THE TAXICAB AS PUBLIC TRANSPORTATION IN BOSTON

Drew Austin (corresponding author)
Port Authority of New York & New Jersey
(317) 372-1320
91 Nevins St. #2
Brooklyn, NY 11217
aaustin@panynj.gov

P. Christopher Zegras
Massachusetts Institute of Technology
Department of Urban Studies and Planning
(617) 452-2433
(617) 258-8081 (fax)
77 Massachusetts Avenue, Room 10-403
Cambridge, MA 02139
czegras@mit.edu

ABSTRACT

This paper investigates the taxicab and its role as a form of public transportation, using Boston's taxicab system as an opportunity to study the mode's function in the city as well as its relationship to other forms of transportation. In many American cities, the taxicab is an important but frequently overlooked public transportation mode, and it represents a significant opportunity to provide mobility in many places where conventional mass transit cannot do so in a cost-effective manner.

The central inquiry of this paper is when and where the taxicab operates as a complement or a substitute to Boston's mass transit system, and which factors appear to affect its fulfillment of each role. Taxicab activity in Boston is analyzed using trip-level data recorded for Boston taxicabs during the past two years, mapping taxicab activity and specifying regression models that illuminate significant relationships between the taxicab, transit access, and other characteristics of the urban environment. Evidence suggests that the taxicab acts as both a mass transit substitute and complement in Boston, and that this tendency varies by transit line and time of day. These models are also used to infer the existence of unmet demand for taxicab service.

I. INTRODUCTION

The taxicab is an important but easily overlooked component of urban transportation systems in the United States, making significant contributions to urban mobility and constituting the only public transportation available in certain urban areas (Frankena and Pautler 1984). Operationally, taxicabs exhibit great flexibility: A taxicab can transport a passenger directly between any two locations in a city at any time, although regulatory constraints may limit this ability. In cities or districts with higher densities of taxicab activity, a passenger can typically hail a cruising taxicab spontaneously. A public transportation system should provide mobility between any two points in a city, but trains and bus routes are too far from many origins and destinations to accomplish that objective alone (Alexander 1977); thus, taxicabs augment fixed-route transit in many cities.

Despite its importance as a mode of transportation, the taxicab receives less attention from planners and policymakers than other publicly available modes found in cities, and does not benefit from the direct subsidies that support mass transit. Furthermore, aside from the objectives of protecting customers and preventing excessive competition, current taxicab regulations reveal few coherent goals for the taxicab's role in the urban transportation system, and in general they do not articulate a vision for the industry.

If the taxicab fails to fill gaps in the accessibility pattern that Boston's other transportation modes create, it may not be serving its optimal purpose. If the taxicab should, in fact, fulfill a specific purpose or set of purposes, then a nuanced understanding of how the taxicab currently functions in cities is a necessary prerequisite to understanding how its role might change. This paper examines the taxicab system of one major U.S. city, Boston, to assess the taxicab's recent performance there and draw conclusions that have relevance for other cities as well.

This paper's central question is the following: *How is taxicab activity distributed throughout Boston, and does supply appear to match demand effectively?* More

specifically, this paper inquires what observed taxicab activity reveals about total demand for taxicab travel by investigating the factors that appear to influence (or at least exhibit a significant correlation with) taxicab supply and demand in Boston, as manifested in the form of trips that actually occur. The relationships observed between Boston's taxicab activity and its transit network, in particular, are vital clues about how taxicab supply and demand relate to overall supply and demand for public transportation in the city, and how the taxicab functions as one component of that larger urban transportation system. Complete records of individual trips by Boston taxicabs, which the City has collected for the past two years, enable the mapping and regression analysis of taxicab activity that will help to answer to these questions.

II. BACKGROUND AND LITERATURE REVIEW

Literature that addresses the taxicab's role in urban transportation tends to occupy one of three tiers corresponding to its breadth of inquiry: At the highest tier, studies situate the taxicab within the complete multimodal transportation system and consider how the taxicab system can best fit the city it serves. The second tier of literature treats the urban context and other transportation modes as exogenous, evaluating the taxicab industry in terms of social efficiency but confining its scope to that mode alone. The third tier, finally, focuses attention on a single taxicab stakeholder group—most frequently taxicab operators—and examines how that group might better achieve its own goals, such as operating more profitably.

TIER ONE

The first tier of literature considers the taxicab as part of a larger urban transportation system, typically emphasizing the taxicab's optimal role within that system and within cities. In a comprehensive historical review of the taxicab industry, Gilbert and Samuels (1982) cite conventional transit's inability to provide satisfactory mobility to certain urban areas in a cost-effective manner, and see taxicabs as one solution to that problem. Their book's historical account examines the taxicab's role through this lens, supporting the argument that public transit programs and subsidies should incorporate taxicabs.

Webster et al. (1974) advance a similar argument, emphasizing “improvement in intra-city public transportation within urbanized areas through better integration of taxi services with mass transit” (6-3). They cite key operational advantages of the taxicab as a mode, including its low capital requirements and its ability to serve a wide range of origin-destination pairs.

Cervero (1997) advances a similar case for paratransit in general. Paratransit, he states, can encourage modal shifts away from cars, increase travel choices, enhance mobility in poor neighborhoods, and shoulder a portion of transit systems’ peak demand. Cervero offers a Berkeley case study in which unsubsidized shared-ride taxicabs effectively extended existing bus service between a transit station and a racetrack four miles away. More than 60 percent of rail passengers transferred to taxicabs to reach the racetrack and the taxicab operators matched the competing bus route’s $2 fares. Evidence therefore suggests that a symbiotic relationship between taxicabs and mass transit is feasible and desirable, although rare.

TIER TWO

The second tier of taxicab literature focuses more narrowly on the taxicab industry, studying demand for the mode and inquiring how taxicabs might increase their benefits to passengers or society (including drivers and owners). Net social benefit, as conceived by much of this literature, is the sum of aggregate consumer surplus and profit, the latter of which is often assumed to be zero under perfect competition. By invoking the idea of a social optimum, this tier differs from the first in a critical way: This literature assesses the taxicab industry’s contribution to social welfare independently of its relationship to other transportation modes.

Many have studied the taxicab industry’s fare controls and entry restrictions in order to understand how each affects the equilibrium of taxicab supply and demand in various cities (Douglas 1972; Schroeter 1983; Koehler 2004; Schaller 2007). Others contend that properly informed regulations can contribute to socially optimal or second-best outcomes but acknowledge the difficulty of obtaining “suitable information” (Beesley and

Glaister 1983, 594; Cairns and Liston-Heyes 1996). In general, this literature asks how the taxicab industry can maximize its efficiency for a given fare price—a critical question, but one that addresses taxicab supply and demand in place of overall mobility.

