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ADOPTION OF EXCLUSIVE AND POOLED TNC SERVICES IN SINGAPORE AND THE U.S.

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ABSTRACT
On-demand mobility services provided by transport network companies (TNCs) have experienced significant growth in their adoption and diversification of services in major metropolitan cities around the world. This study presents analysis of primary data from Singapore, exploring the sociodemographics of TNC users, who (among these TNC users) is more likely to pool their trips, and what modes these services are replacing. We compare these results to a comprehensive literature review of similar studies of TNC users in the metropolitan U.S. We find that the sociodemographics of TNC users in general are similar in Singapore and the U.S.: younger, highly educated, and higher income individuals are more likely to have used TNC services. On the other hand when differentiating by type of TNC service, we find that younger individuals from households that do not own a car are more likely to have pooled in Singapore, while employment is an important predictor in the U.S. We also find differences in mode substitution; while TNC trips in the U.S. primarily induce additional trips or replace trips by public and non-motorized transport, in Singapore they primarily replace personal/private vehicle trips. In Singapore, we explore mode substitution by exclusive and pooled TNC services separately, finding that pooled trips draw more from public and non-motorized transport, while exclusive trips replace more personal/private vehicle trips. These results suggest that people in Singapore view exclusive and pooled TNC services as distinct travel options that may be more closely related to other private or public transport, respectively. Differences between Singapore and the U.S. highlight the importance of accounting for local context and suggests that the quality of all travel alternatives in the urban area will affect the mode substitution of TNC trips.

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INTRODUCTION

On-demand mobility services provided by transport network companies (TNCs) have experienced significant growth in adoption in major metropolitan cities all across the world since the introduction of Uber in the United States in 2010. The rapid adoption of TNCs and the diversification of the services they offer (like exclusive versus pooled trips) can expand mobility and accessibility for urban residents, but also pose significant challenges for transportation researchers, policymakers, and planners. Therefore, it is critical to understand who is adopting these new services, how much people are willing to pool trips, and the potential impacts of these services on transportation decisions and travel patterns across different modes.

While there is a growing body of literature answering these questions in the context of the U.S., little information is available about who uses these services in other cities and countries around the world, particularly in emerging economies. As these services continue to expand internationally—with Uber operating in over 60 countries and 700 cities worldwide (2019) and many local and international competitors joining the market—more information is needed to determine which individuals are adopting these services and how they are affecting travel choices in other urban transportation markets. There are a few notable exceptions, with studies looking at how individuals use TNC services in Santiago, Chile (Tirachini & del Río, 2019) and Hangzhou and Chengdu, China (Wang, Chen, & Chen, 2019; Li, et al., 2019).

Furthermore, very few survey studies differentiate by type of TNC service. Most TNCs primarily offer *exclusive service* in which a driver is paired with a single rider (or rider party of up to 4 people) serving a single trip. Examples of exclusive service include UberX and Lyft Classic in the U.S. and GrabCar Economy or Premium, Ryde, and Gojek GoCar in Singapore. However, an increasing number of companies are also offering *dynamically pooled (or ridesplitting) services* that match a rider (or rider party of 1 or 2 people) with other riders (or rider parties) in the same vehicle. Examples of pooled service include UberPOOL and Lyft Shared (previously Lyft Line) in the U.S. and GrabShare or Ryde Carpool in Singapore. While pooled services are available in fewer markets worldwide, many policymakers and advocates for sustainable mobility are excited about their potential to expand mobility, without significant increases to vehicle-miles-traveled in dense cities. At the system-level, use of pooled rather than exclusive TNC services can have very different implications for travel-related externalities, such as congestion and vehicle miles traveled (Schaller, 2018; Zheng, Chen, & Chen, 2018; Alexander & González, 2015). At the individual-level, choosing the pooled services over an exclusive trip can save the traveler money making pooling more price competitive with public transit, but at a cost of longer and less certain travel times. Therefore, it is critical to differentiate between private and pooled TNC services. Some studies have modeled this tradeoff between private and pooled TNC services using choice experiments (e.g., Liu, et al., 2018; Asgari & Corkery, 2019; Shabanpour, Golshani, & Mohammadian, 2018; Cahyo, Burhan, & Burhan, 2019; Naumov & Keith, 2019) and others have looked at how attitudes and other individual attributes predict intention to use these service (e.g., Amirkiaee & Evangelopoulos, 2018; Alemi, et al., 2018b; 2019). However, few survey studies of actual TNC trips (from revealed preference survey data) have differentiated between private and pooled services.

In this study we address these remaining knowledge gaps by investigating who uses TNC services and how they are used in an urban context outside of the U.S., specifically Singapore,

and by explicitly differentiating between exclusive and pooled services. In particular, we address three research questions comparing primary data analysis in Singapore with related findings from existing surveys in the U.S.:

1. Who uses TNC services (both exclusive and pooled)?
2. Among TNC users, who pools (more)?
3. What modes are exclusive and pooled TNC trips replacing?

This study combines two data collection efforts to support a comparative analysis between the Singapore and the U.S. First, we collect primary survey data for a sample of Singaporean citizens and permanent residents and estimate a series of regression models to predict use of TNC services by individual sociodemographics. Second, we perform a systematic review of related survey findings on TNC use in the U.S. We choose the U.S. as our comparator because it remains a primary market for TNCs and is, to date, the most studied. We conclude with a discussion of the implications and limitations of this comparative analysis and a call for continued research into TNC use in different urban contexts that clearly differentiate between exclusive and pooled services.

TNC USE IN SINGAPORE: FINDINGS FROM PRIMARY DATA COLLECTION

Sample

An electronic, computer-based survey was administered to current residents of Singapore from mid-February to mid-April, 2019. Survey respondents were recruited by Qualtrics, a professional panel and survey company, and were screened for eligibility (being 18 years or older and a permanent resident or citizen of Singapore). Responses were restricted to permanent residents or citizens of Singapore to allow for direct comparisons between our sample sociodemographic characteristics and population data provided by the Singapore Department of Statistics. In doing so, we may be excluding certain types of TNC users by limiting to this sampling frame, such as tourists and expats and others living and working in Singapore who are not permanent residents or citizens.

