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Understanding the use of private and shared bicycles in large emerging cities: The case of Sao Paulo, Brazil

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ABSTRACT

This study presents a survey and a series of analyses performed to better understand the use of private and shared bicycles in a city where bicycle infrastructure and bicycle-sharing systems are recent and still limited. Using descriptive analysis, a multivariate ordinal model and a binary choice model, we (1) explore the profile of bicyclists before and after the expansion of dedicated infrastructure and we identify behavioral differences between newcomers and experienced bicyclists; (2) analyze factors associated with frequencies of work and non-work bicycle trips, and (3) examine the role of bicycle sharing systems in promoting bicycle usage and as a multi-modality enhancer. The results show that the expansion of bicycle infrastructure seems to stimulate under-represented segments of the population, such as women and low-income individuals, to start cycling. Travel time reveals to be an important predictor of cycling frequency for both work and non-work purposes, suggesting that cycling can be a competitive alternative to cars and transit in large, dense and congested cities. We also observe that shared bicycle systems play a fundamental role in multi-modal travel and in introducing new users to the bicycle mode.

1. Introduction

The increase in motorization and drive-alone trips in large cities of emerging countries has become a transportation challenge as traffic congestion, accidents, noise and air pollution reach unbearable levels. These negative externalities question the sustainability of the automobile-oriented urban development model and encourage the formulation of strategies to improve the use of other modes of transportation in emerging cities. In this context, Brazil has approved an Urban Mobility Law (Brazil, 2012) that establishes that cities with more than twenty thousand inhabitants must elaborate and periodically update urban mobility plans. The law mandates urban development to prioritize non-motorized travel modes and transit. As a result, accommodating bicycles in transportation infrastructure has become an important consideration in the planning agendas of many Brazilian cities. For instance, the city of Sao Paulo, has recently adopted measures to stimulate the use of bicycles with the implementation of about 400 km of bicycle lanes and two bicycle sharing systems.

The growing interest in urban cycling as a transportation alternative goes beyond emerging economies, as demonstrated by the last two decades of published research on cycling in Europe, North America and Australia (Pucher and Buehler, 2017). European cities that were precursors in the adoption of bicycles as a structural transportation element (such as Copenhagen and Amsterdam) are current examples of how investments on bicycle infrastructure can promote multiple benefits in terms of traffic, welfare and quality of life (Fishman, 2016a). The resurgence of urban cycling has also been helped by the creation of bicycle sharing systems, which made bicycle use even more flexible and accessible. For instance, since the launching of the first large-scale bicycle sharing system in 2005 in Lyon, France, and the successful ***Vélib*** system in 2007 in Paris, France, the concept of shared bicycles has quickly expanded to become a global trend. As in 2017, more than 1200 bicycle sharing systems were operating around the globe (Pucher and Buehler, 2017).

Compared to walking, bicycles allow for longer and faster trips, serving both as an independent mode and as a feeder to public transit. Furthermore, bicycles provide levels of flexibility that, in relatively dense environments, are analogous to private motorized modes, while also being environmentally friendly and accessible for people of practically all social classes. Despite the many benefits of cycling as a transportation mode, allocating resources and infrastructure space to bicycles in areas where their fraction of daily trips is still small can be a very unpopular measure. This is because increasing bicycle infrastructure often means reducing road space for other travel modes.

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Therefore, many city managers, especially in developing economies, are reluctant to direct their limited resources to developing connected networks of bicycle lanes. In that sense, Handy et al. (2014) point to the role of cycling research in identifying the most effective strategies to increase bicycle mode share and in showing tangible evidences of the benefits brought by such strategies.

Considering the scarce literature on bicycle use outside developed countries and aiming at providing guidance to cities with limited resources and saturated transportation networks, this study presents an exploratory examination of the use of bicycles in the context of a large metropolitan city in Brazil. The data is derived from online and field surveys with bicyclists of the city of Sao Paulo, where investments toward bicycle infrastructure were made for four years (2013 through 2016) and then ceased. This well-defined period of investments provides the opportunity for an exploratory investigation of how increased cycling infrastructure (dedicated lanes and bicycle sharing systems) relates to the characteristics of bicyclists (such as socio-demographics, vehicle ownership and travel behavior) and the intensity of use of this mode (cycling frequency).

Specifically, this analysis sheds light on three main topics that have important implications to urban cycling planning: (1) characterization of bicycle users including changes in the profile of users associated with bicycle infrastructure expansion, and behavioral differences between newcomers and experienced bicyclists, (2) factors associated with frequencies of work and non-work bicycle trips, and (3) the role of bicycle sharing systems in the promotion of bicycle usage and as a multimodality enhancer. While the first analysis is based purely on descriptive statistics, the second and third analyses rely on a bivariate ordered probit model and a binary probit model, respectively. The bivariate ordered probit approach is used to jointly model the frequency of work and non-work trips performed by bicycle while the binary model is used to analyze the choice between using a private or a shared bicycle for a given trip. Together, the results from these two models bring interesting insights to understanding bicycle use.

The remainder of this paper is organized as follows. In the next section, we present the context and previous literature that form the background to this study. Section 3 describes the development of the data collection and the resulting sample. The three main analyses are developed in Section 4 and are followed by conclusions and policy recommendations in the final section.

2. Background

The majority of literature on bicycle use refers to Europe, North America and Australia (for reviews, see Heinen et al., 2010; Buehler and Dill, 2015; Götschi et al., 2016; Pucher and Buehler, 2017), with scattered recent efforts focusing on newly industrialized countries (see Zhang et al., 2014; Sá et al., 2016; Majumdar and Mitra, 2015; Verma et al., 2016; Zhao et al., 2015; Zhang et al., 2017 for studies involving cities in Brazil, India and China). Moreover, the scenarios under which a significant portion of bicycle studies take place are medium and small-sized cities (Heinen et al., 2010). Since the current study is held in a large metropolitan city in South America, where urban dynamics are probably different from the ones depicted by most previous analyses, we start this section by describing the study area. Then, to situate this work among previous research, we present a brief overview of the bicycle use literature focusing on the three topics under analysis: (1) impacts of bicycle infrastructure on bicycle use, (2) cycling frequency and its predictors, and (3) the use of shared versus private bicycles. The intent of the section is not to present an extensive review of the literature, but rather to outline the background of the discussion that follows.

2.1. The context: bicycle policy and infrastructure in the city of Sao Paulo

Sao Paulo is the main city of one of the largest metropolitan areas in the world (23 million people). The city alone accommodates 12 million people in a dense environment of on average 7 thousand inhabitants per square kilometer (IBGE, 2017). Central areas present higher densities, higher access to jobs and activities, and better transportation infrastructure than peripheral neighborhoods. Poorer segments of the population live in these peripheral areas and usually present longer commutes and lower accessibility levels (Pereira and Schwanen, 2013). The latest household mobility survey estimated that close to 44 million trips took place in Sao Paulo per day in 2012 (Metrô, 2012). In that year, the assessed share of non-motorized trips was 32%, but cycling trips accounted for less than 1%. The transportation network in Sao Paulo has been historically saturated and congested. In 1997, the city adopted a traffic management policy in which vehicles with license plate ending with specific numbers are not allowed to circulate within the expanded central area during the morning and afternoon peak periods of a specific weekday. Due to its heavy traffic, varied topography and unstable weather conditions, Sao Paulo has often been characterized as non-bicycle-friendly. However, cultural reasons and a negative association between bicycle use and socioeconomic status have historically played the most crucial role in preventing a more extensive adoption of this travel mode (Malatesta, 2014).

