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Social and trip-level predictors of pooled ride-hailing service adoption in the Greater Boston region

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ABSTRACT

Ridesharing holds promise as a more efficient and sustainable version of emergent ride-hailing services. However, the adoption of pooled services in which individuals pay a reduced fare to share a portion of their ride-hailing trip with other passengers has substantially lagged in popularity to the standard single-party services offered by Uber and Lyft in many American cities. To help guide policies and programs targeted at increasing pooling shares, this study analyzes data collected during fall 2017 from an in-vehicle intercept survey of 944 ride-hailing passengers in the Greater Boston region. These data, which describe the socioeconomic background, mobility options, and trip context of single-party and pooled ride-hailing survey respondents, were used to identify differences in the trip patterns and individual characteristics of passengers adopting the two service types and then estimate the individual-level social and trip-related predictors of ridesharing for different purposes. The study results are complemented with a discussion of encouraging ridesharing programs and policies.

1. Introduction

The arrival of the global sharing economy has emphasized the importance for transportation planners and agencies to recognize the uncertainty of long-term infrastructure investments in light of changes in travel demand and mode preferences brought on by new technologies (Standing et al., 2019). The rise of commercial ride-hailing companies such as Uber and Lyft, which offer individuals a convenient and reliable option for scheduling mobility-on-demand services, continues to reshape the transportation decisions of residents in American cities as their adoption rates increase and service areas extend beyond urban cores (Gehrke, 2020). The swift growth of ride-hailing services is clearly evident in Boston, where 42.2 million of Massachusetts's 81.3 million ride-hailing trips logged in 2018 originated; marking a citywide increase of 7.3 million trips (121%) and statewide increase of 16.5 million trips (125%) from the previous year (Department of Public Utilities, 2019). However, growth in pooled ride-hailing services (also referred to as ridesharing or ride-splitting services)—where multiple passengers share a vehicle for some or all of their ride-hailing trip—has been much more limited than the standard single-party option (Tirachini, 2019). A recent study by the Union of Concerned Scientists (Anair et al., 2020) estimated that pooled services comprised just 15% of all nationwide ride-hailing trips. Some policymakers and analysts would like to increase the share of pooled rides as a strategy to combat traffic congestion, vehicle emissions, and other sustainability concerns associated with conventional ride-hailing services (Shaheen and Cohen, 2019).

Unfortunately, understanding the growth and patterns of ride-hailing activity is difficult because service providers are very reticent to share detailed information about their customers and trips made. As a result, researchers have relied on the limited amount of data reported to public agencies, collected from surveys, or assembled from indirect sources. While the evidence base continues to expand, to date, few published studies have examined the patterns and predictors of rideshare activity, with past findings usually limited to inferences from neighborhood-level socioeconomic and built environment determinants (Gehrke, 2020). Utilizing responses from an in-vehicle survey of ride-hailing passengers in the Greater Boston region, this study's objectives are to (1) identify differences in the spatiotemporal patterns and individual characteristics of ride-hailing passengers who adopt pooled versus standard exclusive services and (2) model the individual-level social and trip-related predictors of ridesharing for different trip purposes. By offering new insight into the social factors that help facilitate or dissuade individuals from adopting pooled ride-hailing services and expanding these empirical findings with a discussion of encouraging

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business models and transportation policies, the authors hope to advance the conversation as to how cities can best promote more efficient and sustainable outcomes related to ride-hailing service utilization.

2. Literature review

This section synthesizes the findings from previous studies of pooled ride-hailing service, with a focus on those which have examined the social, environmental, and trip-specific determinants of its adoption. In general, this evidence has suggested that individuals who opt for pooling instead of adopting the standard exclusive (or single-party) ride-hailing service tend to be younger and more educated. Moody et al. (2019), in their online survey of ride-hailing activity in the United States, found that a respondent's age was negatively associated with the use of ridesharing. In a study of Seattle passengers of the short-lived UberHOP, Lewis and MacKenzie (2017) similarly noted a majority of adopters of this ridesharing option were 30 years of age or younger and had a four-year college degree. Examining DiDi Chuxing ride-hailing activity, Wang et al. (2019) also discovered most surveyed ridesharing passengers possessed a Bachelor's degree, but that individuals residing in lower-income households preferred public transit over ridesharing adoption. While in another online survey of ride-hailing activity in several American cities, Sarriera et al. (2017) confirmed that pooled adoption is favored by individuals who are 30 years old or younger, but that ridesharing may cater equally to individuals from lower- and higher-income households. Brown (2020), however, found that ride-hailing trips beginning or ending in lower-income neighborhoods of Los Angeles County were more likely to be shared, suggesting that price sensitivity may be a strong factor in pooled service adoption. Accordingly, ride-hailing adoption, and in particular the tendency to utilize discounted pooled services, appears to favor younger adults who are increasingly multimodal and may view the new automobility option as a replacement for personal car access (Brown, 2019; Tirachini, 2019).

Concerning the last point, prior studies have suggested that individuals who favor the ridesharing option may have lower rates of car ownership than standard ride-hailing passengers. Sarriera et al. (2017) found individuals without access to a personal vehicle or a subscription to a car-sharing service are more likely to use pooled ride-hailing services, while Chen et al. (2018)—in a study of ride-hailing activity in China—noted that individuals without private vehicle access preferred ridesharing but that a pooling option was also favored by vehicle owners. Tang et al. (2020) discovered that many individuals with access to a personal vehicle in China tended to adopt ride-hailing services due to a lack of available public parking or legal limitations on private vehicles; a more general outcome of ride-hailing service availability that has also been found to exist in the American context (Gehrke et al., 2019).

