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Who loses and who wins in the ride-hailing era? A case study of Austin, Texas

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ABSTRACT

Ride-hailing has redefined vehicle access and has the potential to reduce travel difficulties for transit-poor areas and people with poor access to private and public transportation resources. Due to the lack of data, current studies lack a holistic understanding of how transportation resources serve different social groups and places in the ride-hailing era in low-density areas. This study uses multiple sources of data in Austin, Texas to understand: (1) how ride-hailing usage, transit supply, and vehicle ownership distribute across neighborhoods with different densities, income, and racial and ethnic compositions; (2) who are ride-hailing users among those with and without private vehicles, and how their ride-hailing usage and attitudes towards ride-hailing versus transit differ. Our study has shown that the ride-hailing services have provided residents living in low-income, low-density neighborhoods, and neighborhoods with a majority of Hispanics with an alternative transportation mode. However, residents living in low-density and low-income neighborhoods still use ride-hailing services less frequently than those living in high-density and high-income neighborhoods. The user survey further shows that ride-hailing users without private vehicles tend to be racial and minorities or younger people with higher education attainments. Ride-hailing services provide people with a convenient and safe transportation mode, regardless of their vehicle ownership. Our study shows the importance of ride-hailing in mitigating the social and spatial disparity and the opportunity of integrating ride-hailing and transit in transportation planning in low-density areas.

1. Introduction

Ride-hailing services have redistributed transportation resources in a city. For one thing, it redefines vehicle access and provides flexible vehicle trips for those who cannot afford vehicles, those who have physical limitations resulting in driving difficulties, or those who are always paranoid about finding parking lots in cities (Brown, 2019; Fleming, 2018). For another thing, it may replace or supplement public transportation services in different places. While some ride-hailing users choose ride-hailing services in their access/egress trips, many others prefer to use ride-hailing services instead of public transit for more comfortable, convenient, and flexible services (Dong, 2020a; Jin et al., 2019).

In car-dependent cities developed after the automobile age, such as Houston in the United States, can ride-hailing services mitigate the spatial and social disparities in access to transportation resources? In particular, can ride-hailing services fill up the travel needs in areas where vehicle ownership is relatively low and public transit services are not available? Can ride-hailing services reduce the travel difficulties of those who do not have access to vehicles and public transportation resources?

The current literature has three gaps to answer the above questions. First, the data of almost all existing ride-hailing studies are from a single source, either ride-hailing GPS data or the ride-hailing user survey. However, data from a single source cannot provide a complete picture of answers to the above questions. Second, current studies on low-density areas and small- and medium-sized cities remain scant. Finally, related to the second gap, the role of ride-hailing services in transport equity in low-density areas is not clear in transport policies.

This study aims to fill up the above research gaps by examining the

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spatial and social disparities of ride-hailing services in Austin, Texas, in the US. We first use ride-hailing service GPS data and other open data to understand how ride-hailing services, transit services, and vehicle ownership differ in neighborhoods with different densities and demographic and socioeconomic compositions. We then use a survey on 250 ride-hailing users in Austin to analyze the socioeconomic and demographic attributes of those who have vehicles versus those without vehicles and their different perceptions of ride-hailing services versus transit services.

The remaining part of the paper is organized as follows. The next section reviews the literature on how ride-hailing usage interacts with private vehicles and public transit at the neighborhood and individual/household levels. In Section 3, We introduce Austin's city context and how we use various data sources to examine spatial and social disparity in ride-hailing usage. Section 4 presents the spatial and social disparities of ride-hailing usage at neighborhood and individual levels. The paper concludes with a summary of the main findings and research and policy implications in Section 5.

2. Literature review

Ride-hailing services have reshaped the transportation resource distribution across different places and various social groups. At least two literature reviews have synthesized the current research and practices intersecting ride-hailing services and transport equity (Dill and McNeil, 2020; Palm et al., 2020). This section focuses on spatial and social disparities of ride-hailing services at the neighborhood and individual levels.

2.1. Spatial and social disparities of ride-hailing services at the neighborhood level

Ride-hailing services do not serve different areas within a city equally. Several studies showed that ride-hailing services were more prevalent in neighborhoods with greater population density, higher shares of people with young people, non-whites, and those with higher shares of zero-vehicle households (Brown, 2019; Edwards, 2020; Yan et al., 2020; Yu and Peng, 2019). However, conclusions regarding ride-hailing usage across neighborhoods of different income levels and racial/ethnic composition are mixed. While some studies (Brown, 2019; Edwards, 2020) demonstrated that ride-hailing usage was less common in high-income neighborhoods, another study concluded oppositely: ride-hailing demand was negatively related to the share of low- and middle-wage workers in a neighborhood (Yan et al., 2020). Edwards (2020) further noted that high-income and low-income riders had different hailing preferences. The most evident difference is that high-income households had higher frequencies of using luxurious vehicles, such as SUVs.

Several studies focused on how well ride-hailing services helped the transit-poor neighborhoods (Barajas and Brown, 2021; Jiao and Wang, 2020; Jin et al., 2019; Kong et al., 2020; Young et al., 2020). Several studies found that ride-hailing services supplemented services of places where public transit services were poor and replaced public transit services in transit-rich areas, where travel times of two modes were similar but transit services were more affordable than ride-hailing (Jin et al., 2019; Kong et al., 2020; Young et al., 2020). However, several other studies tend to agree that ride-hailing services still underserve areas with poor transit services and larger shares of transit-dependent populations. Residents living in neighborhoods whose transit services dominated by bus services travel had fewer ride-hailing services, while those living in neighborhoods most of whose transit services were rails generated more ride-hailing trips (Barajas and Brown, 2021). Similarly, Jiao and Wang (2020) found that ride-hailing services in New York City, the US, served the neighborhoods with more extensive transit services and fewer transit-dependent populations better.

2.2. Social disparities in ride-hailing usage using individual-level data

While spatial analysis reviewed in Section 2.1 shows the spatial disparity in ride-hailing usage, aggregated data are not sufficiently informative in the social disparity of ride-hailing users. As Brown (2019) acknowledged in her research, the ride-hailing usage of residents living in a neighborhood masks the heterogeneity of travel preferences and habits of residents living in that neighborhood. For example, not all persons living in a low-income neighborhood are low-income. These studies also shed little light on the underlying reasons for choosing one travel mode versus the competing ones. National and regional travel surveys and ride-hailing user surveys are helpful to understand the social disparities of ride-hailing usage.

