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Public Bikesharing and Modal Shift Behavior: A Comparative Study of Early Bikesharing Systems in North America

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Abstract

Public bikesharing—the shared use of a bicycle fleet by the public—is an innovative mobility strategy that has recently emerged in major North American cities. Bikesharing systems typically position bicycles throughout an urban environment, among a network of docking stations, for immediate access. This paper discusses the modal shift that results from individuals participating in four public bikesharing systems in North America. The authors conducted an online survey ($n = 10,661$ total sample), between November 2011 and January 2012, with members of four major bikesharing organizations (located in Montreal, Toronto, the Twin Cities, and Washington D.C.) and collected information regarding travel-behavior changes, focusing on modal shift, as well as public bikesharing perceptions. The survey probed member perceptions about bikesharing and found that a majority in the surveyed cities felt that bikesharing was an enhancement to public transportation and improved transit connectivity. With respect to modal shift, the results suggest that bikesharing generally draws from all travel modes. Three of the four largest cities in the study exhibited declines in bus and rail usage as a result of bikesharing. For example, 50% of respondents in Montreal reported reducing rail use, while 44% and 48% reported similar shifts in Toronto and Washington D.C., respectively. However, within those same cities, 27% to 40% of respondents reported using public transit in conjunction with bikesharing to make trips previously completed by automobile. In the Twin Cities, the dynamic was different, as 15% of respondents reported increasing rail usage versus only 3% who noted a decrease in rail use. In all cities, bikesharing resulted in a considerable decline in personal driving and taxi use, suggesting that public bikesharing is reducing urban transportation emissions, while at the same time freeing capacity of bus and rail networks within large cities.

Keywords: *Public bikesharing, modal shift behavior, survey, North America*

1. Introduction

Public bikesharing—the shared use of a bicycle fleet by the public—has had a transformative impact on many North America cities. Bikesharing systems, which trace their origins to Europe in the 1960s, have embraced a number of technological innovations that have expanded their scope and public utility. The key innovation is technology that permits the automated locking and unlocking of bicycles and user communication with a central system that manages the check-out and check-in of bicycles. This new form of “IT-based” bikesharing has found widespread popularity across the world and was first established in North America about six years ago. First appearing as a small program in 2007 in Tulsa, Oklahoma, public bikesharing proliferated rapidly following its launch in Montreal in 2009. Soon after, major cities in Canada, the United States, and Mexico launched public bikesharing programs, changing the way users travel within these cities. The expansion of public bikesharing has been coupled with a renewed emphasis on the goals of increasing active transportation, reducing driving, decreasing carbon dioxide (CO₂) and criteria emissions, increasing public transit ridership, and enhancing accessibility and mobility. Public bikesharing was originally established as a means to facilitate better first- and last-mile connections aimed at bridging the gap between commuters, their homes and workplaces, and mainline public transit systems. It has served as a new mode, drawing new populations to the use of the bicycle. As of July 1, 2013, there were 25 operational programs in the U.S., three operational in Canada, and one operational in Mexico.

Similar to carsharing, bikesharing allows users to access publicly available bicycles on an “as-needed” basis. Bikesharing kiosks are typically unattended, concentrated in an urban environment with a network of locations enabling an on-demand, low-emission mobility option. Many bikesharing operators are responsible for the cost of bicycle maintenance, storage, and parking (similar to carsharing or short-term auto access). Trips can be one-way or round trip. Generally, short trips (e.g., less than 30 minutes) are free for annual members. Users can often join a bikesharing program on an annual, monthly, daily, or even per trip basis. Users can pick up a bicycle at any kiosk by swiping their credit card, a membership card, and/or by mobile phone. When they end their trip, they can return it to: 1) any dock (one-way trip); 2) the same dock (round-trip service); or 3) anywhere within a geo-fenced location for dockless IT-based bikesharing

By addressing the storage, maintenance, and parking aspects of bike ownership, bikesharing encourages cycling among users who may not otherwise use bicycles. Additionally, the availability of a large number of bicycles in multiple dense, nearby locations, frequently creates a “network-effect” encouraging the use of bikesharing for regular trips (e.g., commuting, errands). For local governments, public bikesharing offers a low-cost form of public transportation and may be a cost-effective solution for mitigating CO₂ emissions and extending the reach of motorized public transportation systems.

As bikesharing has grown, so too has the curiosity about its overall impact on travel behavior. Specifically, the nature of modal shift engendered by bikesharing is a key question towards understanding the impact of systems on vehicle emissions, public transit ridership, and active transportation modes like walking and bicycling. The most direct and conclusive way to address these questions is to ask users how their travel patterns have changed since they joined bikesharing. To advance this understanding, this paper presents the results of a survey of bikesharing (n =10,661 total sample) conducted in partnership with four IT-based bikesharing programs in North America (two programs in the U.S. and two in Canada) between November 2011 and January 2012. The remainder of this paper is organized into five key sections: 1) historical overview; 2) review of public bikesharing impacts, with an emphasis on North America; 3) study methodology; 4) member survey results; and 5) conclusion.

2. Historical Overview

This section provides a brief historical overview of public bikesharing. The concept was first introduced decades ago in Europe and has continued to advance there, particularly since the mid-1990s. France had been an epicenter of early IT-based (third-generation) fully automated public bikesharing (or

“bicycle transit”) activity. For example, in 2007, the city of Paris launched Vélib’, one of the world’s largest public bikesharing programs following other notable program launches in La Rochelle and Lyon.

As in Europe, the first North American public bikesharing program launched as a free system in Portland, Oregon in 1994. Over the next five years, similar public bikesharing programs emerged, all of which were modeled after either white-bike systems, which are also known as free bike systems, or alternatively as coin-deposit systems, which require a refundable coin deposit to use a bicycle [0]. Bikesharing has evolved from these earlier systems to the deployment of IT-based bikesharing today [0]. This evolution has been categorized into four key phases or generations, which are summarized in Table 1. This paper largely examines IT-based systems, which include several elements of fourth generation systems (e.g., flexible, clean (or mobile solar) docking stations).

