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Car-Sharing and Public Parking in Boston

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CAR-SHARING AND PUBLIC PARKING IN BOSTON

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This PAE reflects the views of the author and should not be viewed as representing the views of the PAE's external client, nor those of Harvard University or any of its faculty.

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Executive Summary

Car-sharing organizations (CSOs) in Boston are presently limited to placing their shared cars in private parking spaces. However, they have asked the City of Boston to allocate public parking spaces to their shared cars. The City of Boston Mayor's Office commissioned this Policy Analysis Exercise to answer the following question: **How should the City of Boston respond to the request from CSOs?**

This decision is made all the more difficult due to the scarcity of public parking in many parts of Boston. Since residents lose a public parking space when it is allocated to a shared car, there need to be compensating benefits to offset this added inconvenience. Consequently, in allocating public parking spaces to shared cars, **the City of Boston wants shared cars to be substitutes for private vehicles and complements to public transportation.** This broad goal breaks down into the following specific goals (in order of priority):

1. Increase residential public parking availability
2. Improve mobility access for the carless
3. Reduce citywide Vehicle Miles Travelled (VMT) and Greenhouse Gas (GHG) emissions
4. Maximize city revenues (or minimize losses)

Empirical research from other cities provides compelling evidence that these goals are achievable. There is relatively strong evidence that:

- » One shared car can take four private vehicles off the street through vehicle shedding, thus reducing parking demand and increasing parking availability.
- » Shared cars improve the mobility access of the carless.

There is also modest evidence that car-sharing reduces VMT and GHG emissions.

Therefore, this report recommends that **the City of Boston view car-sharing as a social benefit and allocate public parking spaces to shared cars.** In doing so, the City of Boston should:

- » Establish a formal process for allocating public parking spaces to CSOs.
- » Jointly conduct meetings with CSOs in neighborhoods where public parking spaces will be allocated to shared cars.
- » Require that CSOs share relevant data with the City of Boston in order to support its future allocation decisions.

Given the large body of research around its impacts, the City of Boston should prioritize allocating parking spaces to shared cars in the A-to-A model. However, it should also proceed with the 150-

car pilot¹ of the A-to-B model to better ascertain the impacts of this promising innovation in car-sharing.

To maximize the benefits of car-sharing, the City of Boston should allocate spaces to shared cars within 400 meters of areas (encapsulated in 250mx250m cells) that have:

- » More than three privately owned vehicles driven less than 16 miles a day (see Figure 8)
- » The poorest access to public transport as quantified by an immobility score that is greater than or equal to 0.457 (see Figure 9)

To strike a balance between covering the city's costs and accruing the benefits with higher priorities, permits for the parking spaces should be priced no higher than the price set in the Request for Proposals (RFP): \$3,500 per permit per year. As the scale of the benefits is proportional to the number of shared cars, the City of Boston should even consider reducing the price in the future. The permits should be valid for two years.

When allocating additional public parking spaces to shared cars, the City of Boston should adopt a three step policy: allocate, evaluate, and allocate again. Each annual allocation should be incremental and involve no more than 50 cars per CSO. The City of Boston then needs to evaluate the impacts of car-sharing through relevant metrics: the number of residential parking permits issued, CSO membership increases, parking infringements, and peak-hour usage. More spaces should only be allocated if the impacts are broadly positive.

Finally, to examine the impacts of car-sharing in Boston, the City of Boston and several CSO partners should conduct their own randomized study. This study will take place over four years and examines the impact of having a shared car in close proximity on household vehicle holdings, VMT and GHG emissions, and CSO membership status.

¹ Boston Transportation Department, "DriveBoston: A Request for Proposals for a Boston Vehicle Sharing Program," February 2, 2015, <https://t.co/w7YRh47ihp>.

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Chapter 1: Public Parking Spaces for CSOs?

Currently, car-sharing organizations (CSOs) operating in Boston are limited to using only private parking spaces for locating their cars. Interested in expanding their networks, these CSOs have asked that the City of Boston allow them to use public parking spaces as well. Should the City of Boston allocate some of its oversubscribed public parking spaces for exclusive use by car-sharing organizations (CSOs)? If so, what allocation policy should be adopted such that it provides the most value to the city and its residents? For the City of Boston, this issue is especially contentious because there is insufficient public parking for residents.

Car-sharing

Car-sharing provides on-demand access to a fleet of cars for short-term rental, often in increments of an hour or less. To access a car, members must be affiliated with the CSO that manages it. These organizations can be either for- or non-profit. The shared cars are often dispersed in decentralized networks and are self-accessing, usually via a wireless

keycard (i.e. no handover of keys is required).² Reservations are made in advance, usually via the web or a smartphone application. Depending on the model of the CSO, users are charged based on the duration of their usage, duration of their reservation, distance travelled, or some mix of these three. Usage charges are made to the member's credit card or deducted from their bank account. Membership in a CSO includes full liability and collision coverage via the CSO's insurance policy; members do not need to purchase their own insurance.³

There are two models of locating cars that CSOs use, which also influence the nature of the trips by members:

- » **A-to-A or Two-way:** This is a more traditional model where shared cars are located at designated parking spaces, referred to as stalls

² Adam Millard-Ball, *TCRP Report 108: Car-Sharing: Where and How It Succeeds*, vol. 108 (Transportation Research Board, 2005).

³ Adam P. Cohen, Susan Shaheen, and Ryan McKenzie, "Carsharing: A Guide for Local Planners," *Institute of Transportation Studies*, December 1, 2008, <http://escholarship.org/uc/item/4kf3x31h>.

or points-of-departure (PODs). Trips with the shared car must begin and end at its designated POD. A car must be returned to its POD within the reservation period or late-penalties are applied by the CSO.

- » **A-to-B or Point-to-point or One-Way:** This is a newer model where shared cars do not have designated parking spaces. Trips can begin and end in any parking space, though the CSO often limits these spaces to certain geographical zones based on their area of operation and their arrangements with the municipality (e.g. within city limits but excluding the central business district). Members do not have to pay parking charges for the spaces where they terminate their trips. Charges are based on the duration the shared car is in use and members often locate a car with the aid of a smartphone application.

Besides how the cars located, there are different models of fleet ownership:

- » **CSO-owned:** In this more traditional model, the shared cars are owned by the CSO. Besides insurance, fuel costs are covered by the CSO and included in the charge.
- » **Peer-to-peer:** In this emerging model, the cars are privately owned and the CSO serves as an intermediary between the user and the owner of the car. This model tends to be A-to-A as the shared car has to be taken from and returned to the owner's private parking space (e.g. their driveway). While insurance is still provided, expenses for fuel are borne by the user of the car.

The term "car" with reference in "car-sharing" is misleading as the vehicles include cars, trucks, and vans.

While there are many similarities, car-sharing differs from the traditional car-rental model in the following ways:

- » **Duration of rental:** Shared cars are often rented on an hourly basis as opposed to a daily basis.
- » **Decentralization:** Shared cars are dispersed in small numbers throughout a geographic location, often a city, whereas rental cars tend to

be concentrated in large numbers in a rental car lot.

- » **Automation:** Transactions involving shared cars require very little human intervention from the CSO because reservations, car access, tracking, and billing are automated. In contrast, a rental car involves manual key handover and post-usage inspection by the rental company.

A typical usage-scenario of a shared car is as follows:

A member of a CSO makes a one-hour reservation for a shared car with a POD in a parking lot near her apartment at 3PM. At 3:05PM, she walks up to the reserved car and accesses it using a wireless keycard that is given to members of the CSO. She drives to a grocery store three miles from her apartment, purchases her groceries for the week, loads them into the car, and she makes the return trip. At 3:55PM, she parks the car in the POD she took it from and locks it using the wireless keycard. Onboard electronics installed by the CSO in the shared car verify that the distance travelled is within the free allotment given to member per reservation and that it has been returned to its designated POD. The car is now available for another reservation.

In 2014, there were 45 CSOs operating in the United States with over 1.6 million CSO members and 24,000 vehicles.⁴ Appendix B: Car-sharing Organizations (CSOs) provides a list of car-sharing organizations and the models that they use.

Status of Car-sharing in Boston

Car-sharing has been established in Boston for over a decade. Zipcar, one of the largest CSOs, was founded in the year 2000 in Cambridge, a city adjacent to Boston, and is currently headquartered in Boston. In the fourth quarter of 2013, Zipcar had an estimated 38,065 members and 178 vehicles within the city's limits.⁵ In addition to Zipcar, Enterprise and Relay Rides also operate in Boston.

None of the shared cars are placed in the public parking spaces owned by the City of Boston. CSOs use private parking spaces instead. These include private

4 Susan Shaheen and Adam Cohen, *Carsharing Outlook Fall 2014 - Volume 3, Issue 2*, November 11, 2014, <http://tsrc.berkeley.edu/sites/tsrc.berkeley.edu/files/Fall%202014%20Carsharing%20Outlook%20Final.pdf>.

5 37 Billion Mile Challenge, "37 Billion Mile Challenge: Datathon Treat," March 10, 2014, <http://www.37billionmilechallenge.org/#the-data>.

parking garages as well as private lots belonging to residential and commercial buildings. However, the high price and limited supply of private parking space limits the number of shared cars that CSOs can locate in Boston and thus, the size of their networks.

The City of Boston recently released a Request for Proposals (RFP) inviting CSOs to apply for public parking spaces in a pilot program.⁶ The RFP was developed in parallel with this report and incorporates some of its preliminary findings.

For the pilot, the city is offering a total of 80 Dedicated Permits for the creation of A-to-A model shared car PODs. Dedicated Permits allocate a public parking space to a specific CSO's shared car. A single CSO can hold no more than 40 Dedicated Permits. In order to pilot the A-to-B model, 150 Free-floating Parking Permits are being offered. A shared car with a Free-floating Parking Permit can be parked in any legal public parking space. Additionally, the shared car and motorist are not subject to meter payment or time limit and residential parking permit restrictions. Only a single CSO will be granted these Free-floating Parking Permits.⁷

City of Boston and the Mayor's Office

Over 617,000 residents distributed across 23 neighborhoods call Boston their home (see Figure 10 in Appendix A: Boston Neighborhoods). The City of Boston municipal government serves these residents as well as 56,000 public school students, hundreds of thousands of people working in the city every day, and tens of millions of visitors and tourists annually.

The municipal government is comprised of 70 individual agencies, commissions and departments with more than 16,000 employees. It is organized in a traditional cabinet structure and its major functional areas include managing public schools; ensuring public safety; stimulating economic, housing and neighborhood development; coordinating human services programs for constituents of all ages; providing necessary infrastructure and basic city services to residents and supporting the operations of all line departments.

The Mayor's Office oversees the key functions of policy development and management planning. With a small staff, it serves two roles: designing policy and implementation strategies for the Mayor and coordinating the work of the various city departments.

This work is complemented by Boston's Mayor's Office of New Urban Mechanics (MONUM). Formed in 2010, Boston's MONUM serves as the Mayor's innovation group. It collaborates with constituents, academics, entrepreneurs, non-profits and city staff to design, conduct, and evaluate pilot projects that improve the quality of city services. These projects are in four major issue areas: Education, Engagement, the Streetscape, and Economic Development.

Public Parking Space Types

There are three primary types of public parking spaces in Boston that are under consideration for allocation to CSOs:

- » **On-Street:** These are curbside parking spaces that are usually used by residential permit holders.
- » **Metered:** Metered on-street parking spaces which are usually found in commercial districts.
- » **Municipal Lots:** Parking lots owned by the City of Boston that provide free parking spaces for anyone.

⁶ Boston Transportation Department, "DriveBoston: A Request for Proposals for a Boston Vehicle Sharing Program."

⁷ Ibid.



Chapter 2: Goals

ALLLOCATING public parking spaces to shared cars leaves fewer spaces for Boston's residents to use for their own vehicles. As public parking is already scarce in many parts of the city, this chapter identifies the beneficial outcomes that would compensate for this added inconvenience. Therefore, in allocating public parking spaces for use by car-sharing organizations (CSOs), the City of Boston seeks the following broad outcome: **that shared cars become substitutes for private vehicles and complements to public transportation.**

This overarching goal is derived from several smaller goals. First, the City of Boston seeks to make parking easier for its residents by **increasing residential public parking availability**. Second, Boston seeks to **improve the mobility choice and access of residents** who do not own their own vehicle. Third, in order to meet the commitments set out in its Climate Action Plan, the City of Boston seeks to **reduce vehicle-miles travelled (VMT) and greenhouse gas (GHG) emissions**. Finally, the City of Boston wishes to **gain a new source of revenue or, at worst, minimize the losses from allocating these spaces to shared cars**. The City of

Boston's decision on whether and how to allocate public parking spaces to CSOs will be driven by the degree to which these goals are met.⁸

Besides the goals above, the recently released Request for Proposals (RFP) contained two additional goals: increasing transportation options at Mobility Hubs and to support main street districts.⁹ Mobility Hubs are part of the Boston Complete Streets Guidelines and seek to bring together several modes of transport at a single curbside location.¹⁰ For example, a Massachusetts Bay Transportation Authority (MBTA) station would have a shared car, bus stop, and bike-sharing rack in close proximity. With the main street districts, the City of Boston seeks to use car-sharing to increase the amount of activity in several main street commercial areas (i.e. Dudley, Brighton, Grover Hall, and Jamaica Plain/South

⁸ These goals were generated through conversations with the client over the course of completing this report.

⁹ Boston Transportation Department, "DriveBoston: A Request for Proposals for a Boston Vehicle Sharing Program."

¹⁰ Boston Transportation Department, "Boston Complete Streets: 5.3: Mobility Hubs," in *Boston Complete Streets Guidelines*, accessed February 11, 2015, http://issuu.com/bostontransportationdepartment/docs/5_3.

Main Streets). These additional goals are not examined separately in this report as they largely overlap with the goals of reducing parking demand and improving mobility access.

Increasing Residential Public Parking Availability

In many parts of Boston, the demand for residential on-street public parking spaces outstrips the supply. The problem is made more intractable by the absence of an on-street space inventory: the City of Boston does not know how many on-street public parking spaces (including those used by residents) it has or where they are. Thus, Boston has no way of knowing the on-street parking supply shortfall.

Due to the shortage of spaces, residents have reported spending significant amounts of time searching for a parking space.¹¹ Beyond the time cost borne by residents, this also introduces costs on others (i.e. externalities) through increased traffic congestion and pollution. Cruising for parking has been reported to account for up to 30% of total traffic in city centers.¹²

The oversubscription of public parking is more acute in areas with high population densities (Figure 12 in Appendix C: Households and Vehicle Ownership). The dark red cells in Figure 1 represent 250 by 250 meter geographical areas (i.e. 250mx250m cells) where parking demand is expected to be the highest. Passenger vehicle counts in these cells are in the upper quartile of all cells in Boston.