Ride-hailing users have some unique socioeconomic attributes compared to non-users. Collectively, current studies agree that ride-hailing users, on average, tend to be wealthier, younger, more educated males (Alemi et al., 2018; Clewlow and Mishra, 2017; Conway et al., 2018; Gehrke et al., 2019; Grahn et al., 2019; Rayle et al., 2016; Young and Farber, 2019). Ride-hailing users also tend to be more tech-savvy. Using data from the Dallas-Forth Metropolitan Area, Lavieri and Bhat (2019) found that ride-hailing users' most important trait is tech-savviness. Intuitively, older adults born without modern technologies generally use ride-hailing applications much less than younger generations (Mitra et al., 2019; Shirgaokar et al., 2021; Vivoda et al., 2018).

Rider-hailing services provide people who lack transportation resources, including transit-dependent people and those without vehicles, with on-demand alternative travel modes. Several studies found that ride-hailing services replaced many transit-dependent riders' transit trips due to ride-hailing services' convenience and efficiency (Dong, 2020a; Lavieri and Bhat, 2019). Dong (2020) further noted that females were more likely to use ride-hailing services for safety concerns on transit. Ride-hailing services also beat taxi services in several cities due to their reliability and affordability (Brown and LaValle, 2020; Dong, 2020b; Rayle et al., 2016).

Ride-hailing services also offer vehicle services for those who depend on vehicles in daily travel but live in zero-car households. Using the recent National Household Travel Survey of the United States, a recent study found that people who had constraints in owning vehicles or driving had more daily trips if they took advantage of the ride-hailing apps (Blumenberg et al., 2021). Using a regional travel survey in California, Brown (2017) distinguished "carfree" households who do not need vehicles from "carless" households that do not have vehicles due to financial constraints or other limitations. She found that the share of zero-vehicle households labeled as "carfree" is only 21%. She further noted that "carless" households had a higher possibility to hold car-shared program memberships. Though her study did not involve ride-hailing services, she stated in her later study in Los Angeles (Brown, 2019) that ride-hailing redefined vehicle access for those who do not have vehicles.

2.3. Research gaps

Together, current studies show the vast spatial and social disparities of ride-hailing services. However, they demonstrate the following research gaps. To begin with, almost all studies used either travel survey data, ride-hailing user data, or ride-hailing GPS data. While the former two sources show the social disparities of ride-hailing usage and the underlying reasons at the individual level, their spatial resolution and coverage underperform the latter source. However, the GPS data show little evidence intersecting the users' socioeconomic attributes and ride-hailing usage.

Second, almost all the studies were conducted in large and dense cities, such as Boston, Los Angeles, and Toronto, where people have extensive access to public transportation services. For the massive cities in the west and south of the US, or other cities developed after the automobile age in Canada and Australia, public transportation is inefficient and mainly serves suburban-downtown commuting (Blumenberg and Manville, 2004; Lucas, 2012). Living in these car-dependent areas is extremely difficult for those who find owning a car is a financial burden or those who are physically incapable of driving.

Third, though the most direct implication of ride-hailing services is providing those without readily convenient access to vehicles with alternatives, it is unclear in the current literature whether ride-hailing services benefit those without vehicles in car-dependent areas. It is also unclear on their preference towards ride-hailing services versus other competing travel modes, such as transit. While some scholars claim that providing vehicles to low-income people are most efficient to reduce travel difficulties for those who live in low-density areas (Blumenberg and Manville, 2004; Fan, 2012), many others argue that promoting public transportation in car-dependent areas are more meaningful to correct the historically inequitable transportation finance across different travel modes, regions, and social groups (Karner and Niemeier, 2013; Taylor and Tassiello Norton, 2009). With ride-hailing services, federal and local governments can potentially reduce vehicle use for many people and use ride-hailing services to integrate public transportation systems. However, current studies lack the understanding of the attitudes towards ride-hailing services over the transit of car owners and those living in zero-car households in the car-dependent areas.

3. Research design

To fill up the research gaps, we use the ride-hailing GPS data and other open data and a survey conducted by the University of Texas to examine the spatial and social disparities of ride-hailing usage in Austin, Texas. In this section, we first justify why Austin, Texas is a desirable case by demonstrating the car-dependent nature of the city. We then introduce the data sources, variables, and analytical techniques for the analysis at neighborhood and individual levels.

3.1. City context: Austin, Texas

With an area of 790.1 km^2, the city of Austin is home to more than 964,000 people (US Census Bureau, 2019). Austin is a well-known sunbelt city located in the transitional area between the Southwestern deserts and the lush, humid regions in the Southeast. Over the past few decades, Austin's population has grown rapidly.

Like other sunbelt cities, Austin developed after the automobile age and depends heavily on daily travel vehicles. According to the report of Statesman, about 73% of residents in Austin drive alone to and from work, whereas the public transit usage is only about 5% in 2016 (Wear, 2017). Compared with Texas's other 4 major cities (Dallas, Fort Worth, Houston, and San Antonio), only Austin has less than 15 percent transit-dependent population (Jiao, 2017). The transit supply is primarily concentrated in the downtown (Daganzo, 2010), while the majority of transit-dependent people, especially the low-income Hispanic population, are located outside the transit-rich areas and are trapped in "transit deserts" (Jiao, 2017). As illustrated in Fig. 1, our neighborhood-level analysis focuses on the city of Austin due to its multimodal nature. Our individual-level analysis focuses on the Austin–Round Rock–San Marcos Metropolitan Statistical Area (MSA).

Despite its car-dependence, Austin's ride-hailing platform provides exemplary ride-hailing services for car-dependent cities alike. Austin developed a uniform ride-hailing platform in 2016, RideAustin, which replaces all TNCs (including Uber and Lyft) and aims to provide affordable ride-hailing services for all citizens living in Austin. Compared with the ride-hailing giants such as Uber and Lyft, RideAustin offers unique travel options. First, RideAustin is a non-profit ridesharing company founded by the local community, whose funding mainly comes from local charities and enterprises' donations. Due to its non-profit nature, riders can pay less if they use ride-hailing services in Austin. For instance, the minimum fare to take a ride by RideAustin is $4.00, which is lower than that of Uber ($5.95). Second, RideAustin offers free medical trips for low-income people who have trouble affording transportation to and from hospitals (Powell, 2017). Third, for people who might not have access to a smartphone, RideAustin has worked with local health institutes to develop an interface that allows patients' doctors to schedule appointments (Goldenstein, 2017).

