Who uses Transport Network Companies? Characterization of Demand and its Relationship with Public Transit in Medellín

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ABSTRACT

Transport Network Companies (TNCs) have become a popular alternative for mobility due to their ability to provide on-demand flexible mobility services. By offering smartphone-based ride-hailing services capable of satisfying specific travel needs, these modes changed urban mobility worldwide. However, few studies have analyzed the impacts in the Latin American context. This research examines the factors affecting the adoption of on-demand ride services in Medellín, Colombia, and explores whether these are substituting or competing with public transit. First, it provides a descriptive analysis that relates the usage of platform-based services with neighborhood characteristics, socioeconomic information of individuals and families, and trip-level details. Next, factors contributing to the election of platform-based services are modeled using discrete choice models. The results show that wealthy and highly educated families with low vehicle availability are more likely to use TNCs than other groups in Medellín. Evidence also points at gender effects, with being female significantly increasing the probability of using a TNC service. Finally, we observe both transit complementary and substitution patterns of use, depending on the context and by whom the service is requested. This analysis contributes to developing policies that promote efficient and sustainable transport systems in the Latin-American region.

Keywords: Transportation, Ride-hailing, TNCs, Public transit, Latin America.

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1. INTRODUCTION

Transport Network Companies (TNCs) offer innovative, on-demand ride-sourcing services that are transforming and streamlining the way mobility needs are met across the globe (Gehrke et al., 2019). Rapidly expanding in the U.S. and abroad, TNCs have recently made their way into emerging and prominent Latin American cities. For example, Uber, which was the first company to offer this service in 2008 in San Francisco, operates in more than 300 cities today, with 47 cities in Latin America, including its biggest market outside the U.S. (Sao Paulo) and other densely urbanized areas (Bogotá, México D.F). The surge of these shared mobility services, where individuals who drive private cars serve as 'drivers' for passengers requesting services via mobile phone applications in exchange for a commission, has spurred a growing body of research, as well as fierce policy and regulation debates (Erhardt et al., 2019). Arguably, TNCs offer several advantages compared to traditional taxi services and other on-demand transportation services, many of which are associated with system features such as seamlessly requesting and paying for rides via cell phone applications and increased efficiency enabled by features such as dynamic pricing and route optimization. However, these services have also generated several concerns among policymakers surrounding their impacts on urban mobility in terms of potential increases in vehicle miles traveled (VMT), traffic safety, emissions, potential competition with public transit, equity of access, and social exclusion of transportation systems, and weak or even non-existent labor protections for TNCs drivers (Wenzel et al., 2019). Additionally, due to their rapid growth and disruptive nature, the services have encountered various degrees of acceptance or resistance across the globe (e.g., city-wide or national banning and large-scale protest by taxi providers).

Despite these concerns, after rapidly gaining popularity and attaining high economic valuation as a business in the United States, TNCs have begun to expand to several foreign markets. For instance, the most valuable company in the industry, Uber, was valued at over 62.5$ billion in 2017 (Alejandro Tirachini & Gomez-Lobo, 2019). By the following year, Latin America was Uber's fastest-growing region globally, with more than 25 million monthly active riders, and Uber's service appeared in over 200 metropolitan areas and across 15 counties (Alemi, Circella, Handy, et al., 2018). However, in most countries of the region, the business remains loosely regulated even after years of operation. The low coverage of public transportation in Latin America and its high costs relative to users income (Rivas et al., 2018; Tun et al., 2020) appear to be some of the reasons why TNCs services, under such an unclear regulatory framework, have rapidly gained an essential share of the mobility market generating great discontent within the incumbent operators.

In spite of the rapid growth in Latin America and the debate surrounding their impacts on mobility in the region, very little has been published regarding TNCs adoption factors. In particular, little is known about the characteristics of individuals using TNCs services in the region, the impacts on travel behavior, and under which circumstances travelers look to TNCs as a preferred alternative for mobility. When considering varying regional dynamics, contexts, and characteristics of public transit systems, these responses could be substantially different in the Latin American region compared to North America. Moreover, this knowledge plays an essential role in understanding the gaps in mobility that these services might be filling and the potential for their integration into a sustainable transport system.

The city of Medellín, Colombia, is presented as a case study to explore determinants and demand patterns for TNCs in Latin America. Since 2005, the number of daily trips in the city has increased from around 4.8 million trips to 6.1 by 2017 (MVC, 2018). Medellín has the most integrated public transportation system in the country. It has a metro-based system that covers almost the whole metropolitan area, with 34,5 kilometers and 28 operating stations all adapted for people with reduced mobility; it also connects with five cable car lines that serve the neighborhoods in the periphery of the city, a tram line, and the rapid-transit bus lines. Along with the feeder buses and the public shared bicycle program (EnCicla), it constitutes the Transport

Integrated System of Aburrá Valley (SITVA, by its acronym in Spanish). The most common transportation mode used in the city is on foot (27%), followed by public transit (33%) and private car (8%). Within low-income families is on foot (30%), followed by public transit (36% of trips), and the car is the most popular among high-income families (52%). According to the metropolitan area government, 18% of the population has access to a private vehicle. By 2017, private vehicle ownership rose from 30 motorbikes and 52 cars per one thousand inhabitants to 81 and 66, respectively.

Entering the Colombian market in December 2013, Uber was the first TNC to begin operations in Medellin (El Tiempo, 2014). Regardless of the well-integrated public system, companies such as Uber and Cabify have gained popularity in the city, such as in the rest of Latin America (El Espectador, 2016). However, it has generated fierce incumbent discontent and even violent responses (El Colombiano, 2017). After more than seven years without a clear regulatory framework, Uber exited Colombia on February 1 of 2020 but just after three weeks reentered on February 20 of 2020, offering a modified service in legal terms in which the user drivers must sign a contract with the company as a technological service provider instead of a transport service provider. Besides Uber, platform-based services, including DiDi and Cabify, have gained high popularity and appear to fill a mobility need for the population segment that can afford it, particularly after the hit of the COVID-19. The Uber demand for business trips has increased by 120% since March of 2020 (M30, 2020).

Using the most recent representative transport household survey of Medellín and a first-source survey conducted on TNCs users' perceptions and travel patterns pre-pandemic, this paper aims to contribute to the literature on ride-hailing by analyzing TNCs users' characteristics vs. non-users. It also seeks to explore the potential public transit complement and substitution effects by examining the mobility patterns of multimodal TNC trips, in which TNCs are combined with other modes for at least one trip stage. The exploratory analysis indicates that TNCs in Medellín are being used by wealthy and highly educated families with low vehicle availability, in line with extant literature studying the North American case. As the main novelty, we also find evidence of a gender effect; being female increases the probability of using a TNC service. Also, we observe both complementary and substitutability effects with public transport services depending on the context and whom the service is requested.

The paper is organized as follows: Section 2 presents a literature review. Section 3 describes the data and methodology. Section 4 provides the results. Finally, we close with a discussion of the results and implications for public policy in the city in Section 5.

2. LITERATURE REVIEW

Although international evidence on the effects of TNCs on urban mobility around the world has proliferated in recent years (Button, 2020; Tirachini, 2019), extant research has focused primarily on the North American context (Devaraj et al., 2020). As argued by Saheen and Cohen (2019), TNCs have presented themselves as ridesharing services that connect drivers with passengers and not as a standard taxi service. These arguments have often been interpreted as a way to avoid regulations. By doing so, companies have gained popularity while redefining the concept of car access.

Several studies based in North America have sought to characterize TNCs users. For example, Dias *et al.* (2017) built on household transport surveys (in the Seattle Metropolitan Area) and bivariate ordered models to identify that, in general terms, the users of TNCs services are highly educated people with high income from the younger generations. In another study, Alemi et al. (2019a) used survey data in California. They found that highly educated, older millennials are more likely to use on-demand ride services than other groups and showed that land mix-use and regional accessibility by car are associated with a greater likelihood of adopting on-demand ride services. In an extension to the previous study in California, the authors Alemi, Circella, Mokhtarian, et al. (2018) identified three distinct clusters of adopters: Well-educated independent millennials with no children living in neighborhoods with good public transport provision, high-income millennials living with their families, and low-income individuals with low education levels living mainly in rural areas (the groups with lower adoption rates). A second extension to the study in California (Alemi et al., 2019b) explored factors affecting the frequency of TNCs services and found that urban factors such as mixed land use and activity density are instrumental for higher use levels. Interestingly, in this case, sociodemographic factors explain adoption but say nothing about the frequency of use.