An examination of Boston's public parking policy reveals the source of the problem: the city neither charges for nor limits the number of permits that it issues to residents despite there being limited on-street spaces. A resident can get a free parking permit, valid for two years, for every vehicle they own. These permits allow holders to legally park in on-street spaces within their designated residential zones. However, there is no guarantee that the holder will find a space.¹³

As of 2015, Boston has 93,987 active residential

parking permits.¹⁴ The average household in Boston owns 0.73 cars.¹⁵ Figure 11 (in Appendix C: Households and Vehicle Ownership) shows the average number of vehicles per household for each of the city's cells. Though most households only hold one permit, 300 were found to have five or more. One household was found to hold eleven permits.¹⁶

Until recently, city officials and many residents have defended the system. However, the newly-appointed Transportation Commissioner, Gina Fiandaca, has said she will re-examine the existing process.¹⁷

Market mechanisms could provide a first-order solution to the oversubscription of public parking spaces. In one possible implementation, residential permits could be sold through an auction. The price buyers would be willing to pay is a function of the utility they derive from having the right to use a public parking space, which would include the probability of being able to find a space. Eventually, the quantity of public parking spaces demanded would approximate the supply. However, this policy is likely to be unpopular with Boston residents. Caps on the number of free permits per household are an alternative solution though this comes with its own pitfalls. Chief among these is the inability to accurately determine a cap without knowing the total number of public parking spaces.

In light of all this, allocating public parking spaces to shared cars is likely to be well received if it reduces the demand for parking, thus increasing public parking availability. The next chapter of this report assesses the potential for car-sharing to reduce parking demand through reductions in vehicle ownership.

Improve Mobility Access

Approximately 34% of Boston's 251,757 households do not own a car.¹⁸ Members of these households rely on other modes of transportation like walking,

14 Ibid.

15 Tim Reardon et al., *Vehicle Census of Massachusetts*, Vehicle Census (Metropolitan Area Planning Council, March 10, 2014).

16 Wallack, "Boston — Where Parking Is Scarce, but Parking Permits Are Free and Unlimited."

17 Todd Wallack, "Boston Vows to Examine Parking Rules for Residents," *The Boston Globe*, January 26, 2015, <https://www.bostonglobe.com/metro/2015/01/26/boston-vows-examine-parking-rules-for-residents/01d9H0pnJkRXrKxJHzn9rJ/story.html>.

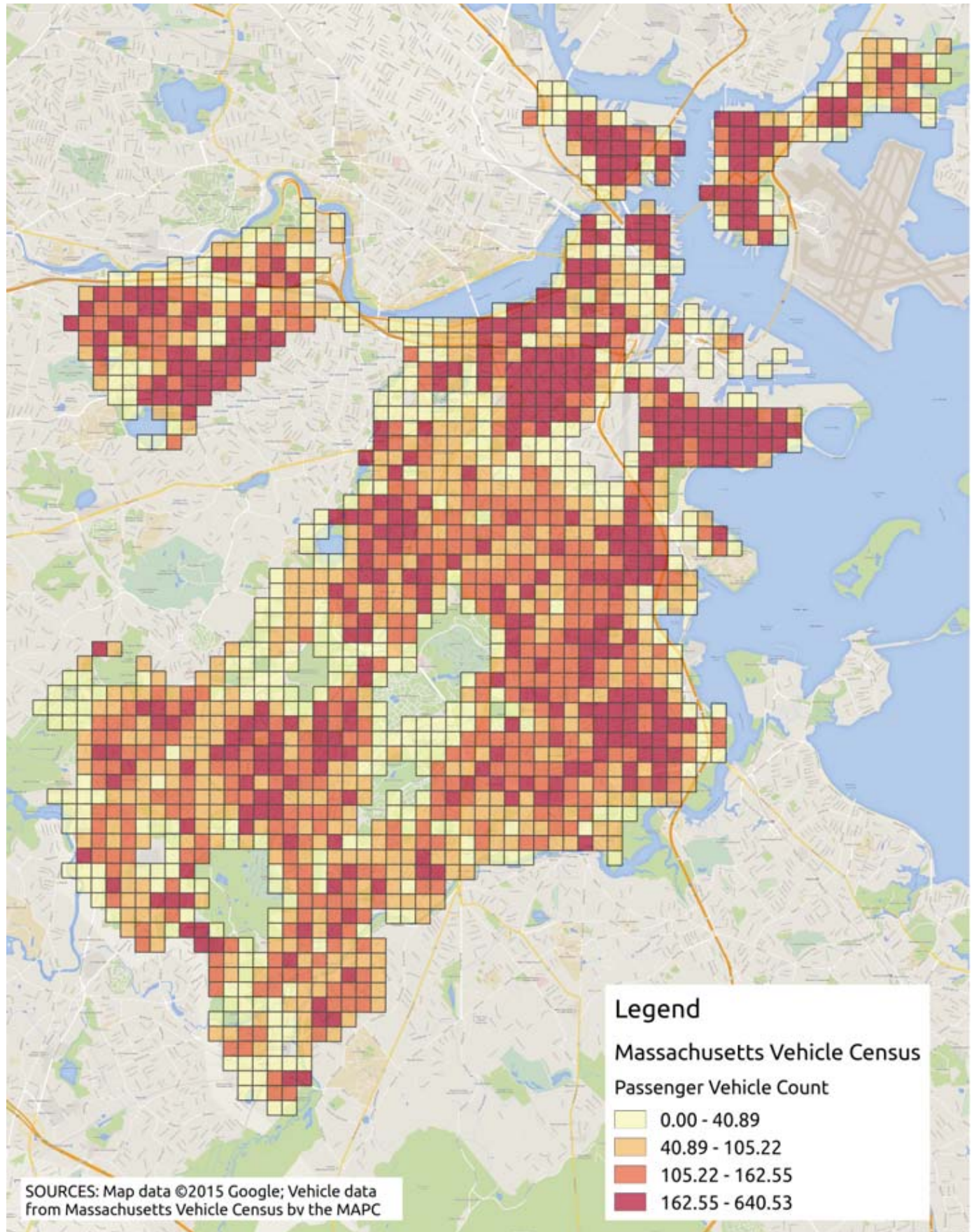
18 U.S. Census Bureau, *DP04 - SELECTED HOUSING CHARACTERISTICS*, 2013 American Community Survey 1-Year Estimates, n.d., http://factfinder.census.gov/bkmk/table/1.0/en/ACS/13_1YR/DP04/1600000US2507000.

11 Todd Wallack, "Boston — Where Parking Is Scarce, but Parking Permits Are Free and Unlimited," *The Boston Globe*, January 20, 2015.

12 Simon P. Anderson and André de Palma, "The Economics of Pricing Parking," *Journal of Urban Economics* 55, no. 1 (January 2004): 1–20.

13 Wallack, "Boston — Where Parking Is Scarce, but Parking Permits Are Free and Unlimited."

FIGURE 1: PASSENGER VEHICLE COUNTS



biking, public transit, taxis, and transportation network companies (e.g. Uber and Lyft) for their mobility. Car-sharing can complement these modes and improve the overall utility of carless households by expanding their consumption set. For example, a shared car can be used to make trips to large wholesalers (e.g. Costco) or stores outside Boston to buy items. Trips such as these would be impossible or prohibitively expensive for a carless household without access to a shared car.

Concerns with mobility are particularly pertinent in parts of Boston where access to public transportation is poor. Residents in these areas have fewer mobility choices relative to other parts of the city. Public transportation in Boston is comprised of the buses (e.g. Silver Line), streetcars (e.g. Green Line), and subways (e.g. Red Line) run by the MBTA or the “T”.

Figure 2 shows mobility scores¹⁹ for areas around Boston. The scores were calculated using data from the MBTA and the grid framework from MassGIS.²⁰ They serve to approximate access to public transport for a given 250mx250m cell as a function of its (straight-line) distance from MBTA stations and bus stops. The service frequency of those stations and stops is also taken into account by the scoring function. Higher mobility scores (represented by deeper shades of blue in Figure 2) indicate an area has greater access to public transportation in terms of proximity and service frequency. West Roxbury, Dorchester, Jamaica Plain, Roslindale, Hyde Park, Roxbury, Brighton, Allston, South Boston, Charlestown and East Boston all contain areas that have mobility access that is below the city median (i.e. less than 4.05 or the bottom five deciles).

As such, the City of Boston should seek improve the mobility access of residents in these areas when allocating public parking spaces to shared cars.

Reduce Vehicle Miles Travelled and Greenhouse Gas Emissions

In 2011, Boston set the goal of reducing citywide GHG emissions to 25% below 2005 levels by 2020 and 80% below 2005 levels by 2050. Thus far, citywide emissions are 17% below 2005 levels, while emissions from

municipal operations have dropped by 25%.²¹

In 2013, 26.9% of citywide emissions were from transportation. The City of Boston has targeted a 17% reduction (0.3 million metric tons) in GHG emissions by 2020. To meet this goal, Boston has targeted a VMT reduction of 5.5% below 2005 levels as well as improved fuel economy for vehicles in the city. Between 2005 and 2013, total VMTs in Boston remained relatively unchanged although VMTs per capita reduced by 0.5%.²²

Allocating public parking spaces to car-sharing is worthwhile for Boston if it produces a net reduction in citywide VMTs and GHG emissions.

Increase Revenue (or Minimize Losses) for the City of Boston

The public parking permits that the City of Boston creates for shared cars can be priced high enough that revenues exceed the costs of maintaining a public parking space, netting the city a profit. Alternatively, the city could choose to subsidize car-sharing by pricing the permits below cost. With this approach, the goal would be to minimize losses.

It is difficult for the City of Boston to accurately price its on-street public parking spaces due to the absence of an inventory and a dedicated budget allocation. The cost of an on-street public parking space is calculated by estimating its share of infrastructure depreciation and maintenance budgets as well as enforcement costs that the spaces account for and then summing those all up. For example, the City of Boston allocated \$21.3 million in its 2015 budget for roadway reconstruction. To calculate one input for the cost of parking, the Mayor’s Office estimated that 5% (or \$1.1 million) of that the roadway reconstruction budget was used for public parking spaces.

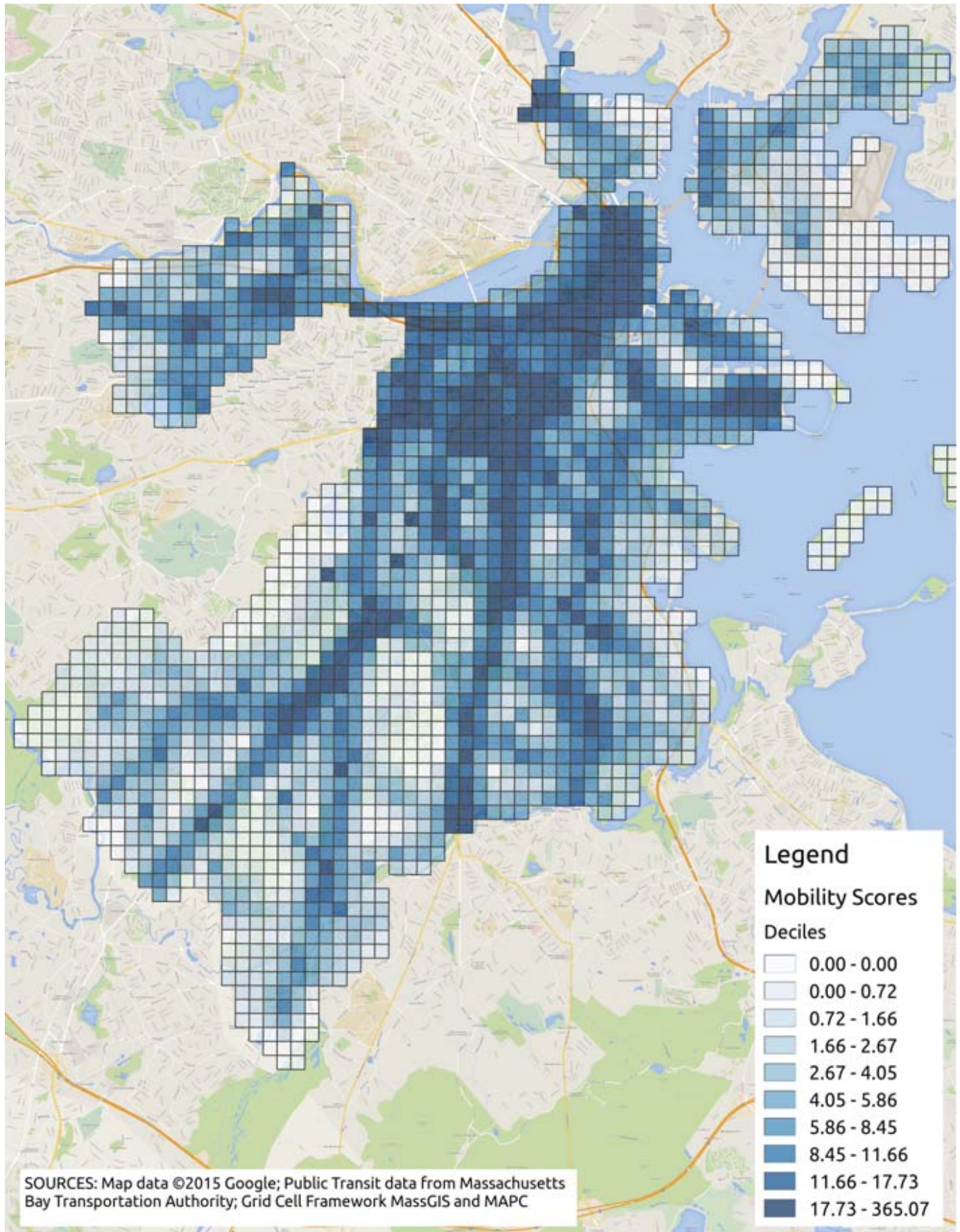
Using this method, an on-street parking space costs the city approximately \$3,500 per year. Metered parking spaces allocated for shared cars will also have the additional cost of foregone revenue that amounts to approximately \$3,900 per year (assuming 100% utilization at 10 hours a day, six days a week, and 52 weeks a year). The City of Boston does know how many parking spaces it has in municipal lots. It also has

19 Matthew Danish, “Exploring Transit and Driving Behavior in MA, with Google Fusion Tables,” April 19, 2014, <https://sites.google.com/site/37billionmiles/>.

20 See Appendix G: Determining Mobility Scores for calculation method

21 Marty Walsh, “Greenovate Boston 2014 Climate Action Plan Update,” January 15, 2015, <http://plan.greenovateboston.org/>.

22 Ibid.

FIGURE 2: MOBILITY SCORES

PARKING SPACE TYPE	ESTIMATED COST TO THE CITY OF BOSTON	PRIVATE PARKING SPACE PRICES	REQUEST FOR PROPOSAL
On-street	\$3,500	\$2,400 - \$4,800	\$3,500 (downtown) or \$2,700 (elsewhere)
Metered	\$3,500 (\$7,400, with foregone revenue)		
Municipal lots	\$2,600		

TABLE 1: CITY OF BOSTON PARKING COST AND PRICE ESTIMATES (PER YEAR)

records of its maintenance and upgrade expenditures for the lots. A parking space in a municipal lot is estimated to cost the city approximately \$2,600 per year. These figures represent the lowest prices that the City of Boston could charge CSOs for parking spaces and not lose money.²³

The highest price that the City of Boston could charge for any of its public parking spaces would be the rental rates of a private parking space in the same area. If the price of a permit from the city exceeds the price of a private parking space in a given area, CSOs are likely to use the private space instead. A quick check on Craigslist²⁴ reveals that off-street private parking spaces in the Back Bay area can go for up to \$400 per month (\$4,800 per year). Private off-street spaces in South Boston go for between \$200 and \$225 per month (\$2,400 to \$2,700 per year).

Table 1 summarizes the previous discussion on prices and also includes the prices that the City of Boston set for shared car public parking permits in its RFP.²⁵

There are several explanations for why the city's cost estimates exceed the lower bound rental prices for a private parking space. The most straightforward is that the city's estimates are inflated due the lack of an inventory or dedicated budget for on-street parking spaces. A more nuanced explanation may involve a spatial dimension where the price of private parking space is correlated with real estate prices in an area, a factor that the city's maintenance costs are not sensitive to.

