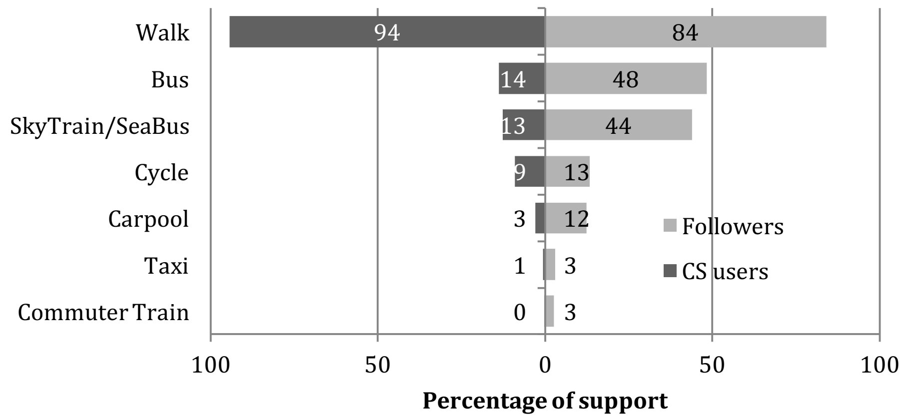

Figure 4.4: Mode of transportation to access CS cars

The financial incentive is more likely to attract Followers who do not have an intention to reduce vehicle ownership via CS participation. In addition, lowering initial CS participation cost seems to have the highest possibility to attract non-vehicles owners, and for them CS could work as a gateway for vehicle use/ownership. In order to maximize the effect of vehicle ownership reduction by CS, the priority should be placed on increasing the supply of CS cars near home, especially within 5 minutes walking distance.

4.5. Discussion and Summary

This study addressed two questions:

a) Examining whether early CS adopters are atypical of the general public; and,
b) Understanding characteristics and limits to further adoption of CS and the implications of these on outcomes associated CS.

By analyzing over two thousand responses from residents of 110 apartment buildings in Metro Vancouver, Canada, we found that Early Adopters are atypical of the general population and can be statistically differentiated from those who have yet to become CS members. Early Adopters, 25% of the sample, tended to live in smaller and more expensive rental housing, have more employed family members, and own fewer cars. A second group, Followers are people who professed an interest to join CS if it was offered at lower cost and with more vehicles within easy access of their homes. This Follower group (50% of the sample) were difficult to distinguish from the remaining 25% who stated that no changes in CS services would induce them to join a CS service (Non-adopters).

Housing ownership status was one of the strongest differentiators between Early Adopters and others. But this variable is highly correlated with length of residency at the current dwelling and negatively correlated with presence of elderly people in the household. These findings suggest that Early Adopters are more likely be at the early stage of establishing their households. Given the very high cost of housing in the study region, early adoption of CS and car-shedding may be a forced budgetary measure rather than a permanent lifestyle choice. The answer to this question cannot be determined in the absence of corresponding research in regions where cost of living is lower as well as longitudinal studies where household circumstances evolve.

The differentiating characteristics of Early Adopters suggest that the next tranche of CS adopters (Followers) may use CS in a different way. Attracting this group to CS through lower cost service or greater access to vehicles is unlikely to lead to the same pattern of vehicle ownership shedding or VKT reduction. Followers are more likely to own houses with more bedrooms and have elderly family members. The mobility of elderly household members alone could radically reshape the patterns of access to and trips taken using CS.

Our findings also suggest that provision of more CS vehicles within easy access of Followers will have the highest impact on car-shedding. Waiving membership fees is more likely to attract non-vehicle owners. Many one-way CS service providers often offer free membership sign-ups. Non-vehicle owners joining CS could mean increasing VKT, and may even motivate future vehicle purchases with improved household financial status. Therefore, we emphasize the necessity of longitudinal and detailed surveys of CS use and its evolution as membership rolls grow. Future surveys should explore not only current but also latent effects of CS on societies.

A quarter of survey participants were identified as Non-adopters. This group offered a narrative explanation of practical and personal reasons why current CS systems are not able to satisfy their mobility needs unless CS systems evolve in ways that are currently considered to be impractical.

Findings in this paper show Early Adopters to have household and trip characteristics that are different to Followers, and Non-adopters. Early Adopters realized the expected benefits from CS. However, how much of their choice to be CS members was due to supportive policies, versus a forced decision vs. a lifestyle choice cannot be answered with the data in hand. Meanwhile, policy makers and CS providers seek to swell the ranks of CS members in the hope of continuing a track record of success in reduced car ownership, congestion and pollution. It is highly unlikely that the manner in which Followers use CS will have the same impacts are Early Adopters.

This study sheds some light on what factors are critical to recruitment of future CS members, However, much remains to be learned to inform public policies that can recruit CS members and yield benefits in terms of reduced car ownership, congestion and pollution in our cities.

Future work suggested in the wake of this study is improvements in survey design and data collection. The study sample was atypical of the general dwellings in the region. The targeted buildings were newly built, were located within walking distance of amenities and over 90% had one or more public transit stations nearby. Surveying people living in other neighbourhoods and housings types is likely to highlight additional challenges in expansion of CS services.

4.6. Acknowledgements

We would like to acknowledge support from Metro Vancouver for this study. We especially appreciate generous input from Raymond Kan. We are grateful for support from the Takenaka Scholarship Foundation from Japan and additional funding from Carnegie Mellon's Climate and Energy Decision Making Center (CEDM) under a subcontract from the US National Science Foundation (SES-1463492). We are grateful for support from the Canada Research Chairs.

Chapter 5: Nudging for Responsible Carsharing: Using Behavioral Economics to Change Transportation Behavior[33]

Chapter 2 and 3 revealed the potential benefits that CS can bring, and Chapter 4 showed the future potential of CS that more people are expected to join CS in the future. Statistical analyses in Chapter 4 also suggested that late adopters, who will join CS from now onwards, have different demographics, lifestyles, and environments compared to that of early adopters. Therefore, it is highly likely that early adopters and late adopters utilize CS services in different ways.

The management of shared properties has been a challenging topic for a variety of scholars and stakeholders. Managing CS vehicles is not an exception, and as newer and more diverse CS members are expected, the management of CS fleets will be even more difficult.

This chapter focuses on this issue of asset management, and in particular, the lack of responsibility among CS users. The novelties in this study are two-folds: the completion of a series of field experiments to coax changes in transportation behavior, and the behavioural economics approach taken in the experiments themselves.

5.1. Introduction

Standard economic theory assumes that humans behave in fully rational ways, hold stable and consistent preferences, and are able to consider all possible options and make the best choice. Since prospect theory (Kahneman & Tversky, 1979), behavioral economics emerged as a new field, challenging basic assumptions of economic theories and providing a more valid model of human behavior. Specifically, behavioral economics not only describes how people

[33] A version of this chapter has been published as Namazu, M., Zhao, J., & Dowlatabadi, H. (n.d.). Nudging for responsible carsharing: Using behavioral economics to change transportation behavior. Transportation, Forthcoming.

systematically deviate from predictions from standard economic theory, but also explains why these deviations occur based on psychological principles. For example, models of behavioral economics assume that human rationality is bounded, and despite having the best intentions, people often behave in impulsive and myopic ways, lack self-control, have limited attention and memory, and yield to social pressure (e.g., (Kahneman, 2003; Schultz, Nolan, Cialdini, Goldstein, & Griskevicius, 2007; Simon, 1982; Thaler, 1980; Thaler & Shefrin, 1981)).

These psychological insights provide a deeper understanding of human behavior, and more importantly, allow the development of simple, cost-effective interventions that can have large impacts. These interventions, called nudges ((Sunstein, 2014; Thaler & Sunstein, 2009)), have been designed to change behavior in a number of domains, such as medical adherence (Mahtani, Heneghan, Glasziou, & R, 2011), physical exercise (Newton, Wiltshire, & Elley, 2009), healthy eating (Wisdom, Downs, & Loewenstein, 2010), retirement savings (Thaler & Benartzi, 2004), energy consumption (Allcott & Mullainathan, 2010), voting (Nickerson & Rogers, 2010), and charitable donation (Slovic, Zionts, Woods, Goodman, & Jinks, 2011).

However, few nudges have been developed and tested in the field of transportation (Metcalfe & Dolan, 2012). The overall goal of our current study is to demonstrate that principles of behavioral economics can be used to design a nudge to change human behavior relevant to transportation. To achieve this goal, we focused on carsharing as a case study, where a randomized field experiment was conducted to examine the effects of a nudge on the behavior of carsharing users.

One specific problem common to carsharing services is that the users often do not inspect the vehicle before starting their trip, resulting in unreported damages to the vehicle and compromising the vehicle and driver safety. Standard economic theory would suggest that the failure to inspect the vehicle is due to a lack of knowledge about the benefits of inspection, or a lack of awareness of the obligation to inspect. A behavioral economic view would suggest that the failure of inspection is due to limitations in memory and attention, or external factors such as being in a rush, but not due to a lack of knowledge or intention. We first conducted an observation study and an interview to understand reasons for neglecting the inspection. As our interview suggests, most users are aware that it is their obligation to inspect the vehicle before their trip, and yet they fail to inspect the car because of other reasons.

From a behavioral economic perspective, we developed a nudge in the form of a reminder card placed on the windshield of the vehicle, in order to remind users to inspect the car before their trip. A number of previous studies have suggested the benefits of reminders on behavior change. For example, text message reminders increased the application for student aid among college students by 12% (Castleman & Page, 2015); increased adherence to medication by over 10% (Hardy et al., 2011; Pop-Eleches et al., 2011; Vervloet, Linn, & van Weert, 2012); increased savings by 6% (Karlan, McConnell, Mullainathan, & Zinman, 2016); and increased physical activity by 26% (Newton et al., 2009).

5.2. A Case Study – Carsharing

Carsharing is a type of short-term car-rental service and has become increasingly popular over the last few decades (Shaheen & Cohen, 2013a; 2013b). Carsharing was first launched in the late 1940s in Switzerland (Shaheen et al., 1999), and has since then expanded to 27 countries over five continents(University of California Berkeley Transportation Sustainability Research Center, 2015b). In 2014, more than 1,600,000 users shared more than 24,000 vehicles in North America alone (Shaheen & Cohen, 2014). This enormous growth accompanies significant improvements in convenience, affordability, and flexibility in rental car usage (Brody & Pureswaran, 2015; Lamberton & Rose, 2012; Rifkin, 2001).

One critical difference between carsharing and conventional car-rental is that carsharing is entirely self serviced, including vehicle reservation, pick-up, and return. While conventional car-rental services require customers to pick up cars at a staffed service office, most carsharing vehicles are kept at unmanned locations where users pick-up and drop-off the vehicle without any interaction with the carsharing organizations' staff. This also means that when using a carsharing vehicle, there is little provider monitoring to check on vehicle condition and attribute damages, say from a collision during the use period, to the driver of record. Instead, most carsharing organizations rely on users to inspect the vehicle before they begin their trip, and report pre-existing damage to the vehicle or self-report any damage that may have occurred during their rental period (e.g., (car2go, 2015b; Zipcar, 2015).

Despite the shared responsibility and the absence of provider monitoring of vehicle condition in carsharing, there is a lack of trust among carsharing members (Bardhi & Eckhardt, 2012). In fact, carsharing organizations are struggling to make their users inspect cars and report damages in a timely fashion. Modo, the first carsharing co-op in North America has repeatedly reminded its members the necessity and importance of vehicle inspection and damage reporting (Modo the Car Co-op, 2015b). The CEO of a carsharing company in Canada also stressed that the lack of vehicle inspection and damage reporting can pose serious safety and security risks (C. Brown & Winter, 2015). The lack of inspection makes it difficult to trace the specific driver who caused the damage. The user obligation to inspect vehicles is one of the characteristics distinguishing carsharing from car-renting services; however, this characteristic increases the difficulty in managing carsharing service (Kahan, 2012).

Given this context, we apply principles of behavioral economics to nudge inspection behavior among carsharing users. In this study, we focused on a one-way carsharing service provided by a company called car2go. The car2go service was introduced in Vancouver, the study area, in 2011 (CNW canada Ltd., 2012). Car2go has three distinctive features: one-way rental, a two-seater vehicle, and per-minute payment system. According to user instructions, the procedure for using a car2go vehicle trips involve the following steps: (1) find a car2go vehicle; (2) place the membership card on the card reader located on the windshield; (3) during the account activation period which takes 15-20 seconds, inspect the vehicle by walking around all four sides of the vehicle; (4) answer questions regarding the interior and exterior conditions of the car, and report damages if found; and (5) start the trip. The importance of vehicle inspection before starting a trip is explicitly stated on the user agreement (car2go, 2014b), and missing damage reports "can result in that Member being held responsible for the repair or cleaning of the vehicle" (car2go, 2014b). Completing an inspection is beneficial for users in order to avoid safety issues and being mistakenly charged for repairs. Rationally, users should be motivated to conduct the inspection. However, the evidence reported below suggests that most users do not perform a proper inspection prior to starting their trip.

5.3. Pilot Studies

5.3.1. Observation Study

The observation was conducted at a designated parking area with 16 car2go vehicle spots at the University of British Columbia (UBC) Vancouver campus. The observation occurred over 5 days (October 22nd, 23rd, and 27th – 29th, 2014) during the morning and afternoon rush hour period (8:00am – 9:00am, 3:30pm – 4:30pm). The rush hour period is determined by the data of vehicle availability from car2go Vancouver's website (car2go, 2014a). For each observation period, we observed trips initiated by users at the parking area. The observation was conducted surreptitiously from a distance to avoid any interaction with car2go users. In total we tracked users' inspection behavior of 34 trips. Among those, 23 trips were started without any inspection, seven trips were started after an incomplete inspection (i.e., checking two or three sides of the vehicle), and only four trips were started with a full inspection (i.e., checking all four sides of the vehicle). In other words, 88% of the trips were started without a full inspection during the observation period. The majority of those who did not conduct an inspection simply waited next to the car during the 15-20 second account activation period.