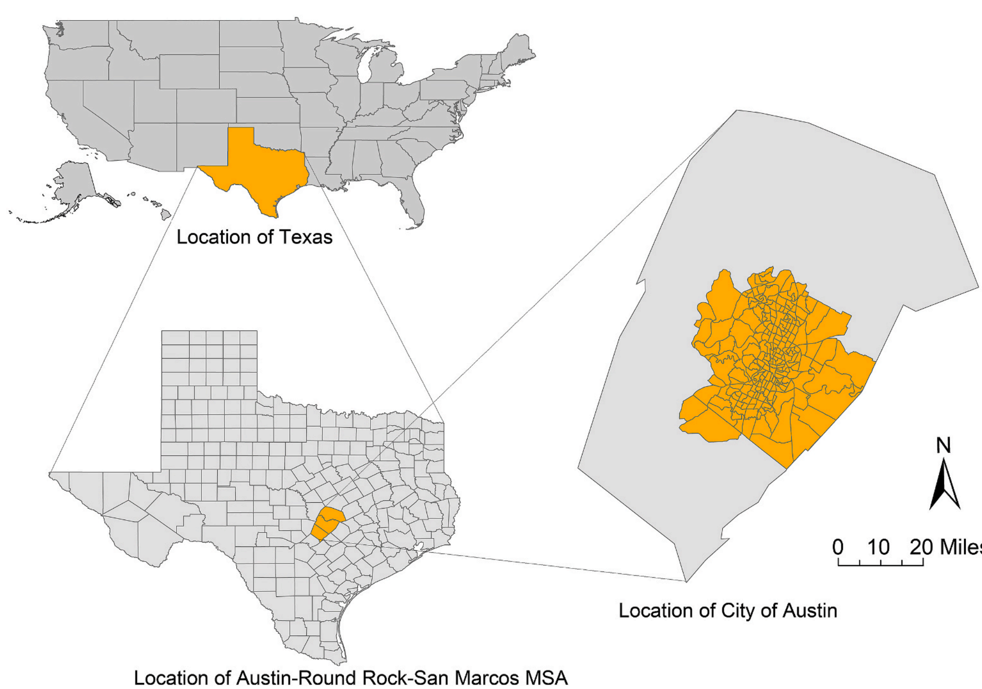

Fig. 1. Locations of Austin–round Rock–San Marcos MSA and city of Austin.

3.2. Neighborhood-level analysis

In the first part of the analysis, we focus on how ride-hailing services, shares of vehicle ownership, and transit supply vary across neighborhoods with different densities and socioeconomic attributes. We are interested in how three types of transportation resources distribute across neighborhoods. In particular, we examine whether the low-income neighborhoods, those with lower densities, and those with a majority of racial minorities have lower access to all three types of transportation resources.

We choose the census tract as the "neighborhood" proxy because it is the smallest unit that provides sufficient information on socioeconomic attributes in the analysis. Aligned with previous efforts (Barajas and Brown, 2021; Brown, 2019; Yan et al., 2020), we analyze neighborhoods based on the following attributes collected in the American Community Survey (ACS) 2014–2018 5-year survey (US Census Bureau, 2017): (1) population density; (2) median household income; and (3) the share of non-Hispanic whites and Hispanics, and African Americans. We deleted 8 census tracts without information on the above three traits. We retrieved census tracts' geographic boundaries in Austin from the Topologically Integrated Geographic Encoding and Reference (TIGER) dataset (US Census Bureau, 2017) with complete information on all attributes mentioned above. We use the information of 212 census tracts for analysis. For further analysis, we categorize the neighborhoods into different subgroups based on the above three traits:

- ***Density***: We classify neighborhoods into low-, middle-, and high-density ones. While the low-density and high-density neighborhoods are those with bottom and top quartile of population density among the 212 census tracts, those in the middle 50% in population density are regarded as middle-density neighborhoods.
- ***Income***: Like neighborhood classification based on density, those with median income values in the top and bottom 25% are classified as high- and low-income neighborhoods, respectively. All other neighborhoods are middle-income neighborhoods.
- ***Racial and ethnic composition***: We identify those with more than 50% of non-Hispanic Whites in their tracts as majority White neighborhoods. Similarly, those with more than 50% of their populations as Hispanics are majority Hispanic neighborhoods. As African Americans and other races are dispersed and take relatively small shares in Austin, few neighborhoods are dominated by other races. All other neighborhoods whose non-Hispanic whites and Hispanics are fewer than a half are labeled as "no majority" neighborhoods.

We measure ride-hailing usage using GPS data collected by the local TNC RideAustin. RideAustin published an open and big data set which includes more than 1.5 million trips between June 2016 and June 2017 by users of the RideAustin platform. We selected the trips whose origins and destinations were located within Austin's city limit and aggregated these trips to every census tract. We measure the ride-hailing usage intensity by three variables:

- ***Pick-ups per 100 people***: We calculate the number of pick-ups divided by hundreds of people living in the census tract. It measures the usage intensity for a neighborhood as a departure origin.
- ***Drop-offs per 100 people:*** We calculate the number of drop-offs divided by hundreds of people living in the census tract. It proxies the usage intensity for a neighborhood as a destination.
- ***Average trip distance per capita:*** We calculate the average trip distance for those who depart from the neighborhood.

Our transit supply data comes from the General Transit Feed Specification (GTFS) data. Following Jiao (2017)'s measurement of transit supply at the neighborhood level, we measure transit supply using the number of bus stops and the frequency of transit services per hour.

When it comes to vehicle ownership, we calculate the percentage of households with zero cars in each census tract from the ACS data (US Census Bureau, 2017) as a proxy of vehicle availability at the neighborhood level.