With regard to environmental predictors of pooled ride-hailing service adoption, Brown (2020) found that dense urban centers have a disproportionately higher share of pooled trips, and that a higher percentage of rideshare trips originated in Los Angeles neighborhoods with a high proportion of residents identifying as a racial or ethnic minority. By analyzing seven months of ride-hailing activity in Toronto beginning in September 2016, Young et al. (2020) determined 15% of these 12 million collected trips were pooled and that the majority of pooled ride-hailing trips originated within five kilometers of the downtown-located City Hall. Districts with a high employment density were also found by Wang et al. (2019)—in a survey of 607 ride-hailing passengers—to produce more ridesharing trips to and from an individual's home; whereas, Hou et al. (2020) modeled the willingness to pay for ride-sharing trips that started or ended in high population or employment density zones in Chicago to be lower than that of standard single-party services. In turn, Wang et al. (2019) discovered pooled ride-hailing service intensity was linked to increased population density, when assessed across several urban districts in Hangzhou. Together, these studies from diverse urban settings point to the likelihood for ride-sharing to occur in denser urban areas, which house and employ more potential riders, offer greater variety in activity locations, and favor more sustainable mobility options that also benefit from shorter trip distances.

In fact, the reviewed literature has commonly concluded that pooled ride-hailing service adoption is most popular for shorter trips, concerning both travel distance and duration. Schwieterman and Smith (2018) noted pooling in the Chicago context was favored when transit services would be less convenient, such as longer trips that may entail transfers or walking longer distances. Using an ensemble learning approach to model ridesharing patterns, Chen et al. (2017) found travel time to be the most significant factor for adopting ride-splitting behaviors. Li et al. (2019), in using a ride-splitting trip identification algorithm, discovered the travel time variability of pooled ride-hailing services due to added trip-level stops was a reason for individuals to adopt an exclusive single-party ride rather than a shared one, but that each service type offered improved travel times in short-distanced trips in comparison to public transit. Given the importance of travel time savings and the cost advantage of pooled services over exclusive ride-hailing rides, minimal detour penalties for longer-distanced ridesharing trips would likely improve the attraction and environmental benefits of this potentially more sustainable ride-hailing option (Young et al., 2020).

Limited insight exists on other trip-specific characteristics associated with ridesharing, with past studies noting that pooled services are typically adopted for discretionary trip purposes and substitute travel by modes other than the private vehicle. In an investigation of ride-hailing activity in Brazilian cities, de Souza Silva et al. (2018) found ridesharing adoption was most common for leisure activities, followed by trips in return to the passenger's residence; whereas, Tang et al. (2020) reported a majority of pooled ride-hailing trips were adopted for the initial leg of commute travel, followed by trips for discretionary activities. As for mode substitution decisions, de Souza Silva et al. (2018) discovered that nearly all sampled ridesharing trips replaced public transit or traditional taxi services, which was corroborated by the Tang et al. (2020) study which found respondents stating that they would have adopted bus services, traditional taxi, and metro rail services if Didi Chuxing ExpressPool (a shared ride-hailing service in China) was not available for their surveyed trip.

Our study builds upon the existing literature in notable ways. Foremost, most studies have only assessed the patterns and predictors of pooled ride-hailing service adoption considering neighborhood-level social and environmental characteristics. These ridesharing studies on the neighborhood effects of its adoption are informative for policy but lack the ability to offer insights into what individual- and trip-specific items can be addressed to best promote more efficient and sustainable ride-hailing activities. Additionally, this study contributes to a global evidence base in which there remain relatively few analyses of the differences between single-party and pooled ride-hailing service adoption.

3. Data and methods

3.1. Case study context

In this study, the Greater Boston region refers to the 101 cities and towns of Metropolitan Boston whose residents and workers are served by its regional planning agency, the Metropolitan Area Planning Council (MAPC). Per 2015–2019 American Community Survey estimates, the region had over 3.36 million residents, with Boston having a population of 684,379, followed by the inner-ring suburbs of Cambridge (116,632) and Quincy (94,207). The entire Greater Boston region's population density is 3.67 persons per acre, with Somerville (30.61 persons per acre), Chelsea (28.23 persons per acre) and Cambridge (27.31 persons per acre) being the densest of the 101 municipalities. Among the region's cities and towns, the average annual household median income is

$118,151; yet economic disparities exist, with the annual household incomes of Lynn ($56,409) and Chelsea ($56,427) being less than half of the regional average. Regarding public transit options, the Massachusetts Bay Transportation Authority (MBTA) operates four subway lines, 12 commuter lines, the Silver Line's bus rapid transit service, and dozens of local bus routes throughout many of the region's communities. However, 60.35% of working adults in the region report driving alone as their primary commute mode, with another 6.95% of residents reporting their means of transportation to work is carpooling and only 17.31% riding available bus, rapid transit, and commuter rail services. One quarter of Somerville residents commute using the subway system, with residents of Malden, Quincy, and Melrose also having a subway mode share above 20 percent; while 15.50% of Chelsea residents commute by bus and residents of Boston, Watertown, and Everett have similar mode shares above ten percent. The growth of ride-hailing services, which was highest in Boston, Cambridge, and Somerville during 2018, have offered residents of the Greater Boston region another mobility alternative as well as a source of competition for regional transit services (Department of Public Utilities, 2019).

3.2. Ride-hailing passenger intercept survey

This study represents a secondary analysis of public data collected by MAPC staff. Over a four-week period beginning in October 2017, an in-vehicle intercept survey of ride-hailing passengers was administered by ten ride-hailing drivers serving the Greater Boston region. Participating drivers were recruited by MAPC staff and equipped with a portable tablet device with a pre-installed version of an 18-question survey instrument. Drivers were employed by one of four ride-hailing companies, resided in one of seven municipalities, and were instructed to ask boarding passengers of their willingness to participate in a voluntary short survey about regional transportation options. Drivers were provided a monetary incentive for their study participation, with additional incentives for each collected passenger survey. Participants were additionally made aware of the survey via two bilingual laminated signs placed on the headrest and dashboard of each ride-hailing driver's vehicle, with surveyed ride-hailing passengers invited to enter a random drawing to win a gift card to an electronic commerce company.