A total of 1780 partial responses were collected. Of these responses, 192 were found to be ineligible and did not complete the survey and another 119 were screened out by sociodemographic response quotas. An additional 668 were eliminated for failing at least one of four attention checks embedded throughout the survey. These attention checks were embedded in Likert-format questions and consisted of clear directions to select a specific answer (such as "Please choose 'strongly agree'"). This left a final, cleaned sample size of 801 complete responses. This sample size is well within the range of reported sample sizes for similar studies from U.S. metropolitan areas (see Table 5).

Quotas were enforced to control sample representativeness for five age brackets, five household income brackets, and household car ownership. Towards the end of the data collection period, the quota for household car ownership was relaxed due to lagging response rates. Comparing the sociodemographic characteristics of our sample to the population of Singapore, we find that our sample underrepresents the elderly, those with low educational attainment, and households with very low incomes. On the other hand, it overrepresents males as well as larger households that own cars (see Table 1). These discrepancies between sample and population statistics may be

due, in part, to the electronic method of data collection. However, the discrepancies are small enough that they do not threaten the validity or generalizability of our regression model results, especially when including all sociodemographics as predictors.

Table 1. Sample representativeness of the Singapore population

Sociodemographic characteristic	Population (%)	Sample (%)
Age*		
18-29	21.1	26.5
30-44	24.6	30.8
45-54	19.5	24.3
55-64	18.6	13.0
65 and older	16.2	4.9
Male**	49.1	53.2
Monthly household income (S$)*		
Below 2,500	20.4	4.6
2,500-5,999	19.8	26.7
6,000-9,999	21.2	30.2
10,000-14,999	17.4	22.7
15,000 and over	21.1	15.8
Educational attainment (age 25+)**		
Below secondary	28.6	0.2
Secondary	17.2	10.6
Post-secondary (non-tertiary)	8.9	5.6
Diploma/professional qualification	14.6	23.9
University	30.7	59.7
Household owns car (0/1)**	42.1	62.4
Average household size*	3.4	3.7

Note: -- = data not available; population statistics from Singapore Department of Statistics * = (2015), ** = (2018)

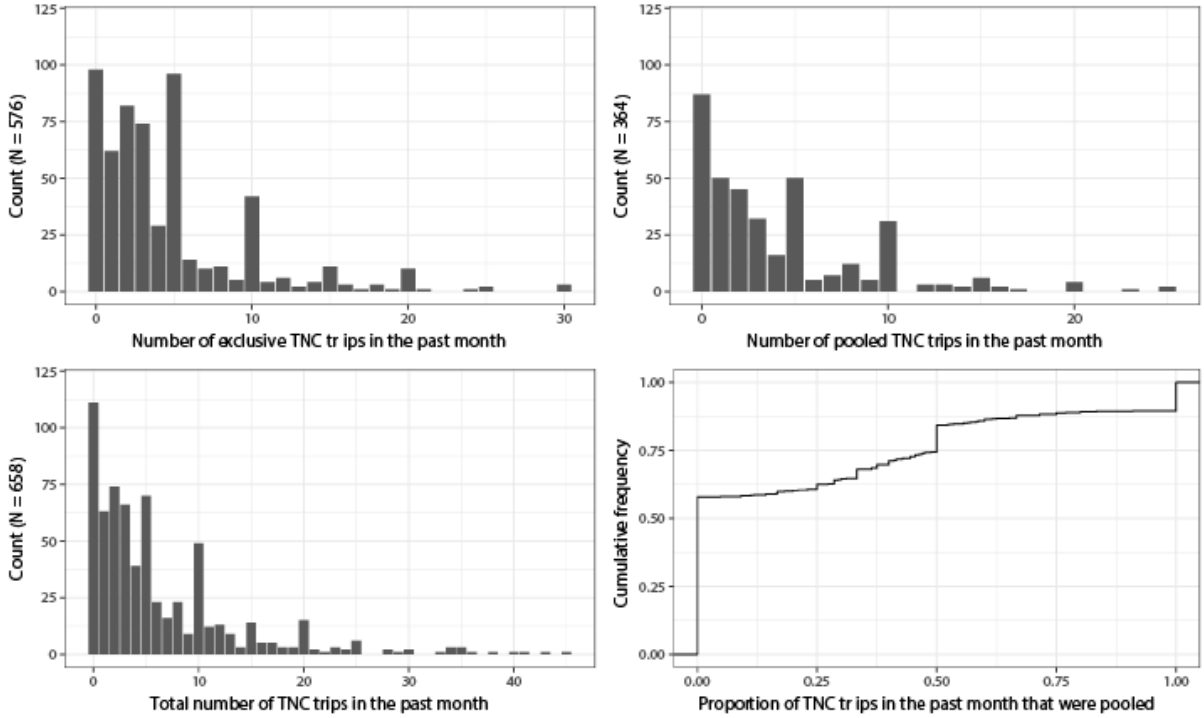
Variables

The questionnaire consisted of a series of blocks that asked individuals about their current travel behavior, use of TNC services, and attitudes towards autonomous vehicle technology. This paper specifically analyzes responses to the questions on current use of TNC services (referred to as "ridehailing" in the survey). First, individuals were asked: "Have you ever used these ridehailing services (as a passenger)?" with response choices of "No: I have never used a ridehailing service," "Yes: I have used a private (or exclusive) ridehailing service," and/or "Yes: I have used a shared (or pooled) ridehailing service." Individuals were allowed to accept both yes responses. Those who indicated that they had used one or both types of TNC services were then asked how many trips they had taken by this service in the past month.

A brief investigation of the raw data shows that, among our 801 respondents, 658 (82%) say they have used some form of TNC service, with 294 (37%) reporting that they have only used an exclusive service, 82 (10%) reporting that they have only used a pooled service, and 282 (35%) reporting that they have used both exclusive and pooled services. Across all respondents in our sample, we observe a total of 2,637 trips by exclusive TNC service and 1,475 trips by pooled TNC service, demonstrating that use of exclusive TNC services is more common and frequent

than use of pooled TNC services in Singapore. For TNC users, we look at each individual's reported number of TNC trips in the past month. We find that the total number of TNC trips has a mean of 6.26 and a median of 4, with a highly right-skewed distribution (see Figure 1). This suggests that most TNC users take very few trips each month in Singapore.