Young and Farber (2019), who compared the socioeconomic and trip characteristics of TNCs users to that of non-users for the case of Toronto, confirmed that the usage of TNCs is a phenomenon among wealthy, younger generations. Interestingly, the authors argue that the rise in TNCs usage correlates with a significant decrease in taxi ridership and an increase in active modes of travel when considering specific market segments. For the Latin American context, de Souza Silva et al. (2018) analyzed the case of Brazil, and their results showed that the majority of TNCs trips were replacing taxi and public transport trips. Safety and cost were the main reasons that influence the decision of sharing trips via ride-splitting. Similar results were found by Moody et al. (2021) in Mexican cities, in which frequent use of TNCs services was positively correlated with the use of public transport and taxi but negatively correlated with the use of private cars and motorcycles; and TNCs trips were more likely to substitute public transport and taxi trips. The study's most relevant determinants of TNCs usage were rated safety, travel time, travel time reliability, and price. Tirachini and del Río (2019) found that the probability of sharing a non-pooled TNCs trip decreases with household income and increases for leisure trips in Chile; the monthly frequency of TNCs use is more significant for wealthier and younger individuals, and car availability is found to be not statistically significant to explain the frequency of TNCs use. In line with previous studies, their results flagged concerns about increased traffic and TNCs potentially being mainly a substitute rather than a complement to public transit. It also highlighted the need for further research that considers the travel patterns of non-users in the analysis and explores the potential effect of TNCs on reducing car ownership in the Latin American context.

A variety of studies explore the impact of TNCs services on the usage of motorized transport, arriving at mixed results. According to Brown (2018), TNCs have brought this redefinition by differentiating car ownership from car accessibility, bringing equity implications in Los Angeles, California. They found that TNCs services are being used mainly by people that live in high-income neighborhoods, but the usage is more frequent among the minority of users that live in low-income neighborhoods. Clewlow and Mishra (2017) presented correlational evidence between the usage of TNCs and vehicle ownership; they found that most users (91%) had not made any changes concerning whether they own a vehicle. Gehrke et al. (2019) published the paper to assess trip level attributes identifying a substitution effect of TNCs services from more sustainable options. They analyzed the case of the Greater Boston region in 2017 and concluded that adopters of these services tend to be relatively younger and more educated and that residents of compact neighborhoods with public transit were more likely to increase their mobility because of the usage of TNCs.

In terms of other impacts, Heano and Marshall (2019) retrieved data from a quasi-experiment in Denver, Colorado, and found that when accounting for mode replacement and issues such as driver deadheading, TNCs leads to approximately 83.5% more vehicle VMT than would have been driven had TNCs not existed. Wenzel *et al.* (2019) obtained a large sample of trips in Austin, Texas, and quantified TNCs drivers' distance between ride requests. They found that among trips that occurred within 60 minutes from each other, 55% drove more miles between ride requests, translating into 26% more VMT than the scenario before TNCs started to operate. For the Latin American case, Tirachini and Gomez-Lobo (2019) use survey data and Monte Carlo simulations to analyze the impact of TNCs in Santiago, Chile, and conclude that although TNCs applications substantially increase the average occupancy rate of vehicles due to shared or pooled TNCs, the net impact is an increase in vehicles miles traveled compared to before their entrance.

Erhardt et al. (2019) combined travel time data and information from TNCs applications and found that TNCs are the most significant contributor to growing traffic congestion in San Francisco. They point to the need for policies that address TNCs impacts on congestion as a crucial challenge for planning sustainable cities. It is particularly relevant for Latin America since four cities are already in the top ten most congested cities worldwide (INRIX, 2020). Recent estimates for the region suggest that the costs of congestion in LAC cities every year are around 0,7% of its GDP and is expected to increase considerably in the following years because of increase in travel demand, high rate of urbanization, the boom of e-commerce, and change in modal preferences towards the use of car caused by the Covid-19 (Calatayud et al., 2021).

The following section presents the data collected to analyze TNCs users' characteristics in Medellín and identify the main factors that lead individuals to choose these services over public transit and traditional private alternatives.

3. DATA AND METHODS

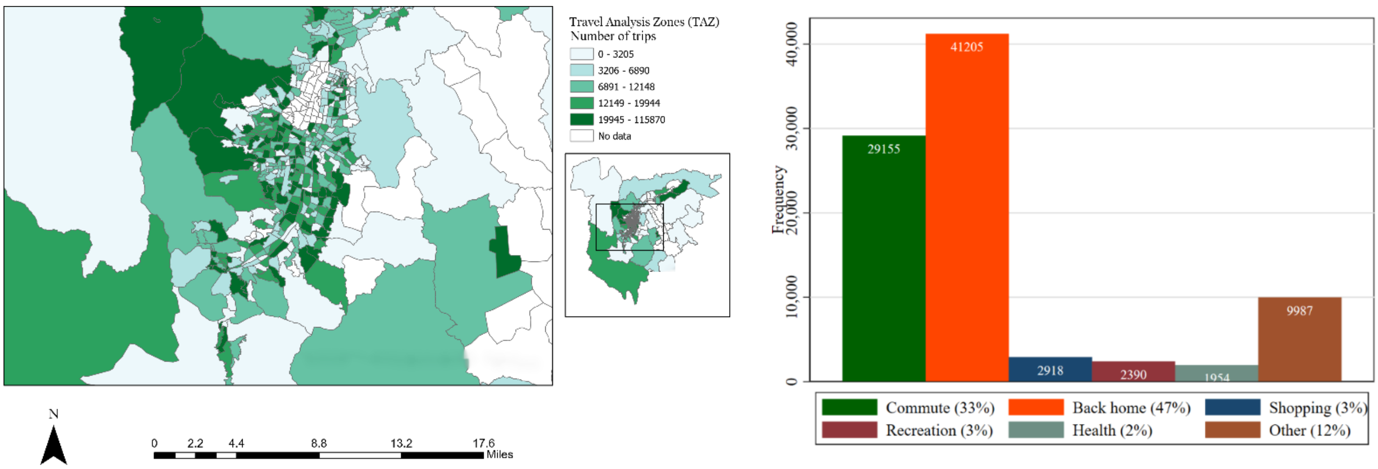
The data used in this study comes from the most recent version of the Household Travel Survey (HTS) conducted between September 1 and December 31 of 2017 in Medellín, Colombia. This dataset is composed of information on 87,609 trips in total during this period, with a sample of 15,966 households and 38,454 individuals. The survey is intended to capture each family member's trips during the day before the interview (last 24 hours). The survey asks for the origin and destination of the trip, the hour of departure and arriving, the frequency of these trips, and the trip motive. It divides each trip into stages, where the criteria to define a stage is the usage of one transportation mode for the same trip motive. For instance, walking would count as one stage regardless of the distance and time until the individual walked to take a bus or a taxi. The maximum number of stages is seven, and the survey provides information on the mode used in each stage for a given trip. Also, it collects socioeconomic information at the individual and household levels; we review this information in the next section.

According to the global results of this survey, the number of trips in the city grew by 26% from 2005 to 2017. The population grew by 23% over the same period (UN, 2019). The percentage of people who make daily trips in the metropolitan area went from 65% to 69% between 2005 and 2012, and in 2017 it reached 74%. Likewise, the average travel time increased; between 2005 and 2012, it had gone from 25 to 33 minutes, and in 2017 it reached 36 minutes on average.

Figure 1a plots the geographical distribution of the trips' origin by quintiles and by the most disaggregated travel analysis zone (TAZ) in the study area defined by the HTS, which is smaller than an administrative unit. The survey provides information about trips to Medellín and surrounding municipalities comprising the Metropolitan Area of the Aburrá Valley since many people travel every day from those municipalities to Medellín mainly to work. The TAZ with the highest generation of trips is in the higher income southeast area of the metropolitan area, followed by the central west and finally the northern areas. **Figure 1a** presents trip origins by TAZ, while **Figure 1b** presents the survey's trip motives distribution. As is common in the urban mobility patterns, the most frequent trip motives are commuting and home, followed by shopping, recreation, and health.

Although the dataset specifies different variations of a single transportation mode (e.g., walk one block, walk two blocks, until walking more than 19 blocks), we aggregate the modes into seven categories. The last category is described as "By a private car requested through a platform", this category is what we label as a TNC service. In the dataset, observe a total of 153 trips made using a TNC service in the last 24 hours; in other words, those were nonfrequent events at the time of the survey.

We complement our analysis with primary data from a survey commissioned by the Inter-American Development Bank in the metropolitan area of Medellín. The questionnaire gathered data on 2,033 users in the area during the second semester of 2020, asking carefully about pre-pandemic travel patterns: their primary mode of travel, frequency of and motives for TNCs usage, perceptions regarding security and safety in TNCs versus other modes, and questions designed to measure the extent of usage of TNCs as a complement versus a substitute for public transit. The instrument was designed to capture pre-pandemic travel behavior and avoid possible bias born after lockdowns.



(a) Origin of trips

(b) Distribution of trip motives

Figure 1. Urban mobility in Medellín and surrounding municipalities in 2017

We first conduct an exploratory analysis of TNCs usage in Medellín to understand the differences in characteristics of individuals who use TNCs and the extent to which ride-hailing trips are used in combination with the public transit or as the only mode of transport. Next, to identify the determinants of TNCs' services usage in Medellín, we run a logistic specification defined in **Equation 1** in which y_k takes the value of one in the trip *k* involved a TNC in at least one stage and zero otherwise; x_i is a vector including characteristics at the individual level, those are, age, gender, and education; δ_j includes household variables as the number of family members, number of vehicles, and socioeconomic stratification (SES)[3]; the vector γ_k relates to trip particularities, including dummy variables for the hour of the day without public transit and peak hours, trip frequency, and trip motive as categorical variables. Finally, the vector φ_l includes the number of trips per bus stop and the total number of places of interest in natural logarithm (environment-related controls).

$$Pr(y_k \neq 0 \mid x_i, \delta_j, \gamma_k, \varphi_l) = \frac{\exp\left(x_i'\beta + \delta_j'\tau + \gamma_k'\rho + \varphi_l'\omega\right)}{1 + \exp\left(x_i'\beta + \delta_j'\tau + \gamma_k'\rho + \varphi_l'\omega\right)} \tag{1}$$

[3] SES is an administrative classification in Colombia for residential properties based on value, location, and access to various services; the government commonly uses it to target social programs, taxes, among others. This categorization is a six-level scale in which SES 1 refers to the lower socioeconomic class and SES 6 the highest socioeconomic class.