Table 1. Overview of public bikesharing generations

<p>First generation: “Free bikes”</p>	<p>Bicycles are typically painted one color, left unlocked, and placed randomly throughout an area for free use. First-generation systems do not use docking ports. In some of the systems, the bikes are locked; users must get a key from a participating local business and may also need to leave a credit card deposit, but actual bike use is free. Many first-generation systems eventually ceased operations due to theft and bicycle vandalism, but some are still operating as community-based initiatives.</p>
<p>Second generation: “Coin-deposit systems”</p>	<p>Bicycles have designated docking stations/parking locations where they are locked, borrowed, and returned. A deposit, generally not more than US\$4, is required to unlock a bike. While coin-deposit systems helped reduce theft and vandalism, the problem was not eliminated, in part because of user anonymity. Many second-generation systems are still in operation.</p>
<p>Third generation: “IT-based systems”</p>	<p>IT-based systems use electronic and wireless communications for bicycle pickup, drop-off, and tracking. User accountability has been improved through the use of credit or debit cards. Third-generation bikesharing includes docking stations, kiosks, or user interface technology for check-in and check-out, and advanced technology (e.g., magnetic-stripe cards, smartcards, smart keys). Although these systems are more expensive than first- or second-generation systems, information technology enables public bikesharing programs to track bicycles and access user information, improves system management, and deters bike theft. IT-based systems are responsible for public bikesharing’s recent expansion in both location and scale.</p>
<p>Fourth generation: “Demand-responsive / multi-modal systems” [1]</p>	<p>Demand-responsive, multi-modal systems build upon the technology of third-generation systems by implementing enhanced features, such as flexible, clean docking stations or “dockless” bicycles; demand-responsive bicycle redistribution innovations to facilitate system rebalancing; value pricing to encourage self-rebalancing; multi-modal access; billing integration (e.g., sharing smartcards with public transit and carsharing); real-time transit integration and system data dashboards; and global positioning system (GPS) tracking. They may also include electric bicycles. Fourth-generation bikesharing is an evolving concept that has yet to be fully deployed.</p>

3. Public Bikesharing Impacts

Public bikesharing systems have reported a number of environmental, social, and transportation-related benefits. Bikesharing provides a quicker, low-emission means to access public transportation or to make short-distance trips between docking stations [0, 0]. It is likely that the convenience of accessing a bicycle, coupled with the speed a bicycle can achieve for mid-range trips, is a key attraction. Bikesharing may be able to achieve some trips faster than public transit (including wait time), and it extends the catchment area of public transit facilities. In this way, bikesharing has the potential to play an important

role in bridging the gaps in existing transportation networks, as well as encouraging individuals to use multiple transportation modes. Other benefits emerging as a result of bikesharing include increased mobility, which stems from the provision of bicycles that can be taken from point to point and then released from user responsibility. Bikesharing is also thought to provide economic benefits in the form of cost savings to bikesharing members who do not pay for trips completed within 30 minutes, outside of their membership fee. Shopping patterns of bikesharing users may also shift more towards regions that are near bikesharing stations, providing a benefit to local shops in the downtown and neighborhood regions of the city. The modal shift towards the bicycle may also have impacts on traffic, emissions, and health as people substitute active transportation modes for motorized transportation [0].

Although before-and-after studies documenting public bikesharing benefits are limited, a few North American programs have conducted member surveys to record program impacts. Table 2 presents a summary of trips, distance traveled, and estimated CO₂ reductions from studies completed in the U.S. and Canada, including results from the authors' 2011/2012 survey of four public bikesharing operators in North America. In addition to studies that have demonstrated reduced CO₂ emissions and a modal shift toward bicycle use, evaluations indicate an increased public awareness of bikesharing as a viable transportation mode. A 2008 study found that 89% of Vélib' users said the program made it easier to travel through Paris [0]. Fifty-nine percent of Nice Ride Minnesota users said that they liked the "convenience factor" most about their program [0]. Denver B-cycle achieved a 30% increase in riders and a 97% increase in the number of rides taken in 2011 [0]. These studies coupled with anecdotal evidence suggest that public bikesharing programs have a positive impact on the public perception of bicycling as a viable transportation mode.

Table 2. Impacts of public bikesharing in North America

<i>Canada</i>	Year of Data	Trips per Day	Km per Day	CO₂ Reduction (kg per Day)	Change in Vehicle Ownership	Respondents Driving Less Often
BIXI Montreal	2011	20,000 [6]			-3.6% [6]	36.3% [6]
BIXI Toronto	2011				-2.0% [6]	25.4% [6]
<i>United States</i>	Year of Data	Trips per Year	Km per Year	CO₂ Reduction (kg per Year)	Reduction in Vehicle Ownership	Respondents Driving Less Often
Boulder B-cycle	2011	18,500 [8]		47,174 [8]		
Capital Bikeshare (D.C.)	2011	1,249,454 [7]			-2.1% [7]	41.0% [7]
Denver B-cycle	2011	202,731 [9]	694,942 [9]	280,339 [9]		
New Balance Hubway (Boston)	2011	140,000 [10]				
Madison B-cycle	2011	18,500 [11]		46,805 [11]		
Nice Ride Minnesota (Twin Cities)	2011	217,530 [7]			-1.9% [7]	52.4% [7]
San Antonio B-cycle	2011	22,709 [13]		38,575 [13]		

The emission-reduction estimates shown in Table 2 vary substantially across studies due to different assumptions about user behavior, trip distribution, and trip substitution. Key assumptions that influence CO₂ reduction estimates pertain to public bikesharing trips that displace automobile trips. Other previous work that has specifically addressed modal shift from bikesharing in North America is relatively limited due to its recent adoption. One published study conducted a telephone interview in Montreal to estimate the modal shift that occurred as a result of the BIXI launch in 2009 and 2010. Researchers found that bikesharing drew modal share from all modes, particularly walking, bicycling, and public transportation [0]. In the next section, the authors discuss the methodological approach taken in this study with respect to data collection and analysis.

4. Methodology

This paper is based primarily on data collected from a member survey that was completed between November 2011 and January 2012 in partnership with public bikesharing operators in four North American cities including: Montreal (n=3,322); the Twin Cities (Minneapolis and Saint Paul) (n=1,238); Toronto (n=853); and Washington D.C. (n=5,248). Based on approximate membership data from the four locations, the overall response rate was approximately 15%. The survey was administered online for all programs and surveyed both annual and 30-day subscribers. These four cities all operate bikesharing systems with the same technology as the original BIXI system in Montreal. One limitation that has since emerged of this methodology is that activity data published by bikesharing operators has shown that usage reflects a notable share of casual users (i.e., individuals who purchase bikesharing trips on an as needed basis and do not commit to longer-term memberships; also known as “24-hour” users). These users include tourists and perhaps others experimenting with bikesharing or who need it on an infrequent basis. They also include users who try the system as casual users and then join as annual users. However, these users are not identified by the system beyond a credit or debit card. Without an email or other contact information, the identity of the casual users is unknown, and those that remain occasional participants cannot be surveyed through an online member survey. A common approach to sample this population is an intercept survey. While new approaches to capture data from casual users are underway in the authors’ current research, the survey results presented in this paper focus on annual or 30-day bikesharing members, which generally reflect more regular users who experience a lower bikesharing cost overall. Bikesharing memberships were relatively cheap, ranging from US/CA\$65 to \$95 per year for the four cities surveyed, with additional fees for any trips longer than 30 minutes point-to-point. Casual memberships cost between US/CA\$5 to \$7 for a 24-hour period and also had additional fees if trips were longer than 30 minutes. Thus, the pricing structure determines that casual use is generally more expensive than an annual membership after at most 20 days of use.