Questions in this tablet-based survey instrument were divided into three sections pertaining to a ride-hailing passenger's socioeconomic status and personal background, general travel behaviors and mobility options, and context regarding their observed trip. The instrument was offered in English and Spanish languages, with the average survey taking three minutes to complete. Although trip-level spatiotemporal details could not be extrapolated from this survey design, participants were asked to report the ZIP code of their home and primary activities at the trip's origin and destination. With these pieces of information, built environment measures were constructed for home-based trips of subsistence, mandatory, or discretionary purposes and non-home-based ride-hailing trips where the survey respondent returned home. Additionally, time stamps were generated during each administered survey, allowing for day of the week identification and for each sampled ride-hailing trip to be classified as having started in one of four travel periods: morning peak (6:00–9:00 a.m.), mid-day (9:00 a.m.–4:00 p.m.), evening peak (4:00–7:00 p.m.), or night (7:00 p.m.-6:00 a.m.). More information on the design and administration of this ride-hailing passenger intercept survey is provided elsewhere (Gehrke et al., 2018).

In all, 944 valid survey responses were received from the driver-administered survey (89 surveys discarded due to item response incompleteness and attrition), with 920 ride-hailing passengers recording whether they adopted a standard single-party or shared (e.g., UberPool, Lyft Share) service for their observed trip. This latter subsample was used for the descriptive and inferential analyses of this study, with an initial examination of the survey data set given by conducting a two-sample test of proportions. From this test of two independent groups, significant differences in the socioeconomic features, mobility options, and trip characteristics between surveyed ride-hailing passengers who adopted pooled versus standard services were identified.

3.3. Modeling pooled service adoption

To recognize the significant predictors of pooled ride-hailing service adoption, the authors estimated a set of binary logistic regression models. For the first model, the complete sample was utilized to determine the set of individual-level socioeconomic features, mobility options, and trip characteristics that predicted the decision of whether or not a survey respondent selected a pooled service type for their recorded ride-hailing trip. As in previous studies (Chen et al., 2017), ride fare was included as a trip predictor of pooled service adoption to help understand its impact on service trade-offs and due to the unavailability of trip distance or in-vehicle travel time in the data source. Three subsequent models were then estimated to explore the significant predictors of shared service adoption for three trip purposes: home-based trips to all activities, non-home-based trips to home, and non-home-based trips to other activities. In addition to the three classes of individual-level predictors, six built environment metrics describing the passenger's residential context were explored in the binary logistic regression model specification process for the first two trip purposes. These neighborhood-level measures, which have been found in the reviewed literature to also impact ridesharing travel behaviors, included zip code-level calculations of density (persons per acre, jobs per acre, persons plus jobs per acre), diversity (ratio of jobs-to-persons), design (number of four-way street intersections divided by the number of intersections plus cul-de-sacs), and access to public rail or bus rapid transit (presence of rapid transit stations within a zip code).

All four binary logistic regression models were specified using a multistep backwards elimination process. In the first step, the unadjusted correlation between each independent variable and the model outcome was calculated, where variables with a coefficient of an absolute value above 0.1 retained. The correlation between those selected independent variables was then assessed and, amongst those variables that were strongly correlated with one another, the variable with a weaker association with the dependent variable was removed from further consideration. Finally, using this independent variable subset, each model was estimated by iteratively removing independent variables from the fully-specified model until all remaining predictors were marginally significant and the log-likelihood of the reduced model reflected a significant improvement from the prior specification. By estimating the four models, insights into the socioeconomic features, mobility options, trip characteristics, and built environment attributes (for those trips beginning or ending at a survey respondent's home) that predict pooled service adoption can be ascertained.

4. Results

4.1. Differences with pooled ride-hailing trips

Distinguishing sampled ride-hailing trips by service type, Table 1 describes the socioeconomic features, mobility options, and trip characteristics for pooled and standard trips; denoting those variables where a significant difference in the two sample proportions existed. Twenty percent of survey respondents were from passengers who indicated they chose the pooled option for their ride-hailing trip. Overall, surveyed ride-hailing passengers were predominately female, less than 35 years of age, college educated, working, and White, while residing in households that reported the lowest annual incomes and were composed of only adults. Adult ride-hailing passengers who were younger than 25 years of age were more likely to adopt a pooled ride-hailing service, as were those passengers who had not attended college or identified as Asian. White, non-Hispanic ride-hailing passengers and survey respondents who were at least 45 years old were less likely to have chosen the more

Table 1
Descriptive statistics for sampled ride-hailing trips by service type.