Figure 1. Distributions of sample responses for number of TNC trips by type of service and proportion of TNC trips that are pooled



Note: For exclusive trips, the mean is 4.59 trips and the median is 3.00 across the 576 respondents who have used this type of service. For pooled trips, the mean is 4.05 trips and the median is 2.50 trips across 364 respondents.

Respondents were then asked to report what percentage of their exclusive and pooled TNC trips they would have made by other modes had the TNC service not been available. The mode options included personal car, other ridehailing service, motorcycle, taxi, public transport [mass rapid transit (MRT), light rail transit (LRT) and/or bus], walking or bicycling, or none/would not have made the trip at all.

Methods

In order to explore our research questions related to the sociodemographics of TNC users in Singapore, we estimate a series of regression models according to Table 2. For all models, we include the following sociodemographic characteristics of the respondents and their households as the predictor variables: age (years), gender, college and graduate degree attainment (0/1), full time employed (0/1), student (0/1), monthly household income (in S$1000), household car ownership (0/1), and household size (number of people).

First, we consider who is most likely to have used TNC services and who uses them most frequently. We predict whether an individual has used TNC services or not (0/1) using a logistic regression on the entire sample of 801 respondents. Next, we subset the data to those 658

respondents who report having used TNC services and run a negative binomial regression model to predict the frequency (in terms of number of trips in the past month) of TNC use. We adopt a negative binomial regression model to handle the highly skewed count dependent variable (see Figure 1). This approach is better than a simple comparison of sociodemographic characteristics across TNC users and non-users in our sample because it accounts for correlations among different sociodemographic characteristics.

Second, we explore the question of who, among our 658 TNC users, is more likely to pool. We run a logistic regression predicting use of pooling (0/1). Next, we subset the data further to just those 364 respondents who report having used a pooled service and run a beta regression model predicting the proportion of TNC trips in the past month that were pooled (Cribari-Neto & Zeileis, 2010). The beta regression is estimated using a logistic link function and employing endpoint transformation for respondents who reported 0% or 100% pooling in the past month as recommended by Smithson and Verkuilen (2006).

Table 2. Overview of regression models estimated for the Singapore TNC use data

Research question	Dependent variable	Sample (size)	Model type
Who uses TNC services?	Has used TNC service (0/1)	All respondents (801)	Logistic regression
	Frequency of use (number of trips in the past month)	Users of any type of TNC service (658)	Negative binomial regression
Among TNC users, who pools (more)?	Has used pooled service (0/1)	Users of any type of TNC service (658)	Logistic regression
	Proportion of TNC trips that are pooled in the past month	Users of a pooled TNC service (364)	Beta regression

Post-hoc power analysis for t-tests of coefficient statistical significance against $b = 0$ were conducted for all sample sizes used in the analysis: the full 801 respondents, the 658 TNC users, and the 364 respondents who report having used pooling. In all cases, power of over 0.9 was achieved for significance level of 0.05 and a small effect size of 0.2 (Cohen, 1988). Due to the limited number of respondents in our sample that have used pooling, our final model of the proportion of pooled trips may have difficulty detecting smaller effect sizes due to our limited statistical power.

Model Results

Who Uses TNC Services (both Exclusive and Pooled)?

The results of our regression models exploring who has used TNC services and how frequently they used them in the past month are presented in Table 3. Looking first at the model predicting use of TNC service (0/1), we find that individuals who are younger, highly educated, employed full-time, and come from households with higher incomes are significantly more likely to be TNC users in Singapore. We find that employment status and gender are not significantly predictive of having used TNCs in Singapore. Additionally, after controlling for sociodemographic characteristics, household car ownership is not a significant predictor of TNC use in Singapore.

Next, we consider frequency of TNC use in terms of number of trips taken by both exclusive and pooled services in the past month. The model results suggest that more frequent users of TNCs are younger, male, more likely to be employed full-time, and come from higher household incomes than less frequent users. Interestingly, while educational attainment was found to be a significant predictor of whether or not the individual has used TNC service, it was not a significant predictor of the frequency of use (once self-selected as a user).

Table 3. Results of regression models predicting use of TNC services among Singaporean citizens and permanent residents

	Has used TNC service (0/1)		Frequency of TNC use (# of trips in the past month)	
Variable	**b**	**e^b**	**b**	**e^b**
Intercept	3.859***		2.384***	
Age (years)	-0.072***	0.931	-0.029***	0.972
Male (0/1)	-0.137	0.872	0.068***	1.073
College degree (0/1)	0.440*	1.553	0.075	1.071
Graduate degree (0/1)	0.756*	2.129	0.176	1.190
Full-time employed (0/1)	0.422*	1.525	0.238*	1.285
Student (0/1)	-0.597	0.550	-0.135	0.880
Monthly household income (S$1000)	0.071**	1.073	0.018***	1.018
Household owns car (0/1)	0.341	1.406	-0.113	0.891
Number of people in household	-0.114	0.892	0.028	1.027
pseudo R^2	0.158		0.097	

Note: Statistical significance coded as * < 0.10, ** < 0.05, *** < 0.01; statistical significance for the negative binomial regression model of frequency of TNC use determined using a two degrees-of-freedom chi-square test of the full model against a model without the predictor.

Among TNC Users, Who Pools (More)?

Next, we turn our attention to the results of our regression models exploring who uses pooled TNC services (see Table 4). From the model predicting whether or not a TNC user has pooled (0/1), we find that individuals from Singapore who are younger, come from households with higher incomes, and who do not own a car are significantly more likely to have used pooling.