To examine disparities in transportation resources for different neighborhoods, we utilized a two-means *t*-test to examine whether ride-hailing usage, transit supply, and vehicle access are significantly different across neighborhoods with different levels of densities and various socioeconomic attributes.

3.3. Individual-level analysis

In the second part of the analysis, we use a survey conducted by the University of Texas to investigate the disparities of ride-hailing usage among those with vehicles and without vehicles and how they perceive ride-hailing against transit differently. This survey aims to examine how and why people use ride-hailing services for TNC users aged 18 and older living in Texas' four largest metro areas. We subset the 250 samples who lived in the Austin–Round Rock–San Marcos MSA shown in Fig. 1. The survey was conducted by QuestionPro between October 2018 and February 2019. The university Institutional Review Board (IRB) approved the survey. Among Austin TNC user samples, 49 responses lived in zero-car households.

Though the survey supplements the spatial analysis, it has at least two limitations. As the survey does not contain information on the transit usage frequency and transit availability, we thus cannot examine the ride-hailing usage differences across people with different transit usage patterns. Additionally, the survey did not ask the respondents to report their residential locations, and the residential built environment. Therefore, we cannot examine how their transit and ride-hailing usage are related to where they live.

In the analysis, we first examine who are the ride-hailing users and how they use ride-hailing services differently among those who have and do not have private vehicles. This examination involves the comparison of socioeconomic attributes (including age, gender, race and ethnicity, and their highest educational attainment) among TNC users with and without private vehicles. We also investigate their differences in ride-hailing usage patterns based on the time of using ride-hailing, duration of a riding trip, and trip purposes.

Next, we use the responses in the survey to further analyze how ride-hailing users perceive transit versus ride-hailing services differently for those who have and those who do not have vehicles. This investigation shows the underlying reasons for using ride-hailing services versus public transit among people with different transportation resources.

We use Chi-square *t*-tests to examine whether the differences in one trait for vehicle owners and non-owners are statistically significant or not.[1]

4. Findings

4.1. The neighborhood-level spatial and social disparities of transportation resources in the TNC era

Like many other U.S. cities, Austin is racially and economically segregated. As shown in panels B and C in Fig. 2, people with higher income and non-Hispanic Whites are mainly located in the west side. On the contrary, panels D and E in Fig. 2 show that African Americans concentrate in the east part of the city, where most low-income people live. When it comes to the density, as shown in panel A, the densest part of the city is in the middle part of the city, a transitional belt with

[1] For those traits which allow respondents to select more than one option (e.g. travel time), we examine whether a respondent chooses a specific option or not is significantly different among vehicle owners and those living in zero-vehicle households.

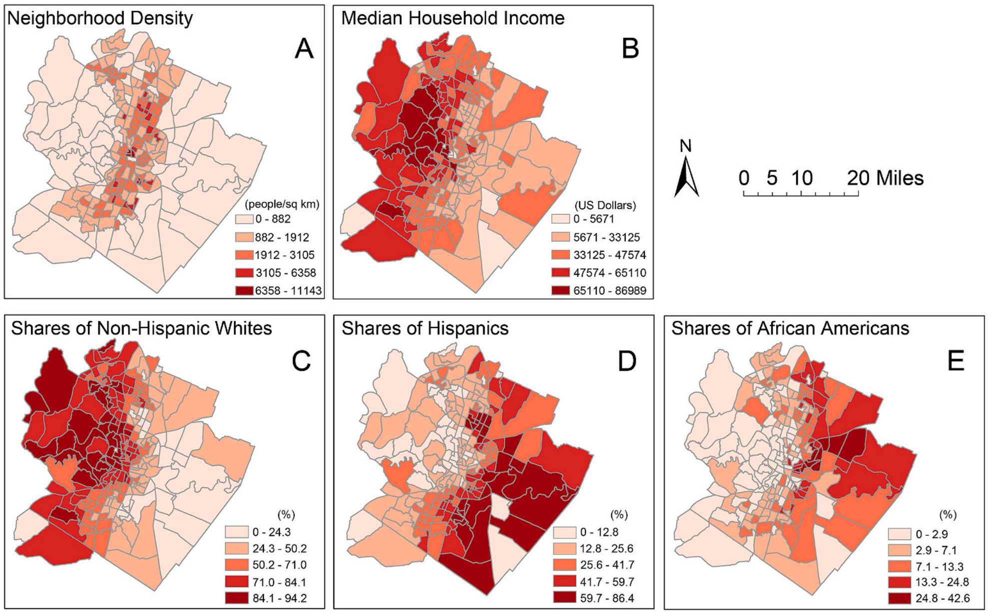

Fig. 2. Density and socioeconomic attributes of Austin's neighborhoods.

multiracial and multi-income groups. All other parts of the city in the western and eastern parts are homogeneously low-density.

Fig. 3 shows the spatial distribution of three different types of transportation resources. It indicates that the core area of the downtown is the place with the most accessible ride-hailing and public transit resources. As shown in panels A and B in Fig. 3, the ride-hailing service pick-up and drop-off locations highly concentrated in several downtown census tracts. The destinations of the drop-off locations were even more concentrated. Residents living in other low-density areas in the western and eastern parts of the city used ride-hailing services much less frequently. When it comes to the trip distance, panel C shows that the farther an individual lived from downtown, the more distance he/she tends to travel by ride-hailing.

The transit supply in Austin highly aligns with the density of the neighborhood. As shown in panels D and E, the census tracts with more than 6 bus stops and more than 60 transit trips per hour are consistent with the concentration of high-density census tracts shown in panel A of Fig. 2.

As for vehicle ownership, the vehicle ownership rates of most Austin census tracts were higher than 90%, with some exceptions in the high-density downtowns. Some other census tracts to the east are low-density but had more than 5% of households that have zero vehicles. Panels A to D further highlight that these census tracts also had low access to ride-hailing and public transit services.