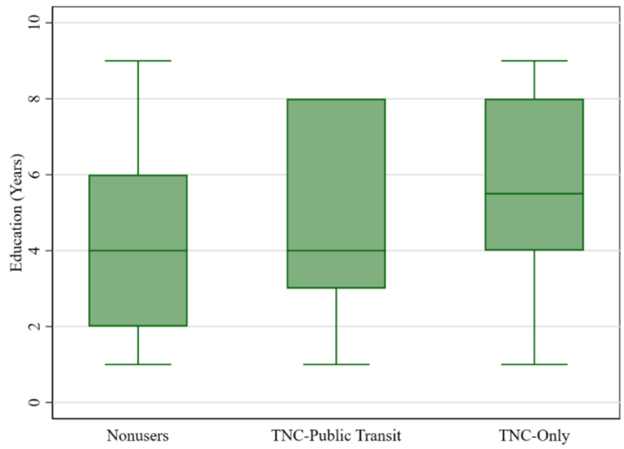
The main limitation of the analysis is the unbalance in sample size between the groups. This data distribution follows the nature of a rare random event. As robustness checks, we run the maximum likelihood logistic model through a bias correction method (BC MLE) recommended by King and Zeng (2001). Later, we estimate the parameters through penalized maximum likelihood estimation (PMLE) (Firth, 1993) to test how consistent the previous two estimates are. All the specifications include clustered standard errors at the individual level since the respondents can report more than one trip in the HTV; and instead of presenting the raw coefficients, we present the odds ratio for ease of interpretation (that is $\partial_p = \exp(b_p)$ with standard error $s_p^{\partial} = \partial_p s_p$, where b_p corresponds to the *p*th estimated coefficient and s_i its standard error) where the ratio represents the effects of a given variable on the odds of using a TNC as part of a trip relative to trips where modes other than TNCs were used.

The following section presents the results of our analysis and is structured as follows. First, we present a descriptive analysis of TNC trips in Medellín. Next, we discuss the results of the logistics regressions and robustness checks. Finally, we analyze complementary survey data perceptions and motives to shed light on the observed results further.

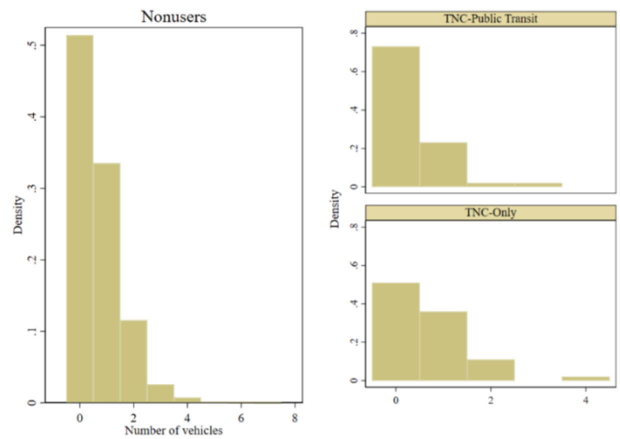
4. RESULTS AND ANALYSIS

4.1 TNCs' demand in Medellín

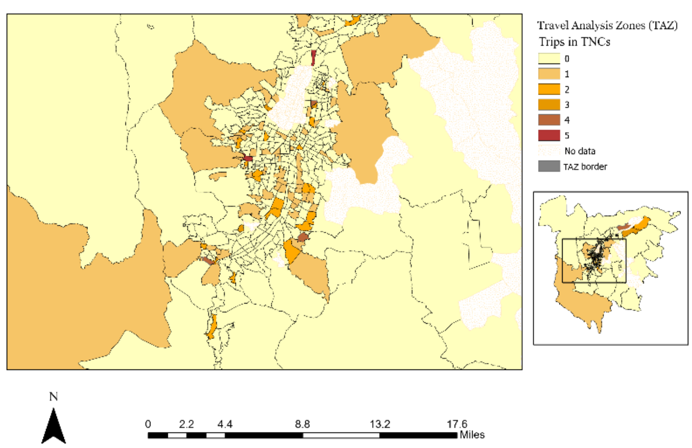
We divided the trip sample into three categories. First, *TNC-Multimodal* trips accounted for the group of trips made with a TNCs service in at least one stage and were complemented with another (or a group of) different motorized mode(s), including traditional public transportation or private mode(s) in the rest of the stages. An interesting observation about this category is that among the entire group of multimodal users (say *TNC-Private* plus *TNC-Public Transit*), only two observed trips made use of a TNC service as a complement of another private motorized vehicle (*i.e*., car or private microbus) and the rest of observations complement the trips with public transportation modes. From this point onward, we refer to this group only as *TNC-Public Transit.* The second category is *TNC-Only* which accounts for those trips in which a TNC service is used for all the trip stages, i.e., door-to-door trips. Finally, *TNC non-users* refer to those trips that do not involve a TNC service in any trip stages. With these categories, we present descriptive statistics at the individual and household levels. We use the SES categorization to classify households. The distribution of the sample between the categories analyzed will be described in detail in the following subsections.



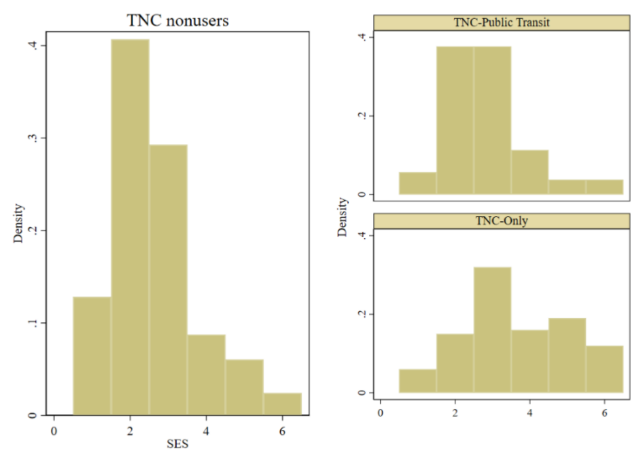
(a). Years of education



(b). Number of own vehicles



(c). Originated trips in TNCs by TAZ



(d). Socioeconomic stratification (SES)

Figure 2. TNCs 'demand characteristics

Table 1 presents descriptive statistics comparing *TNC users* (*TNC-only* and *TNC-Public Transit* users) and *TNC non-users*. The *TNC users* tend to be older, more educated, employed, and female; the household income difference is not statistically significant. Regarding household characteristics, we observe that *TNC users* tend to live with more people but have fewer available vehicles. **Figure 2b** plots the distribution of the latter. Also, there is evidence of a positive relationship between the usage of TNCs and socioeconomic stratification (SES) of the house as one of the most significant differences between the groups. **Figure 2c** plots the geographical distribution of trips' origins made using a TNC service. The zones that generate most TNCs trips are in the southeast region of the metropolitan area, where the high-valued houses are located with less access to the metro system (see **Figures A1** and **A2** in the Appendix). Moreover, travelers also use these services in the periphery of the city. It may be linked with a lack of public transportation coverage, as viewed in the Appendix.

Table 1 Descriptive statistics at the individual and household levels by categories

Group	Total			TNC non-users			TNC users			Mean-Comparison Test	
Variable	N	Mean	Sd	N	Mean	Sd	N	Mean	Sd	Diff	P-Val
Age	38,515	35.6	19.51	38,410	35.6	19.52	105	38.05	18.41	-2.45*	0.09
Gender	38,524	0.49	0.5	38,419	0.49	0.5	105	0.62	0.49	-0.13***	0.00
Education (Years)	38,433	4.13	2.27	38,329	4.13	2.27	104	5.18	2.46	-1.05***	0.00
Household Income (Categorical)	11,586	2.23	1.26	11,558	2.23	1.26	28	2.29	1.08	-0.057	0.81
Employed (dummy)	38,524	0.52	0.5	38,419	0.52	0.5	105	0.62	0.49	-0.10**	0.02
SES (Categorical)	38,524	2.59	1.13	38,419	2.58	1.13	105	3.22	1.34	-0.63***	0.00
Use apps for travel planning (dummy)	13,246	0.13	0.34	13,209	0.13	0.34	37	0.3	0.46	-0.17***	0.00
Number of families in the house	38,524	1.03	0.24	38,419	1.03	0.24	105	1.12	0.51	-0.09***	0.00
Number of family members	38,524	3.75	1.5	38,419	3.75	1.5	105	3.71	1.55	0.03	0.80
Number of vehicles	38,314	0.66	0.85	38,210	0.66	0.85	104	0.51	0.74	0.15**	0.03
Group	**TNC users**			**TNC-Public Transit users**			**TNC-Only users**			**Mean-Comparison Test**	
Age	105	38.05	18.41	44	39	16.78	61	37.36	19.61	1.63	0.65
Gender	105	0.62	0.49	44	0.57	0.5	61	0.66	0.48	-0.08	0.36
Education (Years)	104	5.18	2.46	44	4.73	2.37	60	5.52	2.49	-0.79*	0.05
Household Income (Categorical)	28	2.29	1.08	15	1.87	0.74	13	2.77	1.24	-0.90**	0.01
Employed (dummy)	105	0.62	0.49	44	0.66	0.48	61	0.59	0.5	0.59	0.47
SES (Categorical)	105	3.22	1.34	44	2.82	1.11	61	3.51	1.42	-0.69***	0.00
Use app for traveling (dummy)	37	0.3	0.46	19	0.05	0.23	18	0.56	0.51	-0.50***	0.00
Number of families in the house	105	1.12	0.51	44	1.09	0.42	61	1.15	0.57	-0.06	0.58
Number of family members	105	3.71	1.55	44	3.8	1.56	61	3.66	1.56	0.14	0.65
Number of vehicles	104	0.51	0.74	43	0.35	0.65	61	0.62	0.78	-0.27**	0.03