The Sectorial Cycle Systems, developed in 1981, was the first plan for bicycle use as an alternative mode of transport in the city of Sao Paulo (Malatesta, 2012). This plan was followed by policies and programs in the late 1980's, but only in the last decade (20 years later) such initiatives started to gain more significant momentum. At the national level, the Bicycle Mobility Plan (Brazil, 2007) presents several guidelines to stimulate bicycle use. In Sao Paulo, the municipality 2013–2016 Goals Program (São Paulo, 2013) was essential for the expansion of the bicycle network, which contributed to the implementation of 400 km of new bicycle lanes[1]. As a result, bicycle infrastructure in the city has increased significantly between 2013 and 2016. By 2013, the existing bicycle network had 68 km of bicycle lanes. In 2017, the cycling infrastructure in the city reached 498 km, consisting of 468 km of bicycle lanes (130 km of bicycle lanes were implemented per year between 2014 and 2016) and 30 km of bicycle routes (CET, 2017).

In 2017, Sao Paulo had two relatively small bicycle sharing systems: Bike Sampa and CicloSampa. Both systems had smart bicycle docking stations and allowed the use of apps to view the number of available bicycles and available docking slots at each station. Bike Sampa opened first with approximately 250 bicycle docking stations. Bicycle use was free during the first hour. CicloSampa had only 17 docking stations, and the use was free only for the first 30 min. Both systems applied the same hourly rates after the free period. Fig. 1 presents the bicycle infrastructure and bicycle docking stations from both services.[2] The acronyms ABC and RMSP represent cities/areas that are external to the city of Sao Paulo, and thus, outside the scope of this study. Both bicycle lanes and bicycle sharing stations are predominant in central areas; however, bicycle sharing stations are even more concentrated and limited in area of coverage, showing that peripheral neighborhoods are not served by the system.

2.2. Overview of earlier studies

Bicycle adoption and use have received significant attention from both transportation (see Fishman, 2016a) and public health (see Götschi et al., 2016) literature as contemporary policies try to overcome challenges presented by car dependence and sedentary lifestyles.

[1] Although the authors acknowledge that distinct types of bicycle infrastructure exist, with different levels of segregation from the general traffic, we will often refer to them in the text generically as "lanes".

[2] Please note that we describe the bicycle system and infrastructure as of 2017 because that was the year when the data used in the analyses was collected.

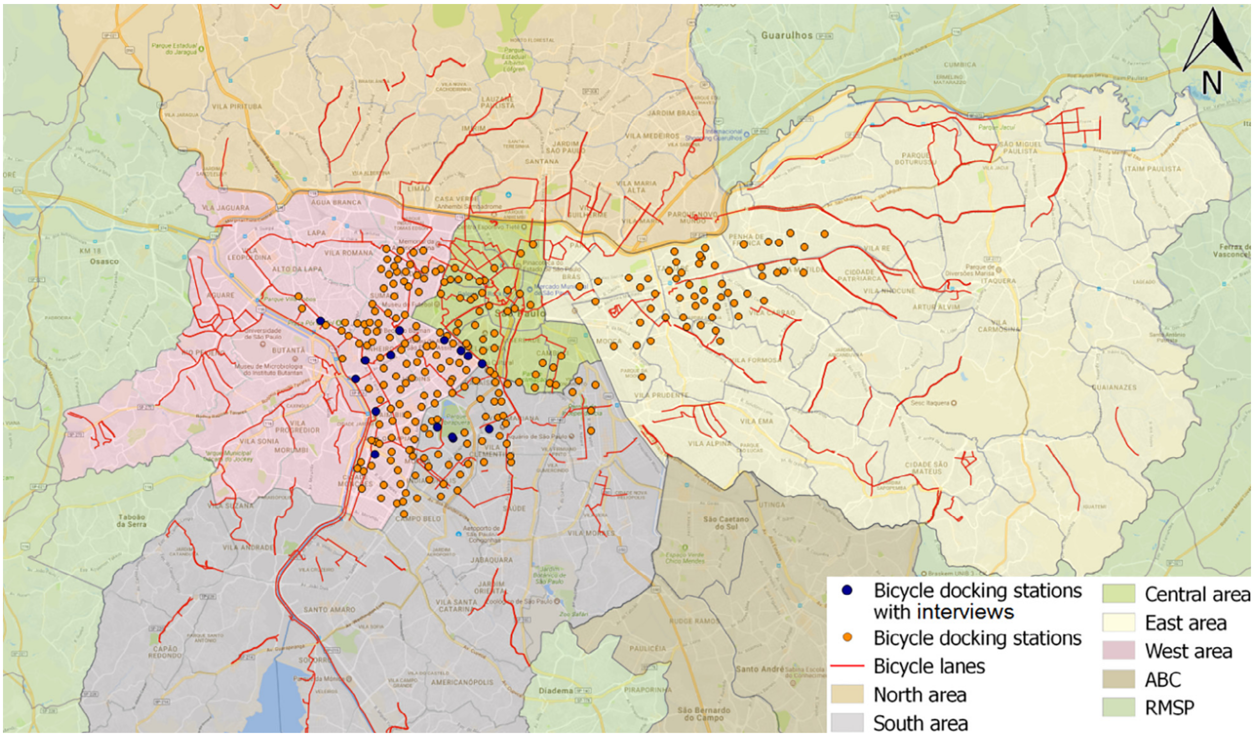

Fig. 1. Spatial distribution of bicycle lanes and stations of shared bicycles.

2.2.1. Impacts of bicycle infrastructure on bicycle use

Impacts of bicycle infrastructure on cycling have been the focus of multiple studies and many literature review articles approach this topic (Heinen et al., 2010; Handy et al., 2014; Buehler and Dill, 2015; Aldred et al., 2016). Buehler and Dill (2015) conducted a review on studies examining the effects of different bikeway networks characteristics on cycling. They identified that studies on this topic are predominant in the United States, Canada and Australia, and are usually held in cities where bicycle networks are limited. The authors also identified that, although most analyses rely on stated-preference surveys of cyclists and sometimes non-cyclists about their current cycling behavior or willingness to cycle under varying infrastructure scenarios, there is an increasing number of revealed-preference studies. An interesting remark made by the authors is that the time required for people to change their behavior after infrastructure is implemented is not clear. They state that one year is probably not long enough, particularly for influencing people to start cycling. Buehler and Dill (2015) also observed that measuring the specific effects of new cycling infrastructure on user behavior is usually not possible because auxiliary initiatives, such as promotional programs, cycling training, safety training for cyclists and motorists, bike-transit integration, enforcement of traffic laws or policies limiting car use, are often implemented together with the new infrastructure.

Regarding differences in perceptions about the importance of cycling separation from motor traffic, Aldred et al.'s (2016) review identified that preference differences are not qualitative, but quantitative. In other words, certain segments, such as women, find the bicycle lane separation more important than other segments, but no group prefers to ride in mixed traffic. Similar results are observed by Buehler and Dill (2015), who emphasize differences in perceptions between experienced bicyclists and non-bicyclists. Pucher and Buehler (2017) argue that one of the main deterrents to more cycling is the perceived danger of cycling on shared roads with motorized traffic. These authors observe that, to increase cycling among vulnerable and risk-averse population groups, separate bikeways and or bicycle paths shared with pedestrians must be available. However, on an investigation about determinants of commuting by bicycle, Heinen et al. (2010) note that, although bicycle infrastructure is important, trip distance is probably the most important built environment factor on the decision to commute by bicycle. Altogether, it is possible that the interaction between land use density and adequate infrastructure is actually necessary to produce increases in cycling shares. Naturally, other factors such as level of experience, attitudes, and perceptions of cost, travel time and health benefits also play an important role on the individual's perceived need for segregated infrastructure (Handy et al., 2014).