Ideally, there would be more accurate information on the cost of public parking spaces to the City of Boston. This would include analysis on the opportunity cost of using that space for wider roads or, in the long-term, real-estate development. However, that analysis is beyond the scope of this report. As such, this report assumes that the city's breakeven price for a permit is the relevant cost in Table 1 and the highest price it can charge is the going rate for a private parking space in a given area.

Goal Priorities

The City of Boston did not explicitly prioritize the goals discussed in this chapter. However, prioritization is necessary for resolving conflicts between goals and informing the recommendations. To address this issue, this report prioritizes the goals as follows:

1. Increase residential public parking availability
2. Improve mobility access for the carless
3. Reduce Vehicle Miles Travelled (VMT) and Greenhouse Gas (GHG) emissions
4. Maximize revenue (or minimize losses)

This prioritization was derived using the following considerations:

- » Whether the goal was explicitly stated in the City of Boston's RFP
- » The confidence in the empirical evidence on the attainability of the goal (see next chapter)
- » The degree to which a given goal conflicts with other goals (see next chapter)

²³ Eleanor Joseph, *Cost of Parking* (Mayor's Office, City of Boston, February 20, 2015).

²⁴ Craigslist > Boston > Parking & Storage: <http://boston.craigslist.org/search/prk>

²⁵ Boston Transportation Department, "DriveBoston: A Request for Proposals for a Boston Vehicle Sharing Program."



Chapter 3: Impacts of Car-Sharing

THE PREVIOUS CHAPTER enumerated the City of Boston's goals for allocating public parking spaces to car-sharing organizations (CSOs): increasing residential public parking availability, increasing mobility access for the carless, reducing citywide vehicle miles travelled (VMT) and greenhouse gas (GHG) emissions, and increasing revenues or minimizing losses. Critically, allocating public parking spaces to shared cars leaves residents with fewer places to park. This tradeoff is only worthwhile if these goals can be achieved.

To determine whether the goals are attainable, this chapter examines the impacts of car-sharing. This effort is complicated by the largely indirect relationship between those goals and the policy for allocating public parking spaces to shared cars. Figure 3 illustrates the complex causal relationships involved.

The City of Boston has two main levers when implementing its allocation policy: **the number of public parking spaces it allocates to shared cars and the price it charges CSOs for those spaces.**²⁶ The causal chain between the City of Boston's allocation policy

and its goals can be found by **starting from the city's policy levers (in blue)** and **following the arrows to a given goal (in pink).**

Though the causal loop diagram in Figure 3 is a powerful tool, it is also fairly complex. In light of this, it is a useful exercise to work through the diagram with an example. Consider the impact on *Public Parking Availability* if the City of Boston exogenously increases the number of *Public Parking Spaces for Shared Cars* while holding the *Shared Car Parking Permit Price* constant:

1. With more public parking spaces allocated to shared cars, CSOs place more shared cars in Boston. The causal relationship is denoted by the **green** directed line between the two variables (*Public Parking Spaces for Shared Cars* and *Shared Cars*) terminating with an arrowhead and a plus sign (+). This indicates that the two variables are positively correlated: holding all else equal, a change in the number of *Public Parking Spaces for Shared Cars* will cause a change in the same direction with the number of *Shared Cars*.
2. As the number of *Shared Cars* increases, they become a viable substitute for residents' own

²⁶ As the magnitude of the impacts is sensitive to the proximity to a shared car, the location of allocated public parking spaces could be considered a third lever. For the sake of brevity and simplicity, location has been omitted from this discussion but is explored further in Chapter 4.

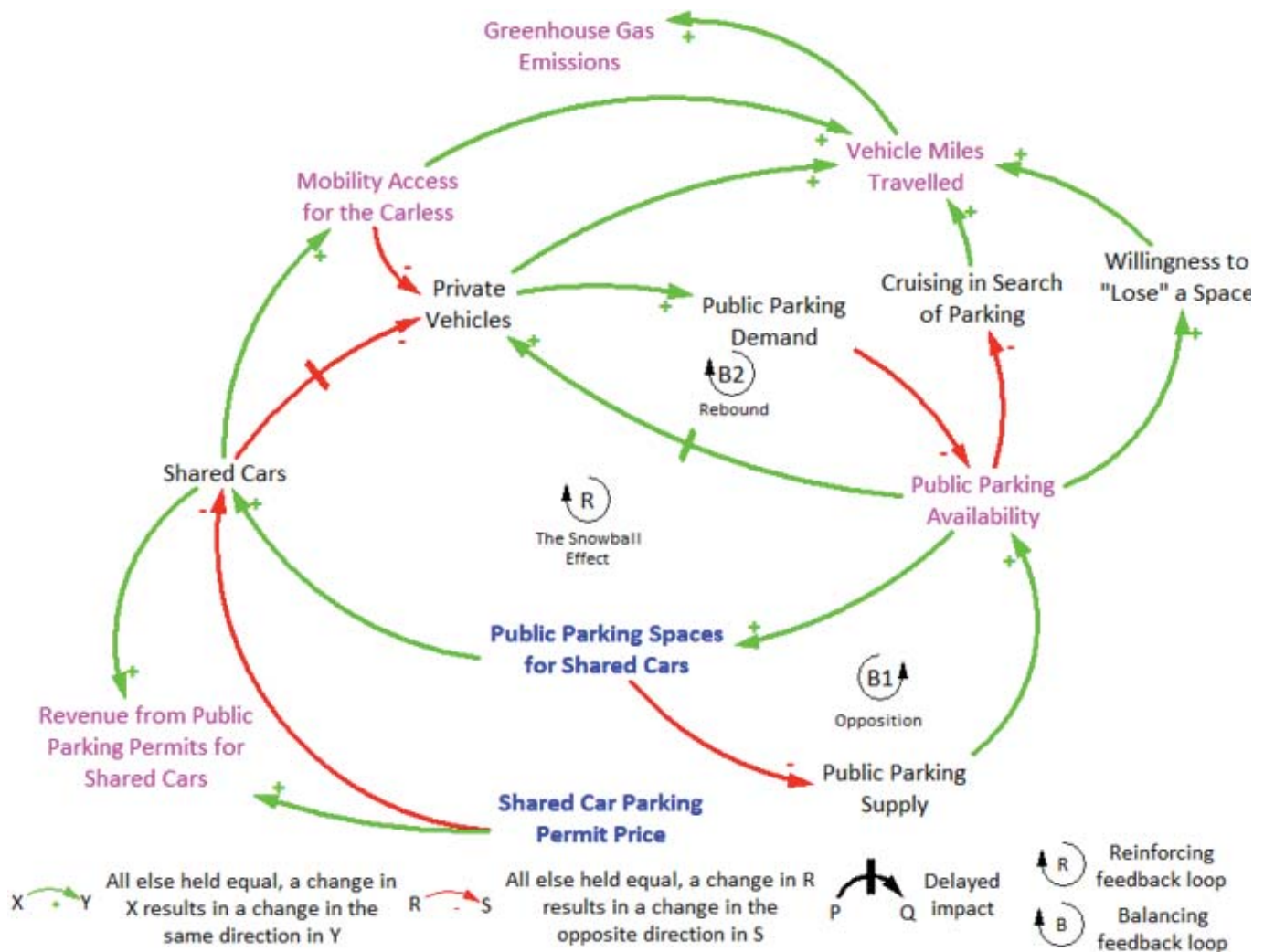


FIGURE 3: POTENTIAL IMPACTS OF ALLOCATING PUBLIC PARKING TO SHARED CARS

cars, causing a decrease in the number of *Private Vehicles* in Boston. This negative correlation between *Shared Cars* and *Private Vehicles* is denoted by the red directed line between two variables terminating with an arrowhead and a minus sign (-). However, this impact does not take place over a period of days, weeks, or months, but rather years. The delayed effect is represented by putting a bar (|) on the directed line between the two variables.

- Furthermore, an increase in the number of *Shared Cars* improves the *Mobility Access for the Carless* in Boston, as they now have access to an additional mobility option.
- Improved *Mobility Access for the Carless* reduces the need for them to purchase their own *Private Vehicles*. Though this doesn't remove any *Private Vehicles* from Boston, it prevents new ones from

being added, hence the negative correlation.

- As the number of *Private Vehicles* decreases, residents do not need as many on-street parking spaces for their cars, reducing *Public Parking Demand*. This is another example of a positive relationship – a decrease in one variable causes a decrease in another variable.
- With lower demand, *Public Parking Availability* increases, achieving one of the goals set by the City of Boston (over the long-term).
- Furthermore, increasing *Public Parking Availability* is likely to mitigate public opposition to allocating public parking spaces to shared cars. This allows the City of Boston to further increase the number of *Public Parking Spaces for Shared Cars*. Notice that the causal chain starting with *Public Parking Spaces for Shared Cars*

Cars has now ended on itself, indicating it is part of a feedback loop. If a feedback loop magnifies (once traversed back to its starting point) an exogenous change to a variable, it is a positive (or reinforcing) feedback loop. This particular reinforcing loop is named “The Snowball Effect” with an “R” surrounded by a clockwise arrow denoting the direction of the loop.

8. Starting again and moving in a different direction, increasing the *Public Parking Spaces for Shared Cars* also reduces *Public Parking Supply* because fewer spaces are available to residents for parking.
9. Decreasing the *Public Parking Supply* also decreases *Public Parking Availability*.
10. This results in opposition from residents, who are likely to apply pressure to reduce the number of *Public Parking Spaces for Shared Cars*. The last three variables are connected in such a way that another feedback loop (indicated with a “B1” and the label “Opposition”) is formed. The *Opposition* loop is a negative (or balancing) feedback loop because it counteracts (once traversed back to its starting point) the exogenous change to *Public Parking Spaces for Shared Cars*.

It is important to note that the model in the causal loop diagram only describes the potential impacts of allocating public parking spaces to shared cars. The remainder of this chapter develops these potential impacts further and explores whether they are supported by empirical evidence from the literature on car-sharing.

Evaluating the Empirical Research on Car-sharing

Substantial research has been done by CSOs and independent transport researchers on the impacts of car-sharing, particularly vehicle shedding and changes in travel behavior.²⁷ This report only considers research from independent transport researchers since it assumes that CSOs have a vested interest in overstating the positive impacts. For example, Zipcar’s website claims “each and every Zipcar takes 15 personally-

owned vehicles off the road.”²⁸ This figure is higher than the most optimistic estimates in the independent studies that this report drew its conclusions from.

Unfortunately, even for the independent research, there are three concerns:

Internal Validity

The first concern is methodological issues with the research that diminishes the credibility of their conclusions around the impacts of car-sharing.

Much of the empirical research relies on surveying members about their behavior before and after they joined a CSO. For example, members were asked how many vehicles they owned before and after they joined a CSO.^{29 30} The difference between the two values is identified as the causal effect of car-sharing. However, this approach ignores the possibility that members may have gotten rid of those vehicles even if they hadn’t joined a CSO. In light of this, there is a strong possibility that many of the impacts are overstated.

Further, most studies do not employ a control group, which renders problematic the conclusions drawn about what members would have done if they had not joined a CSO. For example, some studies try to determine if CSO membership prevents net increases in vehicle ownership. Respondents were asked whether they avoided purchasing vehicles since joining a CSO. Given the speculative nature of the answers, it is likely that these numbers are overstated as well.

This potential misattribution and overstatement of positive impacts (e.g. reductions in vehicle ownership and VMT) to car-sharing represents the primary threat to informed policy decision making: constituents potentially lose a public parking space without the compensating benefit of increasing public parking availability or reducing VMT. To mitigate these problems, this report adopts two approaches when examining the literature.

First, this report ranked research according to factors

28 Zipcar: Is Zipcar for me? <http://www.zipcar.com/is-it#greenbenefits>

29 Clayton Lane, “PhillyCarShare: First-Year Social and Mobility Impacts of Carsharing in Philadelphia, Pennsylvania,” *Transportation Research Record: Journal of the Transportation Research Board* 1927 (January 1, 2005): 158–66.

30 Richard Katzew, “Car Sharing: A New Approach to Urban Transportation Problems,” *Analyses of Social Issues and Public Policy* 3, no. 1 (December 1, 2003): 65–86.

27 Millard-Ball, *TCRP Report 108: Car-Sharing: Where and How It Succeeds*.

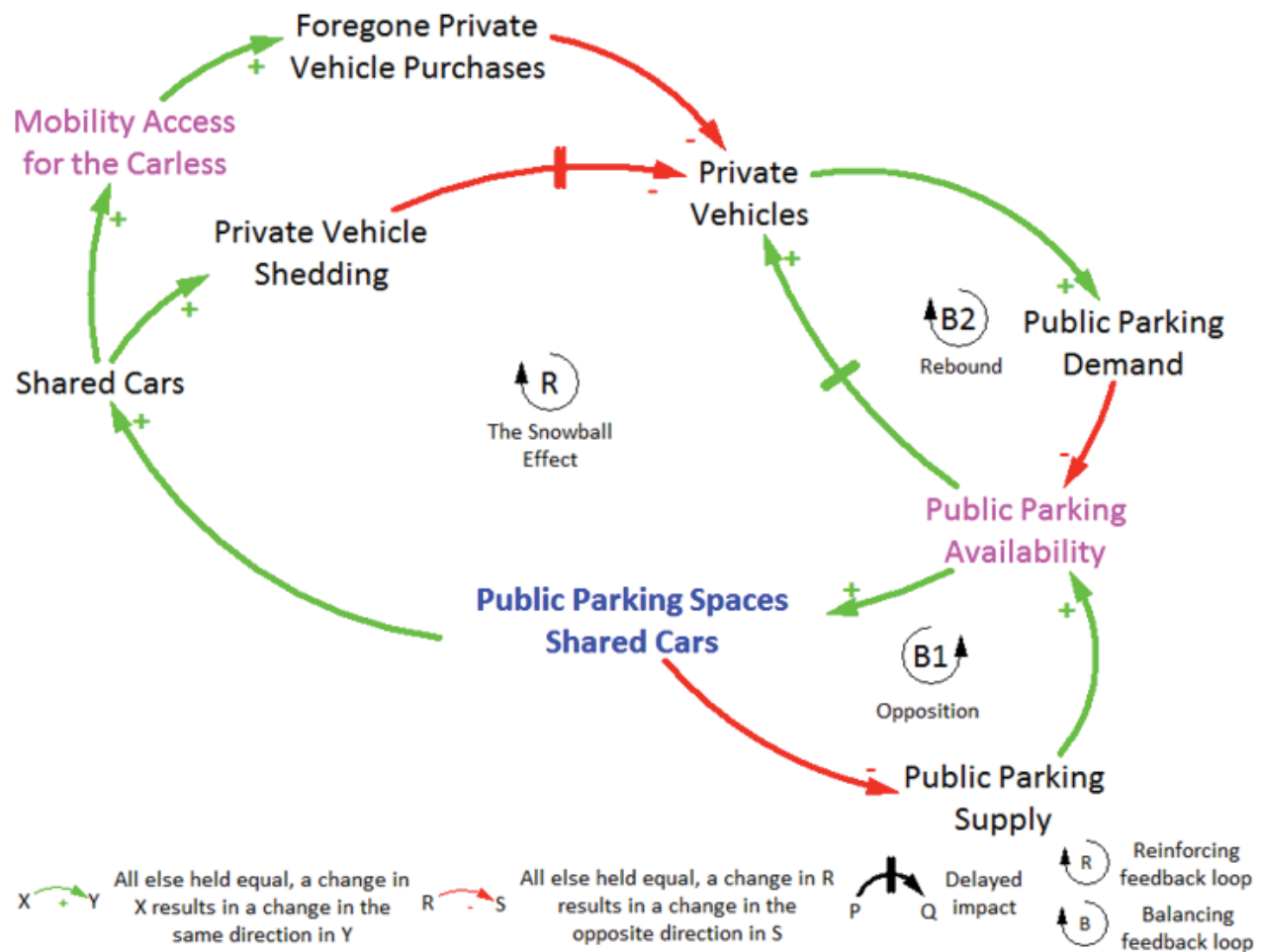


FIGURE 4: IMPACTS ON PRIVATE VEHICLE OWNERSHIP AND PUBLIC PARKING AVAILABILITY

such as the methodology and sample size (see Appendix D: Studies on Impacts of Car-Sharing). It then only drew conclusions from high quality research (see Appendix E: Detailed Review of Shortlisted Studies on Impacts of Car-sharing). Four studies made the final cut. The first is a large-scale survey car-sharing in North America conducted in 2009 by Elliot Martin, Susan Shaheen, and Jeffrey Lidicker.³¹ The remaining three studies were conducted on San Francisco's City CarShare by Robert Cervero and various other authors between 2001 and 2005.^{32 33 34}

31 Elliot Martin, Susan Shaheen, and Jeffrey Lidicker, "Impact of Carsharing on Household Vehicle Holdings: Results from a North American Shared-Use Vehicle Survey."