Finally, among those that have used pooled TNC services, we consider whether sociodemographics are predictive of a greater share of TNC trips that are pooled rather than exclusive. Among our predictors, we find that the coefficients for household income and household car ownership are statistically different from zero. Our model suggests that individuals with lower incomes report a significantly greater share of pooled TNC trips. This makes sense, given that pooled trips are typically less expensive than exclusive trips. Therefore, while having a higher income is marginally predictive of having used a pooled TNC service, it is correlated with much less frequent use of pooled services. These results together may suggest that greater pooling of TNC trips in Singapore are driven more by affordability and travel constraints, and potentially other trip characteristics like travel time and travel time uncertainty, rather than individual sociodemographics.

Table 4. Results of regression models predicting use of pooling among TNC users in Singapore

	Has used pooled service (0/1)		Percent of TNC trips that are pooled (in past month)	
Variable	**b**	**e^b**	**b**	**e^b**
Intercept	2.223***		0.471	
Age (years)	-0.062***	0.940	-0.006	0.994
Male (0/1)	0.159	1.173	-0.176	0.840
College degree (0/1)	0.037	1.038	-0.028	0.973
Graduate degree (0/1)	0.119	1.126	0.211	1.235
Full-time employed (0/1)	0.042	1.043	0.340	1.404
Student (0/1)	0.348	1.417	0.121	1.129
Monthly household income (S$1000)	0.041*	1.042	-0.046**	0.955
Household owns car (0/1)	-0.409**	0.664	0.461**	1.585
Number of people in household	0.033	1.033	-0.097	0.908
precision (phi)	not applicable		0.611***	
pseudo R^2	0.134		0.057	

Note: p-value of two-tailed t-test against b = 0 is * < 0.10, ** < 0.05, *** < 0.01

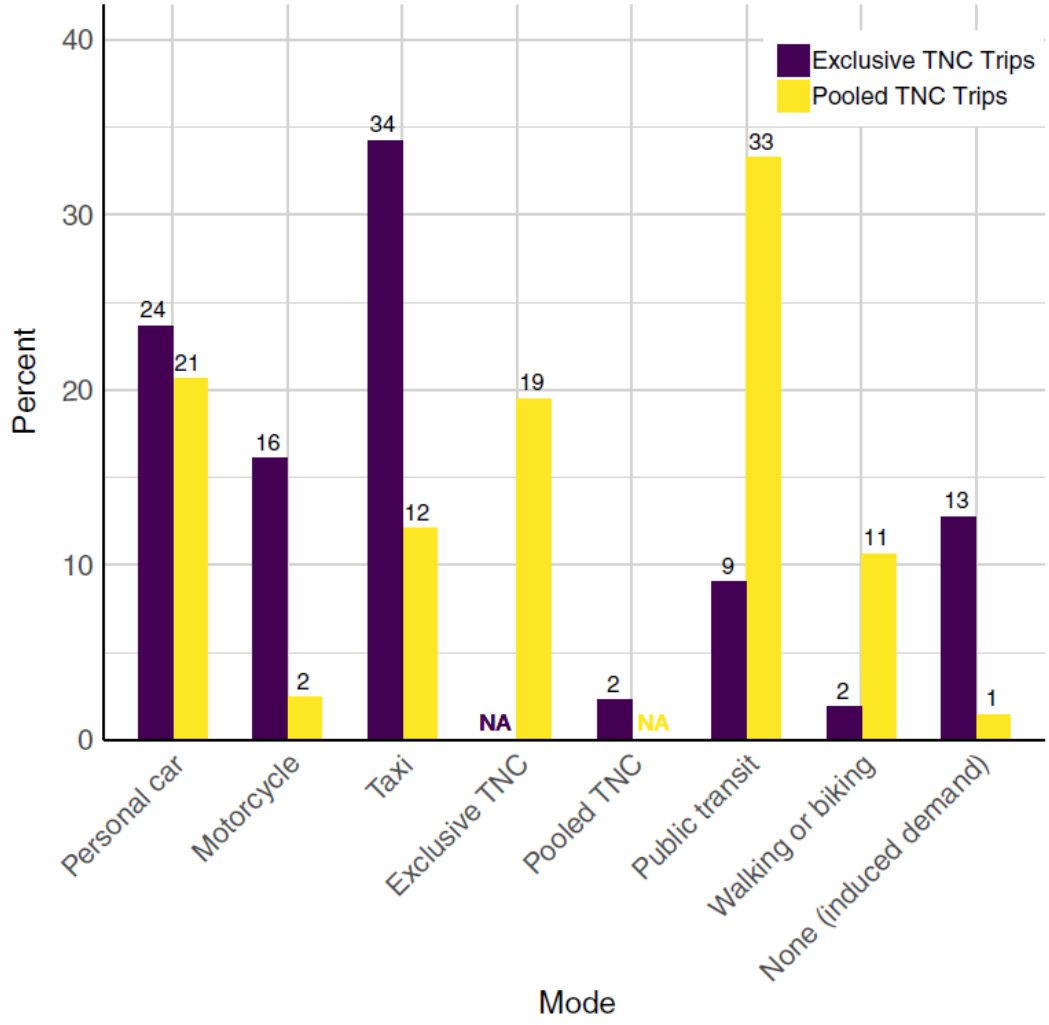
What Modes are TNC Trips Replacing?

Next, we consider the travel modes that TNC trips are replacing. The Singapore survey asked respondents to report the percentage of their TNC trips that they would have taken by each alternative mode. Weighting these responses by each individual's reported frequency of TNC use, we find that the majority of TNC trips in Singapore replace trips by taxi (26%), personal car (23%), and motorcycle (11%). On the other hand, only 18% of trips are replaced by public transit, 5% by walking or biking, and 9% would not have been made at all. Taken together, these results suggest that TNC trips in Singapore are replacing more trips by private, motorized modes and fewer trips by sustainable alternatives.

In addition to investigating mode substitution of TNC trips as a whole, our Singapore survey also asked respondents to report mode substitution separately for their exclusive and pooled trips (see Figure 2). We find that exclusive TNC services are much more likely to replace motorcycle and taxi trips and to serve new trips (induce demand) than pooled TNC services. On the other hand, pooled TNC services are much more likely to replace public and non-motorized transport. These results suggest that pooled TNC trips, with their cheaper fare and potentially longer and less reliable travel times, are seen as substitutes for public transit, biking, and walking, which share similar travel time and cost characteristics.