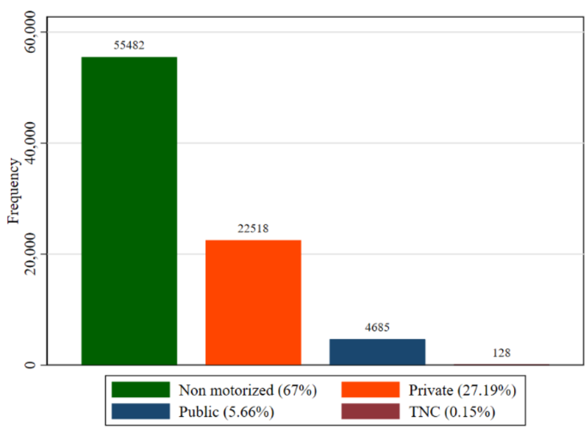
Note: * p<0.1; **p<0.05; *** p<0.01

Looking at the different subgroups of *TNC users* (i. e., *TNC-Only* vs. *TNC-Public Transit*), **Figure 2a** plots the distribution of years of education by categories. *TNC-Only* users, in comparison to *TNC-Public Transit* users, are more educated, wealthier, and they make more use of mobile technologies for planning trips. Consistent with previous results, those in the TNC-Only group compared to the multimodal *TNC-Public Transit* users are mainly differenced in SES (**Figure 2d**) and the number of available vehicles in the house. As a synthesis, we confirm that TNCs usage and its use alone correlates with household wealth and level of education in line with extant literature. However, particularly in Medellín, it also relates negatively to public transit coverage and private vehicle availability.

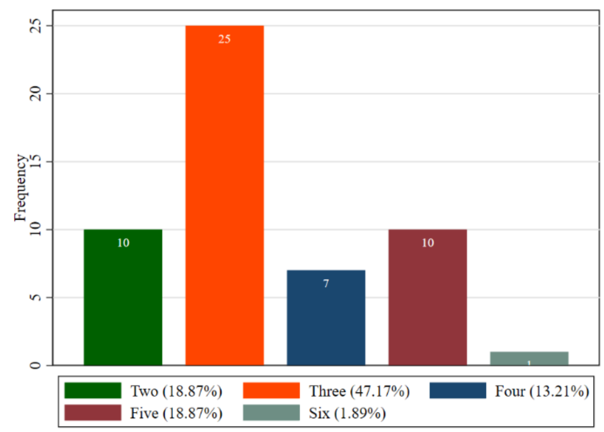
4.2 TNCs' usage patterns

4.2.1 TNCs versus other transportation modes

In the following sections, we present the analysis considering information at the trip level. **Figure 3a** presents the distribution of the type of transportation mode used in the first stage of the trips considering all the observations in the HTS. It is worth noting that the TNCs could be included as trips by a private mode. The total number of trips made by TNC reaches 153, and 128 appear in the first stage of the trip.



(a). Modal distribution in the first stage of the trip



(b). Distribution of stages in multi-modal trips involving both a TNC and Public Transit

Notes: All trips that involve a TNC are included. The trip stages are defined by the number of modes involved.

Figure 3. Usage of TNCs by trip stages.

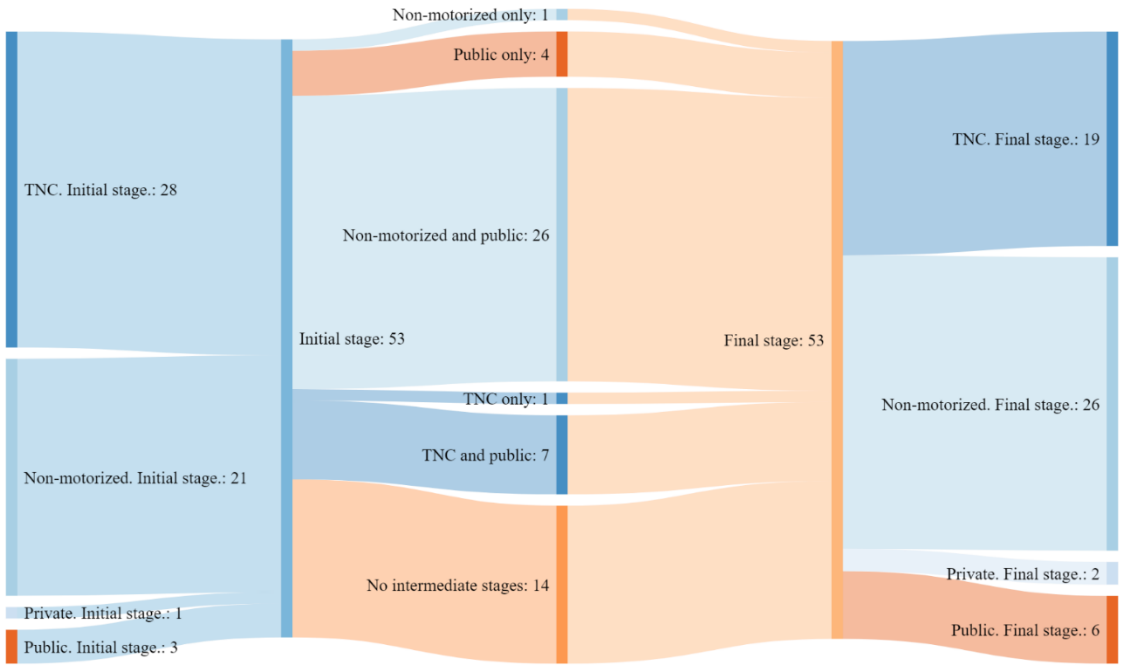
4.2.2 Door-to-door trips by TNCs

All the trips in the *TNC-Only* group involve only one stage. Among the 128 trips involving a TNC service at the beginning of the trip, 65.35% are unimodal trips (or trips taken door to door). These trips could be viewed as a first measure of the potential substitutability that these services represent for traditional transportation modes, assuming that they are not induced trips or trips that may not have been taken absent the availability of a TNC service.

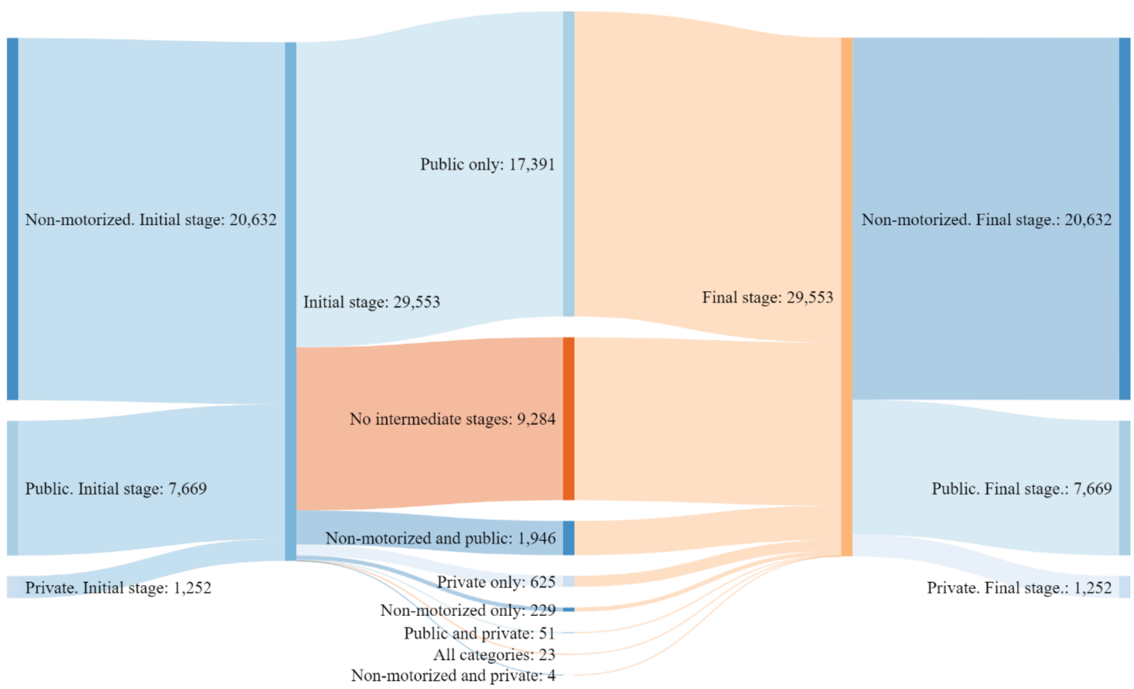
4.2.3 Usage of TNCs in combination with other modes

To better understand those trips that use TNCs to complement other transportation modes (34.65% of the sample), **Figure 3b** plots the frequency of trip stages within the *TNC-Public Transit* group. Interestingly, we find that among the people who use TNCs in combination with modes for a given trip, they are usually combined with more than one different transportation mode. The average number of trip stages in the multimodal groups is 3.4, which is large compared to the overall average considering all transportation modes (1.7), and the average of those trips involving public transit in any of the stages (1.9). As a result of this, there is a large variety of combinations for the intermediate stages.