32 Robert Cervero, "City CarShare: First-Year Travel Demand Impacts," *Transportation Research Record: Journal of the Transportation Research Board* 1839, no. 1 (2003).

33 Robert Cervero and Yuhsin Tsai, "City CarShare in San Francisco, California: Second-Year Travel Demand and Car Ownership Impacts," *Transportation Research Record: Journal of the Transportation Research Board* 1887 (January 1, 2004).

34 Robert Cervero, Aaron Golub, and Brendan Nee, "City CarShare: Longer-Term Travel Demand and Car Ownership Impacts," *Transportation Research*

Record: *Journal of the Transportation Research Board* 1992 (January 1, 2007).

Second, this report uses the lower-bound of projected values from the studies. The policy danger of understating the positive impacts of car-sharing is less than overstating them.

External validity

Another concern is whether the results of these studies can be applied to other contexts (i.e. external validity). Conclusions drawn in other cities from a different time may not be applicable to Boston which has its own set of temporal, geographical, economic, and cultural characteristics.

Policy Relevance

The final concern is that the research on car-sharing exclusively examines behavioral changes of CSO members, not the actual impact of these changes on the communities they live in. Thus, the conclusions

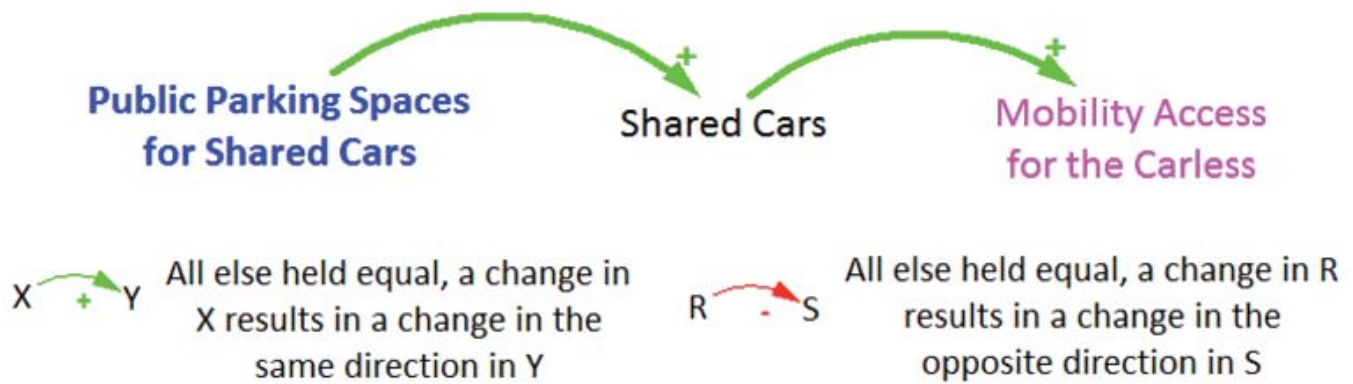


FIGURE 5: IMPACTS ON MOBILITY ACCESS

of the research may have little significance for a policymaker, even if they are statistically significant among CSO members. For example, if a quarter of CSO members give up their cars, but they only represent a small fraction of a city's population, the improvement in parking availability is going to be very modest. Therefore, the degree of impact in Boston is dependent on the proportion of Bostonians that are CSO members.

Private Vehicle Ownership

While most of the impacts of car-sharing studied in the available literature are identical to city's goals (e.g. VMT and GHG), some goals (such as increasing residential parking availability) were not studied directly. For such situations this report works its way backwards along the causal chain from the goal of interest to a relationship that has been studied.

In the case of increasing parking availability, the relevant relationship is between number of shared cars and changes in private vehicle ownership. Intuitively, reducing private vehicle ownership reduces the demand for parking spaces (both public and private), thus increasing public parking availability.

Figure 4 shows the relationships that are relevant to changing private vehicle ownership. It also illustrates how the reduction in vehicle ownership occurs in two forms:

- » Private Vehicle Shedding – members sell a vehicle they own.
- » Foregone Private Vehicle Purchases – members who do not own cars choose to forego or postpone indefinitely the purchase of a vehicle.

The introductory section of this chapter already explained most of the potential impacts from increasing the number of public parking spaces allocated to shared cars. Aside from those impacts, there is also potential Rebound effect caused by a negative feedback loop ("B2") between Private Vehicles and Public Parking Shortage. Over the long-term, as the public parking shortage abates, private vehicle ownership becomes more attractive because finding parking spaces becomes easier. Theoretically, residents purchase more vehicles offsetting some of the earlier reductions. However, there is little documented evidence of this unintended consequence and this report assumes it occurs on too modest a scale to have a major impact.

Empirical Evidence

Among the shortlisted studies, estimates on the number of vehicles shed are relatively consistent and within in a narrow bound. In their large-scale survey of car-sharing in North America, Martin et al. estimate that each shared car takes four to six vehicles off the road.³⁵ Cervero and Tsai estimate that in the two years after City CarShare's launch in 2001, each of its shared cars took six vehicles off the road. When using vehicle purchases for non-member households (i.e. the control group), the same study estimates that each shared car also prevented the purchase of one car.³⁶

In the last of their City CarShare studies, Cervero and Tsai provide a predictive ordinal logit model.³⁷ In this model, CSO membership increases the likelihood of

35 Martin, Shaheen, and Lidicker, "Impact of Carsharing on Household Vehicle Holdings: Results from a North American Shared-Use Vehicle Survey."

36 Cervero and Tsai, "City CarShare in San Francisco, California."

37 Cervero, Golub, and Nee, "City CarShare."

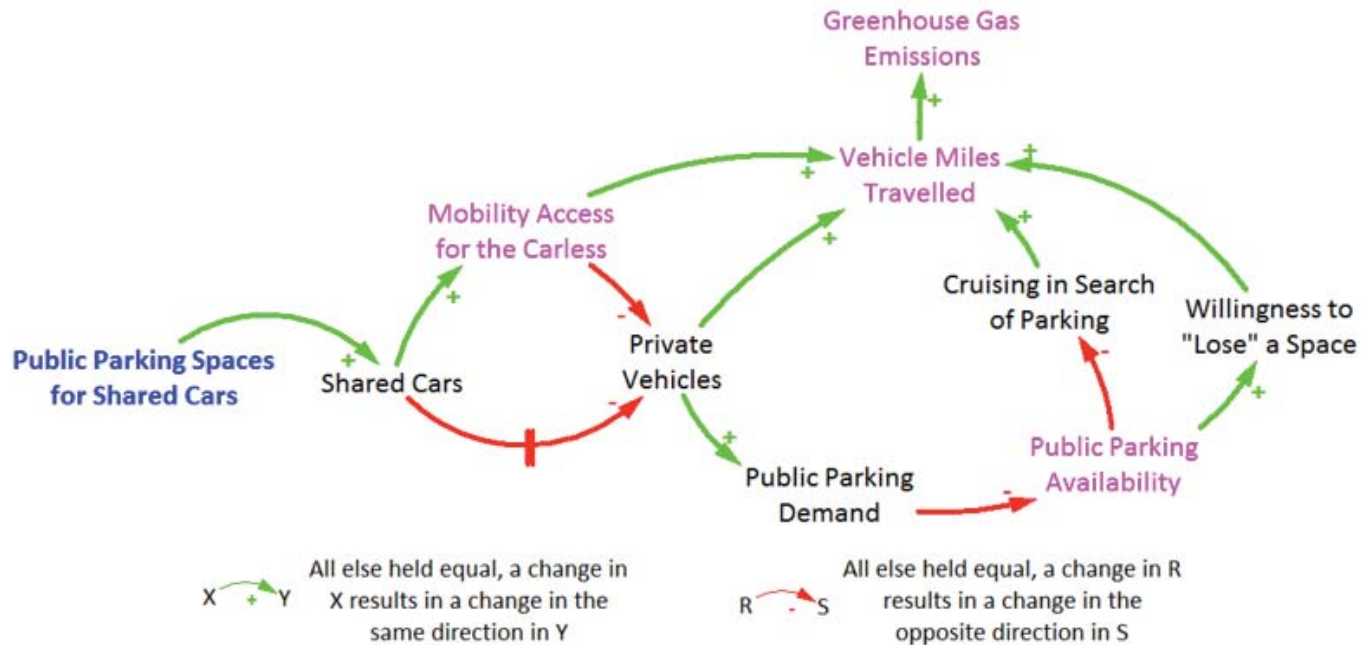


FIGURE 6: IMPACTS ON VMT AND GHG EMISSIONS

shedding one or more vehicles by approximately 11 percentage points.³⁸

Combining this evidence, this report estimates that **each shared car induces the shedding of four vehicles and prevents the purchase of one more**. This represents a **net reduction of four vehicles per shared car** (the shared car represents a one vehicle increase).

Mobility Access

Of all the impacts discussed in this chapter, the impact on the mobility access of Boston residents of allocating public parking spaces to shared cars is the most straightforward. Mobility access is improved because an increase in public parking spaces for shared cars results in additional shared cars, creating wider geographical coverage and greater availability.

Empirical Evidence

In their third study on San Francisco's City CarShare, Cervero et al found that, if a shared car was not available, surveyed members would have most likely not made 30% of their trips. Nearly 40% of those additional trips were for shopping. The newly accessible trips represent a 43% improvement³⁹ in

mobility for City CarShare members.⁴⁰

Another survey of car-sharing members in 2005 found that over 58% of respondents felt that they could access more destinations since joining a CSO.⁴¹

Although it is unable to estimate an exact magnitude, this report concludes that car-sharing does improve mobility access.

Vehicle Miles Travelled (VMT) and Greenhouse Gas (GHG) Emissions

While the relationship between VMT and GHG emissions is straightforward, the relationship between car-sharing and VMT is more complex. This is illustrated by the number of causal chains that end in Vehicle Miles Travelled in Figure 6.

CSO members reduce their VMT by selling the cars that they own, if any.⁴² Most of the costs associated with vehicle ownership are fixed costs (e.g. depreciation, insurance, parking space rental, license, registration, taxes). Once paid, these are regarded as sunk costs. This results in the marginal cost (per trip or distance

otherwise not been made. Thus, the improvement is $(10-7) / 7 * 100\% = 42.86\%$

⁴⁰ Cervero, Golub, and Nee, "City CarShare."

⁴¹ Millard-Ball, *TCRP Report 108: Car-Sharing: Where and How It Succeeds*.

⁴² Ibid.

³⁸ See Appendix F: Predictive Model on Changes in Vehicle Ownership for City CarShare for calculation method

³⁹ Cervero et al found that 3 out 10 trips made in a shared car would have

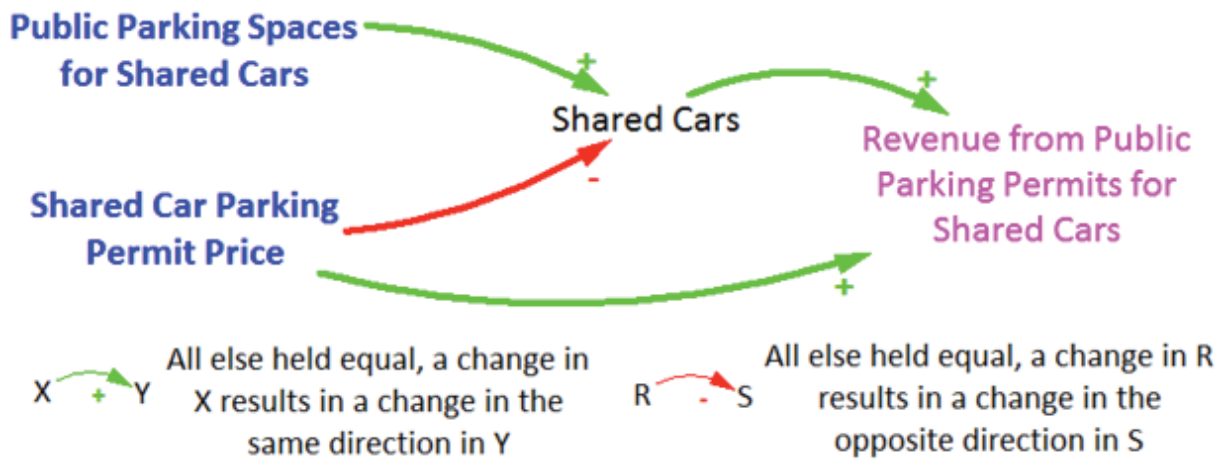


FIGURE 7: IMPACT OF PERMIT PRICES

travelled) for a private vehicle being very small relative to its average cost. When a shared car is used as a substitute for a private vehicle, the marginal costs are much closer to the average cost. Therefore, what results is more judicious use of the shared car relative to other modes (walking, biking, and public transport).⁴³

Furthermore, alleviating the public parking shortage potentially reduces VMT (and GHG emissions) because residents spend less time cruising in search of a parking space.

However, these reductions in VMT could be offset by shared car usage by carless individuals. In the status quo, these individuals do not contribute to Boston's VMT and GHG emission totals. Allocating public parking spaces to shared cars will increase the number of shared cars in Boston and the access of the carless to automobiles. Trips that were previously foregone or made on other modes will be made with a shared car, resulting in a VMT increase. This represents a conflict between the goals of increasing mobility access for the carless and reducing VMT.

In addition, it is also possible that reducing parking demand might encourage an increase in VMT as the problem with finding a parking space abates in Boston. There is anecdotal evidence that people choose to cut down on trips in their own cars because they "lose" their space and have the difficulty in finding parking spaces when they return.⁴⁴

Finally, besides reductions in VMT, GHG emission reductions are also tied to the fleet composition of the CSO and member households. Since they often bear fuel costs, CSOs tend to use fuel efficient vehicles with lower carbon footprints. When shedding vehicles, members may also be giving up older vehicles that are more polluting.⁴⁵

Consequently, the potential net changes in VMT and GHG emissions are contingent upon which of the aforementioned causal chains are dominant.