Finally, we consider trip substitution between exclusive and pooled TNC services. We find that individuals may replace pooled TNC trips with exclusive TNC trips, but not the other way around (see Figure 2). In other words, if pooling were not available, some people would be willing to pay more for an exclusive trip. However, if exclusive TNC services were not available, these trips would not be made by pooling, but instead by an alternative private mode such as personal car, motorcycle, or taxi. All together, these results suggest that people view exclusive and pooled TNC services as distinct travel options that may be more closely related to other private or public transport than to each other.

Figure 2. Mode substitution among Singapore TNC users, weighted by frequency of TNC use



Note: Respondents were asked: "If this private (or shared) ridehailing service hadn't been available, what percentage of these trips would you have made by: personal car, shared (or private) ridehailing service, motorcycle, taxi, public transit (MRT, LRT, and/or bus), non-motorized transport (walking or biking), none/would not have made the trip." Respondents answered in percentages from 0% to 100% for each mode using slider bars; responses across all modes had to add up to 100%.

TNC USE IN THE US: A COMPREHENSIVE LITERATURE REVIEW

To provide context for the findings above from our Singapore survey, here we synthesize key trends across a growing number of studies of TNC users in the U.S., conducted at city, state, and national levels.

Data

There is a growing body of literature on the profiles of TNC users and the impacts of TNC trips on other transportation modes in the U.S. This literature includes studies based on travel survey data (revealed preferences) and studies based on modeling of stated preference choice

experiments. Since our survey deployed in Singapore is a revealed preference survey, we focus our review on U.S. studies using comparable revealed preference methods (survey data asking individuals about their current TNC use). Table 5 summarizes the U.S. survey studies that contain information on any of our three research questions: the sociodemographics of TNC users, the sociodemographics of users of pooled TNC services, and the mode substitution of TNC trips.

Table 5. Revealed preference survey studies of TNC use in the U.S. that contain information on (1) sociodemographics of TNC users (in general); (2) sociodemographics of users of pooled TNC services; and/or (3) mode substitution of TNC trips

Study	Study area	Sample characteristics and data collection	1	2	3
Smith, 2016	U.S. (national)	• On-line/mail survey administered in 2015 • 4,787 adults, including 718 TNC users (143 using services at least once a week) • Representative of U.S. population by age, education, gender, race/ethnicity, and population density	Y	N	N
Rayle et al., 2016	San Francisco Bay Area	• On-street intercept survey of 380 TNC customers in three areas of San Francisco • Data collected May and June 2014	Y	N	Y
SUMC, 2016	7 U.S. metro areas: Austin, Boston, Chicago, Los Angeles, San Francisco, Seattle and D.C.	• Survey of ~4,500 shared mobility users distributed by public transit agencies and carsharing/bikesharing operators	N	N	Y
Alemi et al., 2018a; 2018b; 2019 Circella, et al., 2018	California (state)	California Millennials Dataset: • 1,400 Millennials (age 18-34) and 1,000 Gen X'ers (age 35-50) • Quota sampling for each of six regions of California for three neighborhood types (urban, suburban, rural) • Cell weighting and iterative proportional fitting (IPF) used to correct sample representativeness • Data collected Fall 2015	N	N	Y
Dias et al., 2017	Seattle, WA	2014–2015 Puget Sound Regional Travel Study • On-line and telephone survey • 2,789 adults directly reporting about their travel (including 430 TNC users of which 72 use at least once per week) • Representative of metropolitan region by geographic area, income, household size, employment status and vehicle ownership	Y	N	N

Study	Study area	Sample characteristics and data collection	1	2	3
Sarriera et al., 2017	U.S. metro areas where UberPOOL/ LyftLine are available	• On-line survey via Mechanical Turk • Data collected June-July, 2016 • Convenience sample (non-representative) of 997 individuals who report having used TNCs	N	Y	N
Clewlow & Mishra, 2017	7 U.S. metro areas: Boston, Chicago, Los Angeles, New York, San Francisco Bay Area, Seattle, and Washington, D.C.	• On-line survey • Data collected 2015-2016 • 4,094 urban and suburban residents • Response locations screened for variation in population and housing density • Representative by age, income, and gender	Y	N	Y
Henao, 2017	Denver	• In-vehicle intercept survey of 311 ride-hailing passengers administered Fall 2016	Y	N	Y
Gehrke, Felix, & Reardon, 2018	Boston metropolitan region	• In-vehicle intercept survey of 926 ride-hailing passengers in Oct-Nov 2017	Y	N	Y
NYCDOT, 2018	New York City (5 boroughs)	Citywide Mobility Survey • Online and phone survey • Subset of 616 respondents from 3,603 residents aged 18 and older • Data collected May-June, 2017	N	N	Y
Schaller, 2018*	U.S. (national)	National Household Travel Survey (NHTS) 2017 data	Y	N	N

Moody, Middleton, & Zhao, 2019	U.S. metro areas where UberPOOL/ LyftLine are available	• 2016 data from Sarriera, et al. (2017)
		• Additional data collected in April 2018:
		  ○ On-line survey via Mechanical Turk
		  ○ Non-representative convenience sample of 1,026 TNC users
		• NHTS 2017 data
			Y	Y	N

Lavieri & Bhat, 2019	Dallas, TX	• Online survey collected in Fall 2017 • Convenience sample of N = 1,607 commuters (have primary work place outside of the home)	Y	Y	Y
Bansal et. al., 2019	U.S. (national)	• Survey of 11,902 individuals (ride-hailing users, drivers, and non-users) in U.S. residing in TNC served areas conducted by Strategic Vision Inc. in 2017 • Sample IPF-weighted to be representative of U.S. population	Y	Y	Y

Notes: Y = yes; and N = no. *Also Batbold & Bin-Nun, 2019 and Conway, Salon & King, 2018.

Review Results

Who Uses TNC Services (both Exclusive and Pooled)?