5.3.2. Interview with Car2go Users

To better understand the poor inspection behavior, semi-structured interviews were conducted with car2go users. The interviewees included 11 car2go users, including seven students and faculty members at UBC (See Appendix B). The number of participants was determined based on previous interview studies (Glaser & Strauss, 1971; Mason, 2010), and the fact that little new opinion was gained after conducting 7-8 interviews. Each interview lasted 20 to 30 minutes and the questions covered basic user information, such as length of membership, motivation to join the service and frequency of usage. Interviewees were then questioned about their inspection behavior prior to starting a trip on car2go.

Six out of 11 participants admitted that they usually omit inspection before starting trips. This 55% self-reported inspection omission is lower than that of the observation study (88%). An interesting fact is that five out of six interviewees who omit an inspection on a regular basis knew that the inspection is their obligation given the user agreement, and nonetheless, they often skip the inspection. Respondents C, and F's responses are quoted below. Note that the interior and exterior questions are answered through choosing smiley or frown faces.

Respondent C's case

> *Interviewer: Do you remember how you answered the questions (of interior and exterior conditions)?*
>
> *Respondent C: Happy happy, every time. Just like done done done. I wanna go, I wanna go (…) There are two reasons why I hit happy happy. One is because usually everything is totally fine (…) and the second one is just speed*
>
> *(a short conversation between interviewer and respondent C)*
>
> *Interviewer: In that case do you check exterior before you start trip?*
>
> *Respondent C: Never, I never do that ... I totally should, but I never do that.*

Respondent F's case

> *Interviewer: Did you check outside (of the car)?*
>
> *Respondent F: No I didn't walk around I just look around at the car before I get in and think if there is anything noticeable. Say if I rent a car, I walk around, and if there is a bump on the car, or something, I would take a photo and make sure that when I return it, you know, they don't debt me the damage that is already there. But I don't do that with car2go… Usually it's because I just want to get to somewhere faster and so probably to protect myself, I should do that level, but I just don't… I just wanna go to sleep so I don't wanna inspect a car.*

In the both cases of respondent C and F, present-biased preference seemed to be the cause of the lack of inspection. They were aware that they should do an inspection before using the service; however, they did not. This gap in intention and action can be explained by assuming that participants C and F evaluate saving time and skipping inspection is more valuable than avoiding unnecessary charges and completing their responsibility to use the service. Another quote from respondent E is shown below.

Respondent E’s case

> *Respondent E: "I think those questions are a bit weird. I don't know how many people is gonna take time especially I don't really know if they are charging me for that time or not. ... People are not gonna look around the car"*
>
> *Interviewer: "Did you check the vehicle?"*
>
> *Participant F: "No, I checked inside like fast, but I didn’t walk around especially since they are charging me. ... I don’t think anybody is doing it"*

In the case of respondent E, social norm seems to play a role. While the respondent did not know the behavior of other users, s/he expected them to behave as he did – skipping an inspection.

In addition, none of the respondents skipping an inspection was aware of using the account activation period (usually 15-20 seconds) to inspect the vehicle. Respondent E complained that car2go charges for the time for inspection; however, in reality, s/he was given the time to inspect, but was not aware of it. This could be explained by limited attention. For insurance, respondent C’s saying, “I wanna go, I wanna go” implies that s/he focused on starting the trip as soon as possible. The pay-per-minute system of car2go may even make the user feel more rushed and keen to start the trip immediately. On the other hand, respondent F seemed to be distracted by the desire to go home and sleep.

Given these interview results, we decided to design a simple reminder to conduct an inspection before using a car2go vehicle. We believe that the reminder is practical and cost-effective, and has a minimal impact on the image of car2go service.

5.4. Field Experiment

5.4.1. Nudge Design

We designed a reminder card as the visual prompt. The reminder card was 14 cm by 8 cm, and said "Please INSPECT the car while waiting" (Figure 5.1). We explicitly mentioned "while waiting" so that people realize the availability of time for inspection. Below this message we invited participants to join a prize draw with a smiley face. This smiley face was printed as an injunctive message showing that conducting an inspection is socially preferable. It is known that using injunctive message along with a nudge is an effective way to minimize the boomerang effect (Cabinet Office: Behavioural Insights Team, Department of Energy and Climate Change, Communities and Local Government, 2011; Cialdini, Reno, & Kallgren, 1990; Schultz et al., 2007). The red color of the text was to highlight the card on the blue and white car2go vehicles. On the back of the card, a survey link was provided, and participants were invited to take part in the survey about car2go to win a $30 Amazon gift card (Figure 5.2). This reminder card was placed on the windshield of every car2go vehicle. Note that participants might notice the objective of this study (motivating inspection) by reading the project title on the back of the card. Because the reminder card already explicitly mentioned inspection, being aware of the study objective was not problematic to the experiment.

Figure 5.1: A reminder card (actual scale) was designed as a visual prompt and was placed on the windshield of every car2go vehicle in the experiment.

Figure 5.2: The back of the reminder card.

5.4.2. Field Experiment Procedure

We selected two car2go designated parking areas on the UBC campus for the field experiment based on two criteria: 1) the availability of alternative transportation options, especially public transit services, and 2) the size of parking area. The first criterion was set based on the expectation that the accessibility to other transportation options would affect car2go usage patterns. The second criterion was simply for maximizing the number of observable trips. One of the two selected parking areas is the same as the one in observation study (hereafter referred to as Location A). Location A is the largest car2go parking area on campus with space for 16 vehicles. This parking area is located at the Eastern gateway to the university campus and in close proximity to almost all bus lines serving the campus. The other parking area (hereafter referred to as Location B) has space for 12 vehicles. Location B is at the western-most parking lot on campus and about 15-min walking distance from the bus services.

One location served as an intervention condition where each vehicle had the reminder card on the windshield, while the other as a control condition where none of the vehicles had the reminder card. To minimize the inherent differences between the two locations and external weather factors, the two conditions alternated every day. For example, on day 1 Location A served as the intervention condition and Location B as control, and on day 2 Location A was the control condition and Location B was the intervention condition.

Most of car2go trips started after 12pm, and thus the user behavior was recorded by a remote video camera in each location from 12pm to the time when there was no car2go vehicles left in the parking area (around 5pm). This also means that in the intervention condition, the reminder card was placed on the windshield of each vehicle at 12pm. The experiment was conducted every day for four weeks (from March 2nd to March 27th 2015, excluding weekends[34]). We did not collect information about specific car2go users, however, we recorded their inspection behavior[35].

---

[34] All trips observed on March 2nd were excluded due to a technical error in the video camera in Location A. Due to factors outside our control, observations on Fridays ended at 4pm.

[35] The Video recordings are made using a low-resolution camera from a significant distance. The image is only just clear enough to discern inspection behavior while being too blurred to identify individual users.

5.4.3. Field Experiment Results and Discussion

A total of 979 trips were observed during the four weeks, where 684 trips were initiated at the two locations, and 295 trips were terminated at the locations (Table 5.1). To examine whether there were different usage patterns between the two locations, a two- way analysis of variance (ANOVA) (location × weather conditions) was conducted. Weather was included because weather condition is a major determinant of car2go service demand (car2go Vancouver, personal communication, August 4th, 2014). The dependent measure was exhaustion time, which indicates the time at which all car2go vehicles were taken out. This is one of the most direct indicators of car2go vehicle usage. The analysis indicated that the time of vehicle exhaustion in Location A was earlier than that in Location B ($F(1,30)=6.14$, $p=.02$, $\eta p2= .17$); on average, the supply of cars was exhausted in Location A by 4:24pm, and in location B by 5:19pm. There was no main effect of weather ($F(2,30)=1.94$, $p=.16$, $\eta p2=.11$) or an interaction ($F(2,20)=.71$, $p=.50$, $\eta p2=.05$). Although the weather effect was not statistically significant, cloudy and rainy weathers hastened car exhaustion by 13 and 25 minutes for location A, and 34 and 98 minutes for location B, respectively. We suspect that faster exhaustion rate in location B during inclement weather may be due to the absence of a nearby public transit alternative (the closest bus terminal is a 15-minute walk away).

Moreover, on average, in Location A, 24% of vehicles remained by 4pm and were all gone by 4:24pm, where in Location B, 54% of vehicles were still available at 4pm and all were taken by 5:19pm. We suspect that Location B users contained UBC employees, while Location A was more widely used by younger student members[36]. In the analyses reported below, we focused on trips initiated by a single user who unlocked the car by swiping his or her membership card over the card reader located on the windshield[37] (total 463 trips, 245 trips from Location A and 218 trips from Location B). Since the different patterns of use indicated that the users were two

---

[36] This assumption is supported by the surveys completed on-line, but the self-selection aspects of the survey and small response rates do not permit us to calculate a statistical significance.

[37] A relatively new feature permits access to vehicles via users' mobile phones, but is not widely adopted.

distinct populations at the two locations, we examined the result at the two locations independently.

Table 5.1: Summary statistics of observed trips

		Location A	Location B	Total
Total observed trips	Start	371	313	684
	End	171	124	295
	Total	542	437	979
Trips used for the analysis (Single-passenger trips)	Control	166	135	301
	Intervention	79	83	162
	Total	245	218	463
Average vehicle exhaustion time	Sunny	4:33 PM	6:05 PM	5:12 PM
	Cloudy	4:20 PM	5:31 PM	5:01 PM
	Rainy	4:08 PM	4:27 PM	4:18 PM
	Total	4:24 PM	5:19 PM	4:00 PM

5.4.4. Online Survey

The back of the reminder card invited participation in an online survey. A total of 29 responses were submitted (location A: 12, location B: 17). Among the respondents, 35% answered that they never or rarely inspect car2go vehicles, while more than 60% of the respondents answered that they often inspect the vehicles. This self-reported inspection rate was five times higher than the inspection rate observed in pilot study 1 and repeated during the first week by the control group (12-13%). We suspect some shared traits lead people to take responsibility to inspect their vehicles and participate in the survey.

According to the survey results, the top three reasons for skipping an inspection were: (1) being in too much of a hurry (for 100% of the respondents), (2) believing that the cars are usually fine (for 79% of the respondents), and (3) the lighting condition not being good enough to see (for 78% of the respondents). These results were consistent with the findings from the interview. Since the sample size of the survey was small (n=29), survey results were used as supplementary support for the experiment results.

5.5. Results

5.5.1. Behavioral Change by the Nudge

We examined the inspection behavior from video recordings in both the intervention and the control conditions every day throughout four weeks. We characterized a "proper inspection" as one in which the user walks around all four sides of the car before starting a trip. In each condition, we computed the daily inspection rate as the ratio between trips started after a proper inspection and the total number of trips in a given day. Daily inspection rates by condition and location are summarized in Figure 5.3. The fluctuations seen in the figure are likely from relatively small sample size. Overall, inspection rates in the intervention condition were: Location A: $M=.50$, $SD=.20$, Location B: $M=.40$, $SD=.16$, while that in the control condition were: Location A: $M=.15$, $SD=.12$, Location B: $M=.24$, $SD=.16$.

A two-way ANOVA comparing condition (intervention and control) and week (week 1 to 4) was conducted for Location A and Location B separately to analyze the difference statistically. The main effect of condition was found in Location A ($F(1,11)=19.51$, $p=.001$, $\eta p2=.64$), while the effect was marginal in Location B ($F(1,11)=4.06$, $p=.07$, $\eta p2=.27$). There was no main effect of week in either location (Location A: $F(3,11)=.71$, $p=.56$, $\eta p2=.16$; Location B: $F(3,11)=1.36$, $p=.31$, $\eta p2=.27$), or interaction (Location A: $F(3,11)=.90$, $p=.47$, $\eta p2=.20$, Location B: $F(3,11)=.64$, $p=.61$, $\eta p2=.15$). The inspection rate in the intervention condition remained high throughout the four-week period (week 1-2 vs. week 3-4, Location A: $t(8)=.07$, $p=.41$, $d=.55$, Location B: $t(7)=.14$, $p=.89$, $d=.09$), suggesting that the effect of the intervention card was persistent throughout the whole experiment period. On the other hand, while the inspection rate in the control condition stayed almost constant in location A (week 1-2 vs. week 3-4: $t(7)=.28$, $p=.79$, $d=.18$), Location B showed an increase in the inspection rate in the control condition in the last two weeks (week 1-2 vs. week 3-4: t(8)=2.37, p=.05, d=1.5). Although the difference was marginal (p=.05), the effect size was large (d=1.5).