Empirical Evidence

In all three studies on the impacts of San Francisco's City Carshare, Cervero et al found no statistically significant difference in average VMT between members and non-members.^{46 47 48} However, there were two results that were statistically significant in the third study. First, members had 1.87 fewer mode-adjusted vehicle miles travelled (MVMT) than non-members. MVMT are calculated by dividing VMT by the number of occupants in the vehicle for a given trip. This same study also found that when using a regression model which controlled for factors such as age, income, and vehicle ownership, being a member of City CarShare reduced daily travel by approximately 7 miles.⁴⁹

In examining GHG emissions, a study by Martin et al found that while carless households increased their

43 Karl Steininger, Caroline Vogl, and Ralph Zettl, "Car-Sharing Organizations: The Size of the Market Segment and Revealed Change in Mobility Behavior," *Transport Policy* 3, no. 4 (October 1996): 177–85.

44 Wallack, "Boston Vows to Examine Parking Rules for Residents."

45 Millard-Ball, *TCRP Report 108: Car-Sharing: Where and How It Succeeds*.

46 Cervero, "City CarShare: First-Year Travel Demand Impacts."

47 Cervero and Tsai, "City CarShare in San Francisco, California," -.

48 Cervero, Golub, and Nee, "City CarShare."

49 Ibid.

VMT, there was overall net reduction in VMT among CSO members. This translated into an average net reduction of 0.58 metric tons of GHG per year (t GHG/year) for households that joined CSOs. The study goes on to estimate that foregone trips, due to vehicle shedding, further reduced emissions by 0.26 t GHG/year bringing the “full” reduction to 0.84 t GHG/year. Both of these estimates were statistically significant.⁵⁰

This report adopts the lower bound estimates for each study and estimates that **shared car usage (through CSO membership) results in households reducing their average daily MVMT by 1.87 miles and their GHG emissions by 0.58 metric tons per year.**

Revenue and the Shared Car Parking Permit Price

Thus far, this chapter has discussed the impact of allocating more public parking spaces to shared cars while holding the permit price constant. The negative relationship between the permit price and the number of shared cars in Boston is shown in Figure 7: if the price of the permits goes up, there will be fewer shared cars in Boston. More precisely, CSOs will place fewer cars in Boston if the price is above their willingness to pay for a given quantity of public parking spaces. The converse is also true. Most important, this highlights a conflict between raising revenue and all the other goals that only accrue through more shared cars in Boston.

Empirical Evidence

There is very little research on the price sensitivity of CSOs. However, the response to the RFP provides some insight: CSOs applied for all 80 Dedicated Permits and 150 Free-floating Permits.⁵¹ This indicates that for these quantities of public parking spaces, the price of the permits in the RFP is at or below what the CSOs were willing to pay.

Conclusion

Several themes emerge from this chapter. The first is that some of the goals are in conflict with each other:

- » Increasing the City of Boston’s revenues by charging a higher price for the shared car public parking permits is likely to limit the degree to which other goals are achieved because CSOs will place fewer shared cars in Boston.
- » Improving access to mobility for the carless will potentially run counter to the goal of reducing VMT and GHG emissions.

Nevertheless, the priorities for the goals set at the end of the previous chapter provide guidance on how to resolve this:

- » As maximizing revenue has the lowest priority among all the city’s goals, the price of a public parking permit should be set as low as necessary to achieve the city’s other goals.
- » Improving access to mobility for the carless should take priority over reducing VMT and GHG emissions. However, there is some evidence that the VMT increase of a carless individual who uses a shared car is lower than it would have been if they had purchased their own car.⁵²

Beyond these conflicts, there are two main concerns with regard to the policy relevance of the empirical findings in this chapter to the City of Boston.

First, as stated earlier, all studies focused exclusively on the behavioral changes of CSO members. Thus the magnitude of the actual impacts on the City of Boston is dependent on the number of CSO members in the city.

Second, all studies only examined the A-to-A model of car-sharing. There has been little empirical research done on the impacts of the A-to-B model of car-sharing. The added flexibility and lower price of the one-way trips on the A-to-B model suggest that it may better improve accessibility and induce greater vehicle shedding. However, these same factors may also mean that there might be net VMT and GHG emission increases. VMT and GHG emissions may be further increased if rebalancing is required. Rebalancing is the transfer of shared cars from one location to another in order to ensure sufficient supply or comply with a municipal requirement. The exercise is a short-term cost to CSOs because they have to pay for labor and fuel to transfer the vehicle and earn no revenue

50 E.W. Martin and S.A. Shaheen, “Greenhouse Gas Emission Impacts of Carsharing in North America,” *IEEE Transactions on Intelligent Transportation Systems* 12, no. 4 (December 2011): 1074–86.

51 This information was received through word-of-mouth from the client. Unfortunately, confidentiality requirements prevented the client from revealing more detailed information about the response to the RFP.

52 Martin and Shaheen, “Greenhouse Gas Emission Impacts of Carsharing in North America.”

from rental during the transfer period. This report incorporates the uncertainty around the impacts of the A-to-B model into its recommendations in the final chapter.

Table 2 summarizes the empirical conclusions from this chapter. While there is some uncertainty regarding the exact magnitude of these impacts, this report

is confident that **car-sharing will have beneficial impacts on the City of Boston**. Above all, the estimated reduction in vehicle holdings means that, in the long term, **residents stand to gain at least four parking spaces for every public parking space they lose**.

RESULTS	PRIVATE VEHICLE OWNERSHIP	VMT AND GHG EMISSIONS	MOBILITY ACCESS
Cervero et al	Net reduction of 4-7 vehicles (including foregone purchases)	Daily VMT reduction of 1.87-7 miles	Improved – 43% more trips become accessible
Martin and Shaheen	Net reduction of 4-6 vehicles	GHG emission reduction of 0.58-0.84 t GHG/year	Not studied
Projected impact for this report	Net reduction of 4 vehicles (4 vehicles shed, 1 vehicle purchase foregone, 1 shared car added)	Daily MVMT reduction of 1.87 miles and GHG emission reduction of 0.58 metric tons per year	Improved
Confidence in projected impact	High – The literature on car-sharing consistently finds that it causes a statistically significant reduction in private vehicle ownership. The reports only differ on the magnitude of the reduction and this report uses a conservative estimate.	Low – There is evidence of VMT and GHG emission reductions among CSO members but very few of these results were statistically significant.	High – The evidence supports the intuitive notion that car-sharing improves mobility access.

TABLE 2: IMPACTS OF CAR-SHARING ON SELECTED CITY GOALS (BASED ON AVAILABLE EMPIRICAL EVIDENCE)



Chapter 4: Recommendations

CAR-SHARING organizations (CSOs) have asked the City of Boston to allocate public parking spaces to their shared cars. The first part of this chapter recommends an appropriate response to their request, taking into account the goals discussed in Chapter 3 and the impacts examined in Chapter 4. The second part of this chapter deals with getting more accurate estimates of the impacts of car-sharing in Boston.

Recommendation 1: Allocate Public Parking Spaces to Shared Cars

In considering the response to CSOs, the City of Boston set the following goals:

1. Increase residential public parking availability
2. Improve mobility access for the carless
3. Reduce Vehicle Miles Travelled (VMT) and Greenhouse Gas (GHG) emissions
4. Maximize revenue (or minimize losses)

The previous chapter provides compelling evidence that these goals are attainable through allocating some of the city's limited public parking spaces to shared cars. Where there is uncertainty, it is only around the exact magnitude, not the existence, of the benefits. Accordingly, this report recommends that the **City of Boston approach car-sharing as a social and environmental benefit and allocate public parking spaces to shared cars.**⁵³

To support this allocation policy, the City of Boston should:⁵⁴

- » Establish a formal process for allocating public parking spaces to shared vehicles. CSO engagement should be administered by dedicated staff at a department or sub-department level. The spaces allocated to shared cars should be distinct from spaces allocated for other uses (i.e. with signs and

⁵³ Susan A. Shaheen et al., "Carsharing and Public Parking Policies: Assessing Benefits, Costs, and Best Practices in North America," March 2010, <http://trid.trb.org/view.aspx?id=929240>.

⁵⁴ These build on the policy recommendations elements in Shaheen et al. "Carsharing and Public Parking Policies".

markings), and, if necessary, zoning laws should be amended to reflect this distinction. Parking enforcement officers should ensure that only shared cars use the designated spaces.

- » Conduct joint public consultation sessions with CSOs when allocating public parking spaces in a given neighborhood. City officials should facilitate these sessions.
- » Require that any CSO allocated a public parking space grant the City of Boston access to:
 - Trip-level data that has been sufficiently anonymized
 - Location data for all of its shared cars in Boston (both in private and public parking spaces)
 - Aggregate data on the number of CSO members and their characteristics (car ownership, age, income) for each of the 250mx250m cells in Boston

A precedent has been set for this with the data sharing agreement between Uber, a ride-hailing service, and the City of Boston.⁵⁵

Beyond the considerations above, a sound allocation policy also needs to determine the appropriate car-sharing model, the spatial distribution of the allocated parking spaces, as well as the permit price, duration, and quantity.

Which Model?

Of the two car-sharing models, the A-to-A (two-way) model has been better studied. Thus, this report is more confident in its benefits and recommends **prioritizing the allocation of public parking spaces to A-to-A (two-way) shared cars through Dedicated Permits.**⁵⁶

Nonetheless, the A-to-B (one-way) model is an innovation in car-sharing that holds great promise. For the City of Boston, the major political upside is that A-to-B shared cars do not require a dedicated space.

Hence, there is a lower likelihood of opposition from residents due to the loss of a public parking space. However, the model's novelty and flexibility also means that there is greater uncertainty about its impacts. Therefore, this report recommends **the City of Boston adopt a more conservative policy in issuing Free-Floating Parking Permits⁵⁷ as to better examine the impacts of the A-to-B model.** In light of this, the 150 Free-Floating Parking Permits offered in the Request for Proposals (RFP) are a good start. The next step would be to examine the data from the CSO, particularly trip-level data, to look at the impacts on mobility as well as VMT and GHG emissions.

Where?

A shared car needs to be placed in the right place to have the desired impact. For example, a shared car is unlikely to reduce vehicle ownership (and increase public parking availability) in a given area if it is an hour's walk away. Hence, the allocated public parking spaces must be located where they maximize reductions in vehicle ownership or increase mobility access. For these impacts to occur, **allocated public parking spaces cannot be more than 400 meters away from the target user group.**⁵⁸

It cannot be assumed that the goals of CSOs align perfectly with those of the City of Boston when it comes to choosing the location of public parking spaces for shared cars. An example of poor goal alignment might be the placement of a shared car in an area resulting in reduced public transportation usage and increased VMTs. Conversely, it would also be unwise for the City of Boston to micromanage the process by determining the exact locations for public parking spaces for the CSOs and offering it to them on a take-it-or-leave-it basis. Some areas might not be sufficiently profitable for a CSO.

This report recommends a midpoint on the spectrum: **the City of Boston associates goals with a set of geographical areas and allows the CSO to choose their public parking spaces from those sets.** For example, in order to increase public parking availability, the City of

55 Nicole Dungca, "Uber to Share Ridership Data with Boston," *The Boston Globe*, January 13, 2015, <https://www.bostonglobe.com/business/2015/01/13/uber-share-ridership-data-with-boston/4Klo40KZREtQ7jkoaZjoNN/story.html>.

56 Dedicated Permits allocate a public parking space for a specific CSO's shared car.

57 Free-floating Parking Permits allow a shared car to be parked in any legal public parking space. Additionally, the shared car and motorist are not subject to meter payment or time limit restrictions and residential parking permit restrictions.

58 Jarrett Walker, "Basics: Walking Distance to Transit," *Human Transit*, April 24, 2011, <http://www.humantransit.org/2011/04/basics-walking-distance-to-transit.html>.

Boston identifies 250x250m cells where there are many private vehicles and lets the CSO choose public parking spaces within any of the cells. The city's RFP applied this recommendation with the additional stipulation that access to certain areas was contingent upon placing cars to meet goals in others.

Increasing Public Parking Availability Through Reductions in Vehicle Ownership

CSO members have diverse reasons for shedding vehicles they own including existing vehicles being close to retirement,⁵⁹ environmental concerns, and a shared car being more economical than a private vehicle below certain mileages.⁶⁰ The final reason implies that there are mileages for which average cost of shared car usage are equal to or lower than the average cost of using a private vehicle.

In their study of the impacts of car-sharing in North America, Martin et al. found that 90% of vehicles shed were driven less than 16,000 miles a year and the median mileage on shed vehicles was 7,000 miles a year.⁶¹ Using motoring cost data from AAA, another report suggests that using a shared car is more cost-effective than owning a vehicle at mileages below 5,000 miles a year.⁶² This report assumes that **private passenger vehicles driven less than 6,000 miles a year are the main candidates for replacement by a shared car.**

The map in Figure 8 draws on data from the Massachusetts Vehicle Census and shows the count of low-mileage passenger vehicles geocoded to a given 250mx250m cell in the fourth quarter of 2011. The census defines low-mileage vehicles as those that are driven (on average) under 16 miles a day or 5,844 miles per year. "Hotter" cells, denoted by deeper hues of red, have higher number of low-mileage vehicles than "cooler" cells, denoted by light shades of yellow. The numbers in the cells are the count of low-mileage vehicles in that cell.

Therefore, to increase public parking availability, the City of Boston should allocate public parking spaces within 400 meters of cells with three or more vehicles

59 Martin, Shaheen, and Lidicker, "Impact of Carsharing on Household Vehicle Holdings: Results from a North American Shared-Use Vehicle Survey."

60 Millard-Ball, *TCRP Report 108: Car-Sharing: Where and How It Succeeds*.

61 Martin, Shaheen, and Lidicker, "Impact of Carsharing on Household Vehicle Holdings: Results from a North American Shared-Use Vehicle Survey."

62 Millard-Ball, *TCRP Report 108: Car-Sharing: Where and How It Succeeds*.

with mileages below 16 miles a day (low-mileage vehicles).

One caveat is that this vehicle census data is over four years old and those low mileage vehicles may no longer exist. This issue is mitigated by two factors. First, there is a strong correlation between the number of low mileage vehicles and the number of private vehicles (see Figure 1) in a given cell. Second, cells with many private vehicles in a given year also have many private vehicles in other years. Put another way, the public parking shortage in a given area persists through time. Therefore, the number of low mileage vehicles in the fourth quarter of 2011 is an appropriate proxy for the current number of low mileage vehicles.

Improving Mobility Access

To determine the areas that would gain the most mobility from the addition of a shared car, this report first inverted the mobility score data from Figure 2. It then removed the unpopulated cells such as parks, the Boston Harbor Islands, and Logan International Airport from the data set to produce Figure 9. The cells with deeper shades of blue have higher immobility scores⁶³ (i.e. poorer mobility). **Public parking spaces should be allocated to shared cars within 400 meters of cells with immobility scores in the top quintile (i.e. greater than 0.457).**

How Much and for How long?

As stated in the previous chapter, all 80 Dedicated Permits (with a maximum of 40 per CSO) and 150 Free-Floating Permits offered in the city's RFP were applied for. This implies that the price set for the permits was at or below the price CSOs were willing to pay. The permits were priced at \$3,500 for a dedicated downtown space (or a Free-Floating Permit) and \$2,700 for a dedicated space elsewhere.⁶⁴ These prices are close to the city's estimated cost of maintaining an on-street public parking space.