In Washington D.C., Capital Bikeshare completed its survey independently, inserting a selection of the authors’ survey questions. Capital Bikeshare then shared the raw data for analysis, while the other three programs sent their members a link to take the online survey that the authors operated. Each survey contained questions tailored to the specific cities in which the respondents lived. A reminder email was sent several days after the introductory email for each organization. All of the operators in each city had the opportunity to comment on the survey before administration and could add or request deletion of certain questions.

There were several survey goals. One of the primary objectives was to gain insights on how public bikesharing altered members’ travel patterns along the dimensions of modal shift. The survey contained questions that evaluated the degree to which bikesharing increased, decreased, or did not change the use of specific modes within each city. These questions directed the respondents to evaluate the causal relationship of bikesharing on their relative use of specific modes. These questions were a measure of self-assessment, and beyond evaluating the causal direction of the change, they did not evaluate the magnitude of change or the underlying reasons for trip purpose substitution. A deeper exploration of these questions is being evaluated in an ongoing study. The survey also contained questions that evaluated the degree to which bikesharing was viewed as an extension of public transportation and employed in conjunction with public transit to displace automobile use. Questions also examined the economic impact of bikesharing on local establishments. Results from these questions is provided in the following section, with an emphasis on exploring modal shift across the four cities surveyed.

5. Member Survey Results

5.1. Demographics

Of the total 10,661 respondents, 6,486 came from the U.S., and 4,175 were from Canada. The complete data set consists of all respondents. Table 3 illustrates the complete sample distribution of income, education, age, gender, and race of the survey respondents and the population within each city as defined by data from the US Census and Statistics Canada. For the US, all data were derived from the 2011 American Community Survey. For Canada, the latest available income data were from the 2006 Census, while the distribution of education, age, and, race came from the 2011 Census or the 2011 National Household Survey. The (+/-) indicates where the survey showed the sample over-representing (+) and under-representing (-) the population in the respective demographic category.

Relative to the population within the four cities surveyed, bikesharing members had slightly higher incomes, were younger, more educated, and were of a higher percentage Caucasian than the general population. In addition, bikesharing users in all cities were predominantly male, even though females were in the majority of the population in three out of the four cities. While bikesharing users were skewed towards the young adult demographic, there was notable representation among middle-aged and older respondents, as about 40% of all respondents were 35 years of age or older. Overall, 88% of respondents reported having a minimum of a four-year college degree, and nearly half of the entire sample (46%) also had an advanced (Masters or Doctorate) graduate degree. This characteristic also has emerged as a feature distinguishing carsharing (short-term vehicle access) users, as previous research found that more than 80% of carsharing members had a four-year degree or more [0].

The distribution of the demographic data suggests that bikesharing serves a relatively diverse range of income and age, with a relatively less diverse range of education and race/ethnicity. This may be reflective of initial positioning of early systems within downtown areas with high levels of white-collar employment. It also may reflect characteristics of early adopters, as well as access to credit. To use a bikesharing service at the time of the survey, a credit card was needed. This imposed a constraint on populations that have limited access to credit or chose not to hold credit cards. Bikesharing operators, aware of these constraints, have already taken initiatives to address them (e.g., adding debit and pre-paid cards). Naturally, expansion into the urban periphery may also increase the diversity of system users.

5.2. Modal Shift Patterns

The patterns of modal shift exhibited by annual and 30-day members of bikesharing systems indicate that it may be functioning as its own mode, drawing from other modes including automobiles and public transportation. To evaluate the directional change in modal shift, the respondents were asked to indicate how their use of a specific mode of transportation was altered as a result of bikesharing. For example, in the context of bus usage, respondents in Montreal were asked: "As a result of my use of BIXI, I use the bus..." and could select the responses of: "Much more often;" "More often;" "About the same (bikesharing has had no impact);" "Less often;" "Much less often;" "I did not ride the bus before and I do not ride the bus now;" and "I have changed how I use the bus but not because of BIXI." The survey administered in each of the cities used the name of the bikesharing operator in that city (e.g., Capital Bikeshare, Nice Ride Minnesota). The design of these questions was meant to give respondents a complete set of responses to characterize the direction and causality of modal shift that occurred as a result of bikesharing.

Table 3. Distribution of Respondent and City Demographics

HOUSEHOLD INCOME	Washington DC			Minneapolis			Montreal			Toronto		
	2011 ACS	Survey	(+/-)	2011 ACS	Survey	(+/-)	2006 Census	Survey	(+/-)	2006 Census	Survey	(+/-)
Less than \$10,000	11%	4%	-	12%	5%	-	2%	5%	+	2%	3%	+
\$10,000 to \$14,999	4%	1%	-	6%	3%	-	2%	4%	+	2%	1%	-
\$15,000 to \$24,999	8%	2%	-	11%	6%	-	7%	7%	+	5%	4%	-
\$25,000 to \$34,999	7%	5%	-	10%	8%	-	10%	7%	-	7%	5%	-
\$35,000 to \$49,999	11%	14%	+	13%	14%	+	16%	15%	-	12%	9%	-
\$50,000 to \$74,999	15%	22%	+	17%	16%	-	23%	21%	-	20%	17%	-
\$75,000 to \$99,999	11%	18%	+	11%	13%	+	17%	15%	-	17%	15%	-
\$100,000 to \$149,999	15%	14%	-	11%	18%	+	15%	16%	+	20%	23%	+
\$150,000 or more	18%	19%	+	9%	16%	+	8%	10%	+	15%	24%	+
EDUCATION	Washington DC			Minneapolis			Montreal			Toronto		
	2011 ACS	Survey	(+/-)	2011 ACS	Survey	(+/-)	2011 NHS	Survey	(+/-)	2011 NHS	Survey	(+/-)
Less than high school	13%	0%	-	12%	0%	-	12%	0%	-	11%	0%	-
High school	32%	0%	-	35%	13%	-	18%	3%	-	21%	5%	-
Technical school/Cegep	3%	5%	+	6%	4%	-	34%	14%	-	29%	5%	-
Bachelor's degree	23%	42%	+	29%	45%	+	21%	42%	+	24%	49%	+
Advanced degree	29%	53%	+	17%	39%	+	15%	41%	+	16%	40%	+
AGE	Washington DC			Minneapolis			Montreal			Toronto		
	2011 ACS	Survey	(+/-)	2011 ACS	Survey	(+/-)	2011 Census	Survey	(+/-)	2011 Census	Survey	(+/-)
18 - 24	12%	11%	-	14%	11%	-	12%	10%	-	12%	11%	-
25 - 34	27%	55%	+	27%	40%	+	21%	43%	+	19%	44%	+
35 - 44	17%	20%	+	17%	20%	+	18%	23%	+	18%	27%	+
45 - 54	15%	4%	-	17%	17%	+	17%	16%	-	19%	18%	-
55 - 64	14%	9%	-	13%	11%	-	14%	7%	-	14%	7%	-
65 years or older	14%	1%	-	13%	2%	-	19%	1%	-	18%	2%	-
RACE/ETHNICITY	Washington DC			Minneapolis			Montreal			Toronto		
	2011 ACS	Survey	(+/-)	2011 ACS	Survey	(+/-)	2011 NHS	Survey	(+/-)	2011 NHS	Survey	(+/-)
Caucasian	35%	81%	+	61%	90%	+	74%	90%	+	51%	80%	+
African-American	49%	3%	-	18%	1%	-	8%	1%	-	8%	0%	-
Hispanic/Latino	10%	5%	-	11%	1%	-	4%	3%	-	3%	1%	-
Asian/Pacific Islander	4%	7%	+	5%	5%	+	11%	3%	-	34%	16%	-
Other/Multi-Racial	2%	4%	+	5%	3%	-	3%	3%	-	4%	3%	-
GENDER	Washington DC			Minneapolis			Montreal			Toronto		
	2011 ACS	Survey	(+/-)	2011 ACS	Survey	(+/-)	2011 NHS	Survey	(+/-)	2011 NHS	Survey	(+/-)
Male	47.3%	55%	+	50.3%	55%	+	49%	57%	+	48%	70%	+
Female	52.7%	45%	-	49.7%	45%	-	51%	43%	-	52%	30%	-