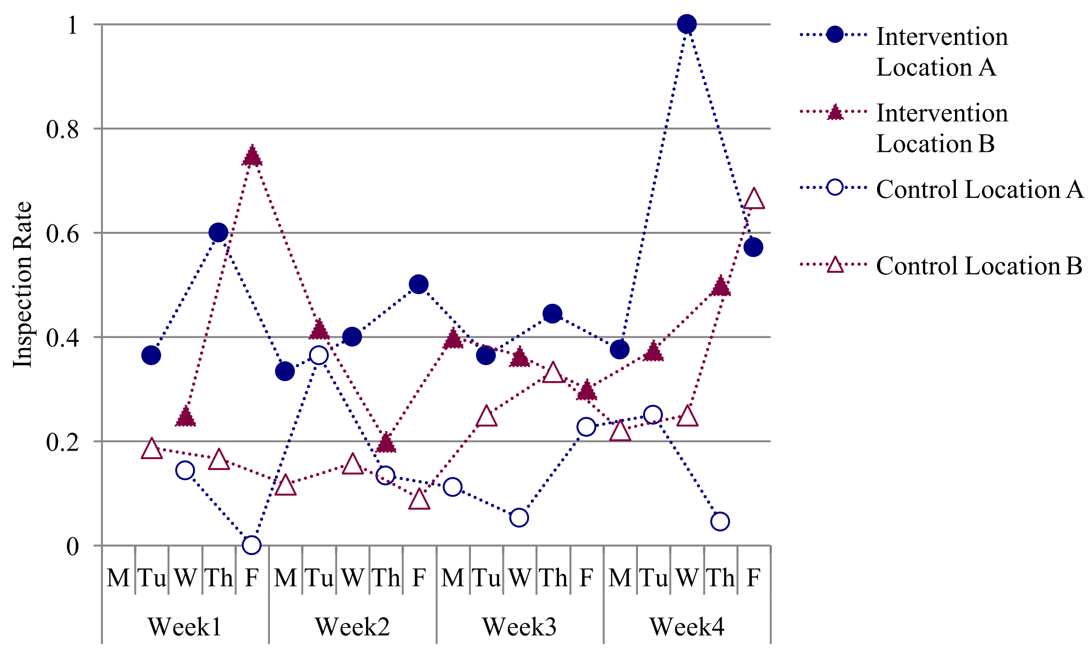

Figure 5.3: Daily inspection rate by condition and location

The upward trend of the inspection rate in the control condition in location B may be driven by learning effects in repeated users. Because the intervention and the control conditions alternated between the two locations across days, the car2go users experienced the reminder card in location B during intervention days, and continued to inspect the car in location B even in the absence of the reminder card (control condition). This learning effect depends on the existence of repeated car2go users in location B. Given factors, such as locational factors (Location B is less exposed to the public so that probably not all car2go users know about the parking) and relatively late vehicle exhaustion time (see Table 5.1), Location B is more likely to have repeating users than Location A.

5.5.2. Nudge Effect in Different Weather

Figure 5.4 presented results by weather conditions. When no intervention card was present, users inspected more often in cloudy and rainy conditions than sunny condition (sunny vs rainy or cloudy in the control condition: Location A: Chi-squared=5.51, p=.02, Location B: Chi-squared=4.34, p=.04)[38]. This is opposite from the finding from the interview: interviewees listed bad weather condition as a reason of inspection omission. One possible explanation here is that user demographics may be different between sunny and rainy or cloudy days, because bad weather can make car2go service more attractive compared to public transit services by providing quick door-to-door mobility. Vehicle exhaustion time (in Table 5.1) supports this argument: cloudy and rainy weather can hasten vehicle exhaustion time by between 13 and 98 minutes compared to sunny days. Taking into account the inspection result, occasional car2go users, such as users who use car2go services only in rainy days, may inspect more often than regular users.

When the reminder card was present, the inspection rate increased in all weather conditions (sunny, cloudy, and rainy) in Location A (sunny: Chi-squared=12.70, p<.001, cloudy: Chi-squared=3.25, p=.07, and rainy: Chi-squared=.94, p=.33). On the other hand, the effect was only present in sunny condition in Location B (sunny: Chi-squared=9.15, p<.01, cloudy: Chi-squared<.001, p=.99, rainy: Chi-squared=0, p=1.00)[39] (see Figure 5.4). One possible explanation of this heterogeneity between the locations is that most of cloudy and rainy conditions were observed during the last two weeks (52% and 96% of trips started in cloudy and rainy condition were observed in the last two weeks). Since the inspection rate in the control condition increased in the last two weeks in Location B, possibly due to the learning effect, the reminder card's effect can be weakened. Another possibility is the visibility of the card: Location B is hidden in the middle of campus where there is less lighting, reducing the salience of the card.

[38] Multiple Chi-square tests were conducted since the sample size was not large enough to conduct a t-test.

[39] Multiple Chi-square tests were conducted since the sample size was not large enough to conduct a t-test.

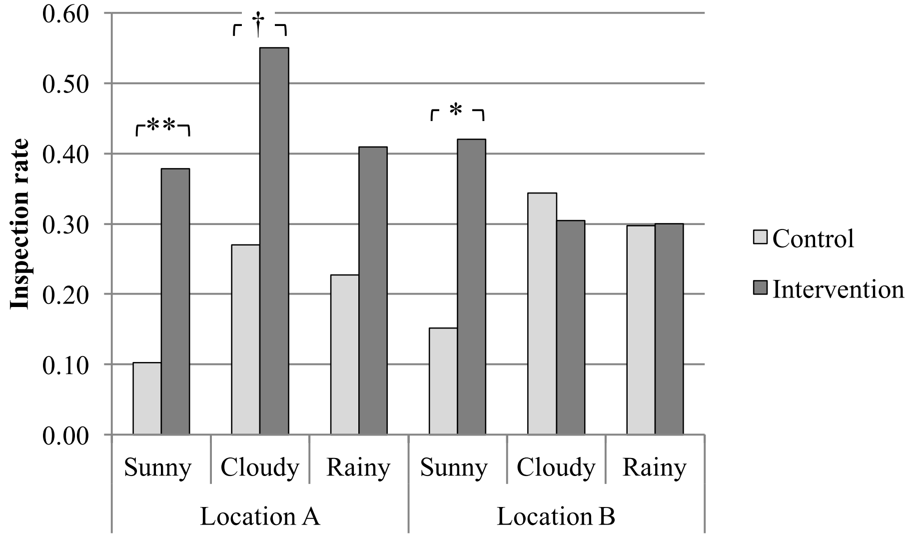

Figure 5.4: Inspection rate by weather conditions. (†p<.1, *p<.05, ***p*<.01)

5.5.3. Nudge Effect by Time

The time of trip initiation also brings interesting insights (see Figure 5.5). First of all, inspection rate in the control condition is higher among users starting trips after 4 pm in both locations (trips started before 4pm vs. after 4pm: Location A: Chi-squared=6.24, p=.01, Location B: Chi-squared=4.43, p=.04). This may result from user demographic difference between before and after 4 pm, because after 4pm trips were highly likely done by commuters returning from UBC to their home. The result implies that those commuters tend to inspect more often than others. In terms of the reminder card, it increased inspection at all times in Location A except after 4pm trips (Location A: 12-2pm: Chi-squared=14.75, p<.001, 2-4pm: Chi-squared=11.27, p<.001, 4-6pm: Chi-squared=.01, p=.94). The inspection rate of after 4pm trips decreased in the intervention condition in Location A. One explanation is the small sample size: most cars were taken out before 4pm at Location A, only 16 trips were observed after 4pm in the intervention condition. In terms of Location B, the intervention card's effect is positive but not statistically significant (12-2pm: Chi-squared=.74, p=.74, 2-4pm: Chi-squared=1.28, p=.26, 4-6pm: Chi-squared=1.49, p=.22).

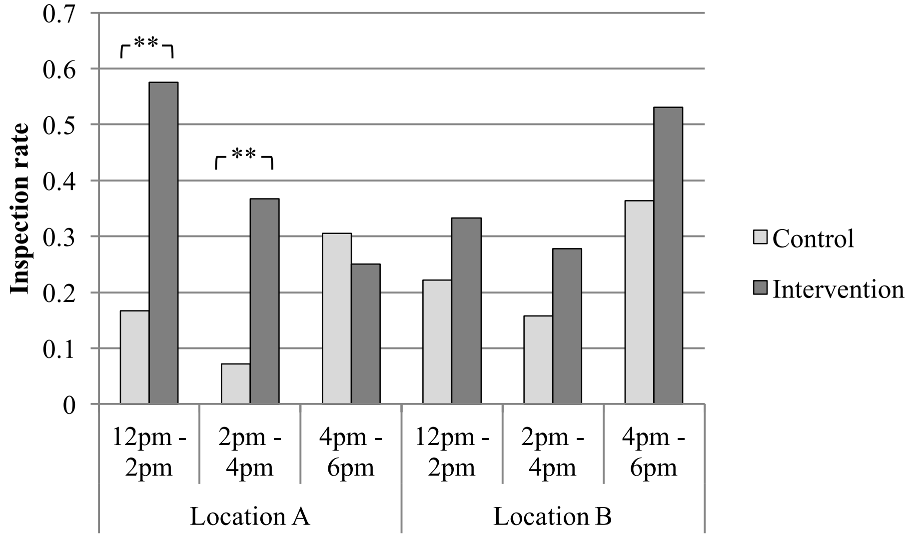

Figure 5.5: Inspection rate by time frame. (†p<.1, *p<.05, ***p*<.01)

5.6. General Discussion

The goal of the current study was to develop a nudge to motivate vehicle inspection in carsharing users prior to starting their trip. In a randomized field experiment, a reminder card prompting inspection was placed on the windshield of the vehicles in the intervention condition, whereas there were no reminders in the control condition. We found that more users inspected the vehicle in the presence of the reminder card than in the control condition (the overall inspection ratio increased to 40-50% from 15-24%). This suggests that the developed nudge, visual reminder was effective in promoting inspection behavior by directing users' attention to the card and facilitating immediate behavior change. Over four weeks, the inspection rate was consistently higher in the intervention condition than in the control condition. This benefit remained the same over time, suggesting that repeated exposures to the reminder card did not diminish the impact of the intervention on inspection behavior. Finally, the external factors and user demographics could affect the impact of the reminder card. Commuting users are likely to inspect more often even without the intervention cards, and bad weather conditions seem to diminish the effect of the reminder card especially in the more isolated location B. The users in location B continued to inspect the vehicles even in the absence of the reminder card in the last two weeks of the experiment, suggesting a persistence effect of the intervention, especially for repeating users.

The benefit of the reminder card was both consistent and persistent in our experiment. However, the overall inspection rate in the intervention condition was around 50%, meaning that only one out of two users inspected the vehicle when the reminder card was present. Although this was a significant improvement from the baseline inspection rate (12%), half of the users still did not inspect the vehicle even in the presence of the reminder card. According to the online survey, 40% of the respondents answered that even with the reminder card, they still did not inspect the car. This suggests that the lack of inspection was not driven solely by lack of attention or forgetting, but by other factors as well.

Given this finding, how could we improve the nudge? A possible approach is to remind users of the possibility of financial charge by omitting an inspection. For the users who did inspect the vehicle, their motivation was to avoid unnecessary charges in case of previous damages. Therefore, the nudge reminder card can be improved by stating: “Please inspect the car while waiting. You may be mischarged”. However, such wording can negatively affect the image of the car2go service.

Another possible approach is providing reward instead. For example, placing a sticker with a code to one of car2go vehicles, and use it as a lucky sticker. Anyone who found the sticker and report the correct code can get a reward or win a prize. This approach stimulates inspection by not only financial motivation but also regret aversion (Kessler & Zhang, 2014). The lucky sticker will not affect the outcome from skipping inspection; however, with the sticker, skipping inspection may be a lost opportunity to win something. Since people feel stronger towards losing than gaining (Tversky & Kahneman, 1991), this approach is likely to motivate people to inspect more than simple reward system. A possible shortcoming from this approach is that the effect is less likely to lead to persistent effect after the removal of the intervention (Kessler & Zhang, 2014).

Rather than implementing a nudge, there is a possibility to minimize the misbehavior by improving customer service. In discussing our findings with frequent users of car2go, we also learned that the process of reporting damage can be very time-consuming. However, unlike voluntary vehicle refueling, time spent reporting damage to the car is charged to users, rather than leading to a credit on their account. This system might have discouraged users to conduct inspections before starting trips.

Throughout the study, the effect of nudge was examined by a randomized field experiment. This approach is more appropriate to examine the effect of a nudge compared to surveys and simulations. However, natural field experiment in which participants do not know that they are participating in an experiment may give a better environment to test the effect of a nudge, since behavior may be affected by the awareness of being in an experiment. Conducting natural field experiment, however, requires a more careful review of the study procedure in order to avoid any violation of freedom of choice and privacy among potential survey participants.

In this study, we used carsharing as an example to apply behavioral economics to make changes in people's transportation related behavior. A small and simple reminder card could improve the inspection behavior; the inspection ratio increased to 40-50% from 15-24%. In addition, the reminder card seems to have a persistent effect in which behavioral change lasts even after the removal of the nudge. This type of small nudge has a huge potential to be implemented in a variety of cases in the field of transportation. We hope that the current study can motivate more nudges to be designed and tested to improve a variety of issues in transportation systems.

Chapter 6: Conclusion

6.1. Brief Summary of Each Chapter

6.1.1. Chapter 1: Introduction

This thesis explores the potential of carsharing (CS) services, a short-term membership-based car rental service. The focus of this thesis lies on understanding how heterogeneity in CS and members at different stages of its adoption in society shape its impacts on Greenhouse Gas (GHG) emissions and car ownership. Past studies have two shortcomings: they do not acknowledge the bias that could arise due to the keen interest of early adopters, and they did not tease out the role of service type in observing outcomes of interest. This thesis consists of four interrelated studies on CS's: impacts on GHG emissions, effects on vehicle ownership, adoption by different types of households, and managing members in active participation in inspection of shared vehicles. All of these studies represent contributions, both in data and methods, to the existing literature.

6.1.2. Chapter 2: Characterizing the GHG Emission Impacts of Car-sharing

Chapter 2 examined use of CS as a mitigation measure against climate change. This study is not the first to discuss the GHG reduction effects of CS. Multiple scholars have reported positive environmental effects caused by CS (see for example, (Loose, 2010; Martin & Shaheen, 2011a)). The novelty of this study is the attention paid to the factors and contexts through which CS impacts are realized. This approach allows understanding the fundamental causes of CS's environmental benefits and quantifying them.

This scenario modeling study revealed that joining CS and switching from private cars to CS vehicles have a potential to cut GHGs by over 30% without changing travel behaviour. This is feasible because CS services provide 1) access to newer and more efficient cars, and 2) opportunities to optimize vehicle size/features. For example, the average vintage of private cars in Canada is 11 years ((The Motor Vehicle Sales Authority of British Columbia, 2014)) while that of CS cars is 3 years ((Modo the Car Co-op, 2015a)). Most CS operators offer compact vehicles and hybrid engine vehicles. Some operators even provide full electric vehicles too

(Kannstätter & Meerschiff, 2015; Kawgan-Kagan, 2014). In addition, using cars through CS service platforms mean that users have a chance to select a car every time they use the service. People often buy oversized cars with more than necessary horsepower for occasional trips. For example, how many people actually need pick-trucks to go for grocery shopping? Are SUVs needed to escort children? By having access to various cars instead of owning one specific car, users benefit from optimizing the choice of cars according to their trip purpose. If this shift from privately owned cars to CS cars is realized along with changes in mode of transportation (e.g. switching from driving to public transit for commuting trips), up to 50% of the total transportation related GHGs could be cut.