Variable	Pooled (n = 185)		Standard (n = 735)		All Trips (n = 920)	
	n	%	n	%	n	%
Socioeconomic Features						
Sex: Female	105	56.5	385	52.3	491	53.3
Sex: Male	78	41.9	346	47.0	424	46.0
Age: 18–24 years old*	50	26.9	100	13.6	151	16.4
Age: 25–34 years old	115	61.8	488	66.3	603	65.5
Age: 35–44 years old	16	8.6	80	10.9	96	10.4
Age: 45 years old or more*	4	2.2	67	9.1	71	7.7
Education: High school or less*	32	17.2	77	10.5	109	11.8
Education: Bachelor's or some college	110	59.1	456	62.0	566	61.5
Education: Master's or PhD	40	21.5	193	26.2	233	25.3
Race/Ethnicity: Asian*	30	16.1	78	10.6	108	11.7
Race/Ethnicity: Black/African American	17	9.1	42	5.7	59	6.4
Race/Ethnicity: Hispanic/Latinx	20	10.8	61	8.3	82	8.9
Race/Ethnicity: White, non-Hispanic*	94	50.5	480	65.2	574	62.3
Race/Ethnicity: Multiracial	8	4.3	17	2.3	25	2.7
Status: Full- or part-time worker	130	69.9	553	75.1	684	74.3
Status: Unemployed or retired	3	1.6	13	1.8	16	1.7
Status: Full- or part-time student	50	26.9	165	22.4	215	23.3
Income: Less than $38,000*	55	29.6	140	19.0	195	21.2
Income: $38,000-$60,000	37	19.9	131	17.8	168	18.2
Income: $60,001-$82,000	24	12.9	101	13.7	125	13.6
Income: $82,001-$110,000	13	7.0	84	11.4	97	10.5
Income: $110,001-$137,000	6	3.2	48	6.5	54	5.9
Income: Greater than $137,000*	17	9.1	117	15.9	134	14.5
Children: 0	165	88.7	623	84.6	788	85.6
Children: 1 or more	18	9.7	105	14.3	124	13.5
Mobility Options						
Cars: 0*	84	45.2	247	33.6	331	35.9
Cars: 1	58	31.2	269	36.5	327	35.5
Cars: 2*	19	10.2	139	18.9	159	17.3
Cars: 3 or more	23	12.4	76	10.3	99	10.7
Private car*	63	33.9	353	48.0	416	45.2
Driver's license*	125	67.2	577	78.4	702	76.2
Carshare membership	17	9.1	83	11.3	100	10.9
Public transit pass	75	40.3	249	33.8	325	35.3
Personal bike*	32	17.2	181	24.6	213	23.1
Bikeshare membership	9	4.8	23	3.1	32	3.5
Parking at residence*	35	18.8	230	31.2	265	28.8
Trip Characteristics						
Mode substitution: Public transit*	92	49.5	291	39.5	383	41.6
Mode substitution: Walk or bike*	32	17.2	76	10.3	109	11.8
Mode substitution: Vehicle	29	15.6	131	17.8	160	17.4
Mode substitution: Taxi*	15	8.1	192	26.1	207	26.1
Mode substitution: No travel	12	6.5	33	4.5	45	4.5
Party size: 1*	122	65.6	423	57.5	546	59.3
Party size: 2	48	25.8	214	29.1	262	28.4
Party size: 3 or more*	14	7.5	95	12.9	109	11.8
Cost: Less than $10*	126	67.7	198	26.9	325	35.3
Cost: $10-$20*	43	23.1	351	47.7	394	42.8
Cost: Greater than $20*	13	7.0	178	24.2	191	20.7
TNC frequency: First ride	1	0.5	9	1.2	10	1.1
TNC frequency: Rarely	4	2.2	33	4.5	37	4.0
TNC frequency: Sometimes	48	25.8	213	28.9	261	28.3
TNC frequency: Regularly	77	41.4	264	35.9	341	37.0
TNC frequency: Frequently	55	29.6	208	28.3	264	28.7
Day of week: Weekday	118	63.4	482	65.5	600	65.1
Day of week: Weekend	67	36.0	253	34.4	321	34.9
Time of day: Morning peak	24	12.9	128	17.4	152	16.5
Time of day: Mid-day	29	15.6	110	14.9	139	15.1
Time of day: Evening peak	38	20.4	130	17.7	168	18.2
Time of day: Night	94	50.5	367	49.9	462	50.2
Purpose: Home-based, subsistence	16	8.6	84	11.4	100	10.9
Purpose: Home-based, maintenance	2	1.1	15	2.0	17	1.8
Purpose: Home-based, discretionary	34	18.3	117	15.9	151	16.4
Purpose: Non-home-based, home*	77	41.4	244	33.2	322	35.0
Purpose: Non-home -based, subsistence	11	5.9	61	8.3	72	7.8
Purpose: Non-home -based, maintenance	7	3.8	17	2.3	24	2.6
Purpose: Non-home -based, discretionary	28	15.1	144	19.6	172	18.7
Reason for use^: Multitasking ability	20	10.8	61	8.3	81	8.8
Reason for use^: Cannot drive*	32	17.2	75	10.2	107	11.6
Reason for use^: Car unavailable	70	37.6	248	33.7	319	34.6
Reason for use^: Parking is difficult/ expensive*	29	15.6	187	25.4	216	23.5
Reason for use^: Transit unavailable	30	16.1	132	17.9	162	17.6
Reason for use^: Quicker than transit*	98	52.7	455	61.8	553	60.0
Reason for use^: Weather	42	22.6	130	17.7	172	18.7

Notes. ^ Multiple responses could be selected; * Significant ($p < 0.05$) difference between service type proportions.

efficient shared service for their trip. Regarding household income, unsurprisingly, ride-hailing passengers of the lowest cohort were more likely to have chosen the less expensive shared service, while the opposite held true for ride-hailing passengers of the highest household income cohort.

Amongst survey respondents, about 70% of ride-hailing passengers lived in car-free or car-lite households, with a near-equal split between those zero and one car households. While more research is needed, this survey finding indicates that ride-hailing services may help facilitate a car-lite or even car-free lifestyle for some of the region's residents. Passengers with limited access to a personal vehicle (no driver's license, no private car, no household car, or no car parking at residence) were significantly more likely to have selected a pooled option for their reported trip, while respondents from households with two cars (a correlate of household income) were more likely to have selected the single-party ride-hailing service. In terms of non-auto mobility options, approximately one-third of all ride-hailing passengers possessed a public transit pass and one-quarter a personal bike, with respondents who owned a bike less likely to have chosen a shared service. In contrast, while not statistically significant, ride-hailing passengers with a bike-share membership were more likely to have taken a pooled trip, pointing to the potential of individuals more accustomed to other shared mobility services having a proclivity to pool.

A unique aspect of this ride-hailing data set is its ability to offer insights on trip-specific characteristics. Of those passengers surveyed, about 42% would have taken public transit for the reported trip if ride-hailing services were not available. Another 12% of all passengers substituted ride-hailing services for walking or cycling. Notably, passengers who opted for a shared service were 19% more likely than passengers of the single-party service to indicate that they would have taken transit, walked, cycled, or not traveled at all if ride-hailing services were not available. Conversely, 44% of non-pooled passengers would have driven themselves or taken a taxi in the absence of ride-hailing services, versus 24% of ridesharing users. In other words, pooled service passengers were more likely to be substituting ride-hailing for a non-auto mode of transportation, complicating the picture of whether pooled services are more or less sustainable for those who choose them. The travel option in the greatest direct competition with standard/non-pooled ride-hailing services, the traditional taxi, was the mode replaced for 26% of all sampled trips; with those trips most likely to have been of an exclusive service.