TIER THREE

The third tier of taxicab literature focuses its analysis on separate stakeholder groups within the taxicab industry—typically operators or passengers—and those groups' specific aims. Several studies have introduced models that predict the spatial distributions and route choices of taxicabs using data on drivers' past behavior, noting these models' capacities to streamline radio dispatching and provide "context-sensitive route recommendations" to drivers (Ziebart et al. 2008, 1; Chang et al. 2010; Phithakkitnukoon et al. 2010). The same models could also offer potential customers the ability to quickly locate vacant taxis. Liu et al. (2009) use data on Shenzhen taxicab drivers' routes and revenue to evaluate their "mobility intelligence," or income-maximizing skill. This body of research seeks specific tools, often technologically-focused, that allow taxicab drivers to operate more efficiently and enable customers to travel more conveniently.

THE ROLE OF THE TAXICAB

Taxicabs function as both public transportation and private enterprise in different situations. American taxicab regulations emerged during the Depression with the primary goal of protecting the industry's profitability rather than ensuring provision of a valuable public service, and in Boston and in many other cities, those regulations remain in effect today. Mass transit systems often operate according to service standards that ensure minimum levels of mobility throughout a city, but no such standards (or subsidies) dictate the spatial distribution of privately-operated taxicab service. Thus, profitability exerts a more powerful influence on taxicab distribution than on the service of other public transportation modes. In general, the constraint that taxicab operators must operate profitable service limits their ability to function as a pure form of public transportation.

When taxicabs do not have a formal relationship to a city's public transit system—the more common scenario—they still function as public transportation, and demand for cruising taxicabs overlaps with demand for mass transit and other modes. In cities with high levels of transit service, such as Boston, the market for taxicabs becomes more complex. How passengers use taxicabs when other modes are available, and when they are not, is a key question that this paper addresses.

One cannot understand the taxicab's role in any city without understanding *whom* the taxicab serves, and recommendations for improving a city's taxicab system should reflect an assessment of who will benefit from those improvements. The spatial availability of taxicabs influences who benefits from them, but so does the nature of urban travel demand. Two particular taxicab customer groups, as described in transportation demand literature, are of interest here: choice riders and captive riders. In light of the taxicab's role as public transportation, the choice between taxicabs and mass transit in cities like Boston, which have both, assumes particular relevance: Taxicab trips that complement mass transit or substitute for it should, logically, correspond somewhat (though not perfectly) to the respective presence of captive and choice taxicab riders.

If the taxicab is operationally suited to provide service where fixed-route transit does not, and if "taxis and transit should be seen as natural complements" (Design Trust for Public Space 2007, 132), then captive taxicab riders, who find themselves temporarily or permanently without access to fixed-route transit, stand to gain the most mobility from that complementary relationship. The taxicab's primary function as a complement to mass transit is the mobility it offers its captive riders, as defined above, and that complementary role has both spatial and temporal components: Mass transit service is not only uneven in its spatial distribution throughout a city, but also in its distribution by time of day. In Boston's case, no transit is available whatsoever during a certain period of the night and the taxicab's captive market share increases accordingly during that time (although overall travel demand decreases). Furthermore, one's location at an origin near a transit station or bus stop does not constitute transit access if transit does

not also serve the desired destination. For these reasons and others, an individual's status as a captive taxicab rider is circumstantial. The effectiveness with which taxicabs serve these captive riders, by filling in the gaps that transit does not reach, is an important question that this paper asks.

TAXICABS IN BOSTON

Boston's large taxicab system is one of many municipal taxicab systems in that metropolitan area. The Hackney Carriage Unit of the Boston Police Department licenses and regulates Boston's taxicabs, and as of 2011, Boston licensed 1,825 taxicab medallions. The Boston Police Department (2008) defines a medallion as "a license granted to a suitable individual to operate a vehicle as a Hackney Carriage in the City of Boston" (3). Although a medallion belongs to an individual, it corresponds to a specific vehicle, or Hackney Carriage, and must remain attached to that vehicle at all times. The municipalities that surround Boston also license taxicabs individually. Cambridge, for example, licenses 257 taxicabs.

While Boston itself accounts for many more taxicabs than any single nearby town, taxicabs licensed by the towns that neighbor Boston add up to a significant share of the area's total. Boston taxicabs are legally prohibited from picking up street hail passengers outside of Boston, and suburban taxicabs cannot pick up street hail passengers within Boston. As a result, Boston taxicabs provide high levels of outbound service and suburban taxicabs provide disproportionate inbound service. In addition to these regulations, the City of Boston sets precise fares for its licensed taxicabs, with meter rates determined by distance traveled. As of January 1, 2011, the "drop rate" for Boston taxicabs was $2.60, covering the trip's first 1/7 mile, while each subsequent 1/7 mile cost $0.40.

III. DATA AND METHODOLOGY

TREATMENT OF DEMAND

Taxicab trips represent *realized demand* or a clearing of the market for travel. A trip occurs when transportation services charging a certain price encounter passengers for whom the relative utility of those services exceed the utility of other available options (including the option of not traveling at all). If one interprets the *generalized cost* of transportation as a combination of a trip's monetary and non-monetary (time) costs, then the spatial and temporal availability of a mode become important factors that influence when and where the market for that mode clears. In situations where willingness to pay exceeds that generalized cost, passenger demand will manifest itself as realized demand; when generalized cost exceeds willingness to pay, it will not. All else being equal, higher taxicab service levels should lead to more realized taxicab demand. While this paper does not attempt to quantify unmet taxicab demand, it examines the characteristics of areas within Boston that the taxicab serves poorly in its capacity as a complement to mass transit. Populated areas that lack taxicab and mass transit mobility alike, exhibiting characteristics that suggest the presence of captive riders, will emerge as the most likely locations that taxicabs underserve.

SCOPE

This analysis confines its scope to the 1,825 medallion taxicabs licensed by the City of Boston—the taxicabs for which detailed trip level data have been collected since 2009. Municipalities adjacent to Boston, such as Cambridge, have substantial taxicab systems of their own that also transport passengers to Boston; however, the lack of available trip-level data for these systems precludes their close examination here.

The full geographic scope of this research extends well beyond Boston's borders, as Boston taxicabs serve many destinations outside of Boston. Different levels of analytical detail are possible at two separate scales: Trips that begin and end in Boston, and trips that either begin or end outside of Boston. Boston taxicabs serve the vast majority of

trips that both begin and end in Boston, so available taxicab trip data will almost completely capture this category. Approximately 82 percent of trips by Boston taxicabs in the four-weekday sample examined here remain within city limits. The second category of trips, those with suburban origins or destinations, is reflected less completely by Boston taxicab data because suburban taxicab systems also serve these trips. Boston taxicabs serve a significantly higher share of outbound trips, which begin in Boston and end elsewhere, than inbound trips, which originate in suburbs.

Due to the research objectives presented here, which emphasize passengers' ability to obtain taxicab service in Boston itself, taxicab trips that originate outside of Boston (2.6 percent of all trips in the four-day sample) are excluded from analysis. Thus, this paper examines two trip categories—Boston-to-Boston trips and Boston-to-suburb trips—and Boston taxicab data should provide nearly complete samples for both categories.