2.2.2. Cycling frequency

The literature identifies multiple covariates with significant impacts on the intensity of bicycle use. Socio-demographic characteristics, vehicle and bicycle ownership, infrastructure availability and its specific design characteristics, urban density and general built-environment, availability of dressing facilities at work locations, weather, trips characteristics (distances), the actual mode shares of bicycle and non-motorized modes, and the bicyclist's level (time) of experience are the most frequent examples (Sener et al., 2009; Heinen et al., 2010; Handy and Xing, 2011; Harms et al., 2014; Fu and Farber, 2017). Although many studies directly or indirectly investigate factors associated with cycling frequency, only a few model cycling frequencies at the individual level (examples are Stinson and Bhat, 2004; Sener et al., 2009; Damant-Sirois and El-Geneidy, 2015; Fu and Farber, 2017; Bhat et al., 2017). Still, none of these studies model bicycle commuting frequency jointly with frequency of bicycle use for other purposes. For instance, Stinson and Bhat (2004) analyzed only commuting frequency, while Fu and Farber (2017) and Bhat et al. (2017) modeled cycling frequency without identifying specific trip purposes. Damant-Sirois and El-Geneidy (2015) modeled cycling frequency for work and non-work purposes but using separate models. Similarly, Sener et al. (2009) also separated these two purposes into different models but used a more sophisticated approach than the previous authors, in which repeated stated frequencies for different seasons of the year were considered. Joint models of cycling frequency for different purposes have been neglected by the literature, but they could have an essential role in determining whether unobserved factors (such as active lifestyle or environmental consciousness) simultaneously affect these two distinct types of use.

2.2.3. Use of shared versus private bicycles

Bicycle sharing has become a very popular topic in the active transportation literature (see Fishman et al., 2013; Fishman, 2016b, for reviews), yet studies that compare the use of shared bicycles and private bicycles are limited. Based on multiple sources of data (regional household travel survey, online survey and field survey) from Washington D.C., Buck et al. (2013) compared demographic and travel behavior characteristics of regular bicyclists (who use private bicycles), short-term and long-term users of the city's bicycle sharing system. Kraemer et al. (2012) used data from the same city to examine safety-related behavior, especially helmet use, of users of private and shared bicycles. Both studies observed significant differences between the users of the two types of bicycles in socio-demographic characteristics and behavior in terms of trip purposes, modes substituted and helmet use. Finally, Fishman et al. (2012) conducted a qualitative study involving focus groups with regular bicyclists, infrequent bicyclists and members of a bicycle sharing program in Brisbane, Australia, to identify factors that could contribute to an increase in the use of bicycle sharing. Although the focus of the study was not the comparison between the behaviors of three groups of users, they observed significant differences in their perspectives regarding bicycle use. In sum, there seems to be relevant heterogeneity among the users of private and shared bicycles, suggesting that the literature could benefit from more research on this topic.

The above literature overview provides a foundation for this study by showing that dedicated bicycle infrastructure and bicycle sharing systems have different effects on the decisions of whether to cycle, how frequently and for what trip purpose, and such effects are also subject to individual heterogeneity. We also observe a lack of studies that investigate cycling environments outside developed countries, specifically, there are few studies that involve systematic analysis through modeling in these areas. Most studies are purely descriptive and do not involve statistical models that allow for the examination of the relationship between multiple covariates simultaneously. In this sense, the multivariate model of cycling frequency and the binary model of bicycle type choice can bring insightful findings to the field.

3. Survey design and data collection

This section describes the survey design and data collection process used to obtain data on the behavior and motivations of bicyclists. The questionnaire was designed around the respondent's "reference trip", which was defined as the latest bicycle trip on a working day in the two weeks prior to the survey completion date (weekends were excluded from the survey due to the small proportion of commute trips). The questionnaire was structured into five blocks, collecting information on:

- Attributes of the reference trip (private versus shared bicycle, purpose, distance, frequency, integration with other mode, alternative mode);
- General bicycle usage pattern (use for purposes other than the one observed in the reference trip, frequency of use to work/school and to other activities, behavior adaptation when raining);
- Infrastructure (existence of bicycle lanes close to home and work, impact of dedicated infrastructure on individual bicycle use);
- Sociodemographic and economic characteristics (gender, age, education, income, occupation, bicycle ownership and car availability, home location and cycling experience); and
- Motivation to use bicycle (financial benefits, health benefits, travel time, existence of bicycle lanes, measured on a 5-point Likert scale).

The survey was originally designed to be conducted through the internet using an online platform (Typeform). A convenience sample of cyclists in Sao Paulo was sought by distributing the survey questionnaire link to mailing lists of local cycling organizations and bicycle-related social network groups (in LinkedIn and Facebook). The online survey was held from May through July 2017. A total of 509 individuals completed the questionnaire, but only 30 reported using a shared bicycle on the reference trip. The limited number of reference trips on shared bicycles led the researchers to a second data collection effort, in the field, intercepting shared bicycle users at bicycle docking stations (the sample of stations visited are shown in Figure 1[3]). The same questionnaire was used, and the reference trip was considered the one that bike-share users were making (starting or ending) at the time of the interview. The field survey was held in June 2017, and 96 shared bicycle users were interviewed, raising the total sample to 605 people.

Both sampling strategies present limitations when considering that the target population for this study would include any adult who used a bicycle in the city of Sao Paulo in the period of interest. On one hand, online surveys distributed via cycling organizations are likely to attract engaged bicyclists who are also customary internet users (skewing the sample to specific socio-demographics, for example, higher income and higher levels of education). Also, online respondents, when asked about the latest bicycle trip taken on a week day in the last two weeks, are likely to more easily recall commute trips than those conducted for non-compulsory activities, affecting the measurement of the outcome of interest. On the other hand, the intercept survey introduces geographic biases, as the characteristics of the reference trip is likely influenced by the built environment in the surroundings of the chosen station. In this sense, the combination of the two sampling methods concatenates different sources of biases. However, because of the difficulty in reaching individuals whose reference trip was by bicycle sharing, the researchers had no practical alternatives to consider. Indeed, Buck et al. (2013) faced similar challenges and also adopted the data collection strategy of combined online and field surveys in a study of similar nature.

Because the data collection strategy did not sample individuals at random and did not generate a sample that represents the population of bicyclists in Sao Paulo (as discussed in Section 3.1), the general distribution (descriptive statistics) of the travel behaviors observed in this study do not provide empirical evidence that is generalizable. However, the obtained data and sample are still useful to derive information on relationships between socio-demographic characteristics, level of experience cycling and other travel behavior characteristics through disaggregate models such as discrete choice models.

3.1. The sample

The sample of bicyclists in this study has a significant portion of individuals with higher education, 48% of the sample have bachelor or associate degrees and 29% have post-graduate degrees. The majority (72%) of the individuals are between 21 and 40 years old, and only 24% are women. Middle income class individuals are prevalent, 36% are lower middle income and 21% are higher middle income, but there is also an important share of individuals with high income (29%). More than 46% of the sample started using the bicycle in Sao Paulo less than 2 years before the survey, and 27% between 2 and 5 years before the survey. Most individuals state to have a vehicle available for their use. While 59% always have a vehicle available, 11% have a vehicle

[3] At the time of the interviews, the main bicycle sharing system – Bike Sampa was in transition to a new concessionaire, partially due to operating and maintenance problems caused by the previous operator. As a consequence, many stations were not fully operational and the number of bicycles available was drastically reduced. This situation required that every morning, before starting their journey, interviewers consulted with the system app to determine which stations had bicycles available and then planned for the day. As a result, the interviews were performed in more central stations rather than evenly spaced thought the entire spatial coverage of the system. Also note that the system malfunction may have influenced the bicycle type choice of regular and potentially new users.