Even though the city can potentially charge a higher price, revenue generation also has the lowest priority among the City of Boston's goals. More important, higher prices could dissuade CSOs from placing cars in Boston in the future, decreasing the magnitude of the associated benefits. Therefore, this report recommends

63 Immobility Score = 1 / Mobility Score

64 Boston Transportation Department, "DriveBoston: A Request for Proposals for a Boston Vehicle Sharing Program."

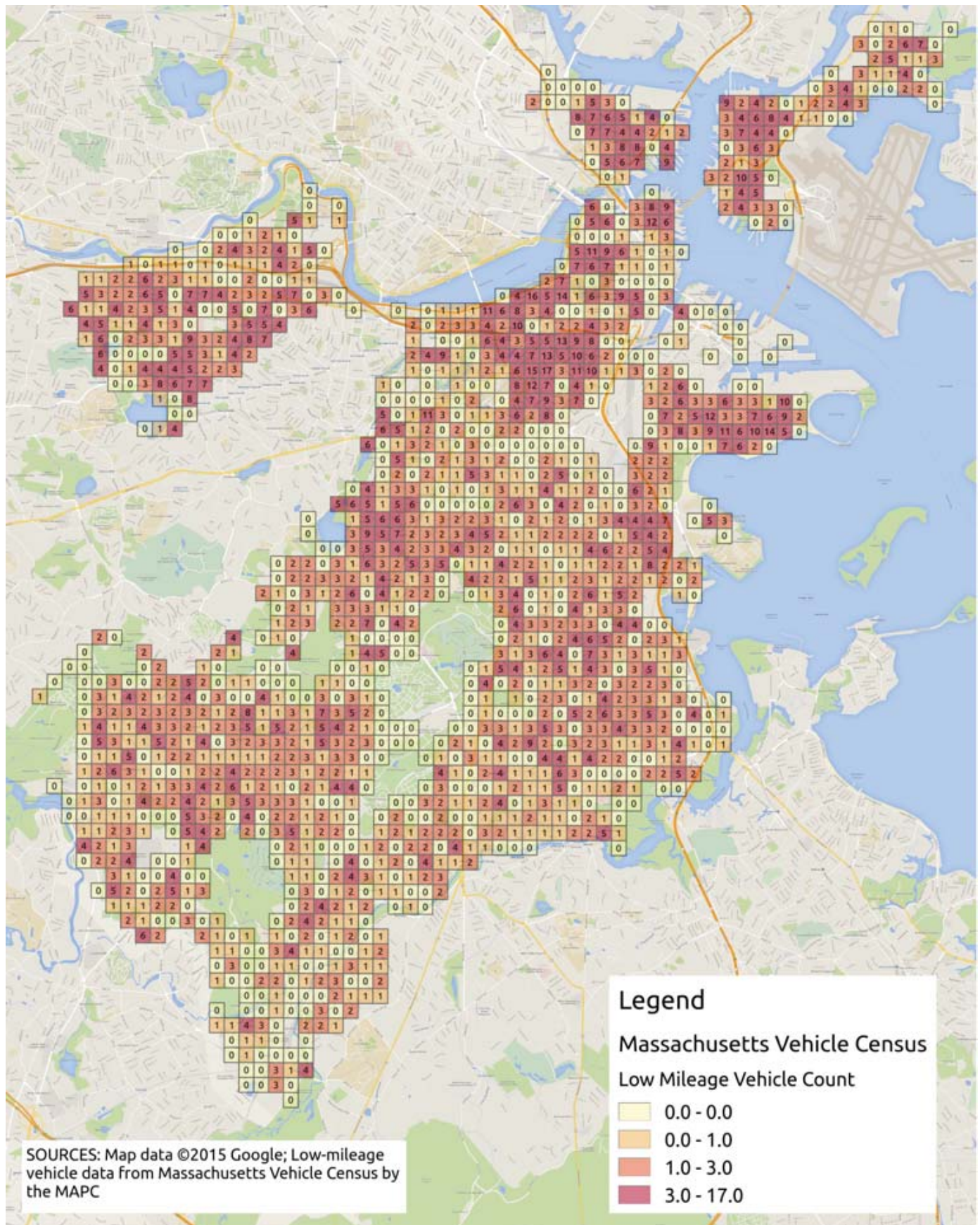
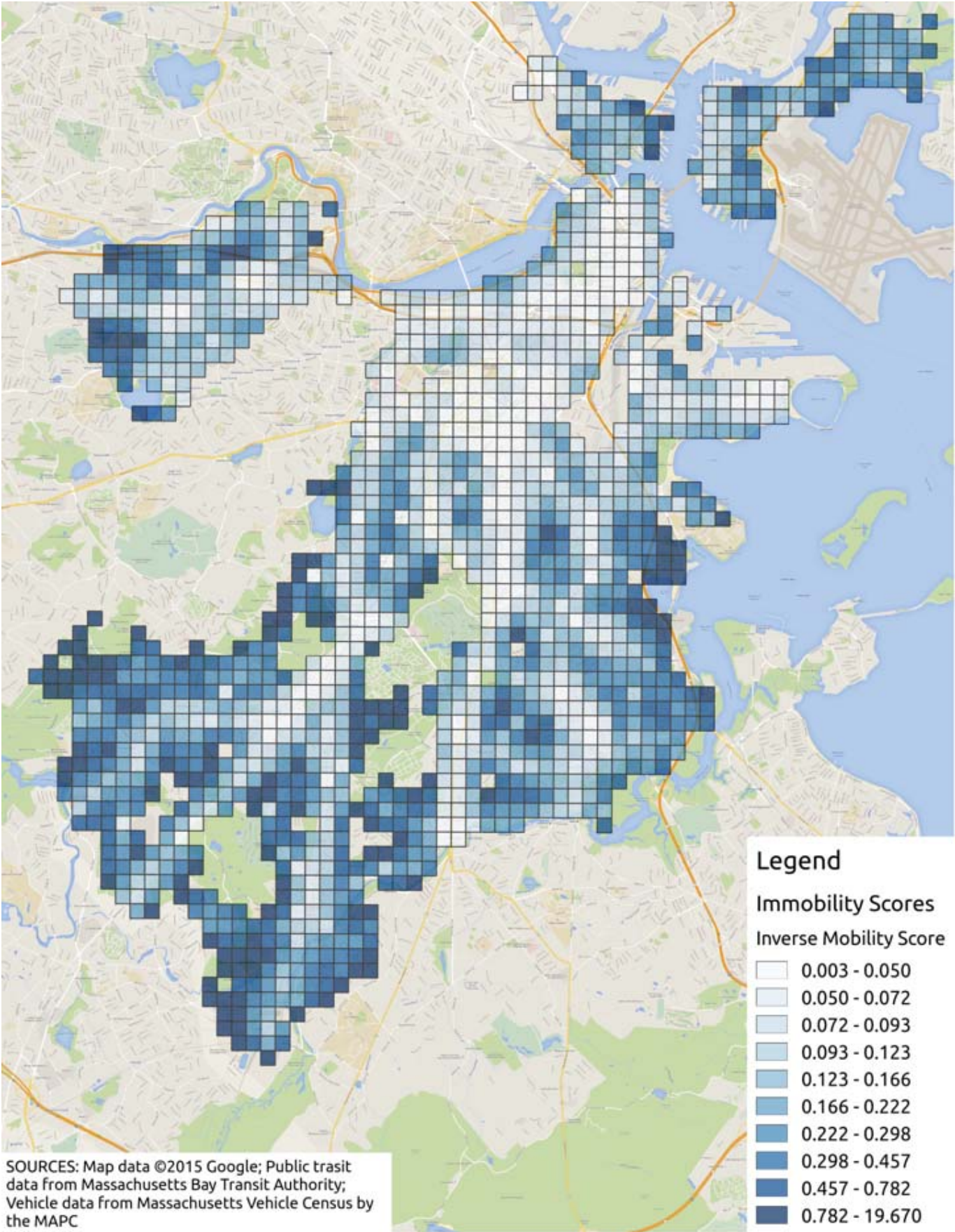
FIGURE 8: VEHICLES WITH LOW MILEAGE (BELOW 16 MILES PER DAY) IN A CELL

FIGURE 9: IMMOBILITY SCORES



the City of Boston retain the pricing scheme from its RFP. Looking ahead, the City of Boston should also consider lowering the permit prices if CSOs begin to demand fewer spaces. This is especially true if the City of Boston believes that the maximum benefits from car-sharing have not yet materialized.

Cervero et al found that the impacts of car-sharing on reducing private vehicle ownership only started to manifest after two years.⁶⁵ Although the City of Boston should eventually verify this duration with its own study (next recommendation), in the interim, this report recommends that **shared-car public parking permits have two-year durations.**

How Many?

Beyond the spaces offered in the RFP, this report recommends **an incremental approach to allocating additional public parking spaces to shared cars (i.e. allocate, evaluate, allocate).** This should be implemented on an annual basis as follows:⁶⁶

1. Allocate a small number (no more than 50) of public parking spaces to shared cars from a CSO.
2. Evaluate the CSO based on a set of metrics. Where necessary, the CSO is expected to provide the relevant data. The metrics are as follows:
 - a. Relative to neighborhoods with fewer (or no) shared cars in public parking spaces, there should be larger decreases/smaller increases in the number of residential parking permits that are applied for in comparable neighborhoods with more shared cars.⁶⁷ For example, if more shared cars are placed in Allston than in Brighton in 2015, the difference in number of residential permits that are applied for between 2015/2016 and 2014/2015 for Allston should be less than Brighton's difference over the same period. If the data is available, a similar approach can be used for car ownership, VMT, and GHG emissions.
 - b. There should be an increase in CSO membership

in the areas around the allocated spaces.

- c. The number of parking infractions that a shared car is involved when outside its designated space in should be low.
 - d. The majority of shared-car utilization should occur in off-peak periods.
3. In the following year, if the metrics in Step 2 appear to be met or exceeded, start again at Step 1.

The practical and political limitations of converting existing residential public parking spaces only further buttress the case for this approach.

Recommendation 2: Conduct an Independent Impact Study

The City of Boston can significantly reduce the degree of uncertainty associated with the impacts of car-sharing by studying it within Boston. To do so, this report recommends that **the City of Boston, in partnership with CSOs, conduct a large-scale randomized experiment over a four-year period.** Instead of the allocation policy from the previous recommendation, CSOs participating in this study will follow the allocation process in the study design.

The unit of analysis for this study will be a household. The causal relationship of interest is the impact of the number of shared cars near a given household on:

- » The number of private vehicles owned by the household as well as their attributes (e.g. year, make, model, fuel efficiency);
- » The household's average daily vehicle miles travelled and GHG emissions;
- » The number of CSO members in the household.

Random assignment is as follows: The participating CSOs pick 80 cells (from the grid in Figure 13) to place shared cars. There needs to be a two-cell gap between each chosen cell to limit crossover effects. The selected cells are then matched into pairs based on the degree to which they share characteristics that could impact the outcomes (e.g. population density, average income). In each of these pairs, one cell is randomly chosen to be in the treatment arm while the other is in the control arm, for a total of 40 cells in each arm of the study.

65 Cervero and Tsai, "City CarShare in San Francisco, California."

66 This approach is a variant of the one adopted by the Washington D.C.'s District Department of Transportation in its policy for allocating public spaces to shared cars. Sam Zimbabwe, Associate Director of the Policy, Planning & Sustainability Administration, provided this information.

67 This is a difference-in-difference calculation without the statistical machinery.

CSOs will only be allocated public parking spaces in cells from the treatment arm. No spaces will be allocated to CSOs in the cells from the control arm. For the duration of the experiment, participating CSOs are prohibited from placing additional shared cars in public and private parking spaces inside a control cell and the two-cell “border” around it. This is also to prevent crossover effects. However, CSOs may place shared cars in private parking spaces within or around the treatment cells provided they notify the City of Boston and do not violate the previous restriction.

The restriction around the control cells might dissuade CSOs from participating in the experiment. To remedy this, the City of Boston should only allocate public parking spaces to participating CSOs for the duration of the experiment. To further incentivize participation, the City of Boston should be willing to allocate more public parking spaces at a cheaper price in the treatment cells.

Using vehicle registry and inspection records from the Massachusetts Registry of Motor Vehicles (a division of

the Massachusetts Department of Transportation), the outcome variables above are examined for households in both arms. This occurs before the study starts and at the end of the four years.

The causal effect will be the difference in the changes in the outcome variables in these two time periods between households in the two arms of the study (i.e. difference-in-difference). “Appendix H: Study Protocol to Examine the Impacts of Car-Sharing in Boston” provides a full explanation of the study design.

One limitation of this design is that it only provides insight into the impacts of the A-to-A model of car-sharing. Since the A-to-B model of car-sharing does not limit a shared car to a single location, this method of attribution is not applicable. That said, the insights from this study will allow the City of Boston to be better informed on the impacts of car-sharing and whether they meet the city’s goals.

Appendices



Appendix A: Boston Neighborhoods

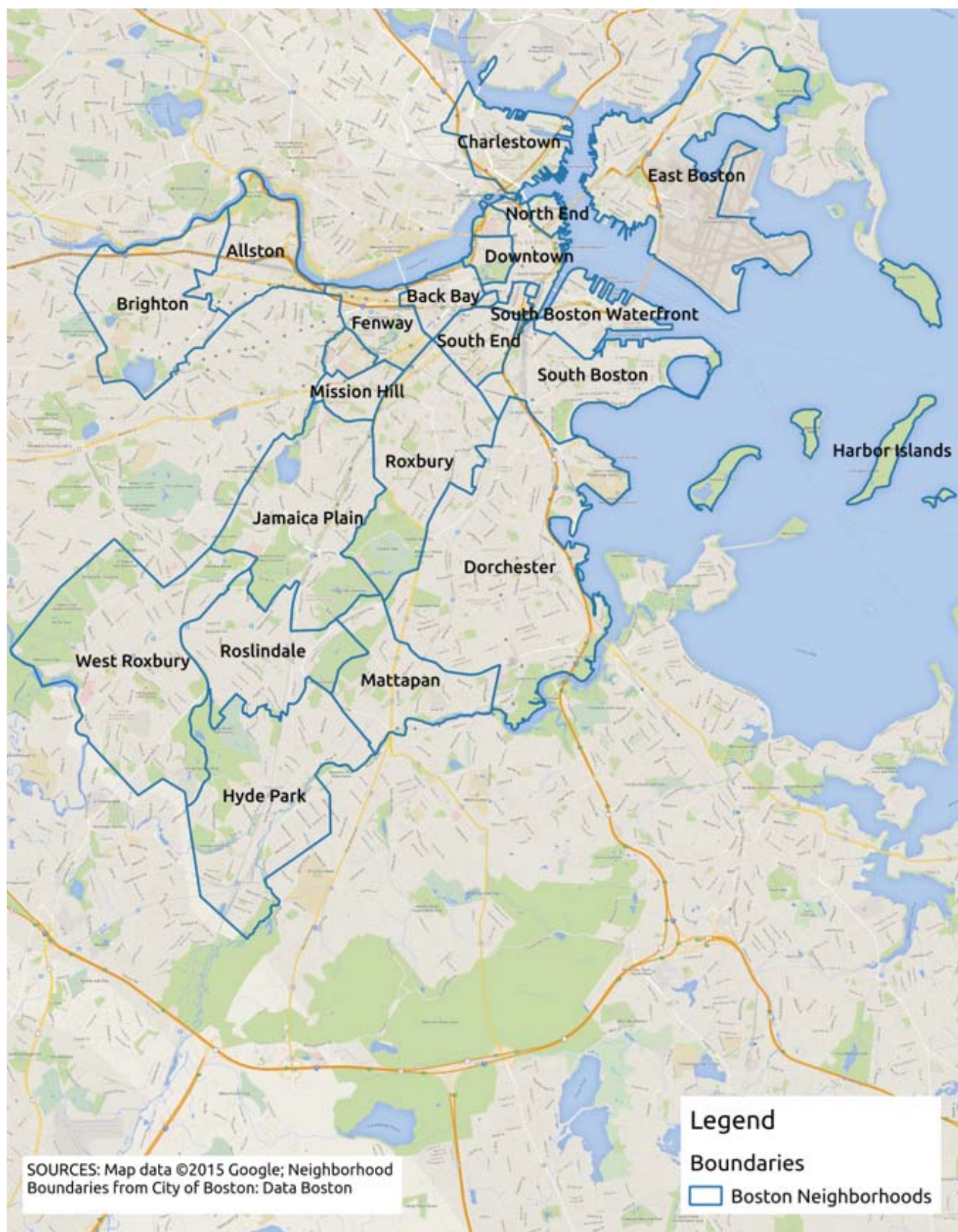


FIGURE 10: CITY OF BOSTON NEIGHBORHOODS

Appendix B: Car-sharing Organizations (CSOs)