This analysis uses a sample comprising four 24-hour weekday periods of taxicab activity: May 12, 2010; August 4, 2010; October 20, 2010; and January 26, 2011. All four sample days are Wednesdays, spread evenly throughout the year. The large volumes of daily taxicab activity in Boston, the difficulty of processing larger quantities of data, and the general consistency observed across these four separate days justify this sample size. Every taxicab trip that begins between midnight and 11:59 p.m. on each date is included in that date's selection (meaning that some included trips end on the following day). Weather, which influences taxicab demand, is fairly consistent throughout the four-day sample. Finally, no known disruptions caused significant data anomalies on any of the four sample days, with the exception of a few professional sporting events that had little visible impact on taxicab activity patterns.

DATA

The data that form the foundation of this analysis are records of trips made by Boston taxicabs. The mandatory installation of rear-seat, self-swipe credit card payment devices in every Boston taxicab in 2009 gave the City the capacity to digitally record

detailed information about every trip, regardless of a customer's actual payment method. Two separate providers, Creative Mobile Technologies (CMT) and Verifone, implemented this technology in Boston's taxicabs and manage the data collection process. Each taxicab trip record comprises a number of trip characteristics, including pickup and drop-off locations (latitude and longitude coordinates), pickup and drop-off times and dates, fares paid, and taxicab medallion numbers. This information, which resides in CMT and Verifone databases, facilitates the mapping of taxicab trip origins and destinations using GIS software.

The taxicab trip data just described are relatively complete and precise, although some data have been excluded from analysis. The majority of trip data remain usable, but exclusion of certain trip records occurs when origin or destination coordinates are missing. In the four-day sample used here, 89 percent of trip records have complete coordinates and are usable in the following analysis. The distribution of trips with missing coordinates appears to be random and unbiased.

METHODOLOGY

Modeling taxicab trip generation requires regressing taxicab pickup counts by census block group, a dependent variable, on characteristics of those trips' origins, including population, land use patterns, and transit access. Separate models are specified for four different times of day, highlighting the factors that are correlated with taxicab service levels and illuminating the taxicab's role as a transit substitute or complement in Boston.

This methodology raises the paper's central question: Do places in Boston with poor transit access also tend to have inferior taxicab service, and does this indicate the presence of unmet demand for mobility? Which parts of Boston are underserved by the taxicab? The taxicab may be more important in areas that lack other mobility options and passengers' willingness to pay, which partially depends upon their income, may be lower in less affluent parts of Boston and not fully reflect the taxicab's importance there. Understanding whether transit access improves the likelihood that an area will generate

taxicab trips, all else being equal, is a first step toward knowing which role for the taxicab—transit complement or substitute—existing conditions favor. If evidence shows that areas with transit access generate more taxicab trips than comparable areas without transit, this will suggest that, in general, taxicabs are less likely to serve those who lack other public transportation options and might depend upon the taxicab more. The question of whether such an outcome occurs due to a lack of taxicab supply, a lack of travel demand, or both follows from that inquiry.

To answer the questions just posed, regression analysis is used to model realized taxicab demand as a product of transit access as well as other temporal and spatial characteristics that influence taxicab activity. By controlling for factors like population, the models specified here isolate the specific relationships between transit and overall taxicab trip generation across census block groups and times of day. Many of these models' independent variables influence taxicab pickup volumes through their impacts on either supply or demand, and this distinction provides evidence of whether taxicab supply or demand is the best explanation when a block group's taxicab activity is lower than expected.

Statistically significant relationships are hypothesized to exist between transit access and taxicab trip generation, but the nature of those relationships is expected to vary by Massachusetts Bay Transportation Authority (MBTA) line and mode (rail or bus). That is, certain types of transit access will be correlated with higher concentrations of taxicab activity, while other types will exhibit negative correlations with taxicab trip generation. Modeling trip generation indicates whether demand for other "public transportation" modes is also higher where transit is available.

The dependent variable in these models is the quantity of taxicab pickups per block group, averaged across the four weekdays in the sample. Each block group therefore constitutes one observation, and the models use 544 observations in all. This unit of analysis allows the models to capture spatial variations in taxicab activity. Four separate models are specified using roughly the same independent variables, and these models

correspond to four separate three-hour periods during the weekday in order to capture different demand patterns (2:00 to 5:00 a.m.; 6:00 to 9:00 a.m.; 4:00 to 7:00 p.m.; 8:00 to 11:00 p.m.). Thus, each model's dependent variable will be the number of taxicab pickups in a block group during a three-hour period. Importantly, the MBTA operates negligible transit service during the overnight observation period, so modeling that period offers insight into taxicab activity when alternative modes are unavailable (and enables useful comparisons with the other three time periods).

The following indicators of transit access serve as independent variables in these models:

- **MBTA rail access:** Four separate variables represent block groups' proximity to the four principal MBTA rail lines (Red, Blue, Orange, and Green) using a function that approximates distance decay. Access to a given line is calculated using the shortest-path distance from a block group's centroid to the nearest station on that line. Each rail access variable assumes a value of zero for block groups within a 0.5-mile distance of that line, and beyond that distance the variable's value increases by the natural logarithm of distance from the rail station. In other words, $x = 0$ when distance from transit d is less than 0.5 miles, and $x = ln(d - 0.5)$ when d is greater than or equal to 0.5 miles. This achieves the purpose of treating block groups within the half-mile walking radius of a transit line uniformly while representing the rapid decline in one's willingness to walk to a transit station beyond that half-mile distance.
- **MBTA Silver Line access:** The Silver Line is a bus rapid transit line and cannot be represented in the same way as rail, because its service levels are generally lower. A dummy variable represents the Silver Line in these models. If a census block group's centroid falls within a 0.5-mile straight-line distance of the Silver Line, that block group assumes a value of 1, and takes a value of 0 otherwise.
- **MBTA bus access:** The number of bus routes accessible from a given census block group at a given time serves as a proxy variable for bus access. A bus

route must intersect a block group to be considered accessible from that block group, and routes with multiple variants are considered as single routes. A second variable represents access to the 11 highest-ridership MBTA bus routes (as listed above) in the same manner. While this approach is crude, the number of bus routes and the complexity of modeling access to each route necessitated simplification. Also, buses are a less competitive taxicab alternative than rail, especially at greater walking distance.

The following list provides brief summary of all other independent variables. Table 1 summarizes all independent variables and dependent variables included in the models specified.

- **Land area:** Total block group land area (km²)
- **Open space:** Total block group open space (km²)
- **Open space %:** (Total open space) / (Total block group land area)
- **Commercial land use %:** (Total commercial land area) / (Total block group land area)
- **Non-residential building volume:** All buildings within a block group whose footprints intersect a non-residential land use, as defined by MassGIS land use codes. Total building volumes are calculated by multiplying each building's footprint area by its height.
- **Zero-car household %:** The percentage of households within a block group that own zero cars, as given by the 2000 Census.
- **Population:** Total population residing in each block group, as given by the 2000 Census.
- **Population density:** (Total population) / (Total block group land area)
- **Intersection density:** Using the GIS Network Analyst tool, Boston's street system is converted into a network with a node representing each intersection. The total number of nodes within each block group is normalized by the block group's land area to calculate intersection density.

