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Estimating bicycle demand in an aggressive environment

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ABSTRACT
The perception of the environment where we move can be a key factor in choosing a transport mode for our daily trips. For example, many cities lack adequate infrastructure or experience environmental conditions that do not favor cycling. We examine the potential demand for using the bicycle as a transport alternative in trips to college in Barranquilla, Colombia, a city with fairly aggressive environmental conditions for cycling. We designed a Stated Choice experiment geared to students and staff living within three kilometers of two college campuses in the city and traveling by bus or bike. We also considered people's perceptions in an effort to understand the reasons why only 2% of Barranquilla's daily trips are made by bicycle. Our mode choice analysis incorporated two latent variables (*unsafety/insecurity* and *convenience*), in addition to typical level-of-service attributes, such as travel time and cost. We found that the perception of *unsafety/insecurity* has an important negative effect on the probability of using bicycle; the possibility of suffering an accident or being mugged, weighs much more than the possible economic savings and improvements in health associated with using the bicycle. In terms of *convenience*, our results suggest that it could be just as important to have showers on campus as bike lanes available on the route. Also, investment in facilities such as free parking for bikes, and strategies such as planting trees in bike paths and sidewalks to provide shade, could significantly encourage cycling.

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Attitudes; bicycle choice; latent variables; perceptions

1. Introduction

For several years, in many Latin American cities the development of road infrastructure and mobility policies have focused on motorized transport, that is, mainly private cars and public transport systems, leaving pedestrians and cyclists relegated to a tertiary role. Worse still, car users used to exhibit aggressive behavior toward users of non-motorized modes, including the invasion of cycleways and sidewalks. All these conditions have discouraged the use of *active transport* modes and have caused them to be perceived as dangerous by their potential users despite their obvious advantages in terms of cost, sustainability, and health.

Fortunately, recent trends toward promoting cycling as a sustainable, alternative transport mode and integrating it with other available modes are encouraging (Akar, Fischer, & Gung, 2013; Rybarczyk & Gallagher, 2014), and some Latin American cities (e.g., Bogotá, Santiago and Rio de Janeiro) are now investing in the construction of more appropriate facilities for cyclists (Sagaris & Ortúzar, 2015; Rodriguez-Valencia, Rosas-Satizábal, Gordo, & Ochoa, 2019). Thus, bicycling is becoming a global trend, not only as a healthy lifestyle practice but also as a more sustainable transport mode. In cities with relatively high traffic congestion rates, daily cycling trips of less than 10 km are normally faster than if done by car (Cervero, Sarmiento, Jacoby, Gomez, & Neiman, 2009). Partly for this reason, the number of daily trips by bicycle in several Latin American cities has increased from around 1% in the 90 s to over 5% in more recent years (Ortúzar, Iacobelli, & Valeze, 2000; Cherry & Cervero, 2006; Gutiérrez, Hurtubia, & Ortúzar, 2020). Furthermore, recent studies have also shown that people who use bicycles for their daily commutes are healthier than those who do not, or who use them only occasionally (de Hartog, Boogaard, Nijland, & Hoek, 2010; Forsyth & Oakes, 2015).

The aims of this study were twofold. First, to examine the potential demand for bicycle trips by members of a college community in their daily commute in Barranquilla, Colombia, a city that is characterized for having an aggressive environment for cycling (i.e., hot, humid, lacking appropriate cycling infrastructure and with aggressive car and motorcycle drivers dealing with severe congestion). Second, proposing specific policies to encourage bicycle use that may be applicable in other cities of similar characteristics. For these purposes, we estimated binary choice models involving two latent variables: *convenience* and *unsafety/insecurity*, in addition to classical trip level-of-service attributes. The first latent variable involved perceptions about the health benefits and cost savings associated with using a bike.

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In turn, *unsafety/insecurity* was related to both the probability of a robbery and the possibility of having an accident while riding a bicycle. The models tested included a random parameter mixed logit structure and a hybrid mixed logit model.

The rest of the paper is organized as follows: Section 2 presents a brief review of factors that influence bicycle demand. In Section 3, we summarize the relevance of using latent variables in the study of bicycle demand. Section 4 presents our data on bicycle use in Barranquilla and its surrounding areas. In Section 5, we discuss our model estimation and results and, finally, in Section 6 we present our main findings and conclusions.

2. Factors influencing the demand for trips by bicycle

In cities with high levels of congestion and pollution, the bicycle has been considered part of the solution to their transport problems, since it allows reducing the number of trips by car. Conditions that make car trips more expensive or less convenient, along with policies that promote attractive public and non-motorized transport options, can make a difference in encouraging more sustainable transportation (Buehler, 2011; Ortúzar, 2019; Pucher, Buehler, & Seinen, 2011; Santos, Behrendt, & Teytelboym, 2010).