The data from these early operators indicates that the direction of the modal shift is not universal across cities. One city, in particular—the Twin Cities of Minneapolis and Saint Paul—showed a less dramatic shift away from bus transit and a shift towards rail use as a result of bikesharing. The other cities by contrast exhibited a more wholesale shift away from bus and rail transit. This result is illustrated in Figure 1, which presents the distribution of modal shift towards and away from the bus in the four cities surveyed. For simplicity and comparability, the three “no change as a result of bikesharing” responses are aggregated into one “no change” category. The question at the top is also paraphrased to be: “As a result of my use of bikesharing, I use the bus...” (where the word “bikesharing” was actually the operator’s name).

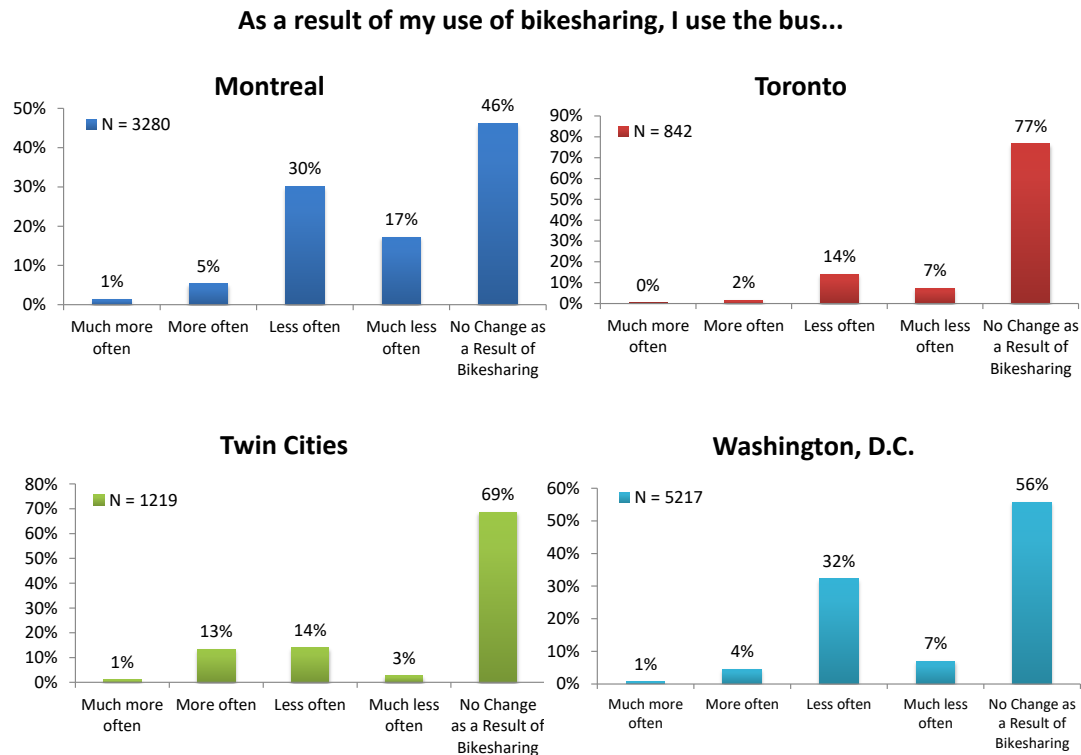


Figure 1. Shift in Bus Usage as a Result of Bikesharing

The results across the four cities show that respondents in Montreal and Washington D.C. exhibited the most notable shifts away from bus usage. In Montreal and Washington D.C., 47% and 39% reported using the bus less, respectively. In contrast, 6% and 5% of respondents reported increasing their bus usage in those cities, respectively. In Toronto, the shift away from bus was smaller at 21% of respondents, but it still contrasts starkly with the 2% that reported increasing bus usage as a result of bikesharing. Notably, in the Twin Cities, more respondents also shift away from bus than towards it, but the difference between those increasing and decreasing is only three percentage points.

A statistical comparison of the four distributions with each other was completed with the Mann-Whitney test, as these are ordinal variables. The test considered the distribution as defined by the four ordinal variables (“Much more often,” “More often,” “Less often,” “Much less Often”), excluding the “No Change” response, which includes factors such as public transit accessibility that would confound an evaluation of shift within those that do have transit access. All distributions were found to be different from each other to a degree that is statistically significant with the exception of the Montreal and Toronto distributions. With these two distributions, it is clear that the shapes are remarkably similar with “Less often” responses nearly double that of “Much less often” responses in both cities. Because the sample sizes are large in all of these cities, most distributions, with modestly different shapes are statistically different, particularly with the distinct case of the Twin Cities. In the discussion of subsequent modal shifts, the authors focus on the underlying dynamics emerging from the comparative interpretations.

A similar pattern across the cities was found for responses to change in rail use. As in the case of bus, respondents were asked in the same form how their use of rail changed as a result of bikesharing. The questions were asked in the context of existing urban rail transit within each city. The names of the specific rail systems were used in each of the surveys. The distribution of responses is provided in Figure 2.