Exploring this type of TNCs trip, the Sankey diagram in **Figure 4a** shows the modal choice in the flow of the trip stages for those who combine TNC's services with other transportation modes. Considering the number of possible modal combinations in intermediate stages (a maximum of seven stages with different transportation modes) and that TNCs services are not common in the middle of a trip, we summarize the trip in three aggregated moments: initial, intermediate (grouping all the intermediate stages), and last stage. The two most frequent combinations in the trips' flow are: First, using a TNC service in the initial stage, followed by a combination of public and non-motorized modes, and finalizing the trip with a non-motorized mode (representing 28% of trips); and second, trips that begin with a non-motorized mode, followed by a public transit mode, or a combination of public and non-motorized modes, and end with a TNC service trip (19% of trips). The remaining 34.65% of trips that requested TNCs' services and behaved as multimodal trips report this service's usage as a first or last mile alternative in a two-stage trip (i. e., no intermediate stages). Thus, we can observe that there is a complementarity between TNCs and public transportation modes. **Figure4b** shows that most travelers use non-motorized and public modes for the first and last stages, once more supporting the hypothesis that the TNCs could complement public transit in neighborhoods where there is not much public transportation coverage and distances do not favor non-motorized modes.



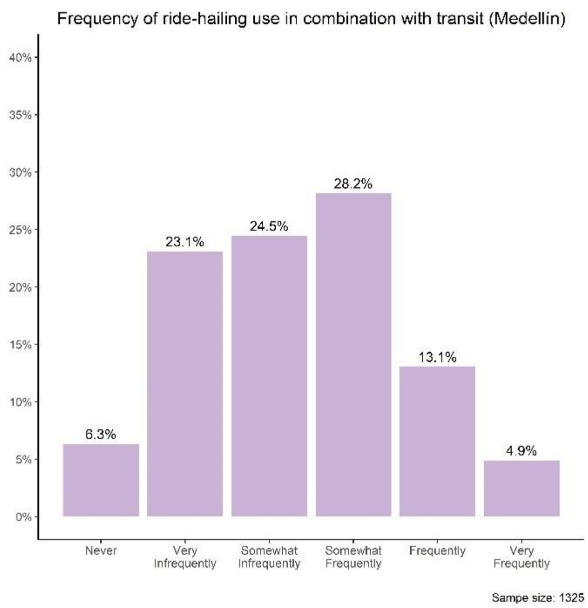
a. ***TNC-Public Transit***



b. ***TNC-nonusers***

Figure 4. Modal choice in the flow of the trips by *TNC-Public Transit* vs. *TNC-nonusers*

Figure 5 displays a complimentary analysis from the primary data gathered in 2020, exploring the frequency of TNCs trips that are made in combination with public transit (left) and the alternative mode that users would have taken if a TNC was not available for their last trip in a TNC (right). Both questions asked respondents to recall their behavior just before the pandemic began. A large proportion of the respondents stated having taken TNCs in combination with transit, with only 6.3% of TNC users stating that they had never done so. Of these, 28.2% stated they combined a TNC with public transit for their trips somewhat frequently, and 18% did so either frequently or very frequently, with a total of 46.2% of respondents stating that they take these types of trips with some degree of frequency. This result is higher than the one seen from the 2017 HTS, suggesting that TNCs have become an important access mode for many transit trips among TNC users.



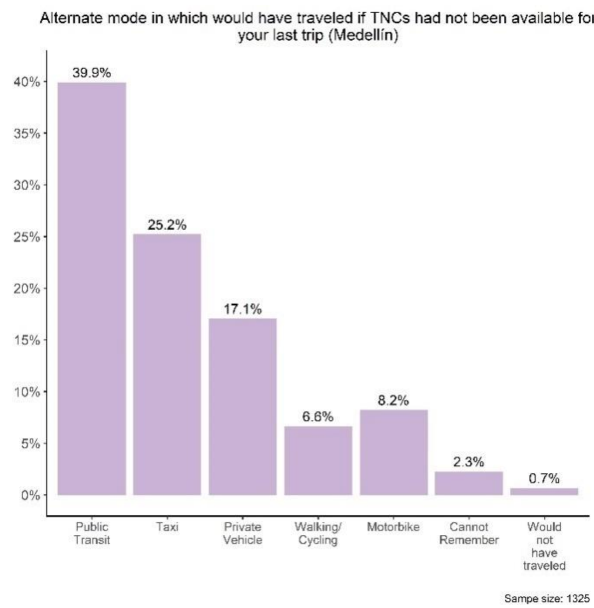


Figure 5. Frequency of TNCs as a substitute versus complement to public transit

Next, respondents were asked to recall their last TNC trip and what mode they would have most likely taken if a TNC was not available. Strikingly, 39.9% stated that they would have taken public transit, compared to 25% taxi and 17.1% private vehicle, suggesting that although TNCs frequently provide access to public transit in Medellín, they are just as likely to substitute public transit for TNCs. A small portion (6.6%) of users would have walked or cycled. Depending upon the distances, this may be an undesirable result in terms of active transport for shorter trips but could also save substantial time and lead to increased access and mobility for longer trips that could have otherwise only been taken on foot. In turn, unlike previous results in Mexico and Brazil, besides the main substitutability effect between TNCs and public transit, we also find evidence of complementarity in the case of Medellín under certain circumstances; in the following section, we look closer to its determinants.

4.3 Land use

We also explore how trip patterns vary by land use, as suggested by Gehrke et al. (2019). The data is retrieved from the Medellín Geoportal. By zooming in on TAZ zones where TNCs' services are being requested, we first look for differences in the count of places of interest disaggregated by type (health facilities, recreation centers, security bases, among others). Later, we explored differences in bus stops disaggregated by bus route type (direct to downtown, circular, among others). We only find statistically significant differences in the average number of residential places (see **Tables A1** and **A2** in Appendix).

4.4 Time efficiency

Finally, we explore whether time efficiency is a determinant of the usage of TNCs. The individuals' subjective value of time (VoT) relative to the cost of a ride in a TNC could determine, at the margin, the decision of using the service or not, and in which stage of the trip. This subjective value of time could change according to the circumstances; for instance, the individuals may value much more when riding in a TNC when it is very late after a Sunday party than a regular commute. In this section, we explore the time spent traveling by various modes and stages.

Considering the whole sample (i.e., *Non-users*, *TNC-Only*, and *TNC-Public Transit*), **Table 2** first summarizes the overall travel time by categories. The average travel time is not significantly different between the trips that use the TNC service as a door-to-door mode and the trips not involving any TNCs' service. However, the average travel time is statistically different when the non-TNCs trips are compared with those that complement a TNC service with a public alternative such as metro or bus.

To get insights regarding the role of travel time, we compare the means between those groups that use a TNC service in the first or last stages and, in the first place, with the primary massive transportation mode (metro); in the second, with the two most critical private competitors, private car and taxi. Here we can identify a difference, statistically significant, in the overall time traveled between TNCs' services and all metro, private car, and taxis, looking at the first and last stages. In almost all the scenarios traveling by a TNC takes more time than traveling by the other modes. However, the difference is negligible in the first stage and suggests that its usage may be determined by unobserved factors such as comfort, perception of security, and others. For the last stage, the difference is significant, suggesting that, besides these unobserved factors, those individuals that combine a TNC's service with other modes may be using it to reach places where there are no other time-efficient alternatives.