In a nutshell, Fig. 3 shows a complex picture of transportation resource distribution in Austin in the ride-hailing era: the small downtown area is multimodal with convenient access to public transit and ride-hailing, which implies that residents living in these areas do not

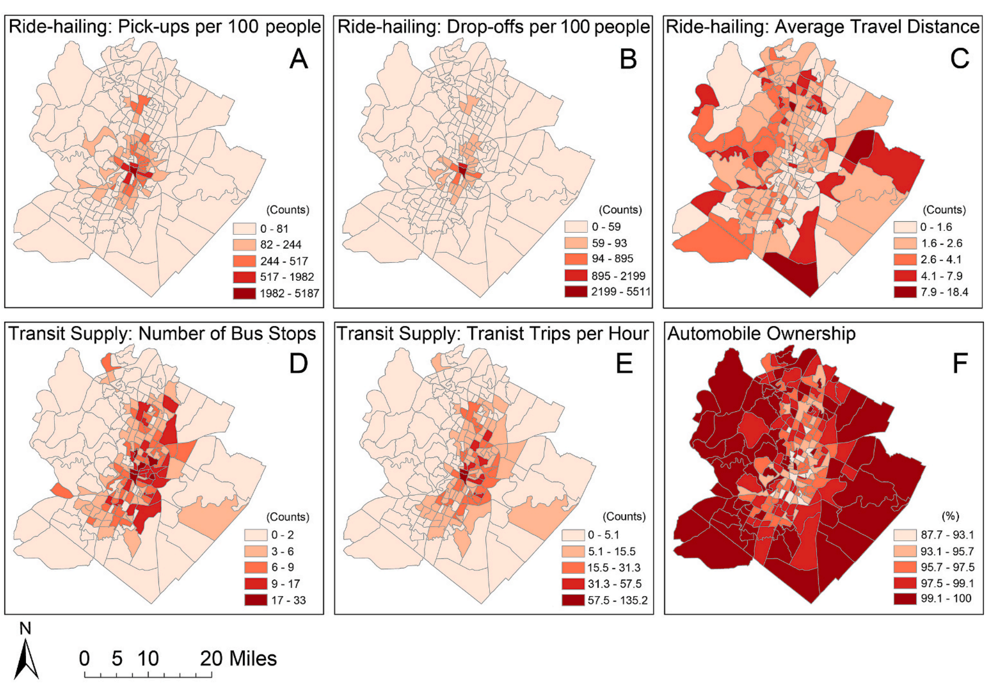

Fig. 3. Transportation resources at the neighborhood level.

need to rely on automobiles. However, many other low-density areas heavily rely on automobiles, with few alternative transportation choices. For some other poor neighborhoods with higher shares of racial minorities, households without vehicles might have more difficulties in daily travel.

Are low-density, low-income neighborhoods, and neighborhoods with a majority of racial minorities have disproportional fewer transportation resources? Table 1 presents the ride-hailing usage, transit supply, and automobile ownership across different neighborhoods. Ride-hailing services provide an additional transportation alternative for low-income community residents. Residents living in low-income communities used ride-hailing services more often than middle-income communities in terms of the pick-ups and drop-offs , though people living in these communities had significantly lower vehicle ownership than middle-income counterparts. Low-income communities also tend to live in neighborhoods with better transit services measured by the number of bus stops and transit trips per hour. Residents living in high-income communities tend to use ride-hailing more and had lower shares of zero-vehicle households. However, the differences compared to the middle-income communities are not statistically significant.

The neighborhoods with a majority of Hispanics have better transit services. Ride-hailing trip origins and destinations also tend to fall in these neighborhoods more. However, the differences in ride-hailing trip frequency are not statistically significant compared to the neighborhoods with a majority non-Hispanic Whites. As shown in Fig. 2, Hispanic-dominated communities in Austin are located in the eastern part of the city. These neighborhoods are predominately intergenerational family-oriented (Sanchez, 2020). Consistent with Brown (2019), ride-hailing services provide additional resources for neighborhoods dominated by racial minorities in low-density areas. As these communities also have better transit services, it seems that ride-hailing services have the potential to reduce the travel difficulties for people living in communities where a majority of the residents are people of color.

Not surprisingly, high-density neighborhoods have better transit supply and lower shares of vehicle ownership than the middle-density neighborhoods. However, low-density neighborhoods, surprisingly, are more frequently chosen as the origin neighborhoods than middle-density counterparts and have longer average travel distance. The results demonstrate that ride-hailing services also can supplement travel needs for low-density, car-dependent neighborhoods.

4.2. Ride-hailing usage among vehicle owners and those living in zero-vehicle households

Table 2 shows the demographic and socioeconomic attributes and travel characteristics of ride-hailing users living in households without and with cars. Compared to TNC users without vehicles, those with vehicles tend to be older and less educated, though the differences in age and educational attainment are not statistically significant. While nearly 60% of TNC users without vehicles were aged between 18 and 30, only less than 50% of TNC users with vehicles were in this age group. While nearly 1 in 5 of TNC users in zero-vehicle households were African Americans, only 7% of TNC users among those with vehicles were African Americans (see Table 3).

Table 2 further shows that ride-hailing services provide a flexible transportation mode for people living in low-density areas, regardless of their vehicle ownership. As the table shows, a large share of the ride-hailing trips happens in the evenings. More than 6 in 10 people who owned vehicles and hailed a ride-hailing service in the Austin region had ever taken the ride after 8 p.m. When it comes to the trip purpose, 84.08% of individuals with cars had the experience of hailing TNC services for entertainment, while more than 20% of those without vehicles had hailed a TNC for business trips. Though we cannot examine the locations of these trips based on the survey, ride-hailing services have various benefits in daily travel, such as lessening the negative emotions during traffic jams and avoiding worrying about searching parking lots. Table 2 also shows that for most trips, ride-hailing services are popular for trips whose one-way travel times were within 15 min, regardless of the users' vehicle ownership.

Vehicle owners and those without private vehicles do not show significant differences in the primary reasons for choosing ride-hailing services. As shown in Table 3, half of the respondents among those who did not have vehicles and 6 in 10 among those who had vehicles reported convenience as the primary reason for using TNC services. The second primary reason-safety-is also consistent across the two groups. More than 30% among those without vehicles and 21.9% of those with vehicles reported that safety was an important reason for using transit services. These two primary reasons are consistent with a recent study (Dong, 2020a) in Philadelphia, Pennsylvania.

However, vehicle owners and those living in zero-vehicle households who use TNC services have divergent attitudes towards ride-hailing services' competing transportation mode-transit. Table 3 further shows that vehicle owners had a more positive attitude towards ride-hailing when comparing the relative convenience of ride-hailing

Table 1
Ride-hailing, transit supply and automobile ownership shares of different neighborhoods in Austin, Texas.