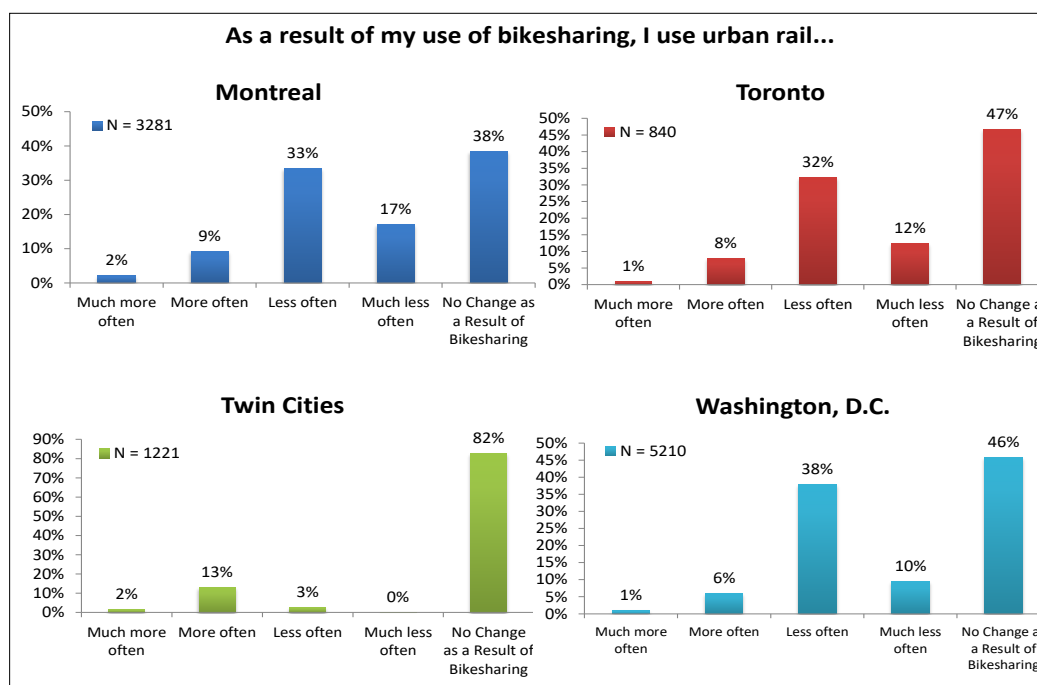


Figure 2. Shift in Rail Usage as a Result of Bikesharing

As with the modal shift away from bus, the results from Montreal, Toronto, and Washington D.C. suggest that bikesharing induced 50%, 44%, and 48% of respondents to reduce their use of urban rail, respectively. It is important to note that in these cities, some respondents did indicate an increased use of rail because of bikesharing. The exception to this broader dynamic was again seen in the data from the Twin Cities, where 15% of respondents indicated increasing their rail use as a result of bikesharing versus the 3% stating a decrease. Another distinction across the four cities is the difference in the “No Change” response. As shown in Figure 3, 82% of respondents showed no change in rail use, whereas in the other three cities 38% to 47% exhibited no change. The additional dissimilarity displayed within the Twin Cities is the result of differences in access and use of the different modes. Similar patterns of distinction are evident in the shifts across other modes, as discussed later in the paper.

The difference in the distribution of the shifts in the Twin Cities for both bus and rail is striking. It is logical to question why bikesharing would cause respondents in three of the four cities to move away from public transit as a result of bikesharing but more towards transit in the Twin Cities. Since this dynamic was unexpected, the survey did not probe the reasons behind such shifts (e.g., time of day, capacity, cost, congestion, etc.). One possible reason for these shifts could stem from the city size, density, and intensity of the public transit system. To illustrate, Table 4 provides some key descriptive characteristics of the four cities at the time of the survey.

One of the immediate distinctions of the Twin Cities (Minneapolis-St. Paul) is the population density; it is the smallest of the four cities and 32% less than the third densest city of Washington D.C. Relative to the other cities, the Twin Cities public transit system is also smaller in terms of rail track, number of buses, and number of rail cars. In terms of use, the number of trips on the transit system within the Twin Cities is far smaller in magnitude. Table 1 shows that there were 78 million unlinked trips on the Twin Cities transit system. This is roughly 20% of the trips on the Montreal system, 19% of the system in Washington D.C., and 16% of the trips in Toronto. Another distinction of the Twin Cities public transit

Table 4. Key Characteristics of the Four Cities in the Survey [0]

Transit Facts	Washington, D.C.	Toronto	Montreal	Minneapolis-St. Paul
Kilometers of Rail Track	341	373	122	40
Number of Buses	1,495	1,811	1,600	885
Number of Rail (or Metro) Cars	1,106	951	759	27
Unlinked trips	418,125,650	477,357,000	388,600,000	78,048,647
Population Facts	Washington, D.C.	Toronto	Montreal	Minneapolis-St. Paul
Population	601,723	2,503,281	1,620,693	667,646
Area (km ²)	177	630	365	288
Population Density (pop/km ²)	3,400	3,972	4,439	2,317
Year of Data	2010	2010 (transit) 2006 (population)	2010 (transit) 2006 (population)	2010

system with respect to rail is its shape. Although the system is undergoing expansion, there only existed the single and relatively straight Hiawatha light rail line at the time of the survey. This meant that traveling on the Hiawatha line in the Twin Cities region implied going in one direction or the other, with no ability to transfer to another intersecting rail line. In contrast, the systems in Montreal, Toronto, and Washington D.C., are all older and more interconnected with crossing rail lines. Bikesharing users in these cities are more likely to encounter congested rail lines and the need to transfer lines (this could lead to time and cost savings with bikesharing). Bikesharing also provides health benefits related to exercise. From this perspective, bikesharing in bigger cities may be opening up capacity on congested bus and rail lines, whereas in smaller, less transit intensive cities, it may provide greater public transit connectivity

Other explanations are certainly plausible to explain the impacts observed in this early study. While the overall sample exhibited a net movement away from rail and bus use, the majority of members perceive bikesharing as a public transit enhancement. Surveys in three of the four cities (excluding Washington D.C.) asked respondents whether they perceived bikesharing to be an enhancement of the public transportation system in the form of a Likert-scale question. The question and the responses are provided in Figure 3 below.

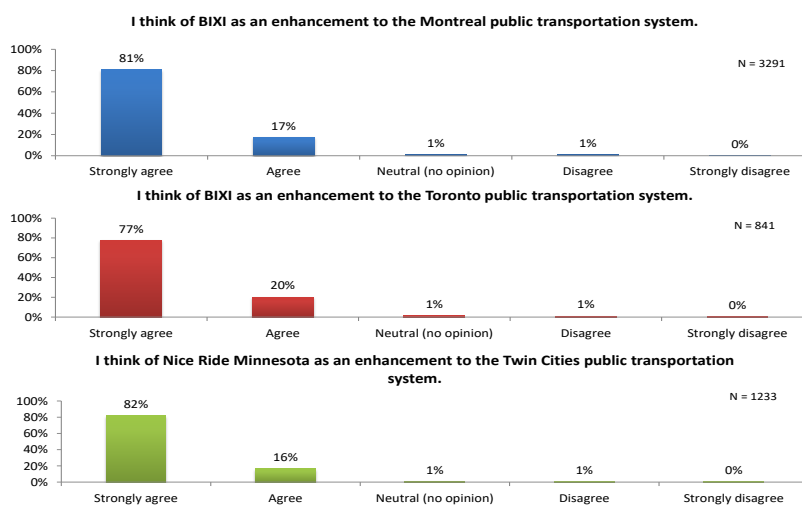


Figure 3. Bikesharing as Perceived Enhancement to Public Transportation

With over 95% agreement in the three cities, the distribution of responses indicates an overwhelming perception that bikesharing enhances public transit. In addition, another Likert question

asked of the same cities suggested that a broader population is using bikesharing in conjunction with transit to displace auto trips. The purpose of this second question was to evaluate whether bikesharing, as a link to public transit, was lowering automobile travel as a result of first- and/or last-mile bike connectivity. The distribution of responses is shown in Figure 4.