Table 2 Travel time in minutes

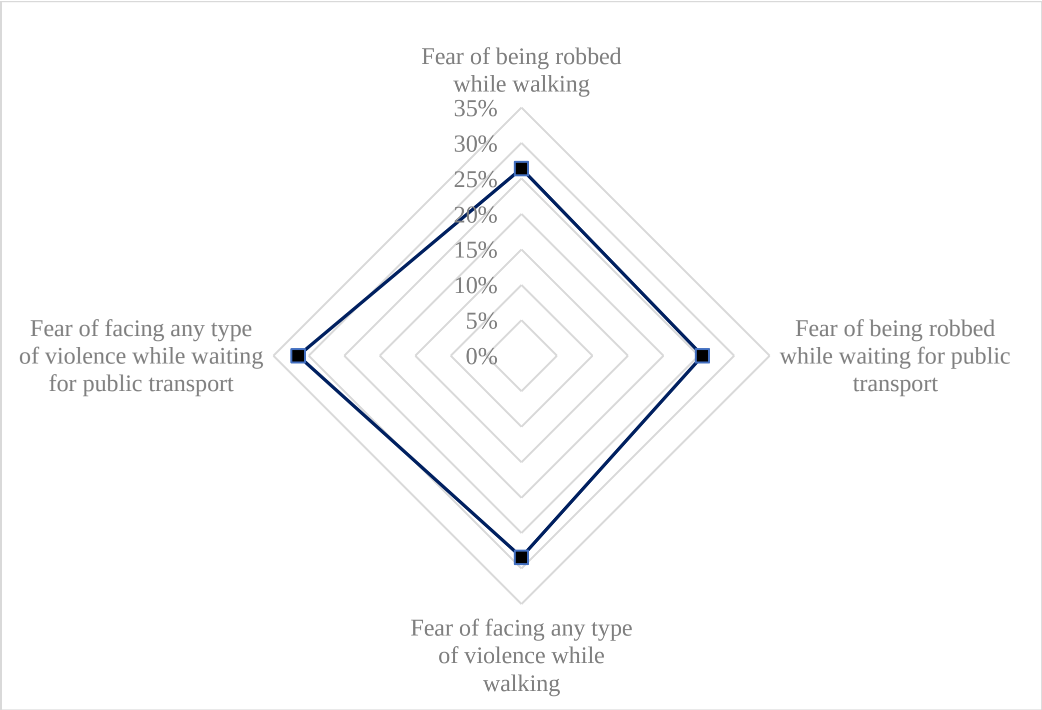
Category		N	Mean	Sd	Min	Max
Nonusers		12,082	31.9	23.38	1	170
TNC-Public Transit		53	61.49	40.4	10	230
TNC-Only		100	32.31	21.2	2	139
			First stage			
TNC	Metro	Diff	Car	Diff	Taxi	Diff
38.29	51.25	12.96**	35.72	-2.56*	28.55	-9.73***
		(7.08)		(1.90)		(1.94)
			End stage			
128.75	68.33	-60.42***	58.33	-70.42**	50	-78.75*
		(17.81)		(31.08)		(46.98)

Note: * p<0.1; **p<0.05; *** p<0.01

4.5 Logistics regression results

Table 3 presents the logistic regression results. Recall that we run a logistic specification defined in **Equation 1** in which y_k takes the value of one in the trip *k* involved a TNC in at least one stage and zero otherwise. At the individual level, the first key finding is related to the fact that in Medellín, being female is associated with a 98% higher probability of using a TNC service over the probability of using a different transportation mode. This result is different from previous research conducted in North America. To further explore this effect, we use the primarily collected data regarding the perceptions and motives for using TNCs in Medellín through five-level Likert scale questions (from "Totally disagree" to "Totally agree"). **Figure 6** plots the questions in which the option "Totally agree" was the most selected and the percentage of users in this category. Interestingly, in the case of Medellín, fear of facing any type of crime or violence while walking or while waiting for the transportation mode to arrive is persistent as a reason for using TNCs services; the last two categories (i.e., "Agree" and "Totally Agree") surpassed the 60% of answers among users. We believe this could be a determinant of a higher preference within females and related to the level of first and last mile usage of the service found in a previous section; it is in line with the findings of de Souza Silva et al. (2018) and Moody et al. (2021).

In contrast, age does not seem to play a role even if we create categories by ranges and focus on the individuals between 20 and 30 years old, which also stands as a difference to previous studies where the use of TNCs is referred to as a "wealthy young generation phenomenon" (Young & Farber, 2019). The effect of a higher level of education is consistent with previous findings. One additional year of education is associated with an 11% higher probability of using a TNC service.



Note: Percentage of answers in the "Totally Agree" category.
Figure 6. Fear perceptions of TNCs users in Medellín

Table 3 Determinants of TNC usage in Medellín

Variable	Categories	Odds Ratio estimates of using TNCs		
		MLE	BC MLE	PMLE
Age		0.997	0.997	0.997
		(0.007)	(0.006)	(0.006)
Female		1.993**	1.972***	1.973***
		(0.540)	(0.451)	(0.438)
Education (Years)		1.118**	1.116**	1.116**
		(0.057)	(0.045	(0.054)
Number of family members		1.209**	1.212***	1.211***
		(0.093)	(0.083)	(0.086)
Number of vehicles		0.497***	0.502***	0.502***
		(0.086)	(0.079)	(0.082)
Socioeconomic Stratification				
	SES1		(Baseline)	
	SES 2	0.772	0.750	0.751
		(0.378)	(0.032)	(0.319)
	SES 3	1.987	1.903*	1.906
		(0.841)	(0.718)	(0.761)
	SES 4	2.648**	2.608**	2.609**
		(1.270)	(1.165)	(1.232)
	SES 5	6.415***	6.237***	6.241***
		(3.431)	(2.815)	(3.034)
	SES 6	14.108***	13.791***	13.792***
		(7.906)	(6.336)	(7.410)
Time of no public transit (dummy)		1.187	1.917	1.745
		(1.243)	(2.001)	(1.464)
Peak hours (AM/PM, dummy)		1.197	1.212	1.212
		(0.263)	(0.296)	(0.291)
Trip frequency				
	Daily		(Baseline)	
	Weekly	2.624***	2.684***	2.680***
		(0.852)	(0.835)	(0.846)
	Monthly	1.463	1.491	1.490
		(0.550)	(0.443)	(0.412)
	Yearly	1.723	2.017	1.990
		(1.024)	(1.189)	(1.122)
Trip Motive				
	Recreation		(Baseline)	
	Commute	1.155	1.145	1.146
		(0.290)	(0.306)	(0.295)
	Back home	0.506	0.636	0.619
		(0.396)	(0.494)	(0.422)
	Shopping	1.901	2.022	2.016
		(0.919)	(0.995)	(0.940)
	Health	0.643	0.799	0.778
		(0.491)	(0.614)	(0.549)
	Other	0.676	0.699	0.699
		(0.255)	(0.295)	(0.284)
Trips per bus strop (Logged)		0.839**	0.838**	0.838**
		(0.074)	(0.072)	(0.073)
Total places of interest (Logged)		1.033	1.026	1.026
		(0.114)	(0.117)	(0.108)
Cons		0.000***	0.000***	0.000***
		(0.000)	(0.000)	(0.000)
Obs		49,725	49,725	49,725
Pseudo R2		0.07	-	-
Log pseudolikelihood		-639.75	-	-603.58

Notes: Columns represent the odds ratio estimates from logistics regressions using maximum likelihood estimation (MLE, column 1), bias-corrected MLE (BC MLE, column 2), and penalized maximum likelihood (PLME, column 3). Significance levels are indicated as follows: * p<0.1; **p<0.05; *** p<0.01. Standard errors are clustered at the individual level and reported in parentheses.

At the household level, all the covariates are statistically relevant. The most critical covariate is SES. If the individual lives in a house that is classified in SES strata five, the probability of using

TNCs is more than five times higher considering the lowest level of SES as the reference point; and if the individual lives in a house that classifies in level six of SES — the highest one — this result more than double. Also, an additional family member in the household is associated with a 21% higher probability. Finally, one additional available vehicle reduces this relative probability by 50%; this is different from the previous studies in Chile but in line with the Mexican case (Moody et al., 2021). **Figure 7** shows that a high percentage of users agreed with the statement that traveling with kids, elders, or disabled people was a reason to use TNCs services; this is in line with results found by Moody et al. (2021) for Mexico City. In addition, TNC usage is also relating to carrying many packages and traveling at night.