These findings suggest a huge potential of CS as a measure to mitigate climate change impacts. However, one critical question rising here is whether CS could be used as a substitute for private cars.

6.1.3. Chapter 3: Vehicle Ownership Reduction: A Comparison of One-way and Two-way Carsharing Systems

Chapter 3 explored the potential of CS as an alternative to private cars, and reduced dependency on vehicle ownership. Given the shortcomings found in existing studies, the study placed its focus on understanding the relationship between CS service types and vehicle ownership: the difference between CS services offering a one-way (free-floating) service utilizing 2-seaters (Car2go) and a two-way service utilizing a range of vehicles (Modo). An analysis of over 3,000 survey responses from CS users in Vancouver shows that users of both Car2go and Modo reduced vehicle ownership after joining a CS service. However, the reduction level differed by CS type; Modo members were close to five times more likely to reduce car ownership compared to Car2go only users. Results also suggest that the two services are used differently. Car2go users utilize the service as a complement to other modes of transportation including: taking transit/taxi, and using pre-owned private cars. In other words, Car2go is an additional option to make their multi-modal travels easier and more convenient. On the other hand, Modo is more likely to be used as the substitute for private car ownership. A further analysis about the possible measures taken under the service termination suggest that CS services have been substituting mobility services previously supplied by private vehicles. Though a careful attention needs to be paid that stated preferences often differ from actual behaviour, the intention to gain a vehicle under the service termination was strongest among users who had both memberships. These findings suggest that the two services are not rivals but complements providing different mobility services. One, internally consistent interpretation of the survey results is that Modo substitutes private vehicle ownership, and Car2go eases a lifestyle with restricted access to private vehicles.

6.1.4. Chapter 4: Is Carsharing for Everyone? Understanding the Diffusion of Carsharing Services

Chapter 2 and 3 showed the positive potential of CS as a method to reduce GHGs and vehicle dependency. These benefits could be multiplied when more people start using CS services. However, extrapolating early adopter outcomes to broader adoption of CS may be misguided. Only a fraction of the whole population has adopted CS, and these service users may be atypical of the broader population in their trip patterns, vehicle usage, preferences, decision-making and economic means. The feasibility of projecting impacts of CS when the service is more broadly adopted depends on whether early adopters are representative of the general population. This chapter explores the question of whether the household characteristics of early adopters, those indicating an interest in possibility becoming members and those who profess to no interest in CS are distinct types of households with potentially different patterns of CS use and impacts therefrom.

Over 2,000 responses from residents living in 110 apartment buildings in Metro Vancouver were analyzed for this study. Based on the survey results, a quarter of the residents were already members of at least one CS service, a half could be persuaded to become members under appropriate conditions, and a quarter were convinced that all else being constant, CS would not meet their mobility needs. The study found that survey respondents with CS memberships had unique characteristics compared to respondents without CS membership, suggesting that early adopters are not representative of the general public. In addition, the regression analyses showed that early CS adopters (respondents with CS memberships) and potential CS adopters (respondents with an interest to join CS) are dissimilar in both demographics and living environments. These findings suggest that future CS adopters are likely to use CS differently from early adopters, meaning that environmental impacts and vehicle ownership reduction observed among early adopters might not be seen among coming adopters. For instance, the vehicle ownership reduction effect reported by other researchers using a 2016 survey when CS was more broadly adopted (Martin & Shaheen, 2016) was much smaller than the vehicle ownership reduction effect found in Chapter 3 which is based on a 2013 survey.

6.1.5. Chapter 5: Nudging for Responsible Carsharing: Using Behavioural Economics to Chang Transportation Behaviour

The management of shared properties has been the focus of many scholars (e.g., natural resource management, tragedy of commons, etc.). Managing CS vehicles is no exception, and as more new and diverse CS members are expected, the management of CS fleet can be expected to become even more difficult. However, the low overhead of CS is only possible because "policing" is part of the CS providers' contract with their members.

This chapter focuses on this management issue, in particular, the lackadaisical attitude of members toward reporting accidents and damage to vehicles and inspection of vehicles before they begin their trip(s). The novelties in this study are two-folds: the completion of a series of field experiments to make changes in member behavior, and the nudging techniques, learned from behavioural economics, used in the experiments.

Pilot studies revealed that close to 90% of users of a CS service did not conduct the mandatory vehicle inspection prior to starting their trip. This inspection process is critical to track any vehicle damages and drivers who are responsible for that, and to detect vehicle malfunctions in a timely fashion – keeping them safe. Interviewing users of the service suggested that the majority of users were aware of the importance and responsibility to conduct an inspection; however, they rarely practiced it.

Resource management literature suggests two conventional approaches to tackle the issues in shared property managements: external regulation (Hardin, 1968) and communal constraint (Ostrom, 1999). However, neither of them works in this context since the external regulation approach has a risk to damage brand images and existing studies show that communal constraint approach has a slight effect among CS users (Bardhi & Eckhardt, 2012; Schaefers et al., 2015).

This study took the third approach, information provision (e.g. nudge and reminder). The field experiment proved the positive effect of this approach. With a reminder card suggesting there is more than enough time to inspect the vehicle before it is opened remotely. This simple approach doubled the rate of vehicle inspection: the observed inspection rate increased from 15-24% to 40-50%. More importantly, the effect persisted after the reminder cards were removed from vehicles.

This reminder card approach was apparently effective; however, it was not effective enough to eliminate all irresponsible behaviour. About a half of the study participants still did not conduct a vehicle inspection even with the reminder cards.

6.2. Discussion

Findings from Chapter 2 and 3 suggest the potential of CS to positively contribute to reduce GHG emissions and vehicle dependency. Without making changes in travel behaviour, switching from privately owned cars to CS cars can reduce GHG emissions by 30% because CS services offer more fuel-efficient cars, and also provide a chance to optimize function and size of a car. If the mode shift from driving to taking public transit is also considered, up to 50% of the transportation related GHG emissions could be cut. In addition, findings from Chapter 3 suggest that CS users reduced vehicle ownership after joining the service, and one CS car had a potential to replace multiple privately owned cars. However, this does not mean that CS promises to always provide these benefits to everyone.

As Chapter 4 clarified, the positive effects found among early adopters do not guarantee that the same effects would be realized among coming adopters (late adopters). This is the one of the two primary findings from this thesis: the dynamics of CS service diffusion process. The GHG emission cut quantified in Chapter 2 is conditional to the usage of CS services. Over 50% of transportation related GHGs could be cut by CS services under the condition where CS services are used as an alternative to private cars and some of trips are done by public transit instead of driving. If CS services are used as an additional mobility and hence increase vehicle kilometre travelled (VKT), CS can increase GHG emissions. Existing studies have reported that a certain number of early adopters utilized CS as an alternative to private cars and also a motivator to use public transit. Therefore, the reported net effects of CS have been positive in many empirical studies. However, findings from Chapter 4 suggest that early adopters of CS are atypical of the general public in many individual and household characteristics. Early adopters are more likely to live in smaller and more expensive rental housings, have fewer household members with more family members employed. They are also likely to own fewer cars. It is highly likely that the roles and meanings of CS for potential adopters are different from that for early adopters. As CS services continue to expand through the broader population, their environmental impacts will continue to evolve. As the adoption stage matures, the usage and roles of CS would be changing hence the effects.

The second primary findings of this thesis, the importance of heterogeneity between CS services, was explored in chapter 3 showing that Modo and Car2go differ in their impact on car ownership. Unfortunately, there is insufficient heterogeneity to specify factors causing this differences in impacts: Car2go and Modo are different in many ways (e.g. one-way and round-trip service styles, by-minute or by-hour rental, low or high cost of membership, or different types of vehicles). However, Chapter 3 confirms that the heterogeneities among CS services affect how the services are utilized; hence what kind of effects the CS services bring to society. The diversity in CS services is expected to increase since there are more technologies to come. Within a few years, connected vehicles, self-driving technologies and advanced battery technologies are expected to be prevalent. The evolution of CS will continue with merging of these technologies. The roles, usage, users and service styles of CS services will change along with the technology innovations. Stakeholders often generalize various CS services as CS; however, the heterogeneities will need a more careful attention and specifically tailored policies in order to ensure CS impacts continue to align with sound urban transport policy.

These dynamic changes will affect how CS services should be maintained. CS services have been facing challenging issues, such as managing shared properties as discussed in Chapter 5. Chapter 5 succeeded to provide a possible countermeasure to deal with irresponsible use of CS. However, this solution does not eliminate all misbehaviors among CS users. Issues in managing shared properties may become even more difficult in the future with more diverse users and CS service models.

6.3. Policy Implication

CS service providers, scholars and policy makers need to be sensitive to evolution dynamics and heterogeneities in CS services. In particular, policies around CS need to be appropriately modified as CS services mature. For instance, in most cities, various CS services are regulated under a single set of rules, for example, all CS vehicles could be parked at residential only parking zones in the City of Vancouver free of charge. The City of Vancouver's justification is that CS contributes to make the city green, which is coherent with thevfindings from Chapter 2; up to 50% of GHG could be cut by using CS services. However, Chapter 3 found that two CS services in the city, Modo and Car2go, had different effects on vehicle ownership reduction, and highly likely, provide different types of mobility services. Moreover, because of its one-way service features, Car2go cars often occupy residential only parking spaces while this rarely happens to Modo cars because the cars need to be returned to specific Modo only parking spaces. When the first set of rules were established to organize CS services, there was less need to consider these differences among CS services. However, as services mature, the heterogeneity in CS service models has grown. The same thing has happened to the CS user population. As CS adoption stage proceeds, more diverse user characteristics are expected. As discussed in Chapter 4, it is highly likely that coming CS adopters are different from early adopters, and for them, CS may play a different role. In order to maximize social and environmental benefits gained via CS, appropriately updating regulations is critical. This timely policy making requires cooperation with CS service providers and scholars. They are able to collectively play a critical role to update the practical effects that CS services are providing to society.

The second implication is the findings about the relationship between financial condition and mobility choice. Overall findings from this thesis suggest that there is a strong correlation between CS participation and financial constraints. The results of analyses in Chapter 3 show that financial motivation had the strongest explanatory power to determine CS users who shed a car after joining the service. Chapter 4 found that Early Adopters of CS tend to live in smaller and more expensive rental housing for a shorter period of time, have more employed family members but fewer elderly members, and own fewer cars. These characteristics suggest that early CS adopters are more likely the newly established households. Considering the very high cost of housing in the study region (typical of other major cities with high CS adoption rates), substitution of private car ownership by CS service may be a budgetary imperative rather than a lifestyle choice. If this is the case, it is policy makers' responsibility to make sure that CS is and will provide required mobility services without suffering quality of life. Moreover, policy makers need to be aware that better economic times and changing demographics may reverse recent trends in car-ownership reductions and the continued impacts of CS may depend on factors outside their control.

6.4. Research Limitations

Two major research limitations need to be addressed; cross-sectional studies and insufficient data. Both Chapter 3 and Chapter 4 are based on responses from cross-sectional surveys. Conducting a survey about CS is an innovative and important step to understand the effects of CS on societies. However, analyses based on a one-time survey targeting a certain population has a high risk of having various bias issues. In particular, it is significantly difficult, if possible, to statistically prove causal relationships among events and findings based on a cross-sectional study. I am aware of this issue, and made an effort to explicitly note that on every points and studies where biases could affect results and their interpretation, as clear as possible. Even so, this is one of the major limitations in my thesis. Another major limitation is data accessibility. This is the first approach to quantitatively understand the effects of CS in the region. Because there was no prior studies or networks to rely on, the resources which I had access to was not abundant. This difficulty resulted in relying on assumptions and expert judgements when quantitative data is not accessible. As I discuss further in the next section, developing a better resource and data sharing environment would accelerate more detailed studies not only in CS studies but also other transportation studies.

6.5. Future Research

Few long-term studies (e.g. panel studies and serial surveys) on CS services are underway or have been conducted. In order to understand up-to-date effects and meaning of CS to society, these long-term studies are crucial. For example, findings from Chapter 4 suggest the discrepancy between early adopters and late adopters. Moreover, findings from Chapter 5 suggest the current difficulties of managing shared properties; as the diffusion of CS services progresses, will the management be more challenging? The conduction of long-term studies is required to answer these questions. With these forward-looking studies, regular reconsideration of existing policies would be more feasible and practical.

Another question is whether CS is chosen as an active preference or passive necessity. This thesis found that financial condition is one of the strongest reasons why people substitute private cars by CS cars (Chapter 3). CS users may choose to give up owning cars because of limited financial budget. More studies are required to clarify what is the true cause of this rapid CS service growth, and whether this trend persists.

The bias in existing studies is another point to be further explored. The majority of existing studies place their focus on people who already adopted to CS, and not the others. Analyses in Chapter 4 found that there are certain number of people who claim CS is not an option for them, because of personal preference, physical accessibility issues, and specific mobility needs to be satisfied. There are a certain population who are not familiar with CS system as well even though the service is physically accessible to them. These people, who are unable to receive benefits from CS services, may need other or additional supports. For example, by equipping child seats in CS vehicles, increasing the availability of wheelchair accessible vehicles, and expanding one-way CS service area, some of these excluded population may be able to receive benefits from CS.

Another set of biases in sampling and stated preference needs to be addressed as well. Most existing studies use voluntary surveys asking opinions about CS. It is highly likely that participants of such surveys are overrepresented by active CS advocates. In addition, stated preference rarely matches with the actual behaviour; humans are rarely able to predict their future behaviour, and they often report false information. Findings from data with these biases involves a high risk to be misleading. Further efforts need to be made to overcome or minimize the effects of these sampling and stated preference biases. Conducting field experiments like the study in Chapter 5, is one effective approach to capture the real behaviour of participants without biases of stated preferences.