Bicycle travel demand and the factors that encourage/discourage bike use have been explored in certain detail recently. Numerous studies have sought to understand the dynamics behind the increase in the use of bicycles in recent years, its influence on transport policy decisions and the main factors that determine the choice of this mode (Handy, Xing, & Buehler, 2010; Kroesen & Handy, 2014; Rossetti, Guevara, Galilea, & Hurtubia, 2018; Rybarczyk, 2018). Most research on this subject has focused on four main factors: demographic and socio-economic variables, environmental and physical factors, determinants of cycling infrastructure, and perception and attitudinal factors (Maldonado-Hinarejos, Sivakumar, & Polak, 2014; Orozco-Fontalvo, Arévalo-Támara, Guerrero-Barbosa, & Gutiérrez-Torres, 2018).

Many studies have shown that socioeconomic variables such as gender, income level, age, and occupation are determining factors in the use of bicycles. For instance, women tend to be more sensitive to risk and proximity to vehicular traffic (Bonham & Wilson, 2012; Frater & Kingham, 2018; Prati et al., 2019) and in many countries female bicycle use is significantly lower than that of men (Emond, Tang, & Handy, 2009; Garrard, Rose, & Lo, 2008; Pucher et al., 2011; Branion-Calles, Nelson, Fuller, Gauvin, & Winters, 2019). On the other hand, the use of the bicycle increases among people without a car available or who have only a single car for more than one driver in the home, demonstrating that owning a car is also a determining factor in bicycle demand (Buehler, 2012; de Kruijf, Ettema, Kamphuis, & Dijst, 2018). Age also plays an important role; studies have shown that the attitude toward cycling changes from adolescence to adulthood and is also influenced by the perception of parents or responsible adults (Underwood, Handy, Paterniti, & Lee, 2014; Carver et al., 2019).

Diverse investigations have also shown that the characteristics of the urban environment, such as the slope of the roads and the presence of networks of well-maintained bikeways (Oliva, Galilea, & Hurtubia, 2018; Rodriguez-Valencia et al., 2019) are important geographical variables in the decision to use the bicycle (Cervero et al., 2009; Vandenbulcke et al., 2011). These factors, together with the presence of traffic calming zones, are also associated with traffic mitigation and a reduction in the risk of accidents for cyclists (Aertsens et al., 2010; Zahabi, Strauss, Manaugh, & Miranda-Moreno, 2011, Vanparijs, Panis, Meeusen, & de Geus, 2015; Chen et al., 2017).

Most studies considering individual perceptions of and attitudes toward bicycle usage concluded that the awareness of safety and the perception of comfort while riding a bicycle, are associated with, for example, the availability of segregated bicycle paths, which directly influence bike choice (Caulfield, Brick, & McCarthy, 2012; Gatersleben & Haddad, 2010; Habib, Mann, Mahmoud, & Weiss, 2014).

In this paper, we evaluate factors that might influence cycling demand in a non-friendly environment. Several factors explain the *aggressive* nature of Barranquilla toward cycling. The lack of appropriate and segregate infrastructure, the adverse weather, which is hot and humid, some security issues, and the hostile behavior of car, motorcycle and public transport drivers against cyclists, discourage the use of the bicycle for commuting trips. Our analysis includes the role of *perceptions* as specific knowledge of latent attributes of each alternative, and *attitudes* as specific latent feelings based on beliefs of individuals toward each mode (Bahamonde-Birke, Kunert, Link, & Ortúzar, 2017).

3. Modeling latent variables to understand cycling behavior

Since the environmental, personal and psychological/social factors listed above are not directly measurable, they must be incorporated into the choice model as latent variables. For this purpose, a hybrid discrete choice (HDC) model was formulated where, through measurement and structural equations (Bollen, 1989), the unobserved (or unmeasurable) utility was related to latent indicators of choice.

For mode i and individual q, there is a relationship between explanatory variables X_{iq}, indicators I_{iq}, latent variables Z_{iq} and the choice model. $\boldsymbol{Z}$ are assumed to be functions of explanatory variables $\boldsymbol{X}$ through *structural equations*; latent variables (LV), likewise, are assumed to explain the indicators $\boldsymbol{I}$ via *measurement equations*. Finally, utilities $\boldsymbol{U}$ are a function of $\boldsymbol{Z}$ and observable variables $\boldsymbol{X}$ (Ben-Akiva et al., 2002). HDC models require specifying and estimating both the structural and measurement equations jointly (Raveau, Alvarez-Daziano, Yáñez, Bolduc, & Ortúzar, 2010; Bahamonde-Birke et al., 2017). The former assumes a random error term ω_{iq} and for identification, its variance was set to one (Díaz, Cantillo, Arellana, & Ortúzar, 2015):