Neighborhood characteristics	Number of census tracts	Ride-hailing			Transit supply		Automobile ownership (%)
		Pick-ups per 100 people	Drop-offs per 100 people	Average travel distance per capita	Number of bus stops	Transit trips per hour	
Income							
Middle-income communities (middle 50%) (reference)	106	0.75	0.71	2.86	4.60	8.77	97.60
Low-income communities (bottom quartile)	53	0.86***	0.82***	2.20*	6.31*	14.60***	96.40**
High-income communities (top quartile)	53	3.26	3.34	2.89	2.85	6.13	98.50*
Race and ethnicity							
Majority non-Hispanic Whites (reference)	138	0.10	0.95	2.80	4.04	8.10	97.80
Majority Hispanics	48	1.86	1.69	2.50	5.56*	12.70*	97.30
No Majority	26	0.95	0.95	2.56	5.71	11.50	96.80
Neighborhood density							
Middle (middle 50%) (reference)	106	0.65	0.70	2.51	5.05	9.42	97.60
Low (bottom quartile)	53	0.86*	0.81	3.89*	2.38***	5.07***	98.80***
High (top quartile)	53	3.45	3.46	1.88***	5.87	14.30*	96.10***
Average		0.47	0.46	2.70	4.59	9.56	0.98

Notes: The stars in cells show the significance of two-sample mean *t*-test values compared to the reference group. ***$p < 0.001$, **$p < 0.01$, *$p < 0.05$.

Table 2
Demographic and socioeconomic attributes and travel characteristics of ride-hailing users living in households without and with cars.

	Users living in no-car households (n = 49)	Users living in households with cars (n = 201)	P-values for Chi-square tests
Demographic and socioeconomic attributes (%)			
Age			
18-25	36.36	28.07	0.2
26-30	22.73	19.74	
31-35	18.18	15.35	
36-45	9.09	21.05	
46-55	9.09	10.09	
55+	4.55	5.70	
Gender			
Male	27.27	29.15	1.0
Female	72.73	70.85	
Race			
White	45.46	56.95	0.2
Black or African American	18.18	7.62	
Asian	9.09	9.87	
All other races	27.27	25.56	
Ethnicity			
Hispanics	22.72	22.87	1.0
Non-Hispanics	77.28	77.13	
Highest educational attainment			
High school graduate (GED) or lower	10.20	50.25	0.2
Some college or associate degree	69.39	3.48	
Bachelor's degree and higher	20.41	46.27	
Trip characteristics			
Time of use ride-hailing (%)			
Early morning (5am–7am)	2.04	17.91	0.01
Morning (8am–10am)	22.45	23.38	1.0
Early afternoon (11am-1pm)	12.24	20.40	0.3
Afternoon (2pm–4pm)	20.41	26.87	0.5
Early evening (5pm–7pm)	16.33	41.79	0.002
Evening (after 8pm)	20.41	60.70	<0.001
Duration of a trip (%)			
0–10 min	50.00	23.25	0.2
11–15 min	13.64	46.05	
16–20 min	22.73	21.05	
21 min or longer	13.64	9.65	
Trip purpose(s) (%)			
Commuting	12.24	21.89	0.2
Entertainment	18.37	84.08	<0.001
Business	22.45	16.92	0.5
Connect to other transportation services	10.20	32.84	0.003
Emergency	12.24	25.37	0.08
Others	4.08	7.46	0.6

services and transit. Nearly all vehicle owners reported that ride-hailing service was more convenient than transit, but only 30.1% of those without vehicles thought ride-hailing was more convenient than transit. A larger share of zero-car users thought that ride-hailing services were more affordable than public transit. However, both groups reported that ride-hailing services were not as reliable as transit. Only fewer than 5% of the respondents stated that ride-hailing services were more reliable than transit.

Table 3
Differences of ride-hailing users' primary reasons of using ride-hailing and stated preference of ride-hailing over public transit.

	Users living in no-car households (n = 49)	Users who live in households with cars (n = 201)	Chi square *t*-test
The primary reason of using ride-hailing			
Affordability	9.09	9.21	0.2
Convenience	50.00	62.72	
Travel time savings	4.55	4.39	
Safety	31.82	21.93	
Other reasons	4.55	1.75	
He/she thinks ride-hailing services is more ... compared to public transit			
More convenient	30.61	96.02	<0.001
More expensive	14.29	38.81	0.002
More reliable	4.08	4.98	1.0

5. Concluding remarks

Ride-hailing has redefined vehicle access and has the potential to reduce travel difficulties for transit-poor areas and people with poor access to private and public transportation resources. Due to the lack of data, current studies lack a holistic understanding of how transportation resources serve different social groups and places in the ride-hailing era. Even less is know in low-density areas, leading to the mismatch between transportation policies and transportation needs.

This study uses large-scale GPS ride-hailing data, open GTFS and ACS data, and a travel survey in Austin, Texas to understand: (1) how ride-hailing usage, transit supply, and vehicle ownership distribute across neighborhoods with different densities, incomes, and racial and ethnic compositions; (2) who are ride-hailing users among those with and without private vehicles, and how their ride-hailing usage and attitudes towards ride-hailing versus transit differ.

Our study has shown that the areas with frequent ride-hailing usage, dense transit supply, and a high share of zero-vehicle owners concentrate in downtown Austin. Ride-hailing services have provided low-income neighborhoods, low-density neighborhoods, and those with a majority of Hispanics with an alternative transportation mode. However, low-density and low-income neighborhoods were still less likely to be ride-hailing origins or destinations than high-density and high-income counterparts. At the individual level, ride-hailing users without private vehicles tend to be racial and ethnic minorities or younger people with higher education. Ride-hailing services provide people with a convenient and safe transportation mode, regardless of their vehicle ownership. While TNC users with vehicles had more positive attitudes towards ride-hailing in its convenience compared to public transit, those without vehicles applauded TNC for its relative affordability.