Unsurprisingly, a majority of survey ride-hailing trips were taken alone, with this trip-embarking party size more likely to have chosen the pooled option that restricts the number of riders for any party to two riders at a pick-up location to ensure vehicle capacity is available if that pooled ride is matched. Most surveyed ride-hailing trips had a passenger-reported cost between $10–20, with a significantly higher proportion of these trips being exclusive. Ride-hailing trips less than $10 were more likely to have reflected the adoption of a pooled service—the less expensive service type; whereas, those trips greater than $20 were more likely to have been of standard, non-shared service. In terms of purpose, 64% of ride-hailing trips were non-home-based, with more than one-half of those trips terminating at the passenger's residence. In line with previous research, ride-hailing passengers of non-home-based trips returning home were more likely to have chosen a pooled service type.

Fig. 1 shows the percentage of sampled ride-hailing trips starting or ending in a survey respondent's residential zip code that were pooled. As anticipated, municipalities located outside of the Greater Boston region's inner core experienced less ride-hailing activity and lower shares of pooled service adoption. Twelve of the 85 zip codes with recorded home-based ride-hailing activity in the study sample had 10 or more trips and a pooled share of at least one-in-four trips. The densely-populated municipalities of Boston, Somerville, and Brookline each had multiple zip codes with relatively higher pooled ride-hailing activity, with the cities of Cambridge and Watertown also each having a zip code meeting these criteria.

In Table 1, the three most popular reasons passengers stated their adoption of ride-hailing services for the surveyed trip were that they believed Uber/Lyft to be quicker than public transportation (60%), they did not have a car available (35%), or they stated parking is difficult or expensive (24%). When examining these ride-hailing adoption reasons for the lowest and highest income cohorts, the first two motivations remain unchanged. However, the third most popular reason for lower-income individuals to choose ride-hailing was related to the weather (21.54%), while, over 20% of sampled passengers with a higher income noted the unavailability of public transit (26.19%) and difficulty or costliness of car parking (22.62%) as a reason for adopting ride-hailing services for their sampled trip. Survey respondents who noted ride-hailing services were quicker than transit or that parking would be difficult or expensive were less likely to have chosen a pooled service for their observed trip, while ride-hailing passengers who reported their reason for ride-hailing adoption being that they cannot drive (e.g., no driver's license, injured, inebriated) were more likely to choose a shared service. Here, it should be noted that this survey instrument item did not include an open-ended or other option to declare an alternative main reason for choosing a single-party or pooled ride-hailing service rather than another mobility option, which may have offered additional insights into the motives for adopting these different service types.

Nearly two-thirds of all surveyed ride-hailing passengers stated that they have utilized this mobility option at least once per week over the past three months, with 29% of passengers noting they adopt ride-hailing services more than four times per week (frequently). Similarly, nearly two-thirds of ride-hailing trips took place on Saturday or Sunday, with one-half of all ride-hailing trips occurring at night or between 7:00 p.m. and 6:00 a.m. There were no significant differences between the samples of pooled and standard services for different categories of ride-hailing adoption frequency, day of week, or time of day. However, Fig. 2 offers a depiction of the prevalence of pooled service adoption in the sample across the four time of day periods per day of the week. With only the exception of Thursdays, surveyed ride-hailing passengers were less likely to select the shared service for travel during the weekday peak periods than off-peak mid-day or evening times. This visualization further confirms that ride-hailing adopters in this study sample do not appear to favor splitting their rides with passengers outside of their travel party any differently on the weekend than they do from Monday to Friday.

4.2. *Determinants of pooled ride-hailing trips*

Utilizing the described socioeconomic, mobility, and trip-related characteristics of the surveyed sample of ride-hailing passengers in the Greater Boston region, Table 2 shows the estimation results for a logistic regression model of pooled ride-hailing service use. Examining the socioeconomic predictors specified in this model for trips of all purposes, the odds of an adult ride-hailing passenger who was younger than 25 years of age adopting a pooled service were higher than that of surveyed passengers in older age cohorts ($\beta = 0.67, OR = 1.95$). When controlling for other model predictors, individuals who identified as Black or African American, who only represented 6.4% of the sample, similarly had greater odds of selecting a pooled service for their observed ride-hailing trip ($\beta = 0.90, OR = 2.47$). While the former association is consistent with previous findings, the latter finding is not and may be associated with other socioeconomic (e.g., household income) or locational attributes omitted from the final model specification.

Turning to mobility and transportation-related factors, an individual with a driver's license was less likely to have opted for the pooled ride-hailing service ($\beta = -0.60, OR = 0.55$); a model finding aligned with the difference in proportions test and a lack of personal vehicle access. Ride-

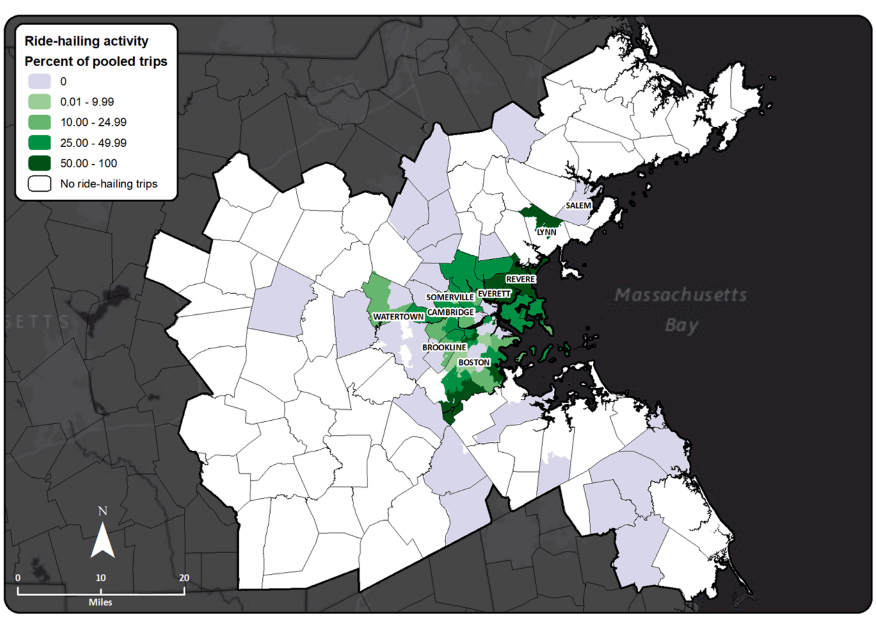

Fig. 1. Spatial distribution of pooled ride-hailing trips across municipalities in the Greater Boston region.