TABLE 1: SUMMARY OF VARIABLES

			Mean	Median	Min.	Max.	St. Dev.	Expected Relationship: Trip gen.	Expected Relationship: Transit subst.	Year	Source
Dependent Variables	Taxicab Pickups per Block Group	AM Pk.	6.1	1.00	-	340	25.1			2010-2011	City of Boston
		PM Pk.	10.4	0.50	-	972	61.7				
		Eve.	9.8	0.50	-	696	48.8				
		Night	1.5	0.25	-	61	5.0				
	Transit Substitute Pickups per Block Group	AM Pk.	2.2	-	-	132	10.0			2010-2011	City of Boston
		PM Pk.	4.0	-	-	431	24.4				
		Eve.	4.1	-	-	306	21.0				
		Night	-	-	-	-	-				
	Transit Substitute Share by Block Group	AM Pk.	16%	0%	0%	100%	24%			2010-2011	City of Boston
		PM Pk.	16%	0%	0%	100%	26%				
		Eve.	17%	0%	0%	100%	27%				
		Night	0%	0%	0%	0%	0%				
Independent Variables	Land area (km^2)		0.2	0.1	0	5.8	0.4	+	0	N/A	N/A
	Open space (km^2)		0.0	0.0	0	2.3	0.2	-	0	1999	MIT Geodata
	Open space (%)		9%	2%	0%	143%	16%	0	-	1999	MIT Geodata
	Comm. LU (%)		13%	8%	0%	100%	16%	+	+	2005	MassGIS
	Non-res. bldg. vol. (10^6 m^3)		0.6	0.2	0	18.3	1.5	+	-	2002	USGS
	Zero-car HH (%)		33%	31%	0%	88%	18%	+	+	2000	U.S. Census
	Population (1,000)		1.1	1.0	0	4.1	0.5	+	0	2000	U.S. Census
	Pop. dens. (1,000 per km^2)		9.3	7.6	0	52.1	7.1	0	-	2000	U.S. Census
	Bus routes		4.3	3.0	0	26.0	4.5	-	+	2007	MBTA
	Major bus routes		1.2	1.0	0	7.0	1.5	-	-	2007	MBTA
	Blue Line dist. (log)		8.0	8.6	0	9.6	2.0	+	-	2006	MBTA
	Green Line dist. (log)		6.2	7.7	0	9.2	3.3	+	-	2006	MBTA
	Red Line dist. (log)		6.7	7.5	0	9.1	2.4	+	-	2006	MBTA
	Orange Line dist. (log)		6.5	7.7	0	8.8	2.7	+	-	2006	MBTA
	Silver Line (dummy)		0.1	0.0	0	1.0	0.3	-	+	2006	MBTA
	Int. density (100 per km^2)		1.5	1.3	0	6.6	0.8	-	-	2007	MIT Geodata
	Class 1 road (dummy)		0.1	0.0	0	1.0	0.4	+	+	2007	MIT Geodata
	Class 2-4 road (km)		0.7	0.3	0	16.8	1.4	+	+	2007	MIT Geodata
	Dist. from center (km)		6.2	5.9	0	15.3	3.4	-	-	N/A	N/A
	Med. HH income ($10,000)		4.2	3.9	0.2	11.3	1.9	+	+	2000	U.S. Census
	Airport dummy		0.0	0.0	0	1.0	0.0	+	0	N/A	N/A

KEY	
+	Positive relationship expected
-	Negative relationship expected
0	No relationship expected

- **Class 1 road (dummy):** Any block group intersected by a Class 1 road (limited access highway) has a value of 1; any block group that does not has a value of 0.
- **Class 2-4 road:** The sum of total kilometers of Class 2, 3, and 4 roadways within a block group (comprising most major roads).
- **Distance from center:** Straight-line distance (km) from Boston's City Hall Plaza (an arbitrarily-defined center) to a block group's centroid.

- **Median household income:** A block group's median household income, as given by the 2000 Census.
- **Airport dummy:** A dummy variable that has a value of 1 for block group 106955, which is coterminous with Logan Airport (see above) and a value of 0 for all other block groups.

Taxicab trip counts are modeled using Poisson regression, which treats an independent variable y as a function of $e^{\theta x}$ (the Poisson regression method is commonly used to specify count models). This approach is appropriate for taxicab trip generation, in which individual taxicab pickups are not coordinated with one another and occur at average rates that appear fairly consistent over time.

If the trip count models indicate that taxicab pickups occur more frequently in areas that enjoy better transit access, this does not necessarily mean that those taxicabs are acting as substitutes for transit. A block group near an MBTA station, for example, may generate many taxicab trips to destinations that the Orange Line does not serve directly, thus complementing the mobility it provides. To the extent that this occurs in transit-accessible locations, the taxicab is still filling gaps in Boston's transit network. If a large share of these trips are transit substitutes, however, then taxicabs and transit are simply transporting shares of the same travel demand. Of course, transit access both reflects and reinforces many of the greatest concentrations of travel demand within a city, so the taxicab should serve some portion of travel demand that mass transit could also potentially carry.

IV. RESULTS AND INTERPRETATION

The primary question this paper asks about taxicab distribution is whether transit access typically corresponds to better or worse taxicab activity. Because realized demand is an insufficient indication of total demand, isolating the most important determinants of realized demand facilitates inferences about which areas have more or less taxicab service than expected, based on their characteristics. Regression analysis enables controlling for certain factors to isolate the specific relationships between taxicab activity

and each factor. Some of these relationships may be causal, although regression modeling cannot prove the existence of causality. The relationships between transit access variables and taxicab trip counts, with other spatial variables controlled for, will partially indicate whether transit-accessible places have concentrations of the kinds of travel demand that taxicabs also tend to serve.

Table 2 summarizes the results of the best Poisson trip count model specifications for each of the four time periods chosen (with significant variables in bold and insignificant variables shaded).