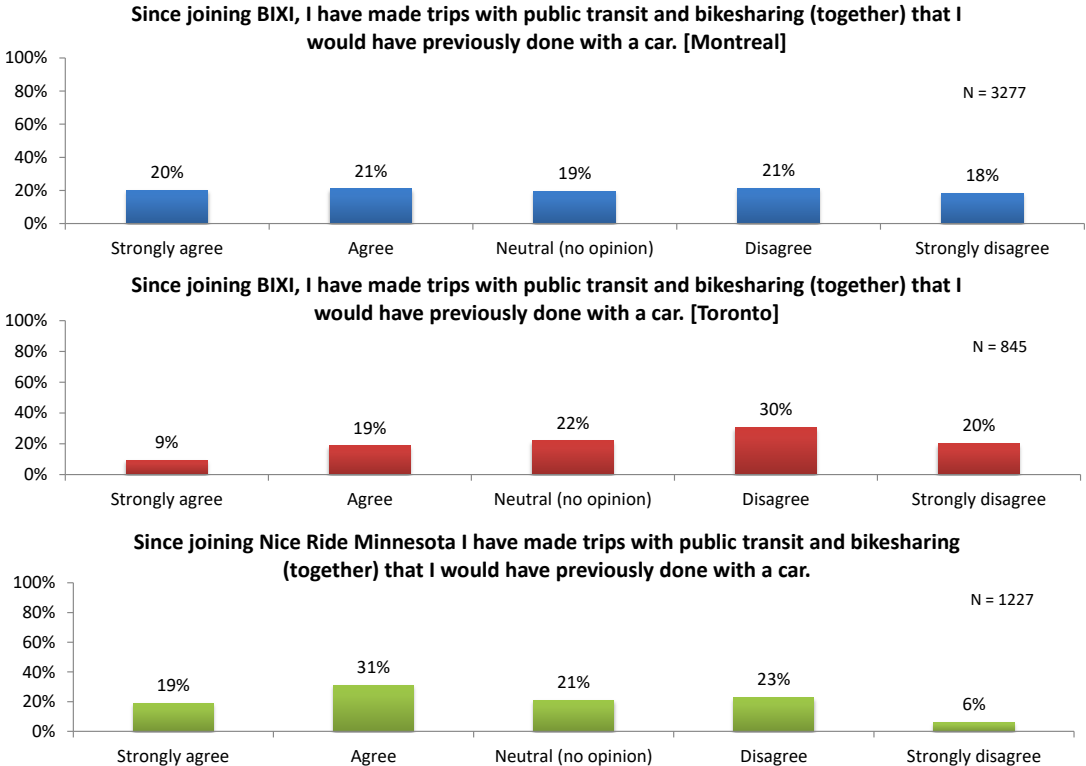


Figure 4: Impact of Bikesharing and Transit Use on Car Travel

As previously noted, in Toronto and Montreal, 44% and 50% of respondents, respectively, indicated using rail transit less overall. In spite of this shift, the response to the questions in Figure 4 indicates that some share of those respondents are using bikesharing with transit to reduce automobile use. In Montreal, 41% reported using public transit with bikesharing to complete a trip that would have previously been made by car. Recall this is a city where only 6% reported using bus transit more overall as a result of bikesharing, and only 11% used rail transit more overall. Similarly, in Toronto, 28% reported using public transit and bikesharing together to complete trips made by car. Whereas only 2% of respondents indicated using bus transit more because of bikesharing, and 9% reported using rail more often because of it. Thus, the data in Figure 4 suggest that even in cities where bikesharing may be lowering overall public transit use, it is providing connections to transit in those same cities and mitigating auto use.

The broader impact of bikesharing on automobile use was asked in a similar causal format. The response to these questions across all four operators confirms the insights drawn from Figure 5. Bikesharing, while exhibiting a mixed and nuanced impact on public transit ridership, is notably reducing automobile use. Figure 6 illustrates the distribution of response to the causal shift question for autos.

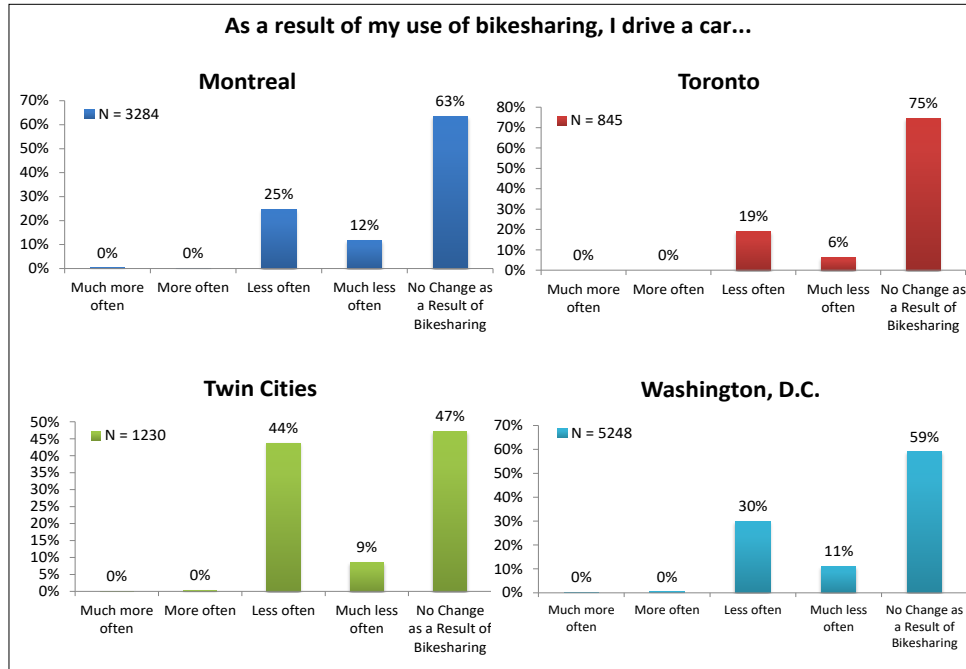


Figure 5: Shift in Automobile Use as a Result of Bikesharing

The results in Figure 5 show that bikesharing is reducing driving most dramatically in the Twin Cities, with 53% of respondents indicating a reduction in driving. In all other cities, the magnitude of shift is less but still ranges between 25% (Toronto) to 41% (Washington D.C.) Interestingly, the impact of bikesharing was even more pronounced on automobile trips taken by taxi. Figure 5 also shows the distinction across cities through the “no change” response. In this case, the Twin Cities exhibit the lowest share of respondents exhibiting “no change” in driving versus more elevated “no change” shares in the larger cities. Figure 6 illustrates the response to the modal shift from taxi use as a result of bikesharing.