NAME	LOCATION MODEL	CAR-OWNERSHIP MODEL	ACTIVE IN BOSTON
Zipcar (http://www.zipcar.com/)	Mostly A-to-A, experimenting with A-to-B	Fleet owned	Yes
Car2Go (https://www.car2go.com/en/)	A-to-B	Fleet owned	No
Getaround (https://www.getaround.com/)	A-to-A	Peer-to-peer	No
RelayRides (https://relayrides.com/)	A-to-A	Peer-to-peer	Yes
Enterprise	A-to-A	Fleet Owned	Yes

Appendix C: Households and Vehicle Ownership

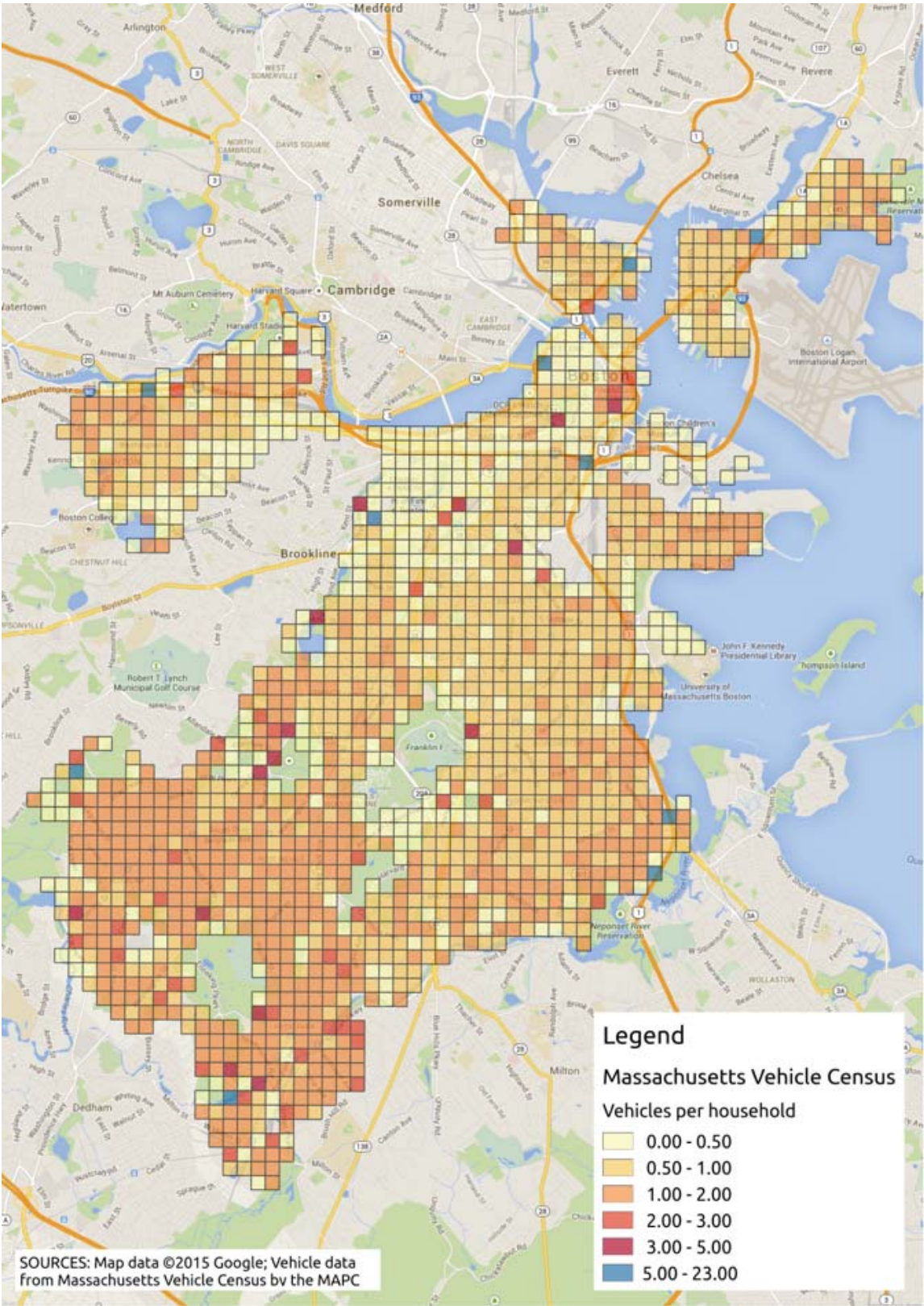
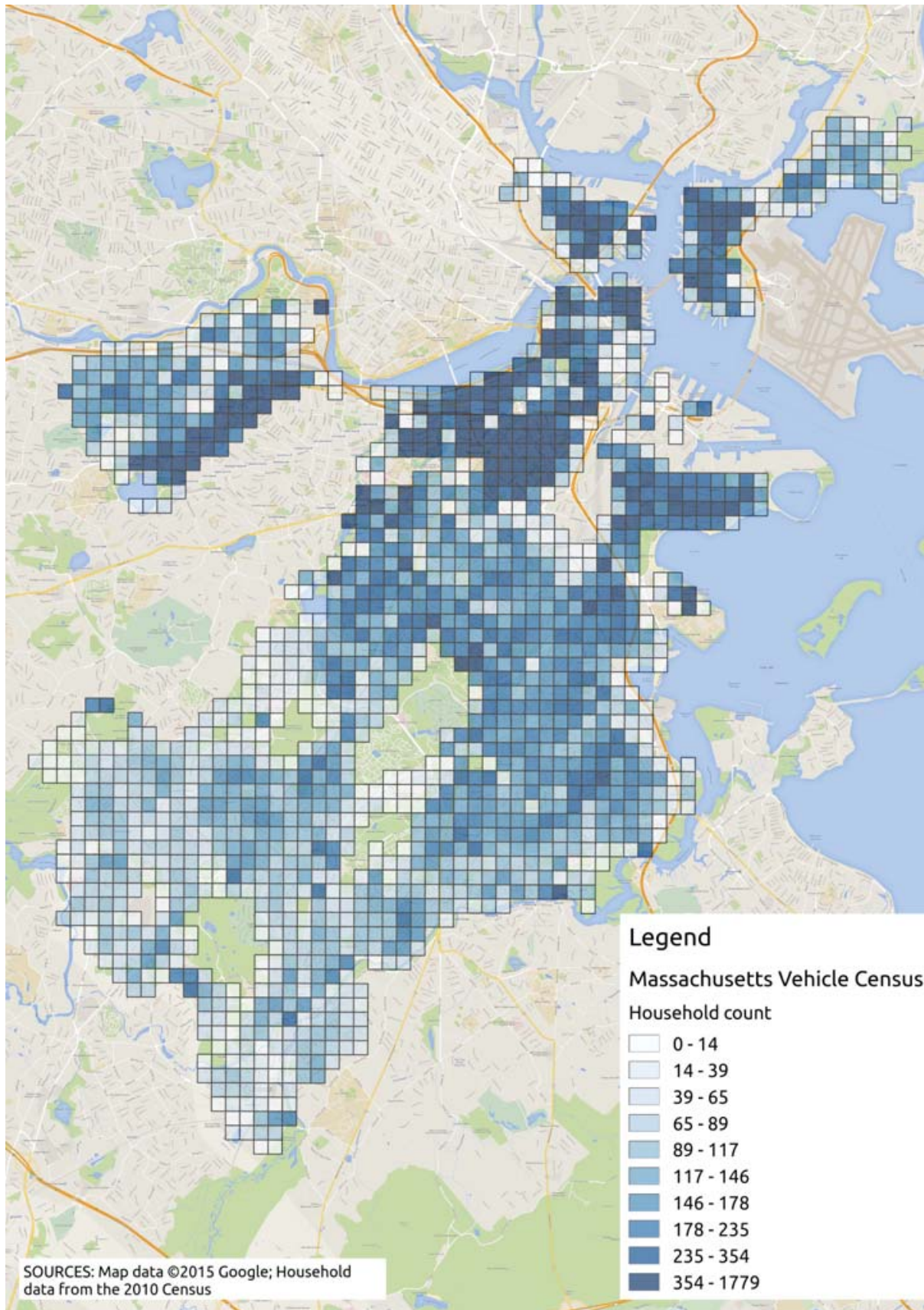


FIGURE 11: VEHICLES PER HOUSEHOLD

**FIGURE 12: NUMBER OF HOUSEHOLDS IN A CELL**

Appendix D: Studies on Impacts of Car-Sharing

STUDY	REGION (YEAR)	VEHICLES SHED PER SHARED CAR	VMT AND GHG EMISSION CHANGES	SAMPLE SIZE	METHODOLOGY	VALIDITY
Clayton Lane. PhillyCarShare: First-Year Social and Mobility Impacts of Carsharing in Philadelphia,	Philadelphia, PA (2003)	23	Reduction of several hundred VMT per month	262	Before-and-after survey	Moderate
Richard Katzev. CarSharing Portland: Review and Analysis of Its First Year	Portland, OR (1999)	3.5	No change	64	Before-and-after survey	Moderate
TCRP Report 108: Car-Sharing: Where and how it succeeds	North America (2004)	13.9	N/A	1,340	Before-and-after survey	Low
Elliot Martin, Susan Shaheen, Jeffrey Lidicker. Impact of Carsharing on Household Vehicle Holdings: Results from a	North America (2008)	4-6; 9-13 (including foregone purchases)	N/A	6,281	Before-and-after survey – controlled for confounders	High
Elliot Martin, Susan Shaheen. Greenhouse Gas Emission Impacts of Carsharing in North America	North America (2008)	N/A	Reduction of 0.58 to 0.84 metric tons per year	6,281	Before-and-after survey – controlled for confounders	High
Robert Cervero. City CarShare: First-year travel demand impacts	San Francisco, CA (2001)	None	None	220	Matched-pair analysis with a treatment and control group	High
Robert Cervero, Yuhsin Tsai. City CarShare in San Francisco, California: Second-Year Travel Demand and Car	San Francisco, CA (2003)	6; 7 (including foregone purchases)	None	516	Matched-pair analysis with a treatment and control group	High
Robert Cervero, Aaron Golub, Brendan Nee. City CarShare: Longer-Term Travel Demand and Car Ownership Impacts	San Francisco, CA (2005)	5	Mode-adjusted VMT reduction 1.87 miles per day; CSO members	572	Matched-pair analysis with a treatment and control group	High

Appendix E: Detailed Review of Shortlisted Studies on Impacts of Car-sharing

For all studies, statistical significance was set at the 5% probability level.

Martin; Shaheen; Lidicker. Carsharing's Impact On Household Car Holdings: Results from a North American Shared-Use Vehicle Survey (March 2010)

Methodology

Ten major CSOs operating in North America sent an email to all members inviting them to take an online survey that opened in September and closed on November 7, 2008. The survey questionnaire used questions to facilitate “before-and-after” analysis. For vehicle shedding, it asked respondents about the changes in household vehicle ownership. Entry into a draw for \$100 worth of car-sharing credit was provided as an incentive for responses.

The population of interest was all CSO members in North America and the final sample size was 6,281 individuals. The final sample excluded two markets: college and exclusive business/government use because the survey was focused on the residential or neighborhood car-sharing models. The study also assigned zero impacts to self-identified inactive members.

To handle potential confounders, questions were included to identify factors such as home or workplace moves that had impacts on travel patterns. Respondents who answered in the affirmative to such questions were excluded from the final sample.

Results

Within the sample of 6,281 individuals, a net (including increases in vehicle ownership) of 1,461 vehicles were shed. Among US respondents, ownership went from 0.55 vehicles per household “before” car-sharing to 0.29 vehicles per household after, a reduction of almost 50%.

To determine industry-wide impacts of carsharing, the researchers projected the results from the sample on the industry in July 2009 (378,000 members and 9,818 vehicles). This extrapolation was done using the following formula:

$$\text{Vehicles Shed per Shared Car} = \{[(100\% - \text{Inactive Share } \%) * 314,390 / 6,281] * 1,461\} / 9,818$$

The 314,390 is the number of households that is derived by scaling the 378,000 membership down by 8% (the proportion business, government, and college members in the sample) then adjusting that figure for the 19% of respondents in the sample who belonged to household with two CSO members. Using sensitivity analysis where the share of inactive members is assumed to be between 15% and 40% across the entire membership, the number of vehicles shed is estimated to be between 4 and 6 per shared car. If foregone purchases are included, this number rises to 9 to 13 per shared car.

Assessment

There are issues with the internal validity of the study in terms of the claim that vehicle shedding was caused by being an active CSO member; it is unclear if the members would not have sold their cars even if they hadn't joined a CSO. The study claims that researchers asked questions to identify confounding factors or events and removed responses from the analysis if either was found. However, the degree to which this reduced omitted variable bias is uncertain. The extrapolation of sample data to the larger population could also potentially be problematic.

That said, the study is relatively sound methodologically and is the largest (in terms of sample size) study of car-sharing.

Martin; Shaheen. Greenhouse Gas Emission Impacts of Carsharing in North America (December 2011)

Methodology

The study employed the methodology and data gathered from “Carsharing’s Impact On Household Car Holdings: Results from a North American Shared-Use Vehicle Survey”. It examined two impacts. The first was the observed impact, which was the physically measurable emission change that resulted from changes in driving behavior for a household with CSO members. The second impact was described as the “full-impact”. This represented the estimated change in emissions due to foregone trips. The study assumes that these foregone trips would have been made if the household had not reduced its vehicle holdings due to car-sharing.

Results

The estimated observed reduction in GHG emissions was 0.58 metric tons per year for member households. The full impact was estimated to be a reduction 0.84 metric tons per year. Both of these estimates were statistically significant.

Assessment

Refer to the assessment of “Carsharing’s Impact On Household Car Holdings: Results from a North American Shared-Use Vehicle Survey”.