$$Z_{iq} = h\left(X_{iq};\lambda\right) + \omega_{iq} \tag{1}$$

On the other hand, the measurement equations express the indicators I_{iq} as functions of the Z_{iq}, with a random error term ν_{iq}:

$$I_{iq} = m\left(Z_{iq};\alpha\right) + \upsilon_{iq} \tag{2}$$

where the indicator may be modeled discretely through an ordered choice model (Greene, 2013):

$$\begin{aligned} I^*_{iq} &= 1 \text{ } if \text{ } \mu_2 < I_{iq} \leq \mu_1, \\ &= 2 \text{ } if \text{ } \mu_1 < I_{iq} \leq \mu_2, \\ &= \ldots \\ &= J \text{ } if \text{ } \mu_{J-1} < I_{iq} \leq \mu_J \end{aligned} \tag{3}$$

Finally, the choice model component incorporates the LV in the specification of the modal utilities:

$$U_{iq} = \theta_i X_{iq} + \beta_i Z_{iq} + \varepsilon_{iq} \tag{4}$$

We assume that the error terms ε_{iq} are independent and identically distributed. Also, given a choice set A_q, the individual choice can be expressed as follows:

$$g_{iq} = \left\{ \begin{matrix} 1 \text{ } if \text{ } U_{iq} \geq U_{jq} \\ 0 \text{ } otherwise \end{matrix} \right\} \tag{5}$$

The parameters α, β, θ, λ are unknown and must be estimated jointly within the HDC model. For this, we used simulated maximum likelihood (Train, 2009; Bahamonde-Birke & Ortúzar, 2014), where the estimation process maximizes the logarithm of the likelihood function (6) over the unknown parameters:

$$max \sum_{q=1}^{Q} ln \, f\left(U_{iq}, I_{iq} | Z_{iq}; \alpha, \beta, \lambda, \theta\right) \tag{6}$$

where Q is the number of individuals in the sample used for estimation.

To formulate our HDC model, we relied on previous studies about perceptions, attitudes and habits regarding the use of bicycles (Kamargianni & Polydoropoulou, 2013; Willis, Manaugh, & El-Geneidy, 2015; Muñoz, Monzón, & Daziano, 2016; Janke & Handy, 2019). In the case of perceptions, the bicycle choice literature is basically focused on: (i) health benefits when doing daily exercise (Bopp, Kaczynski, & Besenyi, 2012; Heinen, Maat, & van Wee, 2011; Muñoz et al., 2016; Thigpen, 2019); (ii) flexibility in trip starting times (de Geus, de Bourdeaudhuij, Jannes, & Meeusen, 2007; Titze, Stronegger, Janschitz, & Oja, 2008); (iii) possibility of saving money by virtue of having lower cost than using a car or public transport, and (iv) better accessibility and mobility in congested cities (Ducheyne, de Bourdeaudhuij, Spittaels, & Cardon, 2012; Fernández-Heredia, Jara-Díaz, & Monzón, 2016). Other perceptions refer to bicycle safety (Habib et al., 2014; Maldonado-Hinarejos et al., 2014; Rossetti et al., 2018; Gutiérrez, Hurtubia, & Ortúzar 2020), and perceptions of relatives and friends toward their own bicycle use and how this affects the individual's choice of using a bike as well (Ducheyne et al., 2012; Gatersleben & Haddad, 2010; Fitch, Rhemtulla, & Handy, 2019). In a Colombian context, Cantillo, Arellana, and Rolong (2015) modeled pedestrian behavior using HDC models, finding that *security/safety* was a relevant LV in understanding crossing behavior. Table 1 presents a summary of the papers just cited with the type of model and LV used in each one.

Based on our literature review, we would like to incorporate two LV into our choice model, related to *unsafety/insecurity* and *convenience* when cycling. We aimed to explore, with the aid of these variables, why the bicycle is used so marginally in Barranquilla, even though at the time of the study, there were about 14 km of new bicycle-lanes available.

4. Cycling in an aggressive environment: the case of Barranquilla

In this section, we illustrate first why we consider that Barranquilla represents an aggressive environment for cyclists, through a summary of the city's transport system. We then describe the data collected for our study in some detail.

4.1. Transport system and demographic information

Barranquilla is the fourth largest city in Colombia, with approximately 1.2 million inhabitants (DANE, 2005). The city itself is the main nucleus of a Metropolitan Area that includes four other municipalities: Malambo, Galapa, Soledad and Puerto Colombia, with a total of approximately 2.0 million inhabitants. Most employment centers and universities are concentrated in the city of Barranquilla, making it the main destination of trips during the morning rush hour.