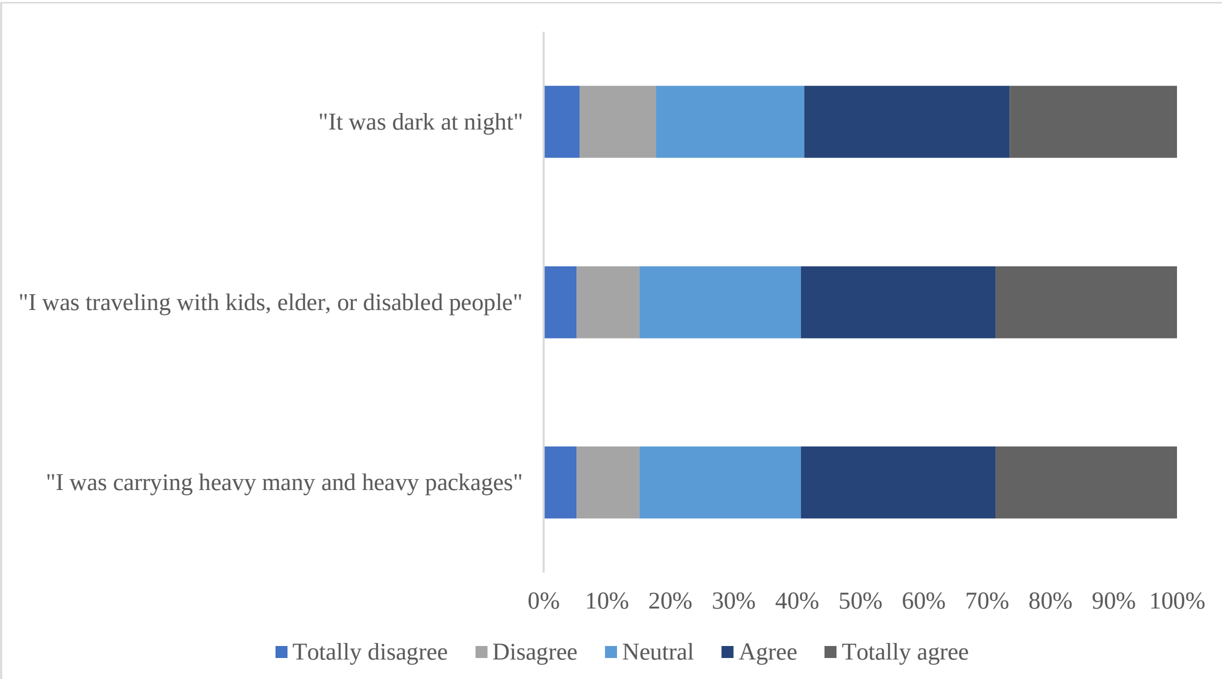


Figure 7. Trip context related to TNCs election

At the trip level, consistent with previous literature, TNC services are not widely used for daily trips in Medellín, but instead may be more frequently used occasionally, weekly. Although having a positive relationship the time of the day in which the service is requested, looking at peak hours is not a statistically relevant determinant to the use of TNCs nor the motive of the trips (**Table 3**).

Finally, the effect of bus stop density is another novel result in the analysis with a negative and statistically significant effect. The coefficient implies that a one percent increase in the number of trips per bus stop in the origin TAZ is associated with a 16% lower probability of traveling with a TNC service. This result suggests that public transit supply within that specific zone decreases TNC usage chances and that TNCs may fill in public transit gaps in the city. Furthermore, it is consistent with the geographical distribution of TNC trips presented in **Figure 2c**; the neighborhoods with higher requests for TNCs' services are residential places with high socioeconomic stratification (SES) and not places close to downtown areas with high daily mobility. In other words, this suggests that TNCs provide service in areas with less public transit coverage.

5. DISCUSSION AND CONCLUSIONS

This paper used the latest Household Travel Survey (2017) and primary data collected in 2020 to characterize the demand for ride-hailing services in Medellín. The selected case is an example of cities where these services have enjoyed high popularity despite the availability of modern integrated public transportation services and a strong emphasis on the promotion of transit in local policy and practice (Levy & Dávila, 2017). The paper builds on the first representative survey that records trips made by TNCs' services in the country, contributing elements to local and international debates about the role of ride-hailing services in urban mobility. The paper takes advantage of trip disaggregation by stages to examine the characteristics of users of TNCs' services vis-à-vis non-users. As part of the comparative analysis, the paper distinguishes between door-to-door users vs. those that use TNC's services in combination with public transit. Such a differentiation enabled the authors to draw relevant insights concerning the different roles of TNCs' services in reconfiguring urban mobility by complementing or competing with public transit.

The findings of this study case confirmed results from previous research in other contexts. On the one hand, and in line with extant literature, TNCs use correlates with household income and individual levels of education. On the other hand, it also indicated a negative correlation with coverage of public transit. Furthermore, when splitting TNC users, the findings reflect that users in the TNC-Only group —who appear to substitute public transit or other modes for TNCs — have higher technology affinity than the TNC-public transit. On the other hand, the case of Medellín sheds light on several novel determinants of the use of TNCs' services. First, we found a strong gender effect, in which being female increases significantly the probability of requesting a TNC service. Second, lower values in the variable of private vehicle availability and higher values in the number of family members in the household play a significant role in the usage of TNCs. Such a finding suggests that, in households with sufficient purchasing power, TNCs offer viable alternatives for individual mobility in the face of limited access to a private car for specific household members. Finally, it opens questions regarding gender inequalities in access to a private vehicle, documented in earlier research (Schwanen, 2011).

Findings presented in this paper also provide evidence of both complementarity and substitution of public transit, with the first being more frequent in longer trips where TNCs play a role as a first-last mile alternative. The logistic analysis confirmed that a household's socioeconomic stratification (SES) and gender (female) are the most significant characteristics. SES and high income as determinants of ride-hailing adoption have been a common finding in ride-hailing research, and it seems to be consistent across developed and developing countries. However, as Sabogal-Cardona et al. (2021) highlighted, findings related to gender in studies in industrialized contexts often find that men are more likely to adopt ride-hailing or do not consider gender as part of the analysis. The strong association between ride-hailing use and gender in this paper and previous research supports the hypothesis that on-demand services such as ride-hailing in Latin America could have a gendered dimension that needs further exploration (Sabogal-Cardona et al., 2021).

This research points to relevant areas for further research regarding the role of ride-hailing services in everchanging urban mobility systems. First, in line with previous research in the region (see Azuara et al., 2019; Oviedo et al., 2020; Sabogal-Cardona et al., 2021; Aleandro Tirachini & del Río, 2019b), this study confirms that Latin American urban contexts can bring new perspectives to understanding the rapid growth of TNCs services in recent years and the degrees to which such services have adapted to the particular social and functional challenges inherent to cities in the region. Second, although the paper provides significant evidence to understand the effect of TNCs on Medellín's urban mobility, additional research is needed to examine their effect on environmental sustainability and road safety, starting by estimating the contributions of TNCs to vehicle miles traveled, energy consumption, and road risks in the local context. Finally, further research on the implications of ride-hailing uptake for social and spatial inequalities and widely documented disparities in access to opportunities in Medellín and other parts of Latin America (Bocarejo et al., 2014; Dávila, 2013; Vecchio et al., 2020). The incipient social focus on analyzing urban mobility innovations is perhaps where more attention is to be devoted to future research on this topic. Whether TNCs are filling mobility needs in transit deserts or providing needed access as first and last-mile feeders to transit are only some of the emerging questions that need further exploration. This research aims to contribute with information that helps to understand the mobility gaps that TNCs' services may be closing, providing much-needed evidence that can inform the design of regulations to achieve better integration with available alternatives and enable to TNCs to contribute to a more efficient and sustainable urban mobility in this and similar contexts.

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APPENDIX

Table A1 Number of places of interest in the TAZ zones by category of TNC user

Group	Total zones			Zones without TNC non-users			Zones with TNC users			Mean-Comparison Test	
Variable	**N**	**Mean**	**Sd**	**N**	**Mean**	**Sd**	**N**	**Mean**	**Sd**	**Diff**	**P-Val**
Total count	471	28	42	377	25	37	94	39	57	-14.05***	0.01
Security	301	0	0	233	0	1	68	0	0	0.01	0.94
Recreation	301	2	3	233	2	3	68	2	3	-0.27	0.22
Commerce	301	4	10	233	4	10	68	5	10	-1.01	0.44
Educative	301	3	4	233	4	4	68	3	3	0.36	0.48
Health	301	1	1	233	1	1	68	1	1	-0.00	0.99
Residential	301	24	30	233	22	27	68	30	38	-8.01**	0.02
Other	301	9	25	233	8	17	68	13	43	-5.45*	0.06
Number of trips*	471	12718	12411	377	10835	10719	94	20270	15553	-9435**	0.00

Group	Total zones			Zones with TNC-Public Transit users			Zones with TNC-Only users			Mean-Comparison Test	
Variable	**N**	**Mean**	**Sd**	**N**	**Mean**	**Sd**	**N**	**Mean**	**Sd**	**Diff**	**P-Val**
Total count	471	28	42	30	46	66	53	40	55	6.03	0.66
Security	301	0	0	25	0	0	39	0	0	-0.01	0.93
Recreation	301	2	3	25	2	3	39	2	2	-0.17	0.79
Commerce	301	4	10	25	5	9	39	5	10	0.20	0.94
Educative	301	3	4	25	3	3	39	4	4	-0.62	0.50
Health	301	1	1	25	1	1	39	1	1	-0.14	0.68
Residential	301	24	30	25	33	48	39	28	32	5.15	0.60
Other	301	9	25	25	12	39	39	15	48	-3.60	0.75
Number of trips*	471	12718	12411	30	22083	18632	53	17728	13958	4356	0.2308

Note: The presented number make use of the expansion factors calculated by RISE. * p<0.1; **p<0.05; *** p<0.01