TABLE 2: MODEL RESULTS

	6:00 - 9:00 am			4:00 - 7:00 pm			8:00 - 11:00 pm			2:00 - 5:00 am		
	Coef	Std Err	Z	Coef	Std Err	Z	Coef	Std Err	Z	Coef	Std Err	Z
Constant	1.78	0.23	7.64	2.32	0.20	11.49	2.64	0.20	13.07	0.28	0.45	0.63
Land area (km²)	1.05	0.13	8.30	1.65	0.10	16.52	1.26	0.11	11.64	1.01	0.29	3.53
Open space (km²)	(0.51)	0.17	(3.05)	(1.16)	0.13	(8.68)	(0.46)	0.14	(3.27)	(0.63)	0.38	(1.68)
Airport (dummy)	(1.71)	0.46	(3.73)	(5.04)	0.34	(14.62)	(3.68)	0.40	(9.30)	(3.23)	1.12	(2.89)
Commercial land use (%)	1.60	0.10	16.01	1.94	0.09	22.55	1.60	0.08	20.03	1.88	0.18	10.28
Non-res. building vol. (1,000,000 m³)	0.04	0.01	5.11	0.04	0.01	6.86	0.03	0.01	5.10	0.04	0.01	2.63
Zero-car households (%)	(0.34)	0.19	(1.80)	(0.26)	0.17	(1.51)	(0.03)	0.17	(0.19)	0.06	0.36	0.17
Population (1,000)	0.44	0.04	11.91	0.30	0.03	8.69	0.15	0.04	4.27	0.35	0.07	5.27
Med. household income ($10,000)	0.06	0.01	4.40	0.03	0.01	2.51	(0.00)	0.01	(0.30)	(0.03)	0.03	(1.25)
Bus routes	0.04	0.00	7.11	0.05	0.00	12.15	0.05	0.00	11.56	0.04	0.01	4.83
Major bus routes	(0.16)	0.02	(8.28)	(0.05)	0.02	(3.57)	(0.09)	0.02	(5.37)	(0.06)	0.03	(2.05)
Distance from Blue Line (log)	0.12	0.01	10.81	0.03	0.01	3.28	(0.03)	0.01	(3.55)	0.10	0.02	4.50
Distance from Green Line (log)	(0.14)	0.01	(16.31)	(0.22)	0.01	(25.85)	(0.27)	0.01	(31.98)	(0.19)	0.02	(11.68)
Distance from Red Line (log)	0.02	0.01	2.07	0.08	0.01	7.96	0.13	0.01	11.81	(0.00)	0.02	(0.16)
Distance from Orange Line (log)	(0.01)	0.01	(0.78)	0.04	0.01	4.54	0.06	0.01	7.21	0.02	0.02	1.24
Silver Line (dummy)	0.05	0.05	1.08	0.13	0.04	3.10	0.19	0.04	4.48	0.15	0.10	1.50
Distance from center (km)	(0.36)	0.02	(21.01)	(0.42)	0.02	(22.50)	(0.42)	0.02	(21.72)	(0.22)	0.03	(7.36)
Intersections (100 per km²)	(0.29)	0.03	(9.66)	(0.34)	0.03	(12.34)	(0.22)	0.02	(9.85)	(0.16)	0.06	(2.86)
Class 1 road (dummy)	0.21	0.06	3.72	(0.24)	0.05	(4.46)	0.09	0.05	1.72	(0.01)	0.11	(0.05)
Class 2-4 road (km)	0.02	0.02	1.22	0.10	0.02	6.12	0.10	0.02	6.12	0.02	0.04	0.45
Pseudo R^2	0.775			0.887			0.850			0.634		
LR	10599			27492			23295			2160		
Total observations	544			544			544			544		

The models specified reveal significant relationships between taxicab trip counts and several explanatory variables. The individual components of these trip count models are discussed in greater detail here:

- **Constant coefficients:** Predictably, the constant coefficients for all four time-of-day models vary along with overall levels of average daily taxicab activity (although the overnight constant coefficient is not significant): The evening

coefficient is highest (2.64) while the morning peak coefficient is the lowest significant constant (1.78).

- **Block group land area and open space:** Both of these variables also exhibit the expected relationships with taxicab trip generation. A block group's total land area directly affects its trip generation because larger block groups will encompass more taxicab activity on their streets. Similarly, open space is unlikely to generate taxicab trips to the degree that other urban land uses do. In all four models, land area has a significant positive relationship with taxicab pickups and open space has a significant negative relationship with pickups. Both relationships are strongest during the afternoon peak.
- **Logan Airport dummy variable:** The airport is an outlier in Boston's taxicab market and a dummy variable is included in the models to correct for any distortion that it may cause as a trip generator. This variable has a significant negative relationship to taxicab trip generation at all times, with the strongest inverse relationship to taxicab pickups occurring in the afternoon peak. Despite the airport's high taxicab trip generation, other characteristics of the airport's block group (such as land area) would potentially cause these models to predict even higher trip counts for it, hence the negative coefficient values.
- **Population and socioeconomic characteristics:** The positive relationship between population and trip generation is intuitive: People are the source of demand for trips, and more residents in a block group should result in more trips, all else being equal. Non-residential areas generate some of the highest trip counts in Boston, however. If people are traveling from their homes to other activities by taxicab, population captures a portion of that effect. Median household income has a positive relationship with taxicab trip generation during the morning and afternoon peaks, an insignificant relationship to evening activity, and a negative relationship with overnight taxicab pickups. In other words, higher-income areas exhibit more taxicab activity during the day and evening, all else being equal. Most likely, many who can afford to commute to work by taxicab earn high incomes and place greater values on their time. During the

overnight period, lower-income people may represent a higher share of all taxicab passengers, and this relationship supports the taxicab's role as a complement to transit during the hours when transit does not operate. Of course, lower-income travelers may also account for a larger share of all travel demand during the overnight period. Finally, the percentage of households that own no cars exhibit a significant inverse relationship with taxicab trip generation during only the morning and afternoon peak periods. This negative relationship is not necessarily surprising because urban car owners may have an aversion to transit use and take taxicabs when not driving themselves, especially when parking will be scarce at their destinations.

- **Land use and built environment:** Two independent variables, the share of a block group's land area dedicated to commercial use and the total non-residential building volume within each block group, both have significant positive relationships with taxicab activity throughout the day. These two variables together approximate non-residential trip generation. Non-residential building volumes in downtown Boston dramatically exceed those found in peripheral parts of the city, reflecting the great intensity of non-residential uses (and trip generation) that one finds there. Commercial land use share captures additional trip generation that does not correspond to building volume.

- **Urban form and relative location variables:** A block group's straight-line distance from Boston's center is negatively related to trip generation, all else being equal. In other words, peripheral block groups generate fewer trips than central block groups, even after controlling for transit access and the above indicators. This outcome makes sense, as Boston's taxicab supply is expected to be more centrally concentrated. Additional urban form indicators that are significant include intersections per square kilometer, whether a Class 1 roadway (limited access highway) intersects the block group, and the total length of Class 2, 3, and 4 roadways within a block group. More intersections (and presumably smaller blocks) result in fewer taxicab pickups, suggesting that such urban environments are more accommodating to walking and transit use and will thus

generate fewer taxicab trips. Class 1 roadways have the opposite effect during the morning and evening. The presence of other major roads (Classes 2, 3, and 4) has a positive correlation with trip generation throughout the day, but this is most likely a result of better taxicab supply along these types of roads.