In the United States, there is a growing wealth of information regarding the sociodemographic characteristics of users of TNC services. In 2017, the National Household Travel Survey (NHTS) included for the first time a question regarding TNC use. These data suggest that current TNC use is highly concentrated in large, densely-populated metropolitan areas, particularly Boston, Chicago, Los Angeles, Miami, New York, Philadelphia, San Francisco, Seattle and Washington D.C. (Schaller, 2018; Conway, Salon, & King, 2018). This concentration of TNC use in urban areas is unsurprising given that greater population (and thus trip) densities support the efficient operations of these services and matches with previous studies that find higher rates of utilization among TNC users in urban rather than suburban areas (Clewlow & Mishra, 2017; Smith, 2016).

Studies have also considered how age, income, education level, gender, and car ownership vary between users and non-users of TNC services. Nationally, data suggests that use of TNCs (measured as trips per month) is generally higher among younger, more educated, and more affluent individuals. In fact, people ages 25 to 34, with a bachelor's degree, and with household incomes over $50,000 use TNCs at least twice or even three times as often as less affluent, less educated, and older persons (Schaller, 2018). Other surveys corroborate these results regarding age and education, finding TNC users are generally younger and better educated than the overall population in a given metropolitan area (Smith, 2016; Rayle, et al., 2016; Clewlow & Mishra, 2017; Henao, 2017; Gehrke, Felix, & Reardon, 2018). However, evidence regarding income levels are more varied. While many surveys also find that TNC users underrepresent low-income households and overrepresent high-income households (Smith, 2016; Rayle, et al., 2016; Clewlow & Mishra, 2017; Henao, 2017), a survey of Boston area users found that the frequency of low-income respondents was comparable to their share in the metropolitan population (Gehrke, Felix, & Reardon, 2018).

In both the NHTS data and across studies, gender differences are found to be much more modest. Nationally, men appear to be somewhat more frequent users of TNC services than women (Schaller, 2018). This finding that TNC users slightly overrepresent men was also seen in Denver (Henao, 2017) and San Francisco (Rayle, et al., 2016), but other survey results show a fairly even split by gender (Smith, 2016) or even show a slightly higher representation of females among TNC users (Clewlow & Mishra, 2017; Gehrke, Felix, & Reardon, 2018).

Finally, a number of studies have compared car ownership between users and non-users of TNC services. Nationally, not owning a car is highly related to TNC use (Schaller, 2018; Smith, 2016) and as many as 10% of TNC users report postponing the purchase of a new car (Bansal, et al., 2019, Hampshire, et al., 2018). In San Francisco and Boston, the proportion of TNC users that come from zero-car households was found to be much higher than the metropolitan region (Rayle, et al., 2016, Gehrke, Felix, & Reardon, 2018). This strongly suggests that non-car owners may be more likely to be TNC users.

Taken together, these results suggest that TNC users in the U.S. tend to be younger, more highly educated, potentially more affluent, and non-car-owning individuals in dense, urban areas. However, most of these studies explore this question by simply comparing the sociodemographics of users and non-users. This approach may fail to account for the fact that the

different sociodemographics are themselves correlated—for example, having a higher income may be related to higher likelihood of owning a car, while being younger or a student may be related to a lower likelihood of owning a car. Therefore, multivariate approaches are needed to explore how sociodemographics collectively predict use of TNCs. One such multivariate study in Seattle found that being younger (age 18-34 years old), having a college degree, having a lower income, being full-time employed, and being from a household with fewer vehicles are all significantly predictive of greater frequency of TNC use (Dias, et al., 2017). A similar multivariate study in Dallas, TX found that being from a household with very high income (above, $200,000 dollars per year), living in an urban area, and having lower availability of a personal vehicle at home were predictive of greater frequency of TNC use (Lavieri & Bhat, 2019). Another study predicting use of TNC services among individuals in the U.S. based on the 2017 NHTS data found that living in an urban area with greater population density is predictive of greater likelihood of having used TNC services (Conway, Salon, & King, 2018). Furthermore, consistent with much of the above literature, being younger, male, having a college or graduate degree, being employed, having a higher annual income, and being from a smaller household with fewer children and fewer vehicles were all predictive of greater likelihood of having used TNC services; importantly, these effects were significant and substantial even after controlling for the other related variables (Conway, Salon, & King, 2018).

Among TNC Users, Who Pools (More)?

The above analysis looked at the sociodemographic characteristics of users of all types of TNC services. Here we further differentiate TNC users by whether they take exclusive versus pooled trips. Specifically, we consider who among TNC users are most likely to use pooling. In the U.S., we find there are very few studies that break down the sociodemographics of TNC users based on whether they use exclusive or pooled TNC services. One reason for this may be that dynamically pooled services (like UberPOOL and Lyft Shared) remain available in only a limited number of cities in the U.S. This also helps explain why living in metropolitan areas increases the odds of a TNC user to pool compared to living in suburban areas (Lavieri & Bhat, 2019; Bansal, et al., 2019).

One study of TNC users in metropolitan areas in the U.S. compared the proportion of individuals who have used dynamically pooled services to those who have not by sociodemographic group (Sarriera, et al., 2017). They found that younger and unmarried individuals reported significantly higher rates of pooling; whereas, there were no statistically significant differences by gender or household income bracket. Other studies of TNC users in the metropolitan U.S. and Dallas, TX corroborate that the use of pooling decreases with the age of the TNC user (Lavieri & Bhat, 2019; Bansal, et al., 2019), but some have found that this relationship between age and propensity for pooling varies by other sociodemographic characteristics such as education level and gender (Bansal, et al., 2019). Studies have also found mixed results when it comes to the relationship between household car ownership and preference of a TNC user to pool, with some noting a positive (Sarriera, et al., 2017) and others a negative relation (Bansal, et al., 2019).

Another study found that TNC users who are younger and who are employed and non-students are more likely to have used pooling (0/1), while all other sociodemographic characteristics were not significantly predictive (Moody, Middleton, & Zhao, 2019). For the subset of respondents who have used a pooled service, this study found that students, respondents with graduate degrees, and those who are single report the highest percentage of TNC trips that are pooled (0-

100%), while all other sociodemographics were not significant (Moody, Middleton, & Zhao, 2019).