Last but not least, active knowledge sharing among three stakeholders (policy makers, CS providers, and scholars) would bring further benefits to all. Currently, each of stakeholders have a skewed interest to solely pursue their own benefits within their fields. Individuals within one stakeholder category also have different interests and rarely share knowledge openly within the category. As the serial studies in this thesis confirmed, it is unquestionable that CS has a huge potential to bring positive benefits to societies. However, this thesis also found a critical issue; how much of this potential could be realized, is open to questions. As CS carries the word of "sharing", if stakeholders in this field could built a better collaborative "sharing" environment, a large part of the potential of CS may be feasible.

References

Agarwal, A. (2004). *A Comparison of Weekend and Weekday Travel Behavior Characteristics in Urban Areas*. (R. M. Pendyala, Ed.). University of South Florida Scholar Commons.

Allcott, H., & Mullainathan, S. (2010). Behavior and Energy Policy. *Science*, *327*(5970), 1204–1205. Retrieved from http://www.jstor.org/stable/40544368

Autoblog. (2012, June 20). Car2go suspends operation in Lyon, France because of name conflict with Car' Go - Autoblog. *Autoblog*, pp. 1–7. Retrieved from http://www.autoblog.com/2012/06/20/car2go-suspends-operation-in-lyon-france-because-of-name-confli/

Bardhi, F., & Eckhardt, G. M. (2012). Access-Based Consumption: The Case of Car Sharing. *Journal of Consumer Research*, *39*(4), 881–898. http://doi.org/10.1086/666376

Belk, R. (2010). Sharing. *Journal of Consumer Research*, *36*(5), 715–734. http://doi.org/10.1086/612649

Botsman, R., & Rogers, R. (2011). What's Mine is Yours: The Rise of Collaborative Consumption. Toronto: HarperCollins e-books.

Brody, P., & Pureswaran, V. (2015). The Next Digital Gold Rush: How the Internet of Things Will Create Liquid, Transparent Markets. *Strategy & Leadership*, *43*(1), 36–41. http://doi.org/10.1108/SL-11-2014-0094

Brown, C., & Winter, A. (2015, May). In Your Own Words: Operators Manage Security Issues - Article - Auto Rental News. Retrieved May 14, 2015, from http://www.autorentalnews.com/article/story/2014/05/in-your-own-words-operators-manage-security-issues/page/2.aspx

Cabinet Office: Behavioural Insights Team, Department of Energy and Climate Change, Communities and Local Government. (2011). *Behaviour Change and Energy Use* (pp. 1–35).

Canada Mortgage and Housing Corporation. (2007). *RENTAL MARKET REPORT Vancouver and Abbotsford CMAs* (pp. 1–56).

Canada Mortgage and Housing Corporation. (2008). *RENTAL MARKET REPORT Vancouver and Abbotsford CMAs* (pp. 1–56).

Canada Mortgage and Housing Corporation. (2010). *RENTAL MARKET REPORT Vancouver and Abbotsford CMAs* (pp. 1–57).

Canada Mortgage and Housing Corporation. (2011). *RENTAL MARKET REPORT Vancouver and Abbotsford CMAs* (pp. 1–58).

Canada Mortgage and Housing Corporation. (2012). *RENTAL MARKET REPORT Vancouver and Abbotsford CMAs* (pp. 1–57).

Canada Mortgage and Housing Corporation. (2014). *Rental Market Report: Vancouver and Abbotsford-Mission CMAs* (pp. 1–59).

car2go. (2014a). Car2go Vancouver Website. Retrieved November 21, 2014, from https://www.car2go.com/en/vancouver/

car2go. (2014b). car2goTrip Process Agreement (Canada), 1–15.

car2go. (2015a, January 15). Hello Vancouver Car2go News. *Cargo News Letter*, 1–5.

car2go. (2015b, February 8). car2go Vancouver Website: How Does car2go Work? Retrieved February 8, 2015, from https://www.car2go.com/en/vancouver/how-does-car2go-work/

car2go. (2015c, February 8). Car2go Website: Hello Vancouver. Retrieved February 12, 2016, from https://www.car2go.com/en/vancouver

car2go. (2016a, March 1). Fact Sheet Car2go March 2016. Retrieved September 22, 2016, from https://www.car2go.com/media/data/usa/microsite-press/files/fact_sheet_car2go_march_2016_en.pdf

car2go. (2016b, May 31). Fact Sheet Car2go June 2016. Retrieved September 22, 2016, from https://www.car2go.com/media/data/germany/microsite-press/files/fact_sheet_car2go_june_2016_en.pdf

car2go. (2016c, September 1). Fact Sheet car2go September 2016. Retrieved September 22, 2016, from https://www.car2go.com/media/data/germany/microsite-press/files/fact-sheet-car2go_september-2016_en-2.pdf

car2go US. (n.d.). car2go US, 1–12. Retrieved from https://www.car2go.com/US/en/

careco car sharing club. (2014). *Careco Car-sharing Club User Survey 2013 (part 2)* (pp. 1–3).

Carma. (n.d.). City CarShare - Carma Website. Retrieved October 19, 2016, from https://www.gocarma.com/1/4

CarShare, E. (n.d.). Enterprise CarShare Website: Hourly Car Rental and Car Sharing. Retrieved October 19, 2016, from

Carsharing Association. (2016, January). Carsharing Association Website: What is carsharing? Retrieved January 20, 2016, from http://carsharing.org/what-is-car-sharing/

Castleman, B. L., & Page, L. C. (2015). Freshman Year Financial Aid Nudges: An Experiment to Increase FAFSA Renewal and College Persistence. *Journal of Human Resources*. http://doi.org/10.3368/jhr.51.2.0614-6458R

Cervero, R. (2003). City CarShare: First-year Travel Demand Impacts. *Transportation Research Record*, *1839*, 159–166. http://doi.org/10.3141/1839-18

Cervero, R., & Tsai, Y. (2004). City CarShare in San Francisco, California: second-year travel demand and car ownership impacts. *: Journal of the Transportation Research Board*. Retrieved from http://trb.metapress.com/index/817Q36T04638411U.pdf

Cervero, R., Golub, A., & Nee, B. (2007). City CarShare: Longer-Term Travel Demand and Car Ownership Impacts. *Transportation Research Record: Journal of the Transportation Research Board*, *1992*(1), 70–80. http://doi.org/10.3141/1992-09

Ch2m Hill. (2015). *Transportation Panel Survey 2014 Final Report Submitted to City of Vancouver* (pp. 1–108).

Ch2m Hill. (2016). *City of Vancouver Transportation Panel Survey 2015 Final Report* (pp. 1–95).

Chicago Metropolitan Agency for Planning. (2010). *GO TO 2040/Regional Mobility: Recommendation 11 Increase commitment to public transit* (pp. 288–304).

Cialdini, R. B., Reno, R. R., & Kallgren, C. A. (1990). A Focus Theory of Normative Conduct: Recycling the Concept of Norms to Reduce Littering in Public Places. *Journal of Personality and Social Psychology*, *58*(6), 1015–1026. http://doi.org/10.1037/0022-3514.58.6.1015

City of Vancouver. (2012, November 15). Transportation 2040: Plan as Adopted by Vancouver City Council on October 31, 2012. Retrieved from http://vancouver.ca/files/cov/Transportation_2040_Plan_as_adopted_by_Council.pdf

CNW Canada Ltd. (2012, March 20). car2go Poised For Growth in Vancouver This Spring. Retrieved February 18, 2015, from http://www.newswire.ca/en/story/940701/car2go-poised-for-growth-in-vancouver-this-spring/#

Collaborative Consumption. (2015, September 2). Collaborative Consumption - Sharing Reinvented Through Technology. Retrieved September 2, 2015, from http://www.collaborativeconsumption.com/

Commisso, T. (2016, June 2). Evo Car Share Comes to Burnaby. *Burnabynow*, pp. 1–1. Retrieved from http://www.burnabynow.com/news/evo-car-share-comes-to-burnaby-1.2269370

Commuauto. (n.d.). Commuauto website. Retrieved October 19, 2016, from https://www.communauto.com/

Corey, Canapary & Galanis Research. (2016). *San Francisco Municipal Transportation Agency (SFMTA) Travel Decisions Survey 2015 Summary Report* (pp. 1–33).

Costain, C., Ardron, C., & Habib, K. N. (2012). Synopsis of users' behaviour of a carsharing program: A case study in Toronto. *Transportation Research Part A*, *46*(3), 421–434. http://doi.org/10.1016/j.tra.2011.11.005

Cross, J. S. (2016, March 22). Car2Go Toronto rolling out on-street parking despite City Hall rejection. *Metro News*, pp. 1–2. Retrieved from http://www.metronews.ca/news/toronto/2016/03/22/car2go-to-introduce-on-street-parking-in-toronto-.html

Dahlman, C. J. (1979). The Problem of Externality. *The Journal of Law and Economics*, *22*(1), 141–162. http://doi.org/10.2307/725216

de Lorimier, A., & El-Geneidy, A. M. (2013). Understanding the Factors Affecting Vehicle Usage and Availability in Carsharing Networks: A Case Study of Communauto Carsharing System from Montréal, Canada. *International Journal of Sustainable Transportation*, *7*(1), 35–51. http://doi.org/10.1080/15568318.2012.660104

District Department of Transportation, Policy, Planning & Sustainability Administration, & Administration, S. (2014). *Move DC: The District of Columbia's Multimodal Long-Range Transportation Plan* (pp. 1–172).

Dreher, J. (2015, May 5). Sustaining hierarchy – Uber isn't sharing. Retrieved September 8, 2015, from http://www.researchgate.net/publication/275889451

Dryden, C. (2015, May 4). Car2go car-sharing service to suspend South Bay operations. *Daily Breeze*, pp. 1–6. Retrieved from http://www.dailybreeze.com/business/20150504/car2go-car-sharing-service-to-suspend-south-bay-operations

Durgee, J. F. (1984). Mass Marketing to Fragmented Markets. *Planning Review*. http://doi.org/10.1108/eb054076

Durgee, J. F., & Colarelli O'Connor, G. (1995). An Exploration into Renting as Consumption Behavior. *Psychology & Marketing*, *12*(2), 89–104. http://doi.org/10.1002/mar.4220120202

Engel-Yan, J., & Passmore, D. (2013). Carsharing and Car Ownership at the Building Scale. *Journal of the American Planning Association*, *79*(1), 82–91. http://doi.org/10.1080/01944363.2013.790588

Evo Car Share. (2015). Evo Car Share Website: Car Sharing Vancouver. Retrieved July 27, 2015, from https://evo.ca/

Evo Car Share. (n.d.). Evo Carshare Website. Retrieved October 19, 2016, from https://evo.ca/

Favez, J.-Y., Weilenmann, M., & Stilli, J. (2009). Cold Start Extra Emissions As a Function of Engine Stop Time: Evolution Over the Last 10 Years. *Atmospheric Environment*, *43*(5), 996–1007. http://doi.org/10.1016/j.atmosenv.2008.03.037

Firnkorn, J. (2012). Triangulation of two methods measuring the impacts of a free-floating carsharing system in Germany. *Transportation Research Part A*, *46*(10), 1654–1672. http://doi.org/10.1016/j.tra.2012.08.003

Firnkorn, J., & Müller, M. (2011a). Selling Mobility instead of Cars: New Business Strategies of Automakers and the Impact on Private Vehicle Holding. *Business Strategy and the Environment*, *21*(4), 264–280. http://doi.org/10.1002/bse.738

Firnkorn, J., & Müller, M. (2011b). What Will Be The Environmental Effects of New Free-floating Car-sharing Systems? The Case of Car2go in Ulm. *Ecological Economics*, *70*(8), 1519–1528. http://doi.org/10.1016/j.ecolecon.2011.03.014

Firnkorn, J., & Shaheen, S. (2015). Generic time- and method-interdependencies of empirical impact-measurements: A generalizable model of adaptation-processes of carsharing-users' mobility-behavior over time. *Journal of Cleaner Production*, 1–32. http://doi.org/10.1016/j.jclepro.2015.09.115

Forbs. (2015). Airbnb, Snapgoods and 12 More Pioneers Of The "Share Economy," 1–2. Retrieved from http://www.forbes.com/pictures/eeji45emgkh/neighborgoods/

Geradin, B. E. D. (2015). Efficiencies and Regulatory Shortcuts: How Should We Regulate Companies like Airbnb and Uber? *Stanford Technology Law Review*, 1–33.

Getaround. (n.d.). Getaround Website: Peer to Peer Car Sharing and Local Car Rental. Retrieved October 19, 2016, from https://www.getaround.com/

Glaser, B. G., & Strauss, A. L. (1971). The Discovery of Grounded Theory: Strategies for Qualitative Research (4 ed.). Aldine, Atherton/Chicago, New York: Aldine Publishing Company.

Government of Canada, New Economy Development Group. (2006). *The Co-operative Auto Network* (pp. 1–26). Retrieved from http://www.ic.g c.ca/eic/site/693.nsf/eng /00045.html

Government of Canada, New Economy Development Group. (2005, December 13). Industry Canada: Strategic Policy: Co-operative Auto Network (CAN) Case Study. Retrieved July 9, 2014, from

Habib, K. M. N., Morency, C., Islam, M. T., & Grasset, V. (2012). Modelling users' behaviour of a carsharing program: Application of a joint hazard and zero inflated dynamic ordered probability model. *Transportation Research Part A*, *46*(2), 241–254. http://doi.org/10.1016/j.tra.2011.09.019

Hamari, J., Sjöklint, M., & Ukkonen, A. (2015). The sharing economy: Why people participate in collaborative consumption. *Journal of the Association for Information Science and Technology*, *67*(9), 2047–2059. http://doi.org/10.1002/asi.23552

Hardin, G. (1968). The tragedy of the commons. *New York*.