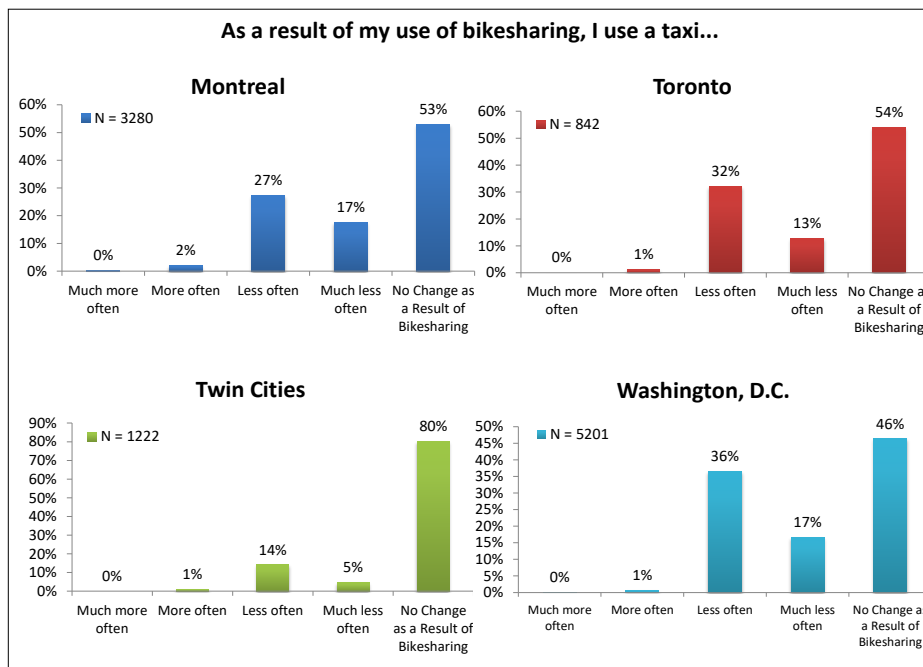


Figure 6: Shift in Taxi Usage as a Result of Bikesharing

Similar to the shift away from personal driving, a large percentage of respondents shifted away from taxi use. Figure 6 shows that the largest shifts occurred in the bigger cities in magnitudes that generally exceeded the shift away from personal driving. Figures 4 through 6 illustrate that bikesharing is reducing auto trips in all four cities. Next, the authors examine the modal shift of bikesharing on non-motorized travel. Overall, 72% of respondents bicycle more often as a result of bikesharing, as shown in Figure 7.

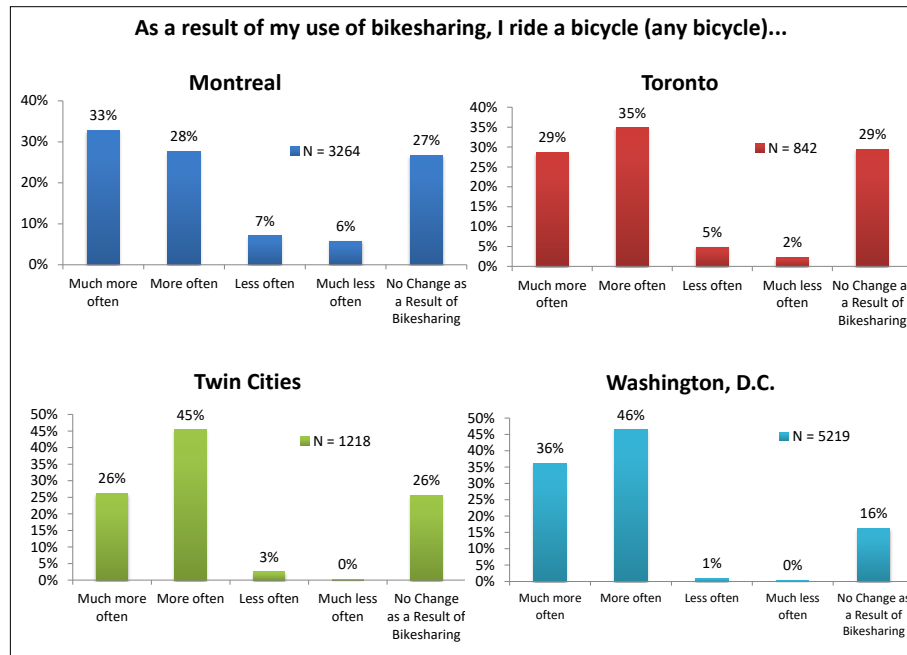


Figure 7: Shift in Bicycling as a Result of Bikesharing

In contrast, the reported shifts in walking are more nuanced and diverse. Figure 8 shows the distribution of shifts in walking across the four cities, revealing that in Montreal, Toronto, and Washington D.C. bikesharing resulted in an overall reduction in walking, whereas in the Twin Cities, overall walking increased.

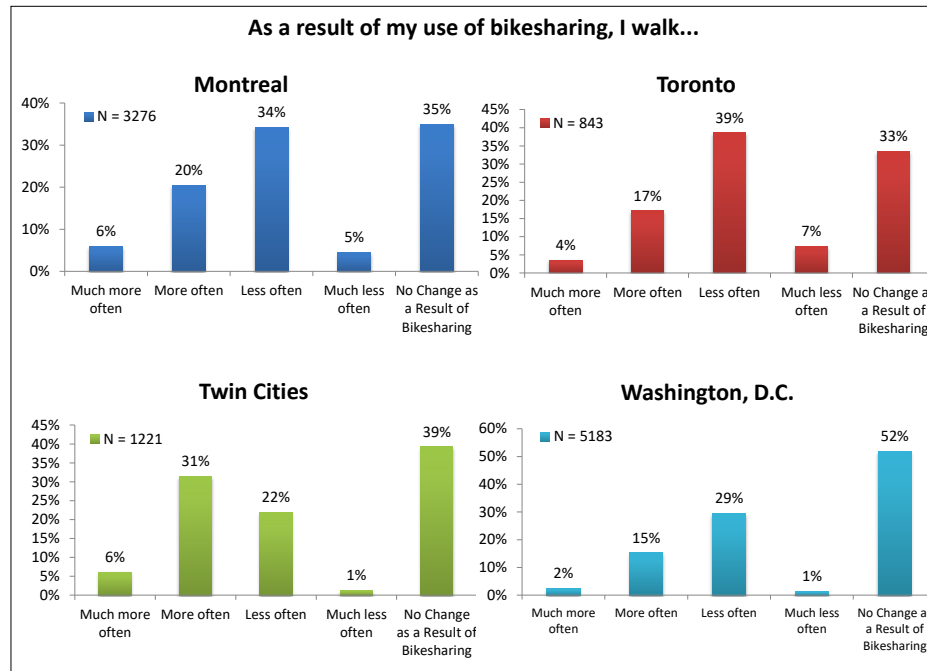


Figure 8: Shift in Walking as a Result of Bikesharing

The shifts in Figure 8 show that bikesharing is both encouraging and discouraging walking in all four cities. In the Twin Cities, overall walking increased among 37% of respondents versus the 23% that decreased walking. In the three larger cities, between 17% to 26% reported increasing their walking as a result of bikesharing in contrast to the 30% to 46% that noted a walking decline. Far more respondents reported increasing their walking than increasing their public transit use, this suggests that walking and bikesharing use are part of public transit substitution occurring in these cities. At the same time, the data also suggest that people are using bikesharing instead of walking; this may reflect the substitution of a walking trip due to the speed advantages of bikesharing.