Cervero. City CarShare: First-Year Travel Demand Impacts (November 2002)

The study analyzes three surveys administered to members and non-members over the first year of City CarShare’s operation in San Francisco, the first of which occurred between mid-February and early-March 2001 before City CarShare’s launch. The remaining surveys were administered 3-4 months and 8-9 months into the program.

Methodology

The study employed a matched-pair analytical approach with a treatment (i.e. members) and control group (i.e. non-members). The control group, referred to as non-members, consisted of individuals who had registered for City CarShare, but had not formally joined as there was no POD in their neighborhood. The treatment group, referred to as members, consisted of those who had formally joined. Sample sizes for the three surveys were 143 members and 155 non-members for the first, 105 members and 94 non-members for the second, 131 members and 89 non-members for the third.

Results

In terms of VMTs, the survey showed an increase in the VMTs of members. This was attributed to the majority of members not owning private vehicles and increasing their VMTs as they added a shared car to their transportation mix. However, this increase was not statistically significant. No significant change in vehicle ownership as observed, although this is attributed to the car-sharing program being relatively new.

Assessment

Refer to combined assessment in “City Carshare: Long-Term Travel Demand and Car Ownership Impacts” below.

Cervero; Tsai. San Francisco City CarShare: Second-Year travel Demand and Car Ownership Impacts

The second in the series of studies on City CarShare to examine its impacts two years after it was launched. Its data was drawn from fourth survey was conducted on members and non-members (i.e. the statistical control group) in early-to-mid March 2003.

Methodology

This study continued to employ the same matched-pair analytical approach in Robert Cervero's "City CarShare: First-Year Travel Demand Impacts" with a sample size of 462 members and 54 non-members.

Results

Once again, no statistically significant decline in VMTs for members relative to non-members was detected.

However, membership did increase the likelihood of shedding a vehicle or foregoing the purchase of one. This result was statistically significant at a 5% probability level. For the typical survey respondent (i.e. non-Hispanic living with unrelated adults in a household with 0.3 cars per member), a member was 27 percentage points more likely to shed a vehicle or avoid purchase than a non-member. Broadly speaking, 6 out of 25 member households give up a car within two years, while 1 in 25 non-member household added a car in the two years of the program. Therefore, a City CarShare vehicle takes 7 (6 shed, 1 avoided) vehicles off the road.

Assessment

Refer to combined assessment in "City Carshare: Long-Term Travel Demand and Car Ownership Impacts" below.

Cervero; Golub; Nee. City Carshare: Long-Term Travel Demand and Car Ownership Impacts (2007)

The third (and final) in the series of studies on San Francisco's City Carshare where a fifth survey was conducted on members and non-members in March 2005, four years after the program was launched.

Methodology

This study continued to employ the same matched-pair analytical approach in Robert Cervero's "City CarShare: First-Year Travel Demand Impacts" with a sample of 527 members and 45 non-members.

Results

While there was no statistical significant decline in VMT among members, when adjusted for mode (walking, cycling, and transit are counted as zero since they add no new vehicles) and occupancy (number of occupants in a motorized vehicle), statistically significant declines of 67% were recorded.

There was little difference in the changes in household vehicle ownership between members and non-members though members were less likely to increase ownership. This is due to the survey asking members if they had gotten rid of a car between 2003 and 2005, which is suggestive that most of the shedding occurred between 2001 and 2003 and subsequently levelled off after 2003. The study also includes ordinal logit model using data over the entire period (2001-2005) in predicting five rank-ordered changes in household vehicle ownership: net reduction of two or more cars; net reduction of one car; no change; net increase of one; or net increase of two or more. The model finds that membership is associated with net declines in vehicles ownership.

Assessment

Methodologically, the City CarShare studies are the strongest among the literature surveyed. The use of matched-pair analysis allows a greater degree of attribution in behavioral changes to the car-sharing as opposed to other factors (e.g. increasing fuel prices). This is because these factors can be assumed to effect members and non-members equally. One concern is that the size of the non-members is small relative to the member sample and declines with each iteration of the study. Though this is probably due to City CarShare expansion over the five years, it introduces a degree of uncertainty about the conclusions that the papers draw.

Appendix F: Predictive Model on Changes in Vehicle Ownership for City CarShare

In the final installment of the three paper series on San Francisco's City CarShare,⁶⁸ Cervero et al created a model using ordinal logit estimates for predicting net changes in vehicle ownership among survey respondents. The following rank orders were used:

1. Net decrease of two or more cars
2. Net decrease of one car
3. No net change
4. Net increase of one car
5. Net increase of two or more cars

The results are in the table below:

CUTOFFS (NET CHANGE IN OWNERSHIP)	COEFFICIENT ESTIMATE	STANDARD ERROR	PROBABILITY
-2 or more cars	-7.301	0.811	0
-1 car	-4.222	0.676	0
No change	-0.26	0.638	0.684
+1 Car	3.644	0.953	0

Location

City CarShare Member (Yes: 1; No: 0)	-0.978	0.402	0.015
Owens a transit pass (Yes: 1; No: 0)	-0.414	0.199	0.038
POD within ½ of residence (Yes: 1; No: 0)	-0.497	0.225	0.028
Has children (Yes: 1; No: 0)	0.514	0.297	0.084
Age (years)	-0.029	0.01	0.003
Drive to work (Yes: 1; No: 0)	2.765	0.479	0

Summary statistics

Sample size	530
R2	0.069
Model Chi-squared (Probability)	61.45 (0.000)

In an ordinal logit, there is a coefficient for each cutoff (i.e. rank order), which together with the other coefficients is used to create a value (S) that is passed through the cumulative logistic distribution function to get a cumulative probability for that cutoff and the ones that are ranked below it.

$$S = \beta_{Cutoff} - (\beta_{Member}Member + \beta_{Transit}Transit + \beta_{Pod}Pod + \beta_{Child}Child + \beta_{Age}Age + \beta_{Drive}Drive)$$

$$\Pr(Y \leq \Delta Change \mid Member, Transit, Pod, Child, Age, Drive) = \frac{1}{1 + e^{-S}}$$

Using the functions above, the estimated probability that a 31 year old, childless, transit pass holder who does not drive to work, and has POD close by will give up 1 or more vehicles (the cumulative probability of the first two ranks) is:

- » 19.25% for members
- » 8.23% for non-members

This means that a member of CityCarshare (with the aforementioned characteristics) was 11 percentage points more likely to give up one or more vehicles (net) than a non-member.

⁶⁸ Cervero, Golub, and Nee, "City CarShare."

Appendix G: Determining Mobility Scores

To calculate mobility scores, this report adopted and modified Matthew Danish's approach.⁶⁹ Using the MBTA's General Transit Feed Specification (GTFS) files and cells MassGIS grid framework, each cell in Boston was given a mobility score as follows:

1. Find all Hubway, bus, streetcar, and subway stations within range of the center of the cell. To be considered within range⁷⁰
 - » a Hubway station would need to be within 400 meters,
 - » a bus stop would need to also be 400 meters,
 - » a streetcar station would need to be 800 meters,
 - » and a subway station would need to be within 1,000 meters.
2. For each of these stations, determine their actual (straight line) distance from the center of the cell as well as their frequency of service (i.e. how many times does a bus or train stop there on a given weekday). For Hubway, the frequency was set at 10, the assumed average number available bikes.
3. Sum the result of frequency divided by distance for all of stations within range of the cell to get the mobility score for that cell.

$$\text{Mobility Score} = \sum_{\text{stop}} \frac{\text{Frequency}_{\text{stop}}}{\text{Distance}_{\text{stop}}}$$

There are several caveats related to this approach:

- » A stop doesn't have to be within Boston city limits to be considered within range of a cell.
- » The distances used for the within range determination as well as the actual distance from the center of a given cell are straight line distances. This means that they could potentially understate the actual (i.e. walking) distances to the station.
- » Besides being privileged in terms of acceptable distances, streetcar and subway stations enjoy an added advantage because their two-way nature (Inbound and Outbound) effectively doubles their frequency.

⁶⁹ Danish, "Exploring Transit and Driving Behavior in MA, with Google Fusion Tables."

⁷⁰ Jarrett Walker, "Basics: Walking Distance to Transit," *Human Transit*, April 24, 2011, <http://www.humantransit.org/2011/04/basics-walking-distance-to-transit.html>.

Appendix H: Study Protocol to Examine the Impacts of Car-Sharing in Boston

Unit of analysis: Household

Unit of randomization: 250mx250m cell

Explanatory variable: Number of shared cars added to the cell since the beginning of the study

Study Duration: Four years

Outcome variables (household level)

- » Number of private vehicles owned by the household as well as their attributes (e.g. year, make, model, fuel efficiency)
- » Average daily vehicle miles travelled and GHG emissions
- » Number of CSO members

Data source(s)

- » Vehicle registry and inspection records from the Massachusetts Registry of Motor Vehicles (a division of the Massachusetts Department of Transportation) – this is the same data that the Massachusetts Vehicle Census was able to access and use.
- » CSO Membership Data
- » Census Data

Sampling Size Selection

In order to detect a 0.11 (or 11%) vehicle ownership reduction⁷¹ with a power of 0.8 and a standard deviation of 1.065 vehicles, the study needs approximately 1,500 households in each arm. This means a sample size of 3,000 households is required. Based on the 2010 census, there are (on average) 125 households in a cell. This means approximately 30 cells are required. However, given the potential for confounders and the small size of the effect, a larger sample of 80 cells is recommended.

Randomization Method

1. Identify partner car-sharing organizations (CSOs) that are willing to participate in the study. An incentive would be to only allocate public parking spaces throughout the City of Boston to CSOs that participate in this study. Additional incentives such as discounting the price of permits or allocating more public parking spaces can also be used.
2. Ask the partner CSOs to choose 80 cells (from the 2,057 250mx250m cells that cover Boston; see Figure 13) where they would like to place at least four additional shared cars in public parking spaces over a two year period. Any cell can be chosen with the condition that there is a two-cell gap between each of the chosen cells to prevent crossover effects.
3. Each cell is matched with another cell that shares similar characteristics. These matching characteristics are:
 - a. Population
 - b. Number of CSO members

⁷¹ This is the reduction detected by Cervero et al in the final installment of their studies on City CarShare.

- c. Average number of vehicles per household
 - d. Average household income
4. From each pair, one cell is chosen at random for assignment to the treatment arm, the other is assigned to the control arm.
 5. The values of the outcome variables above are recorded for all households in the study (i.e. the “before” value).
 6. The experiment begins with the City of Boston allocating public parking spaces to shared cars in the treatment cells. This continues as necessary for the study duration. For the duration of the study:
 - » **CSOs are not allowed to increase the number of shared cars in private or public parking spaces in and two cells out (i.e. the “border”) from cells in the control arm.**
 - » CSOs are allowed to increase the number of shared cars in both private and public parking spaces in and around cells from the treatment arm as long as the previous restriction is respected. The City of Boston needs to be notified about cars added to private parking spaces.

Standard Errors

As the mechanism of assignment is at the cell level, while the unit of analysis is at the household level, clustered standard errors should be used in the analysis.

Measuring the Impact

Model 1 (Difference-in-difference)

For each household let:

- » Y_h : Outcome variable
- » D_h : The number of shared cars in private or public parking spaces within 400 meters of the household
- » T_h : A dummy variable that is set to 0 if the observation was before the experiment started and 1 if was after the experiment started

$$Y_h = \beta_0 + \beta_1 D_h + \beta_2 T_h + \beta_3 (D_h * T_h) + \varepsilon_h$$

The coefficient β_3 on the interaction term ($D_h * T_h$) is the estimated causal effect of a one shared car increase on Y_h .

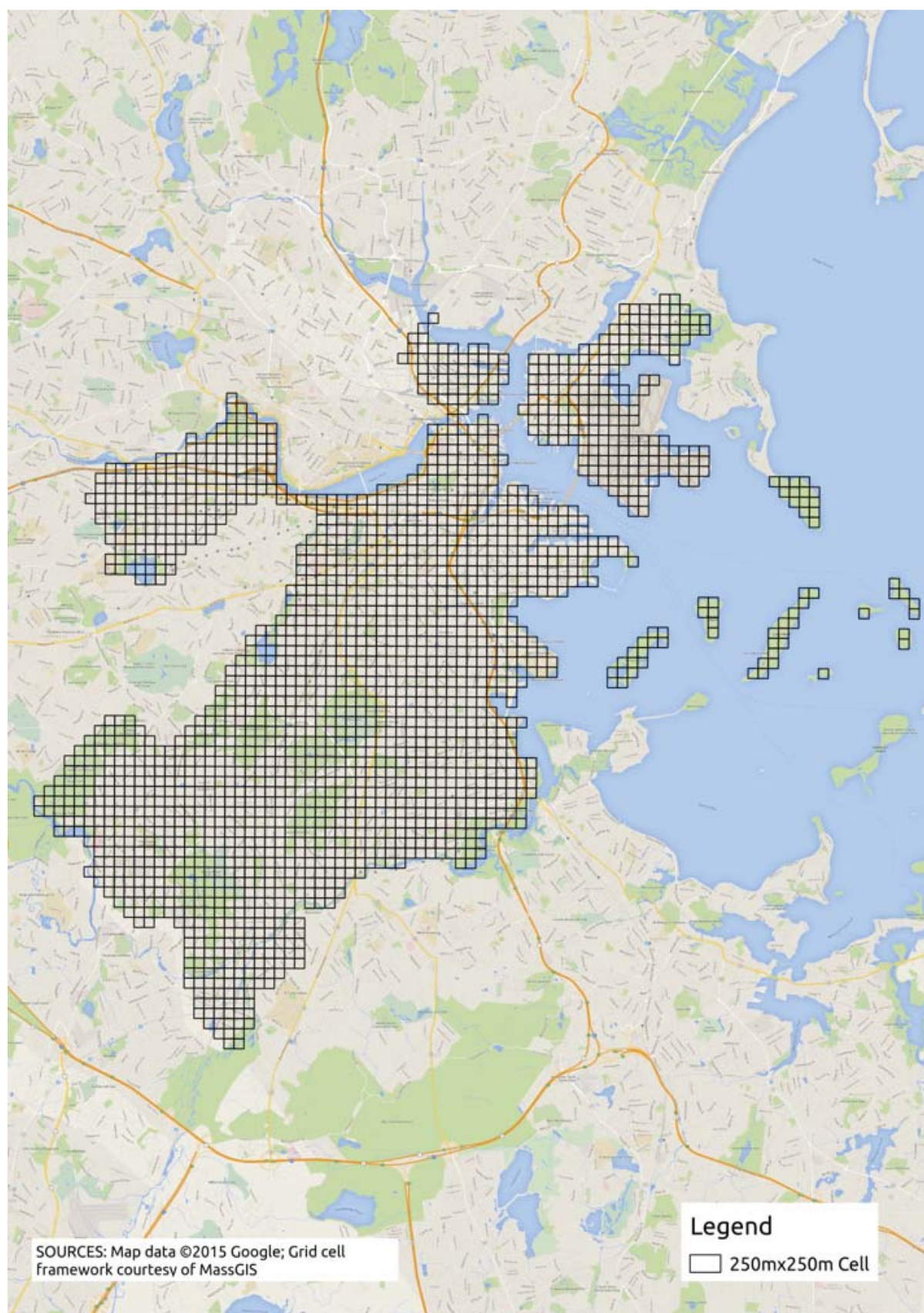


FIGURE 13: 250MX250M CELLS FOR BOSTON