Hardy, H., Kumar, V., Doros, G., Farmer, E., Drainoni, M.-L., Rybin, D., et al. (2011). Randomized Controlled Trial of a Personalized Cellular Phone Reminder System to Enhance Adherence to Antiretroviral Therapy. *AIDS Patient Care and STDs*, 110216131322053–10. http://doi.org/10.1089/apc.2010.0006

Henten, A. H., & Windekilde, I. M. (2016). Transaction costs and the sharing economy. *Info*, *18*(1), 1–15. http://doi.org/10.1108/info-09-2015-0044

Ipsos Reid. (2012). *2011 Metro Vancouver Regional Trip Diary Survey: Final Methodology Report* (pp. 1–122).

Jevons, W. S. (1865). The Coal Question: An Enquiry Concerning the Progress of the Nation, and the Probable Exhaustion of Our Coal-mines.

Kahan, P. D. M. (2012). Cultural Cognition as a Conception of the Cultural Theory of Risk. In S. Roeser, R. Hillerbrand, P. Sandin, & M. Peterson (Eds.), *Handbook of Risk Theory* (pp. 725–759). Dordrecht: Springer Netherlands. http://doi.org/10.1007/978-94-007-1433-5_28

Kahneman, D. (2003). A Perspective on Judgment and Choice: Mapping Bounded Rationality. *American Psychologist*, *58*(9), 697–720. http://doi.org/10.1037/0003-066X.58.9.697

Kahneman, D., & Tversky, A. (1979). Prospect Theory: An Analysis of Decision Under Risk. *Econometrica: Journal of the Econometric Society*, *47*(2), 263. http://doi.org/10.2307/1914185

Kannstätter, T., & Meerschiff, S. (2015). Launching an E-Carsharing System in the Polycentric Area of Ruhr. In W. Leal Filho & R. Kotter (Eds.), *E-Mobility in Europe* (pp. 187–208). Cham: Springer International Publishing. http://doi.org/10.1007/978-3-319-13194-8_11

Karlan, D., McConnell, M., Mullainathan, S., & Zinman, J. (2016). Getting to the Top of Mind: How Reminders Increase Saving. *Management Science*, mnsc.2015.2296–20. http://doi.org/10.1287/mnsc.2015.2296

Katzev, R. (2003). Car Sharing: A New Approach to Urban Transportation Problems. *Analyses of Social Issues and Public Policy*, *3*(1), 65–86. http://doi.org/10.1111/j.1530-2415.2003.00015.x

Kawgan-Kagan, I. (2014). Female Early Adopters of E-carsharing (pp. 1–20). Presented at the European Transport Conference.

Kessler, J. B., & Zhang, C. Y. (2014). Behavioral Economics and Health. *Oxford Textbook of Public Health*.

Klincevicius, M., Morency, C., & Trépanier, M. (2014). Assessing Impact of Carsharing on Household Car Ownership in Montreal, Quebec, Canada. *Transportation Research Record: Journal of the Transportation Research Board*, *2416*, 48–55. http://doi.org/10.3141/2416-06

Knack, R. E. (2005). Pay as you Park. *Planning*.

Korosec, K. (2016, September 28). What San Francisco taught BMW Group about car sharing. Retrieved September 28, 2016, from http://fortune.com/2015/10/12/san-francisco-bmw-car-sharing/

La Mobilite des personnes dans la region de Montreal. (2015). Enquéte Origine-Destination 2013 (pp. 1–194).

Lalonde, M. (2016, September 20). Car2go, Communauto Team Up to Denounce Bylaws. *Montreal Zazette*, pp. 1–6. Retrieved from http://montrealgazette.com/news/local-news/car2go-communauto-team-up-to-denounce-bylaws

Lamberton, C. P., & Rose, R. L. (2012). When Is Ours Better Than Mine? A Framework for Understanding and Altering Participation in Commercial Sharing Systems. *Journal of Marketing*, *76*(4), 109–125. http://doi.org/10.2307/41714502?ref=no-x-route:46cd4f2546f851d1dc321ea0519ec4ae

Lane, C. (2005). PhillyCarShare: First-year Social and Mobility Impacts of Carsharing in Philadelphia, Pennsylvania. *Transportation Research Record*, *1927*, 158–166. http://doi.org/10.3141/1927-18

Le Vine, S., & Polak, J. (2015). Introduction to special issue: new directions in shared-mobility research. *Transportation*, *42*(3), 1–5. http://doi.org/10.1007/s11116-015-9603-4

Le Vine, S., Lee-Gosselin, M., Sivakumar, A., & Polak, J. (2014a). A New Approach to Predict the Market and Impacts of Round-trip and Point-to-point Carsharing Systems: Case Study of London. *Transportation Research Part D*, *32*(C), 218–229. http://doi.org/10.1016/j.trd.2014.07.005

Le Vine, S., Zolfaghari, A., & Polak, J. (2014b). *Carsharing: Evolution, Challenges and Opportunities*. *Scientific Advisory Group Report* (pp. 1–20).

Lee, J. B., Byun, W., Lee, S. H., & Do, M. (2014). Correlation between optimal carsharing locations and carbon dioxide emissions in urban areas. *International Journal of Environmental Science and Technology*, *11*(8), 2319–2328. http://doi.org/10.1007/s13762-014-0640-x

ller, S. S., Weikl, S., Müller, J., & Bogenberger, K. (2015). Empirical analysis of free-floating carsharing usage: The Munich and Berlin case. *Transportation Research Part C-Emerging Technologies*, *56*(C), 34–51. http://doi.org/10.1016/j.trc.2015.03.008

Loomis, J. (2011). What's to Know About Hypothetical Bias in Stated Preference Valuation Studies? *Journal of Economic Surveys*, *25*(2), 363–370. http://doi.org/10.1111/j.1467-6419.2010.00675.x

Loose, W. (2010). *The State of European Car-Sharing: Final Report D 2.4 Work Package 2. Project Momo Final Report D*.

Mackie, J. (2015, July 30). Car Share Numbers Rev Up in Vancouver As Drivers Take the Wheel. Retrieved November 25, 2015, from http://www.vancouversun.com/story_print.html?id=11252730&sponsor=

Mahtani, K. R., Heneghan, C. J., Glasziou, P. P., & R, P. (2011). Reminder Packaging for Improving Adherence to Self- administered Long-term Medications. *Cochrane Database of Systematic Reviews*, (9), 1–61. http://doi.org/10.1002/14651858.CD005025.pub3

Martin, E. W., & Shaheen, S. A. (2011a). Greenhouse Gas Emission Impacts of Carsharing in North America. *Ieee Transactions on Intelligent Transportation Systems*, *12*(4), 1074–1086. http://doi.org/10.1109/TITS.2011.2158539

Martin, E., & Shaheen, S. (2011b). The Impact of Carsharing on Household Vehicle Ownership. *ACCESS Magazine*, *1*(38).

Martin, E., & Shaheen, S. (2011c). The Impact of Carsharing on Public Transit and Non-Motorized Travel: An Exploration of North American Carsharing Survey Data. *Energies*, *4*(12), 2094–2114. http://doi.org/10.3390/en4112094

Martin, E., & Shaheen, S. A. (2016). *Impacts of car2go on Vehicle Ownership, Modal Shift,*

Vehicle Miles Traveled, and Greenhouse Gas Emissions: An Analysis of Five North American Cities (pp. 1–26).

Martin, E., Shaheen, S., & Lidicker, J. (2010). Impact of Carsharing on Household Vehicle Holdings. *Transportation Research Record: Journal of the Transportation Research Board*, *2143*, 150–158. http://doi.org/10.3141/2143-19

Mason, M. (2010). Sample Size and Saturation in PhD Studies Using Qualitative Interviews. *Forum Qualitative Sozialforschung Forum Qualitative Social Research*, *11*(3), 1–16.

Maven. (n.d.). Maven Website. Retrieved October 19, 2016, from https://www.mavendrive.com/#!/

Mayors' Council on Regional Transportation. (2014). *Regional Transportation Investments: A Vision for Metro Vancouver* (pp. 1–48). Retrieved from http://mayorscouncil.ca/wpcontent/uploads/2015/02/Mayors-Council-Vision-Document_June-2014.pdf

McLaughlin, R., & Green, L. (2016, February 2). Finding the Right Car Share Company for You. *CTV Vancouver News*, pp. 1–2. Retrieved from http://bc.ctvnews.ca/finding-the-right-car-share-company-for-you-1.2760075

Meijkamp, R. (1998). Changing Consumer Behaviour through Eco-efficient Services: An Empirical Study of Car Sharing in the Netherlands. *Business Strategy and the Environment*. http://doi.org/10.2307/3009604?ref=no-x-route:14f3ea241d633f695a27686442b350e3

Meijkamp, R., & Theunissen, R. (1996). Car Sharing: Consumer Acceptance and Changes On Mobilty Behaviour. Presented at the Transport Policy And Its Implementation. Proceedings Of Seminar B, Volume P.

Metcalfe, R., & Dolan, P. (2012). Behavioural Economics and Its Implications for Transport. *Journal of Transport Geography*, *24*(C), 503–511. http://doi.org/10.1016/j.jtrangeo.2012.01.019

Metro Vancouver. (2010). *Metro Vancouver Housing Data Book 2010* (pp. 1–109). Retrieved from http://www.metrovancouver.org/services/regional-planning/PlanningPublications/MV_Housing_Data_Book.pdf

Metro Vancouver. (2012a). *Census 2011 Census Bulletin #1: Population and Dwelling Counts* (pp. 1–4). Retrieved from http://www.metrovancouver.org/services/regional-planning/PlanningPublications/2011_CensusBulletin1-Pop_and_Dwell.pdf

Metro Vancouver. (2012b). *Census 2011 Census Bulletin #5: Household & Family Structure in Metro Vancouver* (pp. 1–7).

Metro Vancouver. (2012c). *Metro Vancouver 2011 Census Bulletin Household & Family Structure in Metro Vancouver* (pp. 1–7).

Metro Vancouver. (2012d). *Metro Vancouver 2011 Census Bulletin Population and Dwelling Counts* (pp. 1–4).

Metro Vancouver. (2013). Metro Vancouver's Regional Growth Strategy: Shaping Our Future, 1–80.

Metro Vancouver. (2014a). The Metro Vancouver Car Share Study Summary Booklet (pp. 1–28). Retrieved from http://www.metrovancouver.org/services/regional planning/PlanningPublications/1507 PPE MV Car Share Study l4Oct2OHR.pdf

Metro Vancouver. (2014b). *The Metro Vancouver Car Share Study Technical Report* (pp. 1–101). Retrieved from http://www.metrova ncouver.org/services/regional plannin/PlanningPublications/MetroVancouverCarShareStudyTechnicalReport.pdf

Metro Vancouver. (2015). Registered Vehicles 2001-2015, 1–1.

Millard-Ball, A., Murray, G., Schure, J. T., Fox, C., & Burkhardt, J. (2005). *Car-Sharing: Where and How It Succeeds*. *Transit Cooperative Research Program*. … Board.

Miller, T., Davis, W., & Reed, G. (2002). Effect of county-level income on vehicle age distribution and emissions. ... *Record: Journal of ...*, *1815*, 47–53. http://doi.org/10.3141/1815-06

Modo the Car Co-op. (2015a). API :: Modo :: Carsharing in Metro Vancouver. Retrieved June 2014, from http://www.modo.coop/api

Modo the Car Co-op. (2014, October 2). Modo the Car Coop Website. Retrieved October 2, 2014, from http://www.modo.coop/

Modo the Car Co-op. (2015b, January 7). Pro-Tip: Checking For Damage - Modo. Retrieved May 13, 2015, from http://www.modo.coop/blog/pro-tip-checking-for-damage/

Modo the Car Co-op. (2016). Modo frequency of service use.

Modo the Car Co-op. (n.d.). Modo Car Coop Website. Retrieved October 19, 2016, from http://modo.coop/

Möhlmann, M. (2015). Collaborative consumption: determinants of satisfaction and the likelihood of using a sharing economy option again. *Journal of Consumer Behaviour*, *14*(3), 193–207. http://doi.org/10.1002/cb.1512

Nakao, K. (2011). Carsharing Using Patterns: A Case Study in Kyoto City (Japanese). *Core Ethics*, *11*(119-210), 1–12.

Namazu, M., & Dowlatabadi, H. (2015a). Characterizing the GHG emission impacts of carsharing: a case of Vancouver. *Environmental Research Letters*, *10*(12), 1–10. http://doi.org/10.1088/1748-9326/10/12/124017

Namazu, M., & Dowlatabadi, H. (2015b). Understanding when carsharing displaces vehicle ownership (pp. 1–17). Presented at the Transportation Research Board Annual Meeting.

Namazu, M., & Dowlatabadi, H. (2016). Understanding When Carsharing Displaces Vehicle Ownership. Presented at the Transportation Research Board Annual Meeting.

Namazu, M., & Dowlatabadi, H. (n.d.). Vehicle ownership reduction: A comparison of one-way and two-way carsharing systems. *Transport Policy*, Submitted

Namazu, M., MacKenzie, D., Zerriffi, H., & Dowlatabadi, H. (n.d.). Is Carsharing for Everyone? Understanding the Diffusion of Carsharing Services. *Transport Policy*, Submitted.

Natural Resources Canada. (2015a). *2015 Fuel Consumption Guide* (pp. 1–23).

Natural Resources Canada. (2015b, March 10). Fuel Consumption Testing | Natural Resources Canada. Retrieved June 2, 2015, from http://www.nrcan.gc.ca/energy/efficiency/transportation/cars-light-trucks/buying/7491

New York City Department of Transportation. (2009). *Sustainable Streets 2009 Progress Report* (pp. 1–80).