- **Transit access variables (rail):** Specific relationships between different types of transit access and taxicab trip generation are observed in these model results. A block group's proximity to the Red Line, Orange Line, and Blue Line results in fewer taxicab pickups, all else being equal, although this effect reverses itself on the Blue Line in the evening period (and is insignificant for the Red Line overnight and for the Orange Line in the morning). Distance from the Green Line, on the other hand, exhibits a *negative* correlation with taxicab trip generation at all times of day. That is, a block group's proximity to a Green Line station actually increases its taxicab trip generation. This is also true of the Silver Line throughout the day, although a dummy variable indicates Silver Line proximity. These results seem to indicate that the taxicab is, in fact, something of a complement to rail transit. For a few MBTA lines—especially the Red Line, but also the Orange Line and Blue Line at certain times—taxicab trip generation decreases nearer their stations. This appears consistent with a complementary relationship between taxicabs and transit, in which passengers find taxicab travel more necessary (and its relative utility higher) when transit is less accessible due to distance. The Red Line offers high service levels along a dense corridor of travel demand, so individuals beginning trips near a Red Line station will find it to be a more reasonable alternative to the taxicab for many trips. In the Green Line's case, the opposite relationship between the modes is observed: The nearer a Green Line station, all else being equal, the more taxicab activity occurs. Like the Red Line, the Green Line follows a dense corridor of travel demand, connecting Boston's CBD, the Back Bay, and Boston University. The sharp distinction between the Green Line's relationship to taxicab pickups and the Red Line's may be explained by differences between the two corridors: The Green Line is a light rail line that travels quite slowly in places and must stop for

traffic due to its at-grade operation. Like the Green Line, the Silver Line and the evening-period Blue Line have more taxicab activity nearer their stations. The Silver Line's coefficients can potentially be explained by its lower service levels and slower speeds in comparison with heavy rail transit, as suggested for the Green Line. As a final note, some taxicab trips that begin near rail stations do not serve destinations that rail also serves. Nevertheless, these transit access coefficients provide evidence that taxicab service levels, to the extent that they are manifested as realized demand, sometimes increase along with distance from transit stations and sometimes decrease.

- **Transit access variables (bus):** Two indicators of bus access measure total MBTA bus routes and major bus routes intersecting a block group, respectively. Interestingly, total bus routes are positively related to taxicab trip generation throughout the day while major bus routes are inversely related to trip generation. One possible explanation for this divergence is that the MBTA's highest-frequency bus routes provide sufficient service levels to attract passengers that might otherwise use taxicabs, while its overall bus service is not frequent enough to accomplish this and actually loses passengers to the taxicab. The coefficients for the variable representing major bus routes have their most extreme value during the morning peak, when this bus service is more frequent. When transit service is poor, under this hypothesis, the taxicab's role as a substitute to transit is encouraged.

The variation in taxicab pickups that is not explained by these models manifests itself as their residuals, which are mapped in Figure 1 and Figure 2. Residuals for both sets of models are calculated by subtracting the models' predicted values from the actual observed values for each census block group, and these values are "studentized" by dividing each residual value by its standard deviation.

FIGURE 1: MODEL RESIDUALS

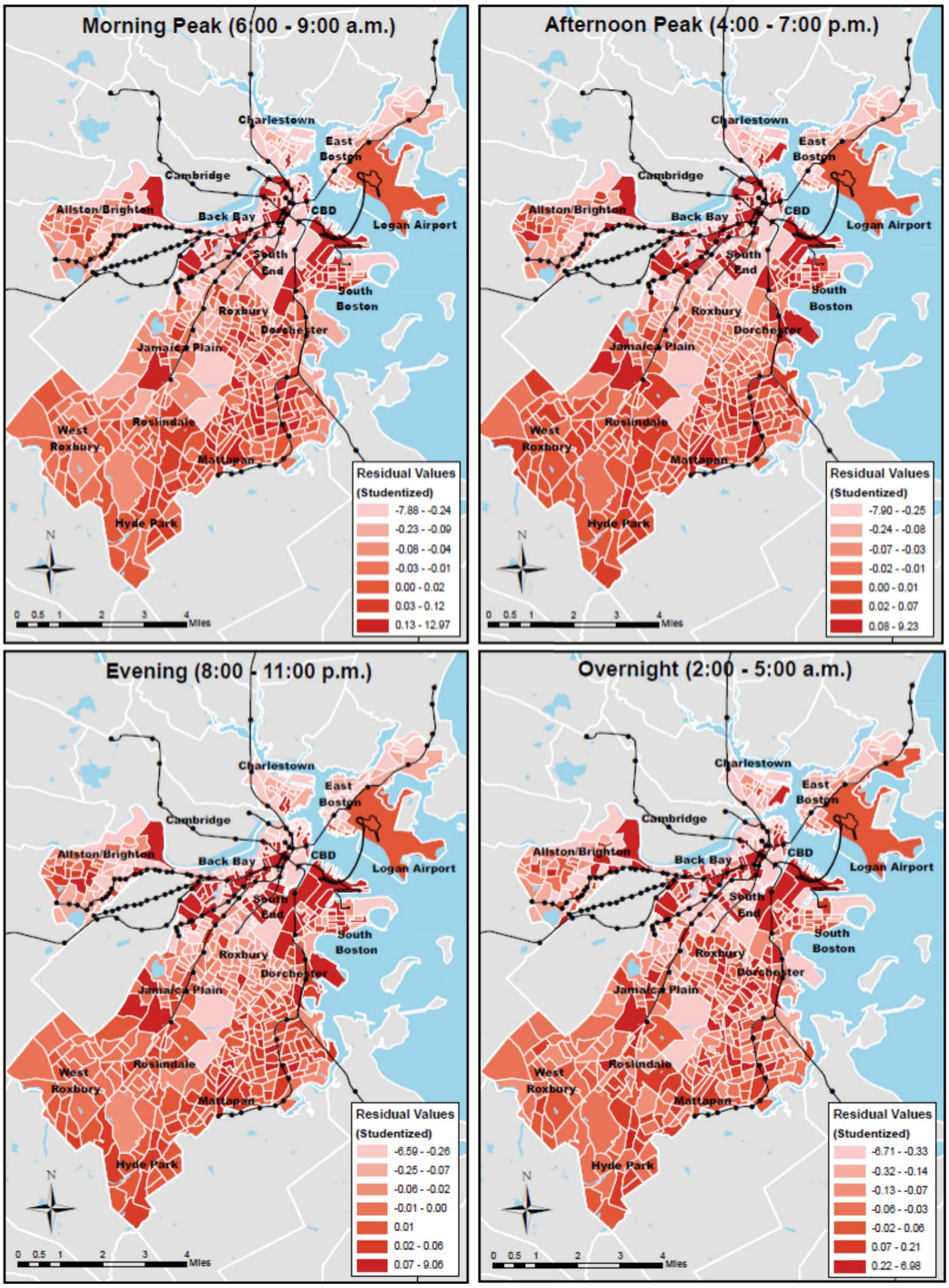
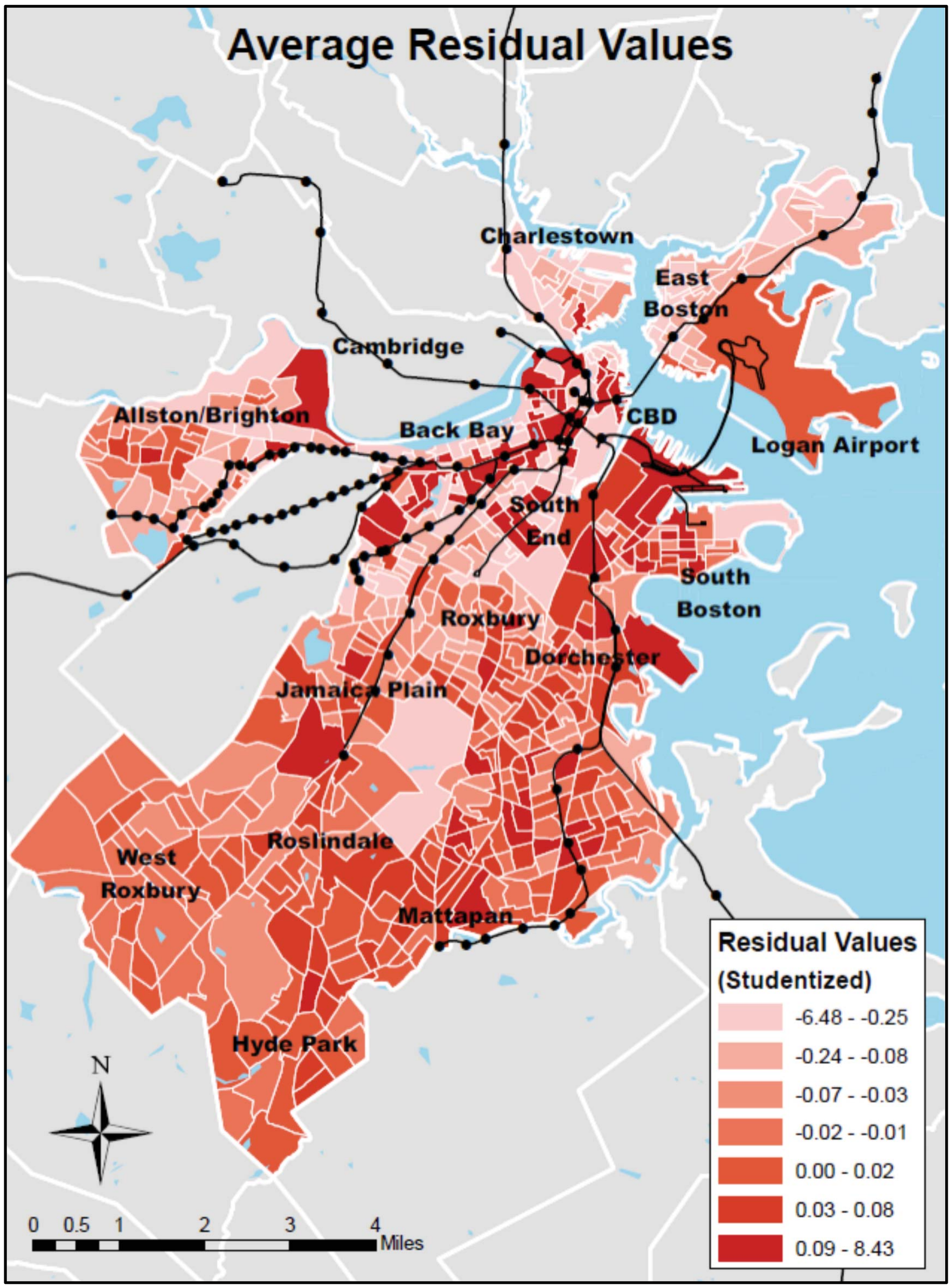