available only sometimes (the remaining 30% do not have a vehicle available). In terms of bicycle ownership, 88% of the sample owns a bicycle. Most individuals stated having a bicycle lane close to home (78%) and close to work (80%). There are limited independent sources of data to assess the representativeness of the obtained sample relative to the population of bicyclists. The most recent household travel survey conducted in Sao Paulo took place in 2012 (Metrô, 2012), when the first bicycle sharing system was initializing its operations and before the expansion of dedicated infrastructure. In that survey, bicycle trips accounted for less than 1% of the trips and the number of respondents that used this mode was very limited (Metrô, 2012). The sociodemographic proportions observed in the household travel survey sample were of 27% of bicyclists with associate, bachelor or higher degrees, 50% between the ages of 19 and 39 years, 13% women, and 50% on the middle-income range (but only 19% with high income). More than 95% of the bicyclists owned bicycles and less than 28% lived in households that owned cars (Sá et al., 2016). In the next sections, we will discuss possible changes in the profile of bicyclists as bicycle infrastructure and bicycle sharing systems were implemented. However, despite these changes, there seems to be clear evidence that the sample used in our study has an overrepresentation of highly educated individuals and high-income individuals, probably because of the internet-based recruiting method and the choice of central bicycle sharing stations for the field survey. Indeed, a more geographically spread field survey conducted in 2016 by one of the major cycling associations of Sao Paulo interviewed 1804 bicyclists and found a 37% share of individuals with higher education degrees. In terms of income, their sample showed 38% middle income class and 12% in the high-income class individuals (Ciclocidade, 2016). In terms of bicycle trip characteristics, most trips in our sample have commute or leisure/exercise purposes and are between two and eight kilometers long, similar to what was observed in the survey conducted by Ciclocidade (Ciclocidade, 2016). However, among commute trips, there is an important share of longer trips (66% of commute trips are longer than 10 km), as shown in Fig. 2. Leisure and exercise trips are concentrated in two ranges, between 2 and 5 km or above 20 km. Shopping trips are the shortest ones and do not usually exceed 5 km. Looking at the modes used as an alternative to bicycle, for commute trips, relying exclusively on the bicycle or using transit (bus or subway/train) are the most common behavior. Alternatively, shopping bicycle trips are often replaced with walking and car trips.

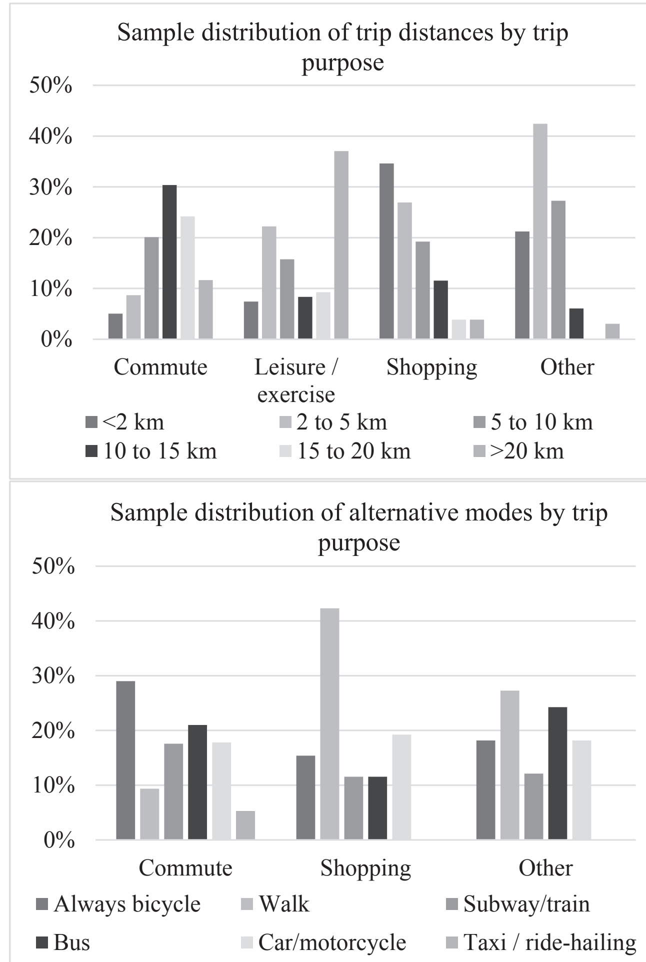

Fig. 2. Trip distances and alternative modes by trip purpose.

4. Analysis

This section presents the three analyses conducted to examine bicycle use. First, we characterize socioeconomic, motivational and travel behavior factors associated with bicyclists of diverse levels of experience and that started cycling under different conditions of bicycle infrastructure. Second, we develop a model of frequency of bicycle trips for work and non-work purposes and identify elements related to the intensity of bicycle use. Finally, the choice between private and shared bicycle for the reference trip is examined through a binary choice model.

4.1. Characterization of users

For this analysis, we segmented the sample into three groups of users based on their time of experience cycling. These time intervals also coincide with three different phases of bicycle infrastructure in the city. Group I (n = 161) is comprised of individuals who started using bicycles five or more years prior to the survey (before July 2012). During this period, there was no bicycle sharing system in the city and the extension of bicycle lanes was very limited. Although no attitudinal information was collected, it may be implied that Group I is the segment with stronger proclivity toward bicycles, since this group adopted this mode even before the infrastructure was available. Group II (n = 163) is characterized by individuals who started using bicycle transport two to five years prior to the survey (between July 2012 and July 2015), period in which the bicycle sharing systems were first installed, and the first stage of the bicycle lane expansion took place. This group can be considered the transition group, or the "early adopters" of the new infrastructure. Group III (n = 281) consists of individuals who started cycling during the second stage of the bicycle infrastructure expansion and during the expansion of the bicycle sharing system. The segmentation of groups allows for an evaluation of changes in user characteristics as the bicycle network was extended as well as a comparison of travel behavior characteristics between new users and experienced users.

4.1.1. Socioeconomic characteristics

All three groups present a similar distribution of education levels and, as discussed earlier, the sample has an overrepresentation of highly educated individuals (more than 70% have at least a bachelor's degree). On the other hand, as shown in Fig. 3, there are relevant differences in age, gender and income distributions between the three groups.

While the group of individuals who started cycling before the existence of the infrastructure (Group I) has a more homogeneous distribution of age, the recent users (Group III) are predominantly younger adults, with more than 80% between 21 and 40 years old. Since Group I is formed by individuals who started to use the bicycle at least five years before the survey, it is probably true that individuals over 40 years old (47% of Group I) started to use the bicycle when they were younger. This result may be indicative that, within a relatively dense