Newton, K. H., Wiltshire, E. J., & Elley, C. R. (2009). Pedometers and Text Messaging to Increase Physical Activity Randomized controlled trial of adolescents with type 1 diabetes. *Diabetes Care*, *32*(5), 813–815. http://doi.org/10.2337/dc08-1974

Nickerson, D. W., & Rogers, T. (2010). Do You Have a Voting Plan? Implementation Intentions, Voter Turnout, and Organic Plan Making. *Psychological Science*, *21*(2), 194–199. http://doi.org/10.1177/0956797609359326

Obenberger, R. W., & Brown, S. W. (1976). A marketing alternative: Consumer leasing and renting. *Business Horizons*, *19*(5), 82–86. http://doi.org/10.1016/0007-6813(76)90039-2

Osborn, J. (2011). Values, culture, social capital, change : the case of The Car Coop.

Ostrom, E. (1999). Coping with tragedies of the commons. *Annual Review of Political Science*. Retrieved from http://www.annualreviews.org/doi/abs/10.1146/annurev.polisci.2.1.493

Petersen, E., Zhang, Y., & Darwiche, A. (2017). Car Sharing in Metropolitan Seattle: Modeling Car Sharing and Auto Ownership (pp. 1–19). Presented at the TRB 96th Annual Meeting Compendium of Papers.

Pop-Eleches, C., Thirumurthy, H., Habyarimana, J. P., Zivin, J. G., Goldstein, M. P., de Walque, D., et al. (2011). Mobile Phone Technologies Improve Adherence to Antiretroviral Treatment in a Resource-limited Setting: a Randomized Controlled Trial of Text Message Reminders. *Aids*, *25*(6), 825–834. http://doi.org/10.1097/QAD.0b013e32834380c1

Prettenthaler, F., & Steininger, K. (1999a). From Ownership to Service Use Lifestyle: The Potential of Car Sharing. *Ecological Economics*. Retrieved from http://www.sciencedirect.com/science/article/pii/S0921800998001098

Prettenthaler, F., & Steininger, K. (1999b). From Ownership to Service Use Lifestyle: the Potential of Car Sharing. *Ecological Economics*.

PricewaterhouseCoopers. (2015). *The Sharing Economy: Consumer Intelligence Series* (pp. 1–30).

Province of British Columbia. (2016, July 14). Rent Increases. Retrieved July 14, 2016, from http://www2.gov.bc.ca/gov/content/housing-tenancy/residential-tenancies/during-atenancy/rent-increases

ReachNow. (n.d.). ReachNow: BMW's Premium Car Sharing Service, 1–5. Retrieved from http://www.bmwcarsharing.com/

Rifkin, J. (2001). The Age of Access: Can Civilization Survive with the Commercial Sphere as the Primary Mediator of Human Life? RESURGENCE-LONDON-NAVERN ROAD.

Rogers, E. M. (2003). Diffusion of Innovations, 5th Edition. Simon and Schuster.

Samaras, C., & Meisterling, K. (2008). Life Cycle Assessment of Greenhouse Gas Emissions from Plug-in Hybrid Vehicles: Implications for Policy. *Environmental Science & Technology*, *42*(9), 3170–3176. http://doi.org/10.1021/es702178s

Schaefers, T., Wittkowski, K., Benoit nee Moeller, S., & Ferraro, R. (2015). Contagious Effects of Customer Misbehavior in Access-Based Services. *Journal of Service Research*, 1–19. http://doi.org/10.1177/1094670515595047

Schor, J. (2014). Debating the Sharing Economy. *A Great Transition Initiative Essay*, 1–15.

Schrader, U. (1999). Consumer Acceptance of Eco-efficient Services. Greener Management International.

Schreier, H., Becker, U., & Heller, J. (2016). *Final Report Evaluation Car-Sharing (EVA-CS) City of Munich* (pp. 1–27). Retrieved from http://www.ris-muenchen.de/RII/RII/DOK/SITZUNGSVORLAGE/3885730.pdf

Schultz, P. W., Nolan, J. M., Cialdini, R. B., Goldstein, N. J., & Griskevicius, V. (2007). The Constructive, Destructive, and Reconstructive Power of Social Norms. *Psychological Science*, *18*(5), 429–434. http://doi.org/10.1111/j.1467-9280.2007.01917.x

Schure, ter, J., Napolitan, F., & Hutchinson, R. (2012). Cumulative Impacts of Carsharing and Unbundled Parking on Vehicle Ownership and Mode Choice. *Transportation Research Record: Journal of the Transportation Research Board*, *2319*, 96–104. http://doi.org/10.3141/2319-11

Seattle Department of Transportation. (2015). MOVE SEATTLE: Mayor Edward B. Murray's 10-Year Strategic Vision for Transportation, 1–76.

Shaheen, S. A., & Cohen, A. P. (2013a). Carsharing and Personal Vehicle Services: Worldwide Market Developments and Emerging Trends. *International Journal of Sustainable Transportation*, *7*(1), 5–34. http://doi.org/10.1080/15568318.2012.660103

Shaheen, S. A., & Cohen, A. P. (2016). *Innovative Mobility Carsharing Outlook Winter 2016* (pp. 1–6). Retrieved from http://tsrc.berkeley.edu/sites/default/files/Innovative%20Mobility%20Industry%20Outlook_

World%202016%20Final.pdf

Shaheen, S. A., Chan, N. D., & Micheaux, H. (2015). One-way carsharing's evolution and operator perspectives from the Americas. *Transportation*, *42*(3), 1–18. http://doi.org/10.1007/s11116-015-9607-0

Shaheen, S. A., Sperling, D., & Wagner, C. (1999). A Short History of Carsharing in the 90's. *Institute of Transportation Studies*.

Shaheen, S., & Cohen, A. (2012). *Innovative Mobility Carsharing Outlook: Carsharing Market Overview, Analysis and Trends*. Transportation sustainability research center, University of California, Berkeley.

Shaheen, S., & Cohen, A. (2013b, July 8). Innovative Mobility Carsharing Outlook: Carsharing Market Overview, Analysis, and Trends. Retrieved October 7, 2014, from http://tsrc.berkeley.edu/sites/tsrc.berkeley.edu/files/Innovative%20Mobility%20Industry%20Outlook_Carsharing_Spring%202013%20FINAL_0.pdf

Shaheen, S., & Cohen, A. (2014, November 11). Innovative Mobility Carsharing Outlook: Carsharing Market Overview, Analysis and Trends. Retrieved February 17, 2015, from http://tsrc.berkeley.edu/sites/tsrc.berkeley.edu/files/Fall%202014%20Carsharing%20Outlook%20Final.pdf

Shared-Use Mobility Center. (n.d.). Shared Mobility Mapping Tool. Retrieved September 22, 2016, from http://maps.sharedusemobilitycenter.org/sumc/

Siee, T. (2014, January). Sharing and Caring | Jacobin. Retrieved October 24, 2014, from https://www.jacobinmag.com/2014/01/sharing-and-caring/

Simon, H. A. (1982). Models of Bounded Rationality: Empirically Grounded Economic Reason. MIT Press.

Sioui, L., Morency, C., & Trépanier, M. (2013). How Carsharing Affects the Travel Behavior of Households: A Case Study of Montréal, Canada. *International Journal of Sustainable Transportation*. http://doi.org/10.1080/15568318.2012.660109

Slovic, P., Zionts, D., Woods, A. K., Goodman, R., & Jinks, D. (2011). Psychic Numbing and Mass Atrocity. *New York University School of Law Public Law Legal Theory Research Paper Series Working Paper*, 1–17.

Smiley, D. (2016, October 1). Car2Go suspending business indefinitely in Miami, Miami Beach. Retrieved October 3, 2016, from http://www.miamiherald.com/news/local/community/miami-dade/article55953225.html

Société de Transports de Montréal. (2013). *STRATEGIC PLAN 2020* (pp. 1–120).

Stasko, T. H., Buck, A. B., & Gao, H. O. (2013). Carsharing in a University Setting: Impacts on Vehicle Ownership, Parking Demand, and Mobility in Ithaca, NY. *Transport Policy*, *30*(C), 262–268. http://doi.org/10.1016/j.tranpol.2013.09.018

Steer Davies Gleave. (2014). *Carplus Annual Survey of Car Clubs 2013/14 Summary Report England and Wales (excluding London)* (pp. 1–40).

Steer Davies Gleave. (2015a). *Carplus Annual Survey of Car Clubs 2014/15 England and Wales (excluding London)* (pp. 1–107).

Steer Davies Gleave. (2015b). *Carplus Annual Survey of Car Clubs 2014/15 London* (pp. 1–101).

Steer Davies Gleave. (2015c). *Carplus Annual Survey of Car Clubs 2014/15 Scotland* (pp. 1–110).

Sunstein, C. R. (2014). Nudging: A Very Short Guide. *Journal of Consumer Policy*, *37*(4), 583–588. http://doi.org/10.1007/s10603-014-9273-1

Terrien, C., Maniak, R., Chen, B., & Shaheen, S. (2016). Good practices for advancing urban mobility innovation: A case study of one-way carsharing. *Research in Transportation Business & Management*, 1–13. http://doi.org/10.1016/j.rtbm.2016.08.001

Thaler, R. (1980). Toward a Positive Theory of Consumer Choice. *Journal of Economic Behavior & Organization*, *1*(1), 39–60.

Thaler, R. H., & Benartzi, S. (2004). Save More Tomorrow™: Using Behavioral Economics to Increase Employee Saving. *Journal of Political Economy*, *112*(S1). http://doi.org/10.1086/380085?ref=search-gateway:49e0a25e4062f7c1ead7d9322634aa06

Thaler, R. H., & Shefrin, H. M. (1981). An Economic Theory of Self-control. *The Journal of Political Economy*. http://doi.org/10.2307/1833317

Thaler, R. H., & Sunstein, C. R. (2009). Nudge: Improving Decisions about Health, Wealth, and Happiness. Penguin.

The Motor Vehicle Sales Authority of British Columbia. (2014, December 2). 11 Years: Average Age of BC Vehicles. Retrieved March 22, 2015, from http://www.mvsabc.com/whats-new/whats-new/11-years-average-age-of-bc-vehicles

TransLink. (2012). TransLink 2010 Annual Report, 1–49.

TransLink. (2013). *2011 Metro Vancouver Regional Trip Diary Survey Analysis Report* (pp. 1–181).

Transport Canada. (2015a). *Canadian Vehicle Use Study Methodological Notes: Annual*

(2014Q1-2014Q4-Preliminary) (pp. 1–51).

Transport Canada. (2015b, March 19). Canadian Vehicle Use Study: 2014 Annual Results. Retrieved March 22, 2015, from http://www.tc.gc.ca/eng/policy/annual-2014-3141.html

Transportation Ecology and Mobility Foundation. (2013). *Analysis of Environmental Burden Reduction by Car-sharing (Japanese)* (pp. 1–96).

Transportation Research Board. (2016). *Between Public and Private Mobility: Examining the Rise of Technology-Enabled Transportation Services* (p. 63). Transportation Research Board.

Turo. (n.d.). Turo Website. Retrieved October 19, 2016, from https://turo.com/

Tversky, A., & Kahneman, D. (1991). Loss Aversion in Riskless Choice: A Reference-Dependent Model. *The Quarterly Journal of Economics*, *106*(4), 1039–1061. http://doi.org/10.2307/2937956?ref=no-x-route:748da395c497740e6c4a2c9f2148b118

U.S. Department of Energy, U.S. Environmental Protection Agency. (2015). *Model Year 2015 Fuel Economy Guide* (pp. 1–47). Retrieved from www.fueleconomy.gov

United States Environmental Protection Agency (US EPA). (2014). *Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends: 1975 Through 2014 Executive Summary* (No. EPA-420-S-14-001) (pp. 1–10).

University of California Berkeley Transportation Sustainability Research Center. (2015a). *Innovative Mobility Carsharing Outlook: Carsharing Market Overview, Analysis, and Trends* (pp. 1–4).

University of California Berkeley Transportation Sustainability Research Center. (2015b, February 17). University of California Berkeley Transportation Sustainability Research Center Website. Retrieved February 17, 2015, from

US Census Bureau. (2011). *Commuting in the United States: 2009 American Community Survey Reports* (pp. 1–20).

Vanagas, G. (2004). Receiver operating characteristic curves and comparison of cardiac surgery risk stratification systems. *Interactive Cardiovascular and Thoracic Surgery*, *3*(2), 319–322. http://doi.org/10.1016/j.icvts.2004.01.008

Vervloet, M., Linn, A. J., & van Weert, J. (2012). The Effectiveness of Interventions Using Electronic Reminders to Improve Adherence to Chronic Medication: a Systematic Review of the Literature. *Journal of the American Medical Informatics Association*. http://doi.org/10.1136/amiajnl-2011-000748)

W, R. (2016, October 10). Car2go shutting down in Copenhagen, pp. 1–4. Retrieved from http://cphpost.dk/news/car2go-shutting-down-in-copenhagen.html

Wagner, S., Brandt, T., & Neumann, D. (2014). Data Analytics in Free-Floating Carsharing: Evidence from the City of Berlin (pp. 897–907). Presented at the 48th Hawaii International Conference on System Science. http://doi.org/10.1109/HICSS.2015.112

Wardman, M. (1988). A comparison of revealed preference and stated preference models of travel behaviour. *Journal of Transport Economics and Policy*.

Wielinski, G., Trépanier, M., & Morency, C. (2015). What About Free-Floating Carsharing? *Transportation Research Record: Journal of the Transportation Research Board*, *2536*, 28–36. http://doi.org/10.3141/2536-04

Wisdom, J., Downs, J. S., & Loewenstein, G. (2010). Promoting Healthy Choices: Information Versus convenience. *American Economic Journal Applied Economics*. http://doi.org/10.1257/app

Wissenbach, I., & Taylor, E. (2014, May 28). Daimler's car sharing business car2go to quit UK, London a challenge. (S. Thomas, Ed.)*Reuters*, pp. 1–3. Retrieved from http://www.reuters.com/article/us-daimler-europcar-carsharing-idUSKBN0E81ZX20140528

Yano, S., Takayama, M., Nakao, K., & Fujii, S. (2011). Analysis of Effect of Carsharing on Travel Behavior (Japanese). *Journal of Japan Society of Civil Engineers, Ser D Infrastructure Planning and Management*, *67*(5), I_611–I_616.