This study has several implications for future research and transportation practices. First, it shows the need to combine different data sources in examining how ride-hailing services reshape social and spatial equity. While large-scale ride-hailing data have the strength to examine the disparity of ride-hailing usage (Brown, 2019) and how ride-hailing services interact with public transit systems in different neighborhoods (Barajas and Brown, 2021; Jin et al., 2019; Kong et al., 2020), they may not speak to ride-hailing usage for different social groups, and people's mode choice and travel behavior decisions in daily practice. Understanding individual-level decisions need more nuanced information through surveys on ride-hailing users (Dong, 2020a; Jiao and Wang, 2020). A tale of two (individual and neighborhood) levels in this study has shown the heterogeneity of transportation resource combination across different neighborhoods and social groups. The richness of the results shows the necessity for future studies to combine different data sources to inform transportation policies related to ride-hailing services.

Second, this study sheds light on ride-hailing usage at the neighborhood and individual levels in low-density areas. Unlike evidence from the big cities like New York (Jiao and Wang, 2020; Jin et al., 2019), Chicago (Barajas and Brown, 2021), and Toronto (Young and Farber, 2019), the relationship between ride-hailing usage and transit services are relatively weak and unclear in Austin. The hot spots of ride-hailing usage concentrate in the small downtown area of Austin. One possible reason is that compared to other countries, Austin is more dependable on private vehicles in daily travel. However, like what is found in Los Angeles (Brown, 2019), low-income communities and social groups depend more on ride-hailing services than their middle-income counterparts. Compared to few dense cities in North America, the role of ride-hailing is more critical for low-density areas like Austin, as these cities were developed after the automobile age, and people depend more on automobiles in daily travel.

Finally, this study has some practical implications in planning for ride-hailing systems and public transit in low-density areas like Austin. With its own platform RideAustin, Austin aims to provide everyone with equitable access to ride-hailing services. Given the importance of ride-hailing services in mitigating the difficulties of disadvantaged groups, practitioners should seize this opportunity to reconsider equitable transportation policies using new transportation technologies. For example, Austin launched the Senior Transportation Program, which aims to provide older adults with affordable ride-hailing services. Older adults aged 60 and older could get free rides to and from lunch for free or pay $6 to finish round trips to and from the daily activity destinations, like barbershops, shopping centers, and doctoral offices. Similarly, Florida's experience shows the potential to promote ride-hailing among the socially disadvantaged with some forms of economic subsidies (Leistner and Steiner, 2017).

Another challenge of promoting transport equity in the ride-hailing era is to narrow the "digital divide". Those who have travel difficulties also have more knowledge or cost burdens in using smartphones or tablets to hail a TNC service. Ignoring this new form of inequality may worsen the existing social and spatial disparity in ride-hailing usage. Many cities have noticed this problem and collaborated with non-profit agencies to promote the hotline platforms, such as GoGoGrandparent, for older adults and other groups with little technical knowledge to ask for rides. Uber also sends their representatives to communities to promote the older adults' understanding of ride-hailing services (Senda, 2017). Some non-profits attempt to build relationships between healthcare providers, ride-hailing users, and themselves to improve users' trust in ride-hailing and help them get to daily destinations (Rieland, 2017).

This study also has some implications for the potential integration of ride-hailing services and public transit investments. The spatial analysis shows that one critical reason for the residents in low-density communities to use ride-hailing services is the poor transit supply compared to their middle-density counterparts. Additionally, the individual-level survey shows that ride-hailing services are widely believed as a convenient and affordable alternative in low-density areas. This study shows the potential of developing public transit systems in low-density areas with the help of ride-hailing. Ride-hailing can provide a way to connect people who live in distant areas to transit hubs (Leistner and Steiner, 2017). Future transportation planning in low-density areas should consider integrating flexible ride-hailing systems and fixed-route transit systems. Another possible path of transportation planning in these areas is to change underutilized bus lines from fixed to on-demand to improve efficiency and equity.

Author statement

The authors confirm contribution to the paper as follows: study conception and design: Alex; data collection: Junfeng, Alex, and Wei; methodology, analysis, and interpretation of results: all authors; draft manuscript preparation: Alex and Wei; funding application: Junfeng. All authors reviewed the results and approved the final version of the manuscript.

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References

Alemi, F., Circella, G., Mokhtarian, P., Handy, S., 2018. Exploring the latent constructs behind the use of ridehailing in California. J. Choice Model. 29, 47–62. https://doi.org/10.1016/j.jocm.2018.08.003.

Barajas, J.M., Brown, A., 2021. Not minding the gap: does ride-hailing serve transit deserts? J. Transport Geogr. 90, 102918.

Blumenberg, E., Manville, M., 2004. Beyond the spatial mismatch: welfare recipients and transportation policy. J. Plann. Lit. 19, 182–205.

Blumenberg, E., Paul, J., Pierce, G., 2021. Travel in the digital age: vehicle ownership and technology-facilitated accessibility. Transport Pol. 103, 86–94.

Brown, A., 2019. Redefining car access: ride-hail travel and use in Los Angeles. J. Am. Plann. Assoc. 85, 83–95. https://doi.org/10.1080/01944363.2019.1603761.

Brown, A., LaValle, W., 2020. Hailing a change: comparing taxi and ridehail service quality in Los Angeles. Transportation 1–25.

Brown, A.E., 2017. Car-less or car-free? Socioeconomic and mobility differences among zero-car households. Transport Pol. 60, 152–159.

Clewlow, R.R., Mishra, G.S., 2017. Disruptive Transportation: the Adoption, Utilization, and Impacts of Ride-Hailing in the United States.

Conway, M., Salon, D., King, D., 2018. Trends in taxi use and the advent of ridehailing, 1995–2017: evidence from the US national household travel survey. Urban Sci. 2, 79. https://doi.org/10.3390/urbansci2030079.

Daganzo, C.F., 2010. Structure of competitive transit networks. Transp. Res. Part B Methodol. 44, 434–446. https://doi.org/10.1016/j.trb.2009.11.001.

Dill, J., McNeil, N., 2020. Are shared vehicles shared by all? A review of equity and vehicle sharing. J. Plann. Lit., 0885412220966732

Dong, X., 2020a. Trade uber for the bus? An investigation of individual willingness to use ride-hail versus transit. J. Am. Plann. Assoc. 86, 222–235.

Dong, X., 2020b. Investigating travel needs and traffic conditions in the TNC era with taxi data. J. Plan. Educ. Res. 0739456X20967433.