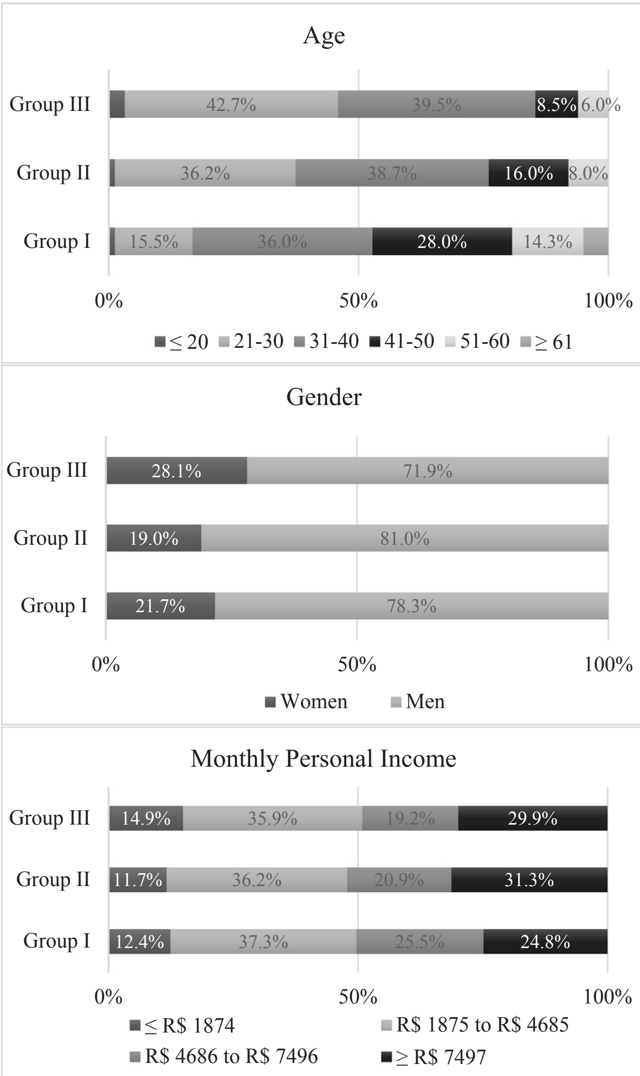

Fig. 3. Socioeconomic characteristics of the three groups of individuals who started using bicycle in Sao Paulo during the three bicycle infrastructure periods. Group I – Started cycling before July 2012; Group II – Started cycling between July 2012–2015; Group III – Started cycling after July 2015.

metropolitan area, bicycle use may remain an attractive option for middle-aged individuals after they develop some experience using this mode. Even though individuals in Group III probably have weaker attitudes toward bicycle use than individuals from Group I, previous studies affirm that cycling experience increases one's positive perceptions and attitudes toward this mode (Gatersleben and Appleton, 2007), which may also contribute to long-term bicycle use by Group III.

The expansion of bicycle infrastructure seems to have contributed to an increase in the share of female bicyclists (a similar result was observed in New Orleans, United States, by Parker et al., 2011). While the proportion of women in Groups I and II is around 20%, in Group III it is 28%. The prevalence of men among the bicyclist population is a common finding in the transportation literature (Heinen et al., 2010; Garrard et al., 2012), especially in cities where cycling is not a popular transportation mode. It is also known that women are more safety conscious (Twaddle et al., 2010) and, therefore, a clear separation between bicycles and motorized traffic may be an especially important feature for women to consider the use of bicycles (Garrard et al., 2008; Akar et al., 2012). Finally, in terms of income, lower middle-income individuals are predominant in the three groups. However, we observe an increase in the share of low income and high-income individuals in Group III. High income individuals reside in central areas of the city, which are denser and have a larger extension of bicycle lanes per unit of area (84% of the bicyclists in the high-income segment declared living close to a bicycle lane), as shown in Fig. 1. In other words, the connectivity between the bicycle infrastructures in the central areas is better, increasing the attractiveness of this travel mode. Additionally, central areas are especially affected by high levels of traffic congestion, and high-income individuals rely almost exclusively on cars; therefore, the improvements in bicycle infrastructure were expected to attract this population segment. On the other hand, despite in lower proportions, bicycle lanes were also installed in more peripheral areas where the low-income populations reside (74% of the bicyclists in the low-income segment declared living close to a bicycle lane). For this segment, it is plausible that bicycles became an alternative and/or a complement to transit.

As observed by Buehler and Dill (2015), the time interval between infrastructure implementation and change in behavior (attraction of new users) is not clear. Therefore, it is possible that more substantial changes in the profile of users will happen in the next years, even without infrastructure additions to the system.

4.1.2. Motivations

The three groups of users present similar opinions regarding the importance of financial and health benefits in the decision to use bicycle as a transportation mode. Around 40% of respondents considered financial benefits extremely important to their decision, and 63% considered health benefits extremely important. The latter result is aligned with the public health literature, which has evidence that active transport, especially cycling, could be an important contributor to general public health by increasing physical activity (Wanner et al., 2012). However, as observed by Stinson and Bhat (2005), the groups diverge in their perceptions of the importance of travel time and existence of bicycle lanes. While 55% of Group I considered travel time extremely important, only 45% of Groups II and III shared the same opinion. The presence of bicycle lanes is extremely important for 63% of Group III, 53% of Group II and only 47% of Group I. Groups I and II were asked if the expansion of the bicycle infrastructure had increased their frequency of bicycle trips; to which 75% and 93% of each group, respectively, answered yes. Overall, the order of importance of attributes in the sample is health benefits, bicycle lanes, travel time, and financial benefits (for the low-income segment, financial benefits are more important than travel time, which is expected since the value of travel time decreases with income). Only Group III was asked to provide the main motivating factors to their use of bicycles. Close to 70% answered the expansion of bicycle lanes, and 35% mentioned the availability of a bicycle sharing system. In regards to the results above, Heinen et al. (2010) identified multiple studies in which inexperienced bicyclists give high value to bicycle facilities. Another important factor raised by respondents was the influence of friends (28%), while educational campaigns and programs from non-governmental agencies influenced less than 10% of these individuals. Opinions and lifestyles of friends may play a stronger social norm effect on the intention to use bicycles than institutional campaigns. Many studies observed social norm as an important determinant to the choice to become a bicyclist (Heinen et al., 2010; Heinen and Handy, 2012; Lois et al., 2015).

4.1.3. Travel behavior

Table 1 presents the distributions of travel behavior variables for the three groups of bicyclists. The differences in travel behavior between the three groups are possibly a consequence of different attitudes and lifestyles, but also levels of experience. It is not only likely that Group I has more “pro-bicycle” attitudes, since they started cycling before infrastructure was available, but also that they developed more skills to use the bicycle and find it easier to travel using this mode. Indeed, all the comparisons of travel behavior between the three groups seem to lead to this rationale. Longer trips are prevalent among users that have

Table 1
Travel behavior characteristics of the three segments of bicyclists.

Variable	Level	Group I	Group II	Group III
Latest trip distance	< 2 km	6.8%	10.4%	12.1%
	2 to 5 km	19.9%	25.8%	37.0%
	5 to 10 km	34.8%	32.5%	28.1%
	10 to 15 km	19.9%	9.8%	11.0%
	> 15 km	18.6%	21.5%	11.7%
Latest trip purpose	Commute (work or school)	72.0%	66.9%	75.8%
	Leisure or physical exercise	16.8%	23.3%	15.3%
	Shopping	6.2%	4.3%	3.2%
	Other	5.0%	5.5%	5.7%
Use of bicycle for more than one trip purpose	Yes	94.4%	88.3%	75.1%
	No	5.6%	11.7%	24.9%
Latest trip bicycle type	Private	96.3%	84.1%	66.6%
	Shared	3.7%	15.9%	33.4%
Alternative mode for latest trip	Always bicycle (leisure)	16.8%	23.3%	15.3%
	Always bicycle (non-leisure)	29.2%	22.1%	19.2%
	Walk	9.3%	9.8%	10.7%
	Subway/train	12.4%	14.7%	14.2%
	Bus	12.4%	12.3%	22.4%
	Taxi/ride-hailing	1.9%	4.3%	4.6%
	Motorcycle	3.7%	1.2%	0.4%
	Car	14.3%	12.3%	13.2%
Frequency of bicycle use for commute trips	Never	9.3%	11.7%	10.3%
	< 1 time per week	8.7%	16.6%	8.9%
	1–2 times per week	18.6%	15.3%	26.7%
	3–4 times per week	30.4%	28.2%	32.7%
	≥5 times per week	32.9%	28.2%	21.4%
Frequency of bicycle use for other trip purposes	Never	3.7%	8.0%	17.9%
	< 1 time per week	11.8%	17.2%	22.4%
	1–2 times per week	36.0%	42.3%	41.6%
	3–4 times per week	28.6%	21.5%	12.8%
	≥5 times per week	19.9%	11.0%	5.3%
Behavior when raining	Mode switch	34.8%	48.5%	59.1%
	Time switch	15.5%	9.8%	11.0%
	Ride in the rain	49.7%	41.7%	29.9%
Bicycle ownership	Yes	98.8%	93.9%	79.4%
	No	1.2%	6.1%	20.6%
Vehicle availability	Yes	60.2%	58.9%	58.7%
	Sometimes	15.5%	8.0%	10.0%
	No	24.2%	33.1%	31.2%