FIGURE 2: AVERAGE RESIDUAL VALUES



The residual values are important in their ability to hint at which parts of Boston the taxicab underserves. Negative residuals represent instances when the model overestimates a block group's actual trip generation, and if these block groups have characteristics that generally reflect high taxicab demand then unmet demand (as opposed to realized demand) may exist there. Roxbury and Jamaica Plain exhibit "overestimated" trip generation, as do Charlestown, East Boston, South Boston, and Allston. Parts of these areas also have poor access to rail transit, meaning the taxicab is failing to fill specific gaps in Boston's public transportation network. Income levels are correlated with better rail transit access in Boston, so many of these apparent taxicab service gaps affect lower-income neighborhoods (although the models control for income). Of course, even areas with few taxicab pickups that appear underserved can access dispatched taxicabs by calling for them; however, areas that rely on dispatched taxicabs experience longer wait times and lower levels of service than areas with high concentrations of cruising taxicabs. The quality of taxicab service at a given location is a product of that service's time and monetary costs, rather than the mere ability to obtain service.

V. CONCLUSIONS

Observations of Boston's taxicab pickup patterns reveal that certain areas generate higher taxicab activity levels than others, while additional clues suggest that Boston's realized demand patterns do not perfectly match its total demand. Having learned that taxicab activity is clustered in certain areas and is sparse throughout other parts of Boston, and knowing that such clustering is a product of taxicab supply and not just demand, the taxicab almost certainly underserves certain parts of Boston. Transit access also varies throughout the city, and gaps in the system—places with below-average transit access—lack a "public" form of mobility that the taxicab could potentially provide. Identifying the existence of unmet travel demand within these gaps would confirm this condition, and the preceding regression analysis was an initial step toward doing so. Future analyses of taxicab service in Boston should investigate the areas that these models' residuals identify as potentially underserved by both taxicabs and transit.

The analysis presented here models trip generation, which is a proxy if not a precise indicator of taxicab service levels. Trip generation is a product of supply (the relative availability, cost, and behavior of taxicabs) as well as demand (the locations and preferences of passengers). Grouping the models' explanatory variables according to whether they impact taxicab supply or demand facilitates inferences of where unmet demand exists. High building volumes, a high share of commercial land use, and high incomes lead to higher trip generation, most likely, by creating demand for taxicab travel. Centrality, on the other hand, primarily influences the supply side of realized demand, as the literature has pointed out tendencies for cruising taxicabs to cluster in downtown areas (Frankena and Pautler 1984; Yamamoto et al. 2008). If a census block group in Boston has few taxicab pickups despite characteristics that predict high demand for the mode, as well as supply characteristics that predict low realized demand, the evidence presented thus far gives reason to believe that unmet demand exists in that location. These models' residuals show which parts of Boston diverge from their predictions, and locations with negative residuals as well as qualities expected to negatively impact taxicab supply are the most likely to be underserved. These conclusions should nonetheless be viewed as tentative, however: A number of potentially relevant variables are omitted from these models, and future research will ideally pick up where this paper leaves off by improving the models' specifications.