What Modes are TNC Trips Replacing?

Finally, we consider how individual mode choice is affected by the introduction of TNC services. This is achieved by asking survey respondents who currently use TNCs how they would have traveled without the availability of these services. This is one way of understanding how individuals are changing their travel behavior in response to the introduction of these TNC services, and informs how TNC services are impacting the broader urban transportation network.

In the U.S., results regarding the mode substitution of TNC trips vary significantly by metropolitan area and by how the survey questions are posed (see Table 6). For some specific user groups, TNC trips appear to be heavily replacing personal vehicle travel. For example, one early study found that their survey respondents—a self-selected group of individuals already using shared modes like public transit, carsharing, or bikesharing—report greater replacement of private vehicle over public transit trips (SUMC, 2016). Another national survey found that those who use TNCs as their primary mode appear to be replacing their own personal vehicles (Bansal, et al., 2019).

For the general TNC user in the U.S., however, TNC services appear to be substituting public transit, walking, and bicycling more than personal vehicle use on a trip-by-trip basis (see Table 6). With a few exceptions, such as Dallas, TX (Lavieri & Bhat, 2019), surveys across different U.S. cities indicate that 34-65% of TNC trips replace public or non-motorized transportation and an additional 3-22% of trips are induced demand. On the other hand, only about 40% would have used a personal vehicle or taxi. Thus, while some TNC trips do replace trips by personal automobile, TNC trips are primarily replacing trips by more sustainable and efficient modes such as public and non-motorized transport. This replacement of trips by more sustainable and efficient modes at current levels of TNC vehicle occupancy are likely to increase vehicle-miles traveled and related congestion in cities (e.g., Henao & Marshall, 2018; Alexander & González, 2015). However, looking only at trip-by-trip replacement may not account for the fact that TNC trips may be used in multimodal tours (Wu & MacKenzie, 2020) or could be providing a backup option that enables individuals to use transit most of the time rather than relying on driving.

Table 6. Summary of existing survey results regarding the substitution of TNC trips for other modes in the U.S.

Study	Mode substitution results summary	Study	Mode substitution results summary
Rayle et al., 2016	"How would you have made this trip if UberX/Lyft/Sidecar were not available? • Taxi = 35.9% • Transit (bus or rail) = 30.4% • Walk = 7.4% • Bike = 1.8% • Drive my own car = 5.5% • Get a ride with friend/family = 0.9% • Other = 10.1% (primarily, different ridesourcing service or carsharing)	Henao, 2017	"For this trip, how would you have traveled if Lyft/Uber wasn't an option" • Public transportation = 22.2% • Drive alone = 19.0% • Walk or bike = 11.9% • Taxi = 9.6% • Carpool = 6.1(ride)/3.2(drive) = 9.3% • Other ridesourcing = 5.5% • Get a ride = 4.5% • Car rental = 4.2%

Study	Mode substitution results summary
	• Would not have taken the trip = 8%
SUMC, 2016	"Thinking about the [ridesourcing] service you selected in the prior question, how would you make your most frequent trip if that service was not available?" • Drive alone or with a friend = 34% • Carsharing = 24% • Bus or train = 14% • Other = 8% (many are taxi)
Alemi et al., 2018a[*, +] Circella, et al., 2018[*, +]	For your most recent trip made by Uber/Lyft, how would you have made this trip (if at all), if Uber/Lyft had not been available?" • Drive car = 38.0%[a] – 40%[c] • Taxi = 48.9%[a] – 50%[c] • Ride from someone (carpool) = 26%[c] – 27.9%[a] • Van or shuttle = 5.8%[a] – 6%[c] • Public transport = 21%[c] – 21.9%[a] • Walk or bike = 18%[c] – 20.1%[a] • Not made trip = 8%[c] – 8.4%[a]
Clewlow & Mishra, 2017[+]	"If Uber or Lyft were unavailable, which transportation alternatives would you use for the trips that you make using Uber or Lyft" • Drive = 21% • Carpool = 18% • Transit = 15% • Walk = 17% • Bike = 7% • Taxi = 1% • Fewer trips = 22%
	• Other = 1.6% • Wouldn't have traveled = 12.2%
Gehrke, Felix, & Reardon, 2018	"How would you have traveled for this trip if ride-hailing services had not been available?" • Public transit = 42.1% • Taxi = 22.8% • Private vehicle = 18.0% • Walk or bike = 12.1% • Not travel = 5.0%
NYCDOT, 2018[*]	"How would you make this trip if not by ride-hail?" • Transit = 50% • Taxi or car service = 43% • Walk = 13% • Car = 12% • Bike = 2% • Would not make trip = 3%
Lavieri & Bhat, 2019	"If ride-hailing were not available, which mode would you have used for the trip" • Private vehicle = 46.3% • Taxi = 38.3% • Transit, bicycle, or walk = 9.6% • Would not have traveled = 5.9%
Bansal et al., 2019[b]	"How would you make your most frequent [ridehailing] trip if this option were unavailable" • Drive personal vehicle = 65.5% • Carsharing or carpooling = 13.3% • Public transit = 14.11% • Walk or bike = 6.6% • Wouldn't make the trip = 0.5%

Notes:

[*] Multiple responses allowed, so percentages total over 100

[+] Responses weighted by frequency of TNC use

[a] For 302 Millennials (age 18-34) and 164 Gen X'ers (age 35-50)

[b] For subset of 256 respondents who list "ridehailing" as the mobility option they use most often

[c] For subset of 208 frequent users and 274 non-frequent (less than once a month) users of TNCs (ages 18-50)

DISCUSSION

In this study, we explore the sociodemographics of users of exclusive and pooled TNC services and discuss trip-level modal substitution of TNC services for primary data collected in Singapore and based on a review of existing studies in the United States. We find that there is variation in who and how TNC services are used across different urban contexts, both within the U.S. and between the U.S. and Singapore. Yet, there are some general trends that hold across multiple studies.