Group I – Started cycling before July 2012; Group II – Started cycling between July 2012–2015; Group III – Started cycling after July 2015.

been cycling for more than two years (Groups I and II). While the latest trip of most respondents was a commute trip (for work or education), the use of bicycle for multiple purposes seem to increase with the level of experience (94% of Group I, 88% of Group II, and 75% of Group III). The use of private bicycles compared to shared bicycles follows a similar trend (only 67% of Group III used a private bicycle for their latest trip compared to 96% of Group I). Participants were asked whether they would sometimes use a different mode for that specific trip (latest bicycle trip). Again, switching modes was less prevalent among Group I. For Group III, the use of bus was more common than for the other groups. As expected, Group I shows a higher frequency of both work and non-work trips than the other two groups; for non-work trips, the difference is especially high. More experienced users also seem to be less affected by rain. Although bicycle ownership is higher among Group I, vehicle availability is very similar for the three groups. Interestingly, not having a vehicle available is less common among Group I, showing that the use of bicycle is mostly voluntary and not a compensatory mechanism to the lack of automobiles. In sum, as observed by studies that investigate attitudinal aspects of bicycle use, Group I is probably formed by people who will cycle under most circumstances (in terms of weather, distances and infrastructure) simply because they like cycling (Gatersleben and Appleton, 2007).

Another interesting result derives from comparing the residential location of the respondents and their answers to whether there is a bicycle lane close to their homes. While there is no significant difference between the distribution of residential locations of the three groups[4] (32% live in the West Area and 30% live in the South Area), Group I members more often declared living close to bicycle lanes (85% versus 80% and 75% of Groups II and III, respectively). Although there is a likely variability within each zone, there may also be a subjective component to this answer. Both attitudes and level of experience of Group I may cause a different perception of proximity relative to the other groups. Fernández-Heredia et al. (2014) and Rondinella et al. (2012) identify a clear difference between the perceptions of distances, comfort, and risk of users that have cycling experience and those that do not have the habit of riding a bicycle. Alternatively, self-selection could also be an explanation for this difference in proportions. Even though Group I gives less importance to bicycle lanes than the other groups, they are more bicycle-oriented and may consider the proximity to bicycle infrastructure as an important attribute for residential location decisions.

4.2. Frequency of bicycle use

In this section, we examine the frequency of bicycle use for work and non-work trips for all commuters in the sample (both trips to work and to school are considered commuting). The final sample contains 590 individuals, from which 37 are students. This analysis is based on a bivariate ordered probit approach, which estimates two ordered probit equations jointly and accommodates the error covariance that may exist between them. A joint estimation of both frequencies is required because it is likely that common unobserved factors influence both the frequency of bicycle trips for work and for non-work purposes. For example, an environmentally conscious individual will probably avoid using motorized modes of transportation for most of her/his trips, regardless of purpose. Multivariate ordered probit models have been used by several studies (see for example, Ferdous et al., 2010, Sener et al., 2015). In the current study, we adopt the same model structure used by LaMondia and Bhat (2012), and Dias et al. (2017), which is presented next.

4.2.1. Modeling methodology

As in the traditional ordered probit model, consider that there are underlying continuous latent variables that, when partitioned, directly relate to the frequency of use of bicycle for work and non-work trips. Let f_q and g_q represent the frequency categories of usage of bicycle for work and non-work trips, respectively, and f_q^* and g_q^* represent the underlying continuous latent variables (latent propensity) for individual q. The larger the latent variable, the greater the frequency of usage. Let m be the index for the frequency of work trips and n be the index for non-work trips. Both m and n take values from 1 to 5, which represent: "never to a few times per year", "1 to 4 times per month", "2 to 3 times per week", "3 to 4 times per week" and "5 or more times per week", respectively. Then, we have:

[4] This analysis was conducted in a very aggregate manner, considering only the seven main areas identified in Fig. 1.

$$f_q^* = \alpha' x_q + \upsilon_q \quad \text{where} \quad f_q = m \quad \text{if} \quad \delta_{m-1} < f_q^* < \delta_m,$$
$$\delta_0 = -\infty, \quad \delta_M = \infty$$
$$g_q^* = \beta' y_q + \eta_q \quad \text{where} \quad g_q = n \quad \text{if} \quad \psi_{n-1} < g_q^* < \psi_n, \quad \psi_0 = -\infty,$$
$$\psi_N = \infty \tag{1}$$

x_q and y_q are vectors containing all exogenous covariates (with no constant term) that affect the latent variables; α and β are vectors of the coefficients associated with the exogenous covariates; δ_m and ψ_n are the thresholds that partition the latent variable into the same number of segments as there are categories; and υ_q and η_q are the random error terms of the latent variable equations. While the marginal distributions of υ_q and η_q are assumed to be standard normal, to accommodate for the potential presence of correlation between these two error terms (due to unobserved factors such as environmentally conscious lifestyle and social norm), they are assumed to be realizations from a bivariate standard normal distribution. Finally, both error terms are also assumed to be independent and identically distributed (IID) across individuals.

The parameters to be estimated in the joint bivariate ordered response model include the α and β vectors, the M-1 δ_m parameters ($\delta_0 = -\infty$, $\delta_M = \infty$, $-\infty < \delta_1 < \delta_2 < \cdots < \delta_{M-1} < \infty$), the N-1 ψ_n parameters ($\psi_0 = -\infty$, $\psi_N = \infty$, $-\infty < \psi_1 < \psi_2 < \cdots < \psi_{N-1} < \infty$), and the θ parameter characterizing the correlation between the error terms. To write the log-likelihood function, define $I_q(m, n)$ as a binary indicator variable that takes the value of 1 if individual q falls in frequency category m for work trips use and frequency category n for non-work trips, and 0 otherwise, and $\Pr[f_q = m, g_q = n]$as the probability of occurrence $I_q(m, n) = 1$. Then, the log likelihood function for the model is:

$$\log L = \sum_{q=1}^{Q} \sum_{m=1}^{M} \sum_{n=1}^{N} I_q(m, n) \log \Pr[f_q = m, g_q = n] \tag{2}$$

Make $b_{qm} = \delta_m - \alpha' x_q$ and $d_{qn} = \psi_n - \beta' y_q$, then, the probability above is:

$$\Pr[f_q = m, g_q = n] = \Pr[\delta_{m-1} < f_q^* < \delta_m \quad and \quad \psi_{n-1} < g_q^* < \psi_n]$$
$$= \Pr[b_{q,m-1} < \upsilon_q < b_{qm} \quad and \quad d_{q,n-1} < \eta_q < d_{qn}]$$
$$= \Phi_2[b_{qm}, d_{qn}; \theta] - \Phi_2[b_{q,m-1}, d_{qn}; \theta] - \Phi_2[b_{qm}, d_{q,n-1}; \theta]$$
$$+ \Phi_2[b_{q,m-1}, d_{q,n-1}; \theta] \tag{3}$$

where Φ_2 is the bivariate cumulative normal distribution function. All the parameters in the model are estimated by maximizing the log-likelihood function above using the GAUSS code provided by LaMondia and Bhat (2012).