REFERENCES

Alexander, C., S. Ishikawa, and M. Silverstein (1977). *A Pattern Language: Towns, Buildings, Construction*. New York: Oxford University Press.

Arnott, R. (1996). ”Taxi Travel Should Be Subsidized.” *Journal of Urban Economics* 40: 316-333.

Beesley, M. E. and S. Glaister (1983). ”Information for Regulating: The Case of Taxis.” *Economic Journal* 93: 594-615.

Beimborn, E. A., M. J. Greenwald, and X. Jin (2003). “Impacts of Transit Accessibility and Connectivity on Transit Choice and Captivity.” *Transportation Research Record* 1835: 1-9.

Berdik, Chris (2004). “Fare Game.” *Boston Magazine*, September 2004.

Bossard, E. G. (2002). *Envisioning Neighborhoods with Transit-Oriented Development Potential*. US Department of Transportation Research and Special Programs Administration, California Department of Transportation, and Mineta Transportation Institute, MTI Report 01-15. Springfield, VA: Mineta Transportation Institute.

Boston Police Department (2008). *Rule 403: Hackney Carriage Rules and Flat Rate Handbook.* Boston, MA.

Cairns, R. D. and C. Liston-Heyes (1996). “Competition and regulation in the taxi industry.” *Journal of Public Economics* 59: 1-15.

Cervero, R. (1997). *Paratransit in America: Redefining Mass Transportation*. Westport, CT: Praeger Publishers.

Chang, H., Y. Tai, and J. Y. Hsu (2010). “Context-aware taxi demand hotspots prediction.” *International Journal of Business Intelligence and Data Mining* 5(1): 3-18.

City of Boston (200). *Boston Transportation Fact Book and Neighborhood Profiles*. Boston, MA.

CMT FleetNet. <https://portal.cmtnyc.com>. Accessed May 12, 2011.

Design Trust for Public Space (2007). *TAXI 07: ROADS FORWARD*. New York: New York City Taxi and Limousine Commission.

Douglas, G. W. (1972). ”Price Regulation and Optimal Service Standards: The Taxicab Industry.” *Journal of Transport Economics and Policy* 20: 116-127.

FareInvestor. <www.fareinvestor.com >. Accessed May 18, 2011.

Frankena, M. W. and P. A. Pautler (1984). "An Economic Analysis of Taxicab Regulation." Washington, DC: Bureau of Economics, Federal Trade Commission.

Gilbert, G. and R. E. Samuels (1982). *The Taxicab: An Urban Transportation Survivor*. Chapel Hill, NC: University of North Carolina Press.

Jackson, K. T. (1985). *Crabgrass Frontier*. New York: Oxford University Press.

Koehler, B. (2004). *Regulating Supply in Taxi Markets*. Master's Dissertation, Department of Economics, City University London.

Liu, L., C. Andris, A. Biderman, and C. Ratti (2009). "Uncovering Taxi Driver's Mobility Intelligence through His Trace." In *Movement-Aware Applications for Sustainable Mobility: Technologies and Approaches*, 105-120.

Massachusetts Bay Transportation Authority (2009). *MBTA Ridership and Service Statistics ("The Blue Book"): Twelfth Edition*. Boston, MA.

MassGIS. <www.mass.gov/mgis>. Accessed May 18, 2011.

Matsushima, K. and K. Kobayashi (2010). "Spatial equilibrium of taxi spot markets and social welfare." Lisbon: Proc. of the 12th WCTR.

Mayor's Office of Transportation (1978). *Boston Taxi Study: Final Report*. Boston, MA.

Meyer, J. R., J. F. Kain, and M. Wohl (1965). *The Urban Transportation Problem*. Cambridge, MA: Harvard University Press.

MIT Geodata Repository. Accessed May 18, 2011.

New York City Taxi and Limousine Commission (2011). *Taxi of Tomorrow Survey Results*. New York.

Phithakkitnukoon, S.. M. Veloso, C. Bento, A. Biderman, and C. Ratti (2010). "Taxi-Aware Map: Identifying and Predicting Vacant Taxis in the City."

Schaller, B. (1999). "Elasticities for taxicab fares and service availability." *Transportation* 26: 283-297.

Schaller, B. (2007). "Entry Controls in Taxi Regulation."

Schaller Consulting (2006). *The New York City Taxicab Fact Book*. New York.

Schroeter, J. R. (1983). “A model of taxi service under fare structure and fleet size regulation.” *Bell Journal of Economics* 14(1): 81-96.

Sigelman, L. and L. Zeng (1999). “Analyzing Censored and Sample-Selected Data with Tobit and Heckit Models.” *Political Analysis* 8(2): 167-182.

Small, K. A. and C. Winston (1999). “The Demand for Transportation: Models and Applications.” In *Essays in Transportation Economics and Policy: A Handbook in Honor of John R. Meyer*, ed. J. Gomez-Ibanez, W. Tye, and C. Winston, 11-56. Washington, DC: Brookings Institution Press.

Teal, R. F. and M. Berglund (1987). “The Impacts of Taxicab Deregulation in the USA.” *Journal of Transport Economics and Policy* 21(1): 37-56.

Teal, R. F., J. V. Marks, and R. E. Goodhue (1979). “Subsidized Shared-Ride Taxi Services.”

Thomson, J. M. (1977). *Great Cities and Their Traffic*. London: Victor Gollancz Ltd.

Tsamboulas, D. A. and A. Nikoleris (2008). “Passengers’ willingness to pay for airport ground access time savings.” *Transportation Research Part A* 42: 1274-1282.

U.S. Census. (2000).

Verifone eFleet. <www.verifone.com>. Accessed May 12, 2011.

Weather Underground. <www.wunderground.com> Accessed May 18, 2011.

Webster, A. L., E. Weiner, and J. D. Wells (1974). “The Role of Taxicabs in Urban Transportation.” Washington, DC: Office of Transportation Planning Analysis, US Department of Transportation.

Yamamoto, K., K. Uesugi, and T. Watanabe (2008). “Adaptive Routing of Cruising Taxis by Mutual Exchange of Pathways.” In KES 2008, Part II, LNAI 5178, eds. I. Lovrek, R. J. Howlett, and L. C. Jain, 559-566. Berlin: Springer-Verlag.

Yang, H., C. S. Fung, K. I. Wong, and S. C. Wong (2010). “Nonlinear pricing of taxi services.” *Transportation Research Part A* 44: 337-348.

Yang, H., S. C. Wong, and K. I. Wong (2002). “Demand–supply equilibrium of taxi services in a network under competition and regulation.” *Transportation Research Part B* 36: 799-819.

Ziebart, B. D., A. L. Maas, A. K. Dey, and J. A. Bagnell (2008). “Navigate Like a Cabbie:

Probabilistic Reasoning from Observed Context-Aware Behavior." In *UbiComp 2008: Proceedings of the 10th International Conference on Ubiquitous Computing*, 322–331. New York: ACM.