Zhou, B. B., & Kockelman, K. M. (2011). Opportunities for and Impacts of Carsharing: A Survey of the Austin, Texas Market. *International Journal of Sustainable Transportation*, *5*(3), 135–152. http://doi.org/10.1080/15568311003717181

Zipcar. (2014). Millennials & the “New American Dream”: A Survey Commissioned by Zipcar (pp. 1–13).

Zipcar. (2015, April 1). Zipcar Privacy Policy. Retrieved March 3, 2015, from http://www.zipcar.ca/privacy-policy

Zipcar. (n.d.). Zipcar Website: An Alternative to Car Rental with Zipcar. Retrieved October 19, 2016, from https://www.zipcar.com/

Zipcar Canada. (2015). Zipcar Website: Car Sharing Vancouver. Retrieved July 27, 2015, from http://www.zipcar.ca/vancouver

Appendices

Appendix A: Travel Behaviour by Household Type

We assumed trip frequencies by trip purpose, travel distance and transportation mode for each household type in order to accurately assume CO_2 emissions. In order to assume such detailed travel behaviour, we presumed 1) the frequency distribution of trips by trip distance and purpose, and 2) transportation mode share by household type, trip purpose and travel distance. Metro Vancouver Trip Diary Survey 2011 (Ipsos Reid, 2012) is the main source to develop the travel behaviour. Since the Trip Diary data is not detailed enough, we made the following adjustments; first of all, travel patterns of household with children, household without children, and retiree household were adopted from travel patterns of households with grade-school or pre-school aged children, households without grade-school or pre-school aged children, and over 65 years old elderly residents. We also took into account the dissimilarities of trip behaviour between weekday and weekend. The Trip Diary examined trips on a weekday (Ipsos Reid, 2012), and it is known that there is about 10% decrease of trip frequency during weekend compared to weekday (Agarwal, 2004). The reductions in commuting and escorting trips are likely key reasons for this observation. We assumed that during weekend, work/post-secondary trips were eliminated, and the frequencies of the other trips were adjusted to satisfy a 10% decrease of the total trip frequency. The assumed travel behaviour is summarized in Appendix1 and Appendix2.

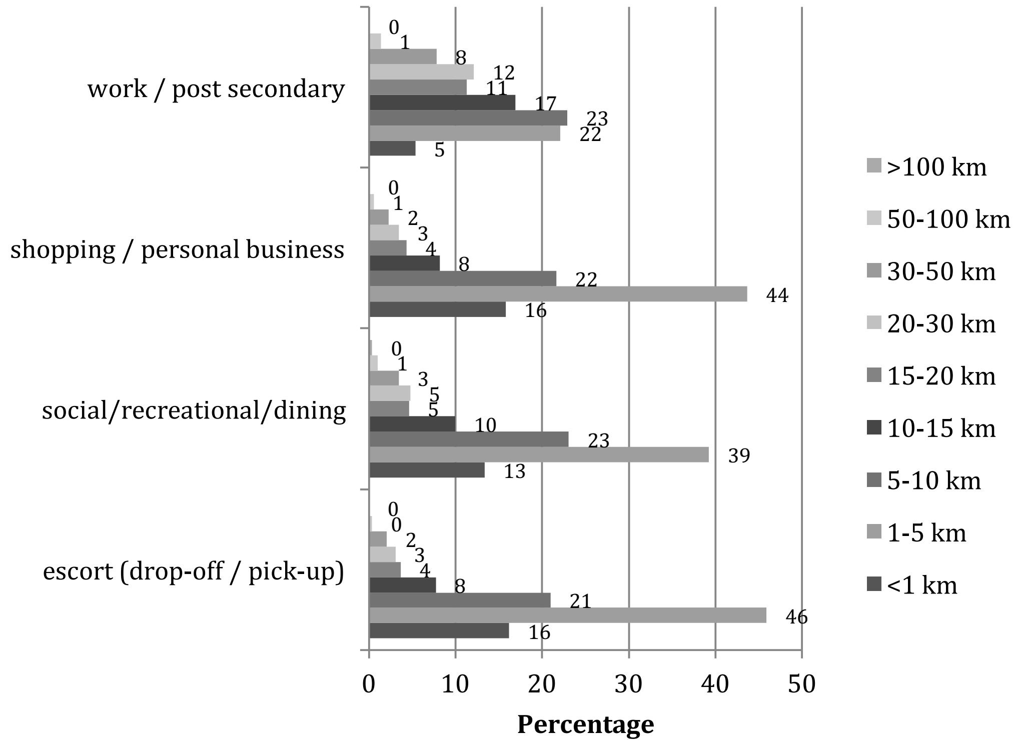

Figure A.1: Trip distance distribution by travel purpose. This distribution was commonly used for all household types.

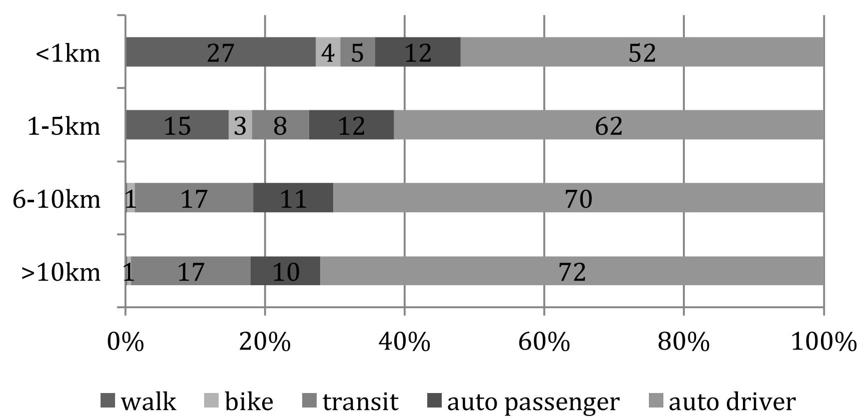

Figure A.2: Transportation mode share by travel distance. Different transportation mode shares were assumed for each household in the calculation. This graph shows the averaged share.

Appendix B: List of Interview Participant and Answers (Chapter 5)

Table B.1: List of interview participant and answers

ID	Gender	Occupation	Membership	Frequency of usage	Inspection	Reasons of no inspection	Reasons of inspection
A	F	Student	2 yr.	2-3/wk. (win.), 1/mo. (sum.)	No	Laziness, assuming the cars are fine	NA
B	F	Student	10 mo.	1/wk.	Yes (always)	NA	No explicit information
C	F	Student	2 yr.	2-3/month	No	Being in a hurry, assuming the cars are fine, laziness	NA
D	F	Faculty	2 yr.	Various	Yes (often)	Weather condition	No explicit information
E	M	Student	5 mo.	2/mo. (win.)	No	Minimizing costs	NA
F	M	Student	4 yr.	2011-12: 1/wk. 2013-14: 1/mo.	No	Being in a hurry, laziness	NA
G	M	Working	3 mo.	1/mo.	No	Laziness, misunderstanding of responsibility	NA
H	M	Working	2 yr.	1-2/mo.	Yes (always)	NA	Avoiding charge
I	F	Student	1-2 mo.	1-2/mo.	No	Being in a hurry	NA
J	M	Working	2 yr.	5/wk.	Yes (always)	NA	Avoiding charge
K	M	Working	1 yr.	1/2 wk.	Yes (always)	NA	Avoiding charge

Appendix C: Sharing is Caring?

Preamble

My thesis explores the meaning and role of carsharing, which is a type of the services often called sharing economy. This appendix gives a brief introduction to the sharing economy. With an understanding of the broader picture of these gaining-in-popularity services, the serial studies done for the thesis could be read as a case study of the sharing economy services.

Sharing Economy

The term "sharing economy" denotes an economy where members share goods, especially durable goods via Information Communication Technologies (ICT) based platforms so that ownership is not required to receive benefits from these goods (Hamari, Sjöklint, & Ukkonen, 2015; Schor, 2014). Carsharing services like Zipcar and car2go or tool-sharing services like the Vancouver Tool Library are good examples; in these sharing services, cars/tools are collectively owned and used by members. Sharing economy services also include ride-sharing services like Vanpools and space-sharing services like Airbnb. These services may enhance and/or promote the efficient use of goods. For instance, 95% of the time, cars are not in-use (Knack, 2005), and over 75% of commuting trips are done by single occupancy vehicles with empty seats (US Census Bureau, 2011). These wastes are seen not only among cars but also other tools. Up to 50 million electric drills are claimed to be unused (Botsman & Rogers, 2011). A great increase of usage efficiency could be realized via sharing economy services if the service demand stays constant.

The idea of focusing on services instead of goods to optimize their usage is not a new idea; the idea itself was already discussed by marketing theorists in the 1970s (Obenberger & Brown, 1976; Schrader, 1999). At that time, however, the idea was not practical enough to attract the critical mass. After more than a decade, the barrier began to lower by integrating ICT technologies. The matching of users and providers of goods has become significantly easier and cheaper to realize, thanks to these ICTs such as the Internet, smartphones, GPS and credit card technologies.

Given those understandings, below is a summary of the common features that are often seen in sharing economy services:

- Membership requirements: To be a member of the service or "sharing community" is required
- Sharing: Capital goods to be shared are collectively owned, maintained or used by members
- Online payment requirements: Payments are done via online payment systems (e.g. credit card, PayPal, etc.)

- Self-service base: Fewer interactions between property users and owners are required

While a wide range of sharing economy services are available at this time (see for example Collaborative Consumption, 2015; Forbs, 2015), they can all be classified into two broad categories: a) peer-to-peer and b) business-to-peer. In peer-to-peer style services, owners and renters are matched via sharing service platforms. Room/house rental services like Airbnb, peer-to-peer CS services like Turo (formally known as RelayRides) and Getaround are examples in this space. In addition to this, ride-sharing services like Uber and Lyft are also considered to be included in this model, although referring to their services as “ride-sharing” has been criticized by some observers (see for example Dreher, 2015).

On the other hand, in business-to-peer style services, organizations offering sharing services are the owners of capital goods they offer for rent using various ITC platforms. Standard CS services, like Zipcar and Car2go, bike-sharing services like Citi Bike and Bixi, and tool rental services, like the Vancouver Tool Library are prominent exemplars of this business model.

Whatever types these services are classified into, most of these sharing economy services share a core trend: a remarkable growth. Every night, eight years old space-sharing service, Airbnb serves places to stay for 425,000 guests (PricewaterhouseCoopers, 2015). Close to 5 million members have been receiving benefits from CS services worldwide (Shaheen & Cohen, 2016). Researchers at PricewaterhouseCoopers estimated that the sharing economy market was roughly 15 billion USD in 2014, and would grow to 335 billion USD by 2025 (PricewaterhouseCoopers, 2015).

Sharing as a Brand

These so-called “sharing economies” are often misleadingly mentioned as the symbol of a more collective and communal economy. For sharing economy advocates, the economy enhances mutual interactions and caring between individuals (Botsman & Rogers, 2011). Conventional sharing activities, like sharing goods among family, are supposed to be altruistic and pro-social with shared responsibilities and ownership (Belk, 2010). On the other hand, sharing economy services normally involve reciprocity, particularly for market exchanges and money trading. As a result, sharing economy services are rarely associated with shared responsibilities and ownership

(Bardhi & Eckhardt, 2012). From this perspective, sharing economy services share their foundation more with renting services, rather than conventional sharing.

Here is a notable quote from Durgee (1995):

"interestingly, because of the negative connotation that renting has in certain population segments, boutiques that offer evening gowns for rent do not refer to them as rented gowns but rather as borrowed gowns" (Durgee & Colarelli O'Connor, 1995, p. 91)

This exact same phenomenon is happening again with sharing economies, and renting is being branded as sharing in order to separate itself from the negative connotations often associated with the concept of renting.

The practice of renting capital goods is a relatively core concept of human society. Humans have used the mechanism of renting since the beginning of their civilizations. In fact, Hammurabi's Code, which is one of the oldest sets of laws in the world developed around B.C. 1700, already legislates land leasing. At that time, peasants were renting land to cultivate, by paying fees to the owners, like some do now for their living spaces. This means that renting, or in other words, access without ownership, was oriented in its infancy to deal with considerably expensive capital goods, such as land and housing.

Renting systems, however, have since expanded to include a wider range of capital goods, especially from the late 20th century onward. The fuels of more recent trends are (Durgee, 1984; Durgee & Colarelli O'Connor, 1995):

1) Movement towards more unique and transitory lifestyle
2) Recent economic situations with more uncertainties
3) ICT innovations, and
4) Stronger preferences for convenience

Some of these expanded renting services are branded as "sharing economy" services.

Effect of Sharing Economy Services

The rising popularity of the sharing economy is forecasted to persist for some time (Botsman & Rogers, 2011; Brody & Pureswaran, 2015; Möhlmann, 2015; Rifkin, 2001). However, it is important to note that their recent boom was also concurrent with the deepest economic recession experienced in seven decades. Therefore, it may still be too early to know whether trends like sustainability and frugality become the new social norms and renting will become a virtue rather than a stigma. If such services become more popular and abundant, what are their social impacts? For example, who are the main users of sharing economy services? Do these services shrink the gap between rich and poor? What about the environmental impacts of sharing services? Theoretically speaking, in the absence of a Jevons' Paradox (Jevons, 1865), sharing services are likely to contribute to lower Greenhouse Gases and other pollutant emissions. However in practice, if a rebound in demand were to occur, what would be the overall change in environmental externalities associated with consuming these services? Is using shared goods the same as using private goods? Using goods that are "mine" seems to be different from using goods that are "yours" or "ours". How do these differences affect the usage and treatment of shared goods?

Though my thesis, focusing on CS, one of many sharing economy services, successfully answered some of the questions listed above, many of the questions are yet to be answered.