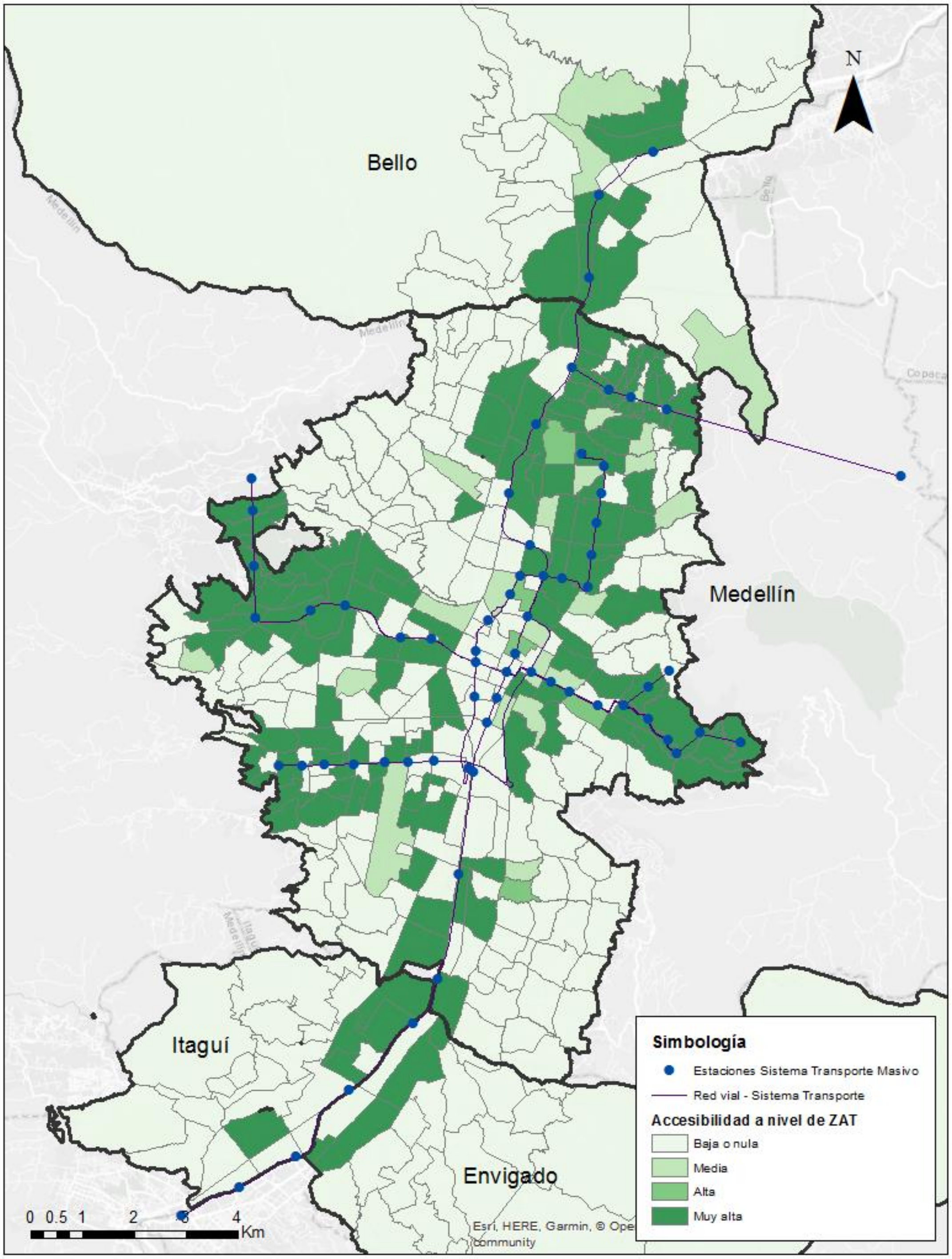
Table A2 Number of stops for public transit in the TAZ zones by category of TNC user

Group	Total Sit Zones			Sit Zones without TNC users			Sit Zones with TNC users			Mean-Comparison Test	
Variable	**N**	**Mean**	**Sd**	**N**	**Mean**	**Sd**	**N**	**Mean**	**Sd**	**Diff**	**P-Val**
All public transit	471	24	36	377	23	36	94	26	35	-3.37	0.41
Feeder	309	4	8	240	4	8	69	4	6	0.09	0.94
Circular	309	3	5	240	3	5	69	3	4	-0.30	0.66
Direct	309	0	1	240	0	1	69	0	1	-0.11*	0.06
Direct to downtown	309	22	26	240	22	26	69	20	24	2.40	0.49
No direct to downtown	309	1	8	240	1	8	69	1	6	0.19	0.85
Integrated	309	6	18	240	6	19	69	8	17	-2.07	0.40
Number of trips*	471	12,718	12,411	377	10,835	10,719	94	20270	15553	-9435***	0.00

Group	Total Sit Zones			Sit Zones with TNC-Public Transit users			Sit Zones with TNC-only users			Mean-Comparison Test	
Variable	**N**	**Mean**	**Sd**	**N**	**Mean**	**Sd**	**N**	**Mean**	**Sd**	**Diff**	**P-Val**
All public transit	471	24	36	30	24	22	53	29	39	-5.31	0.49
Feeder	309	4	8	25	3	5	39	4	7	-1.10	0.47
Circular	309	3	5	25	2	3	39	3	5	-0.88	0.42
Direct	309	0	1	25	0	0	39	0	1	-0.13	0.35
Direct to downtown	309	22	26	25	15	14	39	22	24	-7.06	0.09
No direct to downtown	309	1	8	25	1	6	39	1	7	-0.34	0.83
Integrated	309	6	18	25	7	10	39	9	21	-1.44	0.74
Number of trips*	471	12,718	12,411	30	22,083	18,632	53	17,728	13,958	4,356	0.23

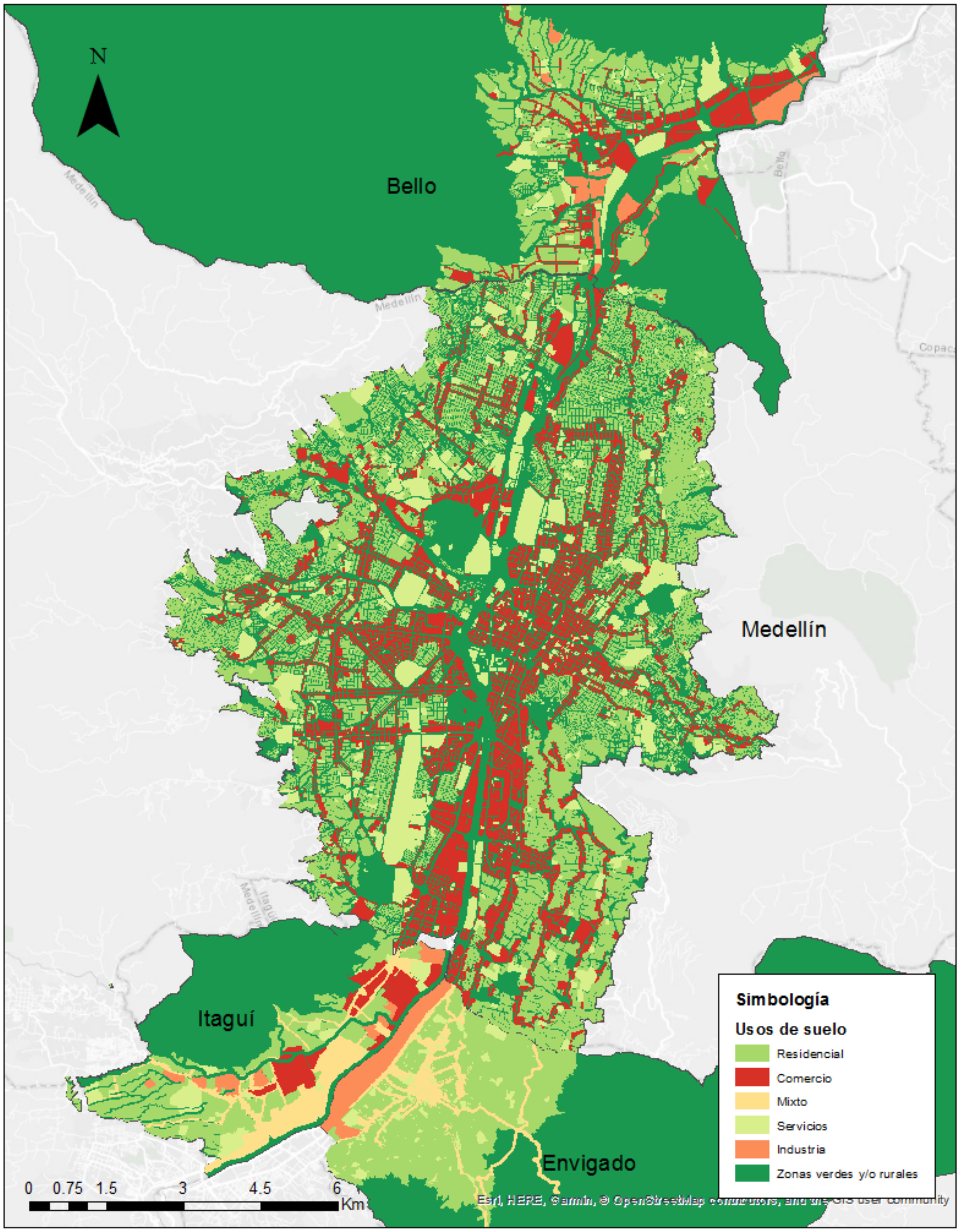
Note: The presented number make use of the expansion factors calculated by RISE. * p<0.1; **p<0.05; *** p<0.01

Figure A1. Accessibility at the level of pedestrian mobility and land use, Medellín, Envigado, Bello, Itagüí



Source: Steer (2020) using administrative data.

Figure A2. Land use in studied municipalities



Source: Steer (2020) using administrative data.