Edwards, M., 2020. Nonstandard ridehail use in Austin. J. Transport Geogr. 86, 102746.

Fan, Y., 2012. The planners' war against spatial mismatch: lessons learned and ways forward. J. Plann. Lit. 27, 153–169.

Fleming, K.L., 2018. Social equity considerations in the new age of transportation: electric, automated, and shared mobility. J. Sci. Pol. Gov. 13.

Gehrke, S.R., Felix, A., Reardon, T.G., 2019. Substitution of ride-hailing services for more sustainable travel options in the greater Boston region. Transport. Res. Rec. 2673, 438–446.

Goldenstein, T., 2017. Pilot Program to Offer Low-Income Patients Free Trips to Doctor [WWW Document]. URL. https://www.statesman.com/NEWS/20170706/Pilot-program-to-offer-low-income-patients-free-trips-to-doctor.

Grahn, R., Harper, C.D., Hendrickson, C., Qian, Z., Matthews, H.S., 2019. Socioeconomic and usage characteristics of transportation network company (TNC) riders. Transportation 1–21. https://doi.org/10.1007/s11116-019-09989-3.

Jiao, J., 2017. Identifying transit deserts in major Texas cities where the supplies missed the demands. J. Transp. Land Use 10. https://doi.org/10.5198/jtlu.2017.899.

Jiao, J., Wang, F., 2020. Shared mobility and transit-dependent population: a new equity opportunity or issue? Int. J. Sustain. Transp. 1–12.

Jin, S.T., Kong, H., Sui, D.Z., 2019. Uber, public transit, and urban transportation equity: a case study in New York city. Prof. Geogr. 71, 315–330. https://doi.org/10.1080/00330124.2018.1531038.

Karner, A., Niemeier, D., 2013. Civil rights guidance and equity analysis methods for regional transportation plans: a critical review of literature and practice. J. Transport Geogr. 33, 126–134.

Kong, H., Zhang, X., Zhao, J., 2020. How does ridesourcing substitute for public transit? A geospatial perspective in Chengdu, China. J. Transport Geogr. 86, 102769.

Lavieri, P.S., Bhat, C.R., 2019. Investigating objective and subjective factors influencing the adoption, frequency, and characteristics of ride-hailing trips. Transport. Res. C Emerg. Technol. 105, 100–125.

Leistner, D.L., Steiner, R.L., 2017. Uber for seniors?: exploring transportation options for the future. Transport. Res. Rec. 2660, 22–29.

Lucas, K., 2012. Transport and social exclusion: where are we now? Transport Pol. 20, 105–113.

Mitra, S.K., Bae, Y., Ritchie, S.G., 2019. Use of ride-hailing services among older adults in the United States. Transport. Res. Rec., 0361198119835511

Palm, M., Farber, S., Shalaby, A., Young, M., 2020. Equity analysis and new mobility technologies: toward meaningful interventions. J. Plann. Lit., 0885412220955197

Powell, J., 2017. RideAustin to Offer Low-Income Patients Free Rides to Doctor's Appointments [WWW Document]. URL. https://www.kxan.com/news/rideaustin-to-offer-low-income-patients-free-rides-to-doctors-appointments/.

Rayle, L., Dai, D., Chan, N., Cervero, R., Shaheen, S., 2016. Just a better taxi? A survey-based comparison of taxis, transit, and ridesourcing services in San Francisco. Transp. Pol. 45, 168–178. https://doi.org/10.1016/j.tranpol.2015.10.004.

Rieland, R., 2017. Lyft and Uber Want to Give Old Folks a Ride [WWW Document]. URL. https://www.smithsonianmag.com/innovation/lyft-uber-want-to-give-old-folks-ride-180961688/. accessed 6.9.20.

Sanchez, E., 2020. Austin Texas East Riverside Gentrification: Mixed-Income Neighborhood or Racially Segregated?.

Senda, T., 2017. Uber, but for Grandma [WWW Document]. URL. https://www.politico.com/agenda/story/2017/09/27/transportation-for-the-aging-population-000531/. accessed 6.9.20.

Shirgaokar, M., Misra, A., Agrawal, A.W., Wachs, M., Dobbs, B., 2021. Differences in ride-hailing adoption by older Californians among types of locations. J. Transp. Land Use 14, 367–387.

Taylor, B.D., Tassiello Norton, A., 2009. Paying for transportation: what'sa fair price? J. Plann. Lit. 24, 22–36.

US Census Bureau, 2019. QuickFacts.Austin city, Texas [WWW Document]. URL. https://www.census.gov/quickfacts/austincitytexas.

US Census Bureau, 2017a. American Community Survey 5-Year Data (2009-2018) [WWW Document]. URL. https://www.census.gov/data/developers/data-sets/acs-5year.html.

US Census Bureau, 2017b. TIGER/Line Shapefiles [WWW Document]. URL. https://www.census.gov/geographies/mapping-files/time-series/geo/tiger-line-file.html.

Vivoda, J.M., Harmon, A.C., Babulal, G.M., Zikmund-Fisher, B.J., 2018. E-hail (rideshare) knowledge, use, reliance, and future expectations among older adults. Transport. Res. F Traffic Psychol. Behav. 55, 426–434. https://doi.org/10.1016/j.trf.2018.03.020.

Wear, B., 2017. So How Do Austinites Get to Work? the Numbers Might Surprise You.

Yan, X., Liu, X., Zhao, X., 2020. Using machine learning for direct demand modeling of ridesourcing services in Chicago. J. Transport Geogr. 83, 102661.

Young, M., Allen, J., Farber, S., 2020. Measuring when Uber behaves as a substitute or supplement to transit: an examination of travel-time differences in Toronto. J. Transport Geogr. 82, 102629.

Young, M., Farber, S., 2019. The who, why, and when of uber and other ride-hailing trips: an examination of a large sample household travel survey. Transp. Res. Pol. Pract 119, 383–392. https://doi.org/10.1016/j.tra.2018.11.018.

Yu, H., Peng, Z.-R., 2019. Exploring the spatial variation of ridesourcing demand and its relationship to built environment and socioeconomic factors with the geographically weighted Poisson regression. J. Transport Geogr. 75, 147–163.