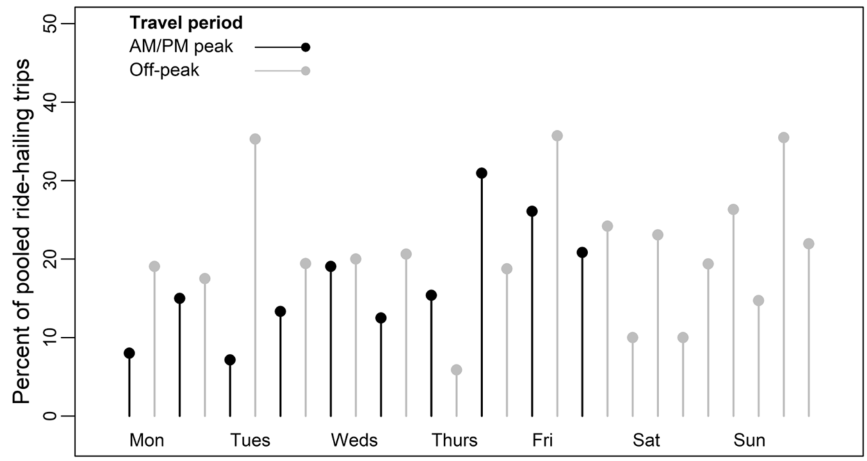

Fig. 2. Temporal distribution of pooled ride-hailing trips in study sample for the Greater Boston region.

Table 2
Predictors of pooled ride-hailing adoption (n = 711).

Variable	B	OR	95% CI	p
Intercept	−2.13	0.12	(0.06 – 0.23)	<0.01
Socioeconomic Features				
Age: 18–24 years old	0.67	1.95	(1.14 – 3.28)	0.01
Race/Ethnicity: Black/African American	0.90	2.47	(1.18 – 5.04)	0.01
Mobility Options				
Driver's license	−0.60	0.55	(0.33 – 0.91)	0.02
Trip Characteristics				
Mode substitution: Taxi	−0.96	0.38	(0.19 – 0.71)	<0.01
Party size: 1	0.40	0.97	(0.97 – 2.33)	0.07
Cost: Less than $10	1.55	4.73	(3.12 – 7.25)	<0.01
Purpose: Non-home-based, home	0.43	1.54	(1.00 – 2.36)	0.05

Notes. Model log-likelihood = -291.56 (df = 8); Null model log-likelihood = -461.75 (df = 1).

hailing passengers who stated they would have taken a traditional taxi service if Uber/Lyft were not available for their observed trip were also more likely to adopt a standard, single-party service ($\beta = -0.96, OR = 0.38$). Regarding party size, ride-hailing passengers traveling alone were more likely to have chosen the pooled option, although this association was only marginally significant. Ride-hailing passengers who pooled with other travelers experienced lower trip costs, with the odds of a trip priced under $10 being over four times higher to have been a pooled service than the standard alternative ($\beta = 1.55, OR = 4.73$). Finally, after controlling for the above determinants, a surveyed ride-hailing passenger had greater odds of selecting a pooled service if the purpose of their trip was a ride back to their residence ($\beta = 0.43, OR = 1.54$).

4.3. Determinants of pooled ride-hailing trips differentiated by trip purpose

A complementary set of models were estimated to identify the determinants of pooled service adoption for three ride-hailing trip purposes (Table 3). For home-based travel, as with the prior full sample model, individuals who identified as Black or African American were found to have higher odds of opting to pool with other passengers ($\beta = 1.79, OR = 5.97$). Surveyed passengers who adopted pooled ride-hailing services for home-based travel were more likely to have noted a lower trip cost ($\beta = 2.39, OR = 10.92$) or reported their reason for use as related to not being able to drive ($\beta = 1.32, OR = 3.76$). In regard to mode replacement, passengers adopting ride-hailing services for home-based trips had greater odds of substituting the shared mobility option

Table 3
Predictors of pooled ride-hailing adoption for home-based and non-home-based travel.

Variable	Home-based trips		Non-home-based trips			
	to all (n = 241)		to home (n = 291)		to other (n = 237)	
	B	p	B	p	B	p
Intercept	−3.53	<0.01	−1.74	<0.01	−3.21	<0.01
Socioeconomic Features						
Age: 18–24 years old			1.01	0.04	0.93	0.03
Education: Bachelor's or some college			−0.77	0.02		
Race/Ethnicity: Asian			0.97	0.03		
Race/Ethnicity: Black/African American	1.79	<0.01				
Mobility Options						
Cars: 3 or more					0.91	0.04
Bikeshare membership					1.99	0.03
Trip Characteristics						
Mode substitution: Public transit	1.03	<0.01				
Cost: Less than $10	2.39	<0.01	1.66	<0.01	1.16	<0.01
Cost: Greater than $20			−1.73	0.03		
TNC frequency: Frequently					1.08	<0.01
Reason for use: Multitasking ability			1.27	0.06	1.16	0.04
Reason for use: Cannot drive	1.32	0.01				

for public transit use ($\beta = 1.03, OR = 2.81$). In this home-based travel model, six measures describing the zip code-level built environment context of the surveyed riders were tested but not found to be statistically significant after controlling for the above socioeconomic and mobility person-level characteristics and available trip-related factors.