4.2.2. Results

Table 2 contains the results for the bivariate frequency model. The thresholds at the top of the table do not have any substantive interpretations. They simply serve the purpose of mapping the latent propensity into the observed frequency levels. This model does not contain a separate constant term because all threshold parameters plus a constant cannot be separately identified (one of them is redundant). It should be noted that initially there were five levels of frequency for each variable, but during estimation, two levels were collapsed because the thresholds between them were not significantly different. Additionally, some variables that were not statistically significant at a 95% confidence level were kept in the model because of their empirical relevance.

While age does not seem to affect the frequency of bicycle use for work trips, older individuals have a higher inclination to use this mode for non-work trips frequently. As discussed in the literature review by Heinen et al. (2010), studies have not reached a consensus on the effect of age on bicycle use. There are both studies that find that cycling decreases with age and studies that find that age is not a significant determinant of bicycle usage when other factors are considered. In terms of gender effects, females present lower cycling frequency propensities for both work and non-work purposes. As discussed earlier, multiple studies indicate that women are less likely than men to use bicycle as a transportation mode (in countries where the mode share of bicycles is low), but research also shows even when they do, they are prone to lower frequencies (Twaddle et al., 2010; Piatkowski and Marshall, 2015). Nevertheless, women who foresee financial benefits as a motivating factor of bicycle use, have a higher propensity to undertake non-work purpose trips by bicycle than other women or men. It is possible that having the bicycle as a transportation option is providing this segment with opportunities to conduct non-work activities which were not accessible otherwise. Conversely, income alone has an inverted U-shape effect on work trips and does not seem to impact non-work trips. High and low-income individuals have a lower frequency propensity to commute by bicycle than middle-income individuals. For low-income individuals, the result is probably associated with residential location. It is typical that these individuals live in peripheral areas that are located far from bicycle infrastructure or that have poor levels of connectivity to the desired destinations (as shown in Fig. 1, although peripheral areas have bicycle lanes, they are sparser than in dense areas). High income individuals live close to bicycle infrastructure but may opt for the comfort of cars (or taxi/ride-hailing) more often, reducing the observed cycling frequencies. Again, Heinen et al. (2010) observed that income does not present a regular pattern in regards to bicycle commuting. Interestingly, we observe that bicycle ownership is associated with an increase in frequency of non-work trips but does not present a significant effect on work trips. It should be noted that close to 88% of the sample own a bicycle, suggesting that the decision of how often to commute by bicycle depends on more than just the mode availability. Vehicle availability in the household is clearly a very important factor that influences the frequency of bicycle use. Similar to past research results (Piatkowski and Marshall, 2015; Fu and Farber, 2017), individuals that do not have a vehicle available, or just have it available sometimes, have higher frequency propensities for both work and non-work bicycle trips. However, it is not possible to determine if bicycle use is contributing to a decrease in vehicle ownership, or if this mode is just a lower-cost alternative. Considering that individuals who have vehicles available sometimes have higher frequency propensities than those who do not have vehicles at all, and that financial causes do not seem to be the main motivation behind bicycle use, the hypothesis of voluntary decrease in vehicle ownership seems plausible. As identified earlier, individuals who have been using bicycles as a transportation mode for more than two years present higher frequencies of bicycle use for non-work trips. While the presence of bicycle lanes close to work[5] contribute to higher usage of bicycle for commute trips, they do not affect non-work trips. The presence of bicycle lanes close to the respondent's home does not show a significant effect on any of the frequencies. As expected, individuals who switch to a different mode when it is raining have a tendency to use bicycles less frequently for both trip purposes. In turn, individuals that switch the trip time when raining seem to use bicycles less frequently for work purposes, which is predictable because, compared to other activities, work has a less flexible schedule. Finally, when travel time is considered as an important attribute for choosing the bicycle mode, it contributes to higher frequencies of work and non-work trips. In a review of surveys conducted in nine different cities in Brazil, Silveira and Maia (2015) also observed that travel time was an important motivator for bicycle use in both medium and large cities, probably because of the unreliability of transit due to traffic and lack of access to transit in certain neighborhoods. In another study conducted in a very different context in Salt Lake City, United States, the belief that using bicycles saved time was also found to have a positive impact on cycling

[5] Presence of bicycle lanes close to work and close to home are subjective measures. As discussed in Section 3, the respondents expressed their proximity perceptions.

Table 2
Results of the bivariate ordered probit model for bicycle use frequency for work and non-work trips.

Variable	Frequency of work trips		Frequency of non-work trips	
	Coefficient	t-stat	Coefficient	t-stat
Threshold 1	−1.293	−8.10	0.481	2.13
Threshold 2	−0.731	−4.68	1.136	4.93
Threshold 3	0.831	5.10	1.954	8.07
Age (base: 41 or older)				
16 to 30 years old	–	–	−0.416	−2.94
31 to 40 years old	–	–	−0.363	−2.93
Gender (base: male)				
Female	−0.198	−1.77	−0.479	−3.21
Additional effect of financial savings as motivation to use bicycle for females	–	–	0.532	2.57
Income (base: R$ 1900 to 7500 per month)				
Less than R$ 1,900 per month	−0.255	−2.66	–	–
More than R$ 7,500 per month	−0.255	−2.66	–	–
Bicycle ownership (base: no)				
Yes	–	–	0.675	3.50
Vehicle availability (base: yes)				
No	0.411	3.74	0.436	4.10
Sometimes	0.526	2.74	0.436	4.10
When started to use bicycle (base: less than 2 years ago)				
2 to 5 years ago (Group II)	–	–	0.232	1.90
More than 5 years ago (Group I)	–	–	0.417	3.28
Presence of bicycle lanes close to work location (base: no)				
Yes	0.351	2.90	–	–
Behavior when raining (base: uses bicycle and does not make any trip change)				
Mode switch	−1.068	−9.80	−0.407	−3.81
Trip time switch	−0.854	−5.44	–	–
Travel time is an important factor to choose the bicycle as travel mode (base: no)				
Yes	0.737	7.48	0.280	2.74
Correlation between both frequencies (t-stat)	0.080 (1.41)			
Sample size	590			
Log-likelihood (Null model)	−1462.96			
Log-likelihood (Full model)	−1295.57			
Pseudo-R^2 (McFadden)	0.114			

– Not statically significant and removed from specification.

frequency (Fu and Farber, 2017).

The dependency parameter between frequency of work and non-work trips revealed to be of small magnitude and not statistically significant, yet it is positive, as expected. This result may be a consequence of the limited sample size. Another possible explanation is that the most common non-work trips in the sample seem to be for leisure and physical exercise purposes. It is plausible that the reasons for work and leisure bicycle trips are very distinct and there is not significant unmeasured dependency to be captured.

4.3. Choice between private and shared bicycles for the reference trip

In this analysis, the choice between a private and a shared bicycle for the reference (latest) trip is examined. A traditional binary probit modeling methodology is applied and the full sample of 605 respondents is considered. The model results are shown in Table 3. As previously mentioned, the sampling method for bicycle type was not random; therefore, the sign and magnitude of the constant coefficient, which would define which type of bicycle is predominant among the population, cannot be assumed to be representative.