A final causal question was asked of respondents in the two Canadian cities related to the economic impacts of bikesharing. This question evaluated whether or not bikesharing has improved the local economy around bikesharing stations. A similarly directed question was asked in Washington D.C., but it was not included in the Twin Cities survey. Figure 9 shows the distribution of response to the three questions, including the exact question given in the Washington D.C. survey.

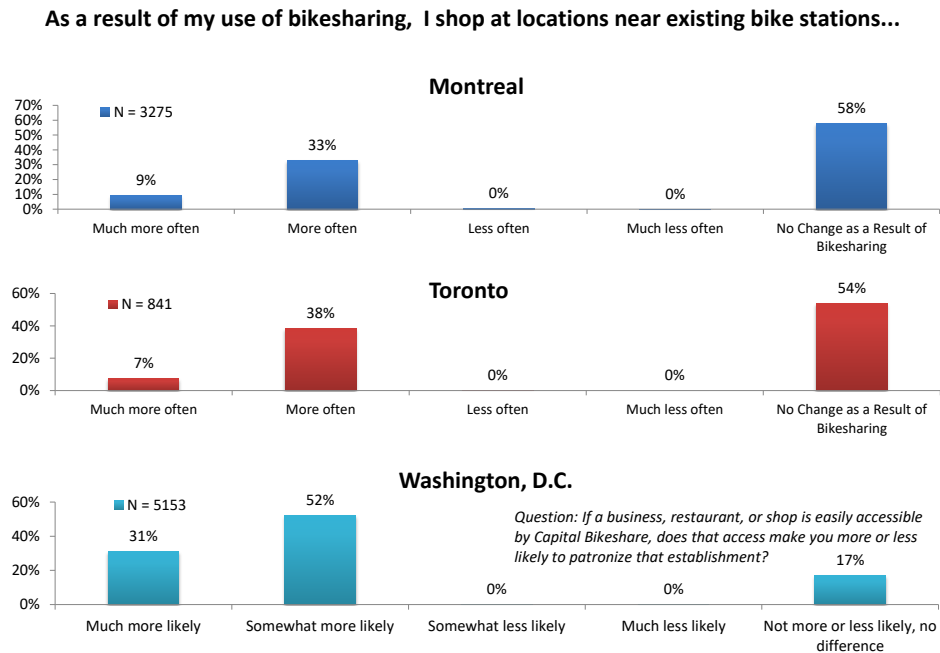


Figure 9: Economic Impacts of Bikesharing Systems

The distributions in Figure 9 suggest that the bikesharing stations have a positive economic impact. When asked in different ways, the general response is similar, although the causal questions showed a less “positive” response than the one asked in Washington D.C. Notably, no respondents indicated that the presence of a bikesharing station would reduce their patronage of nearby businesses. The response to these questions suggests that nearby establishments gain customer traffic from bikesharing members. This study did not address the question of overall revenue. A broader study on revenue, perhaps informed by a more general survey, could help to answer this question.

Finally, the survey asked respondents about their trip purpose. In the Capital Bikeshare survey, respondents were asked to report the purpose of their “most recent” trip, while in the other three surveys, members were asked about their “most common” trip. In both question types, the results were remarkably similar across all four cities. The results showed that the most common trip purpose was to go to work or school among members. In Montreal, 56% reported this trip purpose as the most common, while in Toronto, the Twin Cities, and Washington D.C., the shares were 50%, 38%, and 38%, respectively. The second and third most common trip purposes across the four cities among members were social/entertainment trips and running errands. Combined, these two trip purposes generally comprised ~30% in all four cities, though at different splits. The role that these trip purposes play in the modal shift of bikesharing members is a subject that merits further investigation.

6. Conclusion

The results presented in this paper focus on exploring the overall modal shift exhibited by annual and 30-day members of bikesharing systems in four early cities in North America, which include Montreal, Toronto, Washington D.C., and the Twin Cities (Minneapolis and Saint Paul). The objective of this study was to develop an understanding of how bikesharing shifts travel behavior in a comparative framework.

The survey results show that bikesharing has emerged in these cities as its own transportation mode, generally substituting for all competing modes including driving, walking, and public transit. The results also reveal a fair degree of variance in impact across the cities. Notably, bikesharing was found to advance the broader objectives of transportation sustainability by reducing automobile travel in the form of personal

driving and taxi use in all four cities. These reductions are in part driven by trips in which bikesharing provides a first- and last-mile link to public transit, substituting travel that was previously done via automobile. However, there is a notable distinction in the modal shift experienced across the cities. While bikesharing reduces bus and rail transit use in the three larger cities of Montreal, Toronto, and Washington D.C, it appears to increase rail usage in the Twin Cities. The reasons for this reduction are not entirely clear but in the larger cities, substitution may be occurring because of congested transit networks and improved speed in making trips that are more circuitous with bus and rail lines. In the Twin Cities, which exhibited only a slight decrease in bus use coupled with an increase in rail transit usage, the city's density and size may have played a role. With its more limited and linear rail transit network, bikesharing may have served to provide improved access and egress to transit *more* than it provided a faster alternative to public transit. Further research is needed into bikesharing in the Twin Cities and for cities of similar size to explore whether or not bikesharing may have a distinct interface with public transit in cities that have less dense networks. In such cities, bikesharing may enhance public transit connections in an environment where they were missing. Further study of bikesharing can build on the insights generated from this survey. First, the reasons for modal shift were not evaluated in this study nor were the trip purposes or time of day in which the modal shift occurred. Understanding the underlying modal dynamics, particularly the shift away from public transit, should be further investigated. While the larger cities in the study did show a net shift away from bus and rail, non-trivial shares of members in these cities did shift towards public transit. A key question remains regarding the typology of bikesharing members that shift towards and away from public transit in all cities. Finally, the question design in these surveys evaluated the general direction and causality of the modal shift. A more measurable quantification of such a change requires detailed travel diaries before and after joining bikesharing. The answers to these and other questions would be helpful in future research.

The results of this study strongly suggest that bikesharing has begun to alter the transportation landscape in many North American cities. The growth of bikesharing across the continent has expanded the number of programs operating in the U.S., Canada, and Mexico. As the diversity of cities in which bikesharing operates continues to increase (large, small, urban, and suburban), so do opportunities for understanding its social, modal, and environmental impacts.

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