Analyzing the sample of non-home-based ride-hailing trips that ended at the home location, younger adult ride-hailing passengers ($\beta = 1.01, OR = 2.76$) and individuals of Asian descent($\beta = 0.97, OR = 2.64$) were more likely to have selected the pooled service type than the standard single-party ride, while passengers with a Bachelor's degree or some college education were less likely to have pooled for non-home-based trips to home. Once again, pooled ride-hailing service adoption was strongly associated with trip cost for this most-popular trip purpose, with a positive modeled relationship for trips less than $10 ($\beta = 1.66$, $OR = 5.27$) and negative relationship for trips greater than $20 ($\beta = -1.73, OR = 0.18$). The benefit of multitasking was found to be a marginally significant determinant of passengers adopting a pooled service, which produces longer travel times for ride-hailing passengers than the standard type. As with the previous model also examining ride-hailing travel with a trip end at the surveyed passenger's home location, zip code-level calculations of density, diversity, design, and public transit access were not found to significantly predict the choice to rideshare for non-home-based to home travel.

Similar to the prior model, for those non-home-based ride-hailing trips that did not end at the passenger's residence, adult passengers under 25 years old had greater odds of pooling ($\beta = 0.93, OR = 2.54$), as did those surveyed individuals with a bikeshare membership ($\beta = 1.99, OR = 7.29$). Interestingly, ride-hailing passengers residing in households with high vehicle ownership levels also displayed greater odds of using pooled services for non-home-based trips to non-home locations ($\beta = 0.91, OR = 2.49$), which may be an artifact of the person's household composition or relationship in the household than personal vehicle access. As was the case with non-home-based trips to home, the selection of pooled services for non-home-based ride-hailing trips to non-home destinations was positively associated with low trip costs ($\beta = 1.16, OR = 3.19$) and an ability to multitask when traveling as a passenger in a ride-hailing vehicle ($\beta = 1.16, OR = 3.19$). The most significant determinant of ride-hailing passengers selecting a pooled service option for their non-home-based-other trip was the frequency in which they utilize this mobility option, with surveyed passengers who use ride-hailing services at least five time per week having higher odds of selecting the more efficient shared service type ($\beta = 1.08, OR = 2.93$).

5. Discussion

This study helps illuminate the different characteristics of ride-hailing passengers who opted for pooled rather than exclusive services and reveals the complexity of determining the net carbon impact of ride-hailing services. At first blush, pooled ride-hailing services seem less carbon intensive than exclusive rides since a portion of the pooled passenger's vehicle miles traveled are shared with other parties. However, if pooled ride-hailing services are attracting its passengers away from public transit services with adequate patronage at a higher rate than that of single-party services, then pooled services may, in fact, have the more deleterious effect on transit ridership, traffic congestion, and greenhouse gas (GHG) emissions. A deeper understanding of passenger characteristics, their decision criteria, and trip emission components is needed to enumerate the impacts of the various ride-hailing services more fully, and to set policies that promote more sustainable mobility.

As suggested in our literature review, this study provides evidence that pooled ride-hailing passengers are distinctly different from those who usually adopt exclusive, single-party services: they are younger, lower income, less likely to own a car, and more likely to be substituting ride-hailing for a more sustainable mode. This outcome is likely in part due to the lower price point of shared ride-hailing trips. To the extent that public policies are intended to promote the use of pooled services, they may be encouraging mode shift away from more sustainable mobility options, thereby increasing congestion and GHG emissions. On the other hand, single-party ride-hailing passengers are much more likely to have shifted away from another auto mode (personal vehicle or traditional taxi); thus, policies designed to prompt those individuals to choose pooled services instead of exclusive rides are likely to have a more demonstrable benefit with regard to congestion and emissions.

Of course, the future of pooled ride-hailing faces great uncertainty given the current global pandemic and social distancing mandates. On March 17, 2020, Uber and Lyft suspended their rideshare service options in a concerted effort to help slow the community spread of the coronavirus (Bond 2020). The resumption of pooled ride-hailing services in American cities is not likely to come until public health concerns of driver and passenger exposure to the coronavirus have been assuaged either by the wide availability of a vaccine to provide immunity or implementation of effective safety regulations that adequately prevent the spread of the virus. While questions about an individual's perceptions of ride-hailing vehicle cleanliness were not included in the survey instrument, evidence on traditional taxi service quality suggests that in-vehicle cleanliness is a significant predictor of positive perceptions (Alonso et al., 2018). Perceptions of public health risks related to in-vehicle cleanliness and passenger-to-passenger discriminatory attitudes (Moody et al., 2019) will continue to serve as individual barriers to the growing adoption of pooled services, no matter its societal benefits. At present, Uber and Lyft have partnered with the Centers for Disease Control and Prevention to establish health and safety standards to minimize passenger-to-driver transmission, including the requirement for vehicle occupants to wear face coverings and provision of sanitary products to ride-hailing drivers. Unfortunately, the public health worries become more complex when ride-hailing services are made available to multiple parties, as it's unclear how many customers will be willing to adopt pooled services that may substantially increase their potential exposure to the novel coronavirus. To restore passenger confidence, both practices such as vehicle cleaning and inspections or individual compliance to face coverings and wellness questionnaires as well as physical modifications to ride-hailing vehicles such as plexiglass panels between seats will likely need to be implemented. However, the prospect of future pandemics and the potential need for resumed social distancing raises challenging questions about the long-term prospect of any shared-vehicle mobility option, whether it be ride-hailing or public transit services.

Study findings also reinforce a notion that single-party and pooled ride-hailing services should be treated distinctly in public policies, as two separate mobility options that serve different travel market segments. Given the GHG impact associated with current ride-hailing services, in which an exclusive ride-hailing trip has been estimated to emit nearly 50% more carbon dioxide than a private vehicle trip (Anair et al., 2020), policies should in general discourage single-party ride-hailing service adoption and shift ride-hailing travel to the adoption of pooled services. In this study's sample, only 20% of ride-hailing trips were conducted using a shared service, with shares of pooling never reaching above 40% during any period or a majority in any neighborhood with sufficient activity. The cited Union of Concerned Scientists (Anair et al., 2020) study estimated an even lower pooling share of 15% for all nationwide ride-hailing trips. This pooling share is supported by the aforementioned (Young et al., 2020) Toronto study which also found that only slightly over half (52%) of all observed pooled rides were in fact a shared ride-hailing trip with two or more unique parties being matched; a finding highlighting the limited presence of more-efficient ride-hailing services.