An increase in age and education level is associated with a decrease in the likelihood of using shared bicycles compared to private bicycles. The education result seems to disagree with the literature (Fishman, 2016b); however, it should be noted that studies about bicycle sharing demand do not usually compare these users with users of private bicycles. Indeed, the only study, to the authors' knowledge, to perform such comparison was conducted with Washington, D.C. data by Buck et al. (2013). These authors found that in comparison to regular bicycle riders, bicycle share users were younger and owned fewer cars and bicycles (similarly to this study's results). Although we do not observe isolated gender or income effects on the likelihood of using a specific type of bicycle, low-income women are less likely to use shared bicycles than men in general and high-income women. Ogilvie and Goodman (2012) also observe an underrepresentation of this segment (low income women) among members of a bicycle sharing program in London, United Kingdom. When we analyzed frequency in the previous section, we noticed that women motivated by the low cost of bicycle use tend to pursue more frequent non-work trips. This segment may be opting for private bicycles for flexibility purposes. However, it is also likely that low income women do not have access to shared bicycles because the locations of the bicycle stations do not coincide with the origins and destinations of this segment's trips.

As expected, bicycle owners are less likely to use shared bicycles compared to individuals that do not own a bicycle, and new bicyclists are more likely to use shared bicycles compared to bicyclists that have been cycling for more than two years. This is probably because after using shared bicycles for a certain period, users feel encouraged to purchase a bicycle (Murphy and Usher, 2015). Shorter trips are also associated with the use of shared bicycles, which is probably associated to the arrangement that the first one hour of use of a shared bicycle is free. Compared to leisure, shopping and other activity purposes, commute trips (to work or school) are less likely to be made by shared bicycles, unless the user is using multiple modes of transportation for the same trip. In other words, multi-modal commute trips are more likely to use shared bicycles. Bicycle sharing favors connections between modes because the user does not need to carry the bicycle or look for safe bicycle parking locations. In Sao Paulo, due to a high transit demand, bicycles are not allowed to be carried on buses and are only allowed in subways during evening hours or weekend days. Martin and Shaheen (2014) also observe, in the United States, the use of bicycle sharing as a first-mile/last-mile facilitator to transit access.

Finally, the use of bicycle sharing reveals to be an important

Table 3
Results of the binary probit model for bicycle type choice.

Bicycle type choice on latest bicycle trip	Shared Bicycle (base: private bicycle)	
Variable	Coefficient	t-stat
Constant	−0.372	−0.88
Education (base: Bachelor's degree or less)		
Master's degree or more	−0.546	−2.40
Age (base: 41 or older)		
16 to 25 years old	1.431	4.41
26 to 30 years old	0.896	3.06
31 to 40 years old	0.805	2.82
Combined effect of gender and income (base: all men, and women with income of more than R $2900.00 per month)		
Women with income lower or equal to R $2900.00 per month	−0.598	−1.95
Bicycle ownership (base: no)		
Yes	−2.592	−7.98
Vehicle availability (base: no and sometimes)		
Yes	0.334	1.82
When started to use bicycle (base: two or more years ago)		
Less than 2 years ago (Group III)	0.458	2.68
Trip distance (base: more than 5 km)		
Less than 2 km	2.133	8.26
Between 2 and 5 km	0.980	4.71
Trip purpose (base: leisure, shopping and other)		
Work/school commute	−0.427	−2.11
Additional effect of using more than one mode for a single commute trip	0.651	2.93
Alternative mode for the specific trip (base: always bicycle, car, train and walk)		
Bus	0.719	3.22
Sample size	605	
Log-likelihood (Null model)	−308.85	
Log-likelihood (Full model)	−130.45	
Pseudo-R^2 (McFadden)	0.578	

alternative to bus use. Individuals that alternate between bicycle and bus for a given trip are more likely to use shared bicycles when compared to individuals that use other alternative modes or rely exclusively on the bicycle. Again, Martin and Shaheen (2014) observe similar tendencies; the authors note that in areas with higher population density and more intensive public transit networks, bicycle sharing may offer faster, cheaper, direct connections over short distances that were previous completed by short transit trips. It is interesting to note that while 34% of private bicycle users relied exclusively on bicycles (for that given trip), only 3% of shared bicycle users gave the same answer. In this case, it is not possible to define if the unreliability of bicycle availability at the bicycle sharing station is the cause for this behavior, or if the bicycle is being used as the second option. The distribution of alternative modes for shared bicycle users indicates that 30% use buses, 13% subway, and 20% walk (a very similar distribution was observed by Buck et al., 2013 in Washington, D.C.). The variable representing the behavior when raining did not reveal statistical significance in the model; however, by analyzing the descriptive statistics, we observe that shared bicycle users predominantly (83%) answered "I do not use the bicycle [when it is raining]", while less than half (41%) of private bicycle users stated to have the same behavior.

5. Conclusions and recommendations

This study investigated the use of private and shared bicycles in the city of Sao Paulo, Brazil. Based on data from online and field surveys with bicyclists, impacts of infrastructure expansion, differences in behavior associated with level of experience, predictors of cycling frequencies and the choice between the use of shared and private bicycles were analyzed. Many are the implications of the results. First, the expansion of bicycle infrastructure seems to have contributed to an increase in the proportion of women and low-income individuals using bicycles. Although these segments are still underrepresented, bicycle infrastructure may have a key role in making bicycle a more universally accessible transportation mode. The perceived possibility to use a bicycle can have a direct impact on the quality of life, level of physical activity and overall accessibility of these population segments that would not consider using this travel mode without segregated lanes. Experienced bicycle users, who adopted this mode before the infrastructure expansion, also seem to be using it more often. Considering that this group presents the highest rate of vehicle availability, this increase in cycling frequency may represent direct reductions in car usage, suggesting that overall motorized traffic is also benefiting from such investments. In sum, reducing the investments in bicycle infrastructure in Sao Paulo, as observed in 2017, seems to be a misguided decision.

Second, besides being underrepresented among the bicyclist population (as identified by previous studies), our results show that women and low-income individuals also use this mode less frequently. Understanding the barriers preventing women to rely on bicycles more often is an important topic for future research. Also, low-income individuals would likely benefit from higher connectivity and more dense bicycle networks in peripheral neighborhoods. Indeed, travel time revealed to be a key motivation to frequent bicycle use, suggesting that connectivity, designated traffic signals and priority signs may be important features to keep bicycle travel times attractive to users.

Third, results regarding the choice between using a private and shared bicycle for a given trip reveal that shared bicycle systems have a fundamental role in multi-modal travel and in introducing newcomers to bicycle use. We observed that commute trips, compared to other purposes, are more likely to happen on a private bicycle. However, individuals making connections (using multiple modes for a single commute trip) tend to use shared bicycles. Bicycle sharing stations are, or at least should, be placed to allow not only first-kilometer/last-kilometer travel, but also to enable connections between bus and subway/train stations. The results that individuals who have been using bicycle for less than two years are more likely to not own a bicycle and to have used a shared bicycle in their reference trip suggests that a good shared bicycle system can amplify the effect of bicycle lanes in attracting new users.

Fourth, our results provide initial evidences that bicycles do have the potential to substitute car trips in an emerging metropolitan city in which the transportation network is saturated and the level of congestion is high. Under these circumstances, bicycles allow for very competitive travel times and can attract both car and transit users. Providing the adequate infrastructure seems essential to ensure that lack of safety does not discourage new users from trying this mode.

Finally, it is important to acknowledge that our results are preliminary. This is because the current study relied on a combination of two distinct methods to recruit respondents and each of these methods presented limitations both in terms of data measured and sampling bias (as discussed in Section 3). Thus, future research is necessary to confirm if the observed outcomes can be generalized to the population of bicyclists in Sao Paulo and other similar cities. Additionally, future research should focus on measuring additional variables. Trip level data, including route choice and time of day, could help identify which are the most used bicycle lanes and whether the bicycle is being used to avoid the use of motorized modes in specially congested areas. Larger survey samples, longitudinal data, consideration of non-bicyclists, attitudinal questions as well as users' perceived barriers to bicycle use could also provide substance to more comprehensive analyses to justify more investments on bicycle infrastructure and the development of a well-connected bicycle network.

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Declaration of Competing Interest.

None.

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