When it comes to the sociodemographic characteristics of exclusive and pooled TNC users, our results in Singapore generally match trends observed within the U.S. In Singapore, we find that individuals who are younger, highly educated, and come from households with higher incomes are significantly more likely to have used TNC services in general. Among those who have used TNC services, being younger, full-time employed, and from a household with higher income are predictive of more frequent use of TNCs. When it comes to use of pooled rather than exclusive TNC service, we find that individuals who are younger and who come from households that do not own a car are significantly more likely to have pooled. While we find that having a higher income is marginally predictive of greater likelihood of having used a pooled TNC service, it is strongly correlated with much less frequent use of these pooled services.

When it comes to mode substitution, we find that Singapore and the U.S differ in which transportation modes are being replaced by TNC trips. In the U.S., TNC trips have been found to induce additional trips or replace trips by public and non-motorized transport more than they replace personal/private vehicle trips; whereas, in Singapore, we find the opposite. Our survey suggests that, overall, 60% of TNC trips in Singapore replace trips by taxi, personal car, and motorcycle. On the other hand, only 23% are replaced by public transit, walking, or biking and 9% would not have been made at all. This difference in mode substitution results between Singapore and the U.S. highlights the importance of accounting for local context and suggests that the quality of all travel alternatives in the urban area will affect the mode substitution of TNC trips. We might hypothesize that the high quality and relatively low cost of Singapore's public transit network help it remain competitive with TNC services. On the other hand, the high cost of vehicle ownership and use in Singapore because of vehicle licensing restrictions and dynamic congestion pricing policies, makes TNCs more competitive with private vehicles. However, in U.S. cities where personal vehicle ownership and use is relatively cheap, TNC services are less likely to replace these private vehicle trips. Instead, in car-oriented U.S. cities the convenience and comfort of TNC trips make them competitive with public and non-motorized transport despite their higher price. While we are unable to quantitatively explore the differences we observe between the U.S. and Singapore, our qualitative comparison highlights the need to consider the interactions between sociodemographics, current transportation infrastructure and services, and new TNC services across different contexts.

We further break down the mode substitution results by exclusive versus pooled TNC services for our Singapore sample. We find that pooled trips draw much more from public and non-motorized transport. While our data does not tell us why pooled trips are more likely to substitute trips made by public and non-motorized transport, we can hypothesize that these pooled trips are more similar to public transit in terms of cost, travel time, and the sharing of space with strangers. On the other hand, we find that exclusive trips replace more personal/private vehicle

trips. These results suggest that people in Singapore view exclusive and pooled TNC services as distinct travel options that may be more closely related to other private or public transport options than to each other. While perhaps not surprising given the differences in travel time and cost between private and pooled services, this result may have import implications for sustainable transportation policy. Policymakers concerned with TNCs adding congestion to city streets may look towards requiring pooling through mandates, exemption from fees, or dedicated infrastructure. However, our survey results in Singapore suggest that this might actually encourage the type of trips that compete on a trip-by-trip basis with more efficient public and non-motorized forms of transport. To further complicate this realization of context dependent mode-substitution, results from a survey in Hangzhou, China found the opposite; passengers of shared TNC services reported greater substitution from private vehicles or other car-based modes than exclusive TNC passengers (Chen, et al., 2018). Therefore, future research is needed to compare these findings in other metropolitan areas. These discrepancies underscore the importance of differentiate between exclusive and pooled services when studying the interactions between TNCs and other modes in the transportation network and the need for additional cross-context comparisons.

This study represents one of the first of its kind to explore who uses TNC services in a large urban market outside of the U.S. We purposefully differentiate between exclusive and pooled TNC services for all of our findings on sociodemographics of users and mode substitution. And we compare our findings from primary data collected in Singapore to a review of similar studies from metropolitan areas throughout the U.S. While qualitative comparisons of trends across these geographies are informative, there are a number of limitations to this comparative study that may require additional exploration. In particular, our comparative approach is qualitative. Without access to comparable data from multiple markets that would enable quantitative comparisons, we are limited to discussing overall trends rather than specific statistical findings across different samples.

Additionally, there are time and wording discrepancies among the studies we compare. While the data reviewed in the U.S. and collected in Singapore target areas where TNC services are well established, there are time discrepancies in terms of when the surveys were administered. In this highly dynamic market, the individuals who use exclusive and pooled TNCs and the modes that they replace may be changing as service providers continue to expand and innovate. Additionally, there is no standard way of asking about TNC use across these different surveys. While the questions in our Singapore survey were based on careful literature review of existing studies, most studies use slightly different question framing and wording (for example, asking about mode substitution for the most recent trip vs. trips in the last month). Combined, these discrepancies make direct comparisons between surveys difficult if not impossible, limiting us to only a comparison of general trends.

Finally, there are differences in the actual companies operating in the U.S. and Singapore. In the U.S., Uber and Lyft are the dominant TNCs, whereas in Singapore companies such as Grab, Ryde, and Gojek are the main operators. While this has the advantage of making our findings "operator agnostic," it may also mean that the TNC services experienced by our respondents in Singapore could be different than those experienced by respondents in the U.S.

Conclusions

In this study we address existing knowledge gaps by investigating patterns of use of exclusive versus pooled TNC services in an urban context outside of the U.S.: Singapore. This study collected primary data on who uses TNCs, who among these users are more likely to share rides, and what modes both exclusive and pooled TNC trips are replacing. A survey was conducted in Singapore and the findings were compared with results from a thorough review of related studies of multiple metropolitan areas in the U.S. Our results suggest the need for additional research into TNC use in urban markets worldwide that explore the complex interaction among individual and household sociodemographics, the built environment, and the quality and availability of alternative transportation modes. Furthermore, our study suggests that future research into TNC use should adequately differentiate between exclusive versus pooled services, since it appears that different individuals use these services and that users may see these two services as more similar to other forms of private or shared transportation than to each other.

Data availability

The questionnaire and all code used to visualize, summarize, and analyze the data from the Singapore survey are available at: https://github.com/jcmoody6/singapore-av-survey/tree/master/current-TNC-use. Data collection was approved by the MIT Committee on the Use of Humans as Experimental Subjects (COUHES) under protocol #1803290985, which stipulates that individual data records cannot be shared.

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