When public health conditions permit the resumption of shared ride-hailing services, public agencies can also shift ride-hailing passengers to pooled service adoption through pricing strategies, fee structures, and regulations. In October 2019, a $3.25 drop-off fee was implemented at Boston Logan International Airport for standard service Uber and Lyft trips to complement an existing pick-up fee of the same price. This action from the Massachusetts Port Authority offered ridesharing customers a discounted $1.50 fee for pick-ups and drop-offs as incentive to use pooled services. Statewide or citywide ride-hailing fees can also be enacted at different levels to encourage pooled service adoption in lieu of single-party rides. Public agencies could also consider establishing an additional surcharge on ride-hailing trips that do not begin or end at a designated shared ride stop in specified areas; especially, during peak periods in which traffic congestion is highest and pooling service adoption shares were lowest. While at odds with public transit, Uber launched its Uber Express Pool option—where, for a lower fare, a customer walks up to five minutes per trip end to share a ride-hailing vehicle traversing a predetermined route (à la fixed-route transit)—in Boston during April 2018 as a strategy to increase ridesharing. At workplaces located outside of a transit station walkshed, employers should also seek to provide commuter benefits in the form of eligibility for employees to use pre-tax dollars for commuting with a pooled service.

Finally, the prevalence of ride-hailing passengers from lower-income households raises important equity concerns. In our survey, ride-hailing passengers who reported an annual household income below $38,000 were significantly more likely to rideshare—with 30% of sampled pooled service passengers belonging to this lowest income cohort, indicating a higher level of price sensitivity for pooled ride-hailing passengers. Although pooled services are less expensive than single-party rides, the former option usually costs more than public transit would for a comparable trip (an exception perhaps being for shorter pooled trips with higher occupancy levels), and if adopted regularly would produce a substantial cost burden to low-income households. Programmatic efforts such as Lyft's Jobs Access Program—a short-term strategy for qualifying residents to receive subsidized ride-hailing travel to and from job training programs, interviews, and during the initial three-week period at a new employment opportunity—have been introduced in Boston and other select cities in an effort to mitigate this cost burden by subsidizing trips for lower-income passengers. However, these programs do not address the systemic inequities in transit accessibility. The fact that so many individuals from lower-income households are adopting ride-hailing services indicates that transit is either not available or highly inconvenient for a particular trip, which again highlights a need to invest in frequent, reliable, and comprehensive public transit services that connect lower-income households to many destinations and opportunities.

6. Conclusion

If ride-hailing is to be welcomed by transportation planners and agencies as a more sustainable alternative to the private vehicle, then pooling must be its predominant service type. Ridesharing offers the prospect of a more affordable and efficient approach to the standard, exclusive ride-hailing service adoption with relatively fewer negative impacts to society and the environment. However, its popularity has lagged in comparison to single-party services and there is limited guidance available for public agencies seeking to shift ride-hailing adopters from single-party to pooled services. This study answers this call by collecting and analyzing ride-hailing data for the Greater Boston region to provide new insights into the patterns and individual-level predictors of pooled ride-hailing service adoption.

While previous studies have generally found ride-hailing passengers to be younger, more educated, and wealthier (Gehrke et al., 2019), this study has indicated that pooled services are favored by individuals who are also younger, but tend to have a lower educational attainment level, household income, limited personal vehicle access, and identify as a member of a racial or ethnic minority group. In terms of travel patterns and characteristics, pooled ride-hailing trips were most common in the region's inner core neighborhoods and to occur on the weekend or middle of a weekday, with sampled passengers who opted for ridesharing more likely to state that they would have walked, cycled, or used public transit if ride-hailing services were not available for their observed trip. Since these passengers are adopting ride-hailing services that negatively affect transit ridership and congestion in lieu of more sustainable and affordable mobility options, transportation policies that promote or subsidize pooled ride-hailing services for lower-income households rather than offer a more systemic improvement in transit access and reliability should only be viewed as a stopgap strategy.

Model results confirmed that lower fares are indeed associated with the selection of ridesharing services, while highlighting that a pooled service was more commonly adopted for trips where the passenger was returning home and that a standard service was more likely to have replaced a traditional taxi trip. In turn, the substitution of pooled ride-hailing services for public transit was found to be significant in the models of home-based travel. Coupled with prior findings highlighting the adverse impacts of ride-hailing services on established travel alternatives (Gehrke et al., 2019), these mode substitution findings indicate that traditional taxi services are most likely to be replaced by standard single-party services and that ride-hailing passengers tend to prefer pooling as an alternative to public transit.

Going forward, research in support of pooled ride-hailing service adoption should utilize longitudinal data sets at a population-level that are collected across diverse regions. Due to a lack of available data, studies of ride-hailing adoption across multiple time periods or contexts have been limited (Gehrke, 2020; Sabouri et al., 2020) and as a result have limited external validity. While this study was able to identify individual-level determinants of pooling, the incorporation of attitudinal factors could have offered further nuance in understanding the social barriers to ridesharing adoption (Moody et al., 2019). Also, as mentioned in the Discussion, single-party and pooled ride-hailing services should be treated distinctly in policy actions and therefore future survey designs should distinguish between these service options when investigating mode substitution effects or reasons for ride-hailing adoption. In particular, personal security and public health factors may be more prominently considered when deciding between an exclusive or shared ride-hailing trip. Finally, although built environment attributes were not found to predict ridesharing adoption for travel to or from an individual's residence once their socioeconomic and trip features were specified, more disaggregate contextual measures should be investigated to ensure that policies and programs focused on social factors do in fact appear most likely to increase ridesharing rates.

CRediT authorship contribution statement

Steven R. Gehrke: Conceptualization, Methodology, Formal analysis, Investigation, Writing - original draft, Writing - review & editing, Visualization, Resources, Supervision. **Michael P. Huff:** Formal analysis, Writing - original draft. **Timothy G. Reardon:** Conceptualization, Writing - original draft, Resources, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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