On a normal business day, about 2.2 million trips are made, of which 44% are by public transport (mainly old and badly maintained buses of various sizes, although the city has a Bus Rapid Transit - BRT- system, but this is used by only 2.2% of the total daily trips). Additionally, there are a variety of informal transport services, among which the moto-taxi (see Figure 1), bicycle-taxi (rickshaw, Figure 2) and shared taxi (not regulated) represent 7.4% of the total daily trips (Alcaldía de Barranquilla, 2012).

The number of bicycle trips makes up for nearly 2% of the daily trips (Universidad del Norte, 2018). The city has a fairly new network of 14 km of bike lanes concentrated in two locations: (i) Riomar, a residential and parks area, which encourages only a recreational use of bicycles, and (ii) the North–Central Historical area, which has a small bikeway network connecting a shopping center, several BRT stations, and some educational institutions (see Figure 3). There are no other facilities for cyclists, and it is important to emphasize that the scarce existing bike infrastructure does not constitute a continuous network matching origin-destination (OD) travel patterns in the city (Cantillo, Vargas, Cantillo, & Ramos, 2019).

In addition, weather conditions in the city are not particularly suitable for cycling due to the high average temperature during the day (28 °C), reaching up to a maximum

Table 1. Summary of studies of bicycle demand and biking attitudes and perceptions.

Authors	Latent variable/Approach	Type of Model
de Geus et al. (2007)	Self-efficacy for cycling Physical well-being Ecological-economic benefits Lack of skills/health/motivations Lack of facilities Safety concern	LR
Titze et al. (2008)	Emotional satisfaction Rapidity Physical discomfort Impractical means of transport Cyclists' compliance with traffic rules	LR
Heinen et al. (2011)	Provide status Environmental/mental/health benefits Savings in time/money Flexibility of departure time Traffic safety	MNL
Bopp et al. (2012)	Ecologically friendly attitude Self-efficacy for active commuting Encourage active commuting	Linear regression (LR)
Ducheyne et al. (2012)	Family factors Personal factors Behavioral factors Attitudinal factors Social environmental factors Cognitive factors Physical environmental factors Route factors to school	Multivariate logistic regression
Kamargianni and Polydoropoulou (2013)	Willigness to walk or cycle to school	HDC
Paulssen et al. (2014)	Power Hedonism Security Comfort and convenience Flexibility Ownership	HDC
Maldonado-Hinarejos et al. (2014)	Probike attitude Cycling image Cycling stress Transportation context	HDC
Habib et al. (2014)	City bikeability Safety concern Biking comfort Bike ownership level	HDC
Cantillo et al. (2015)	Health problems/benefits Concern about safety and robbery Savings Lack of facilities Time constrain Weather conditions Traffic congestion	Hybrid discrete choice model (HDC)
Willis et al. (2015)	Review of theory, models, attitudes and perceptions used in the effect of cycling	
Fernandez-Heredia et al. (2016)	Convenience Pro-bike Physical determinants Exogenous restrictions Lifestyle	Confirmatory Factor Analysis
Muñoz et al. (2016)	Lifestyle Safety and comfort Awareness Direct disadvantages Subjective norm Individual capabilities Non-commuting cycling habit	Theory of Plan Behavior and EFA
Muñoz et al. (2016)	Lifetyle Safety Comfort Awareness Direct disadvantages Habit	LR
Rossetti et al. (2018)	Safety	Latent Class
Thigpen (2019)	Pro bicycling Bicycling skills	Latent Markov Model
Janke and Handy (2019)	Liking/Disliking Comfort Desire to bicycling	Qualitative Analysis
Fitch et al. (2019)	Social pressure Enjoyment Self-image Environment	Bayesian analysis
Gutiérrez et al. (2020)	Risk Spontaneity Cycling-related facilities	Hybrid ordinal logit

Figure 1. Moto-taxis circulating in Soledad Municipality.

of 32° C, almost all year round. The city also has a high average relative humidity (around 80%), and two heavy rainy seasons that affect mobility; in fact, in some days, these conditions can even put motorized transport on hold until it stops raining (IDEAM, 2010).

During 2017, Barranquilla experienced some 6,000 traffic accidents (Agencia Nacional de Seguridad Vial, 2018), causing 110 fatalities and about 1,200 injured victims (Instituto Nacional de Medicina Legal y Ciencias Forenses, 2018). Of these statistics, six of the people killed and 85 of the injured were bicycle users. Bicyclists in the city must not only compete for space on the roads with cars and buses, but also with motorcycles for space on the scarce bicycle lanes, which are constantly invaded by them.

Cyclists also experience security issues in the city. Frequent robberies and assaults perpetrated mostly by

Figure 2. Bicycle-taxis circulating in downtown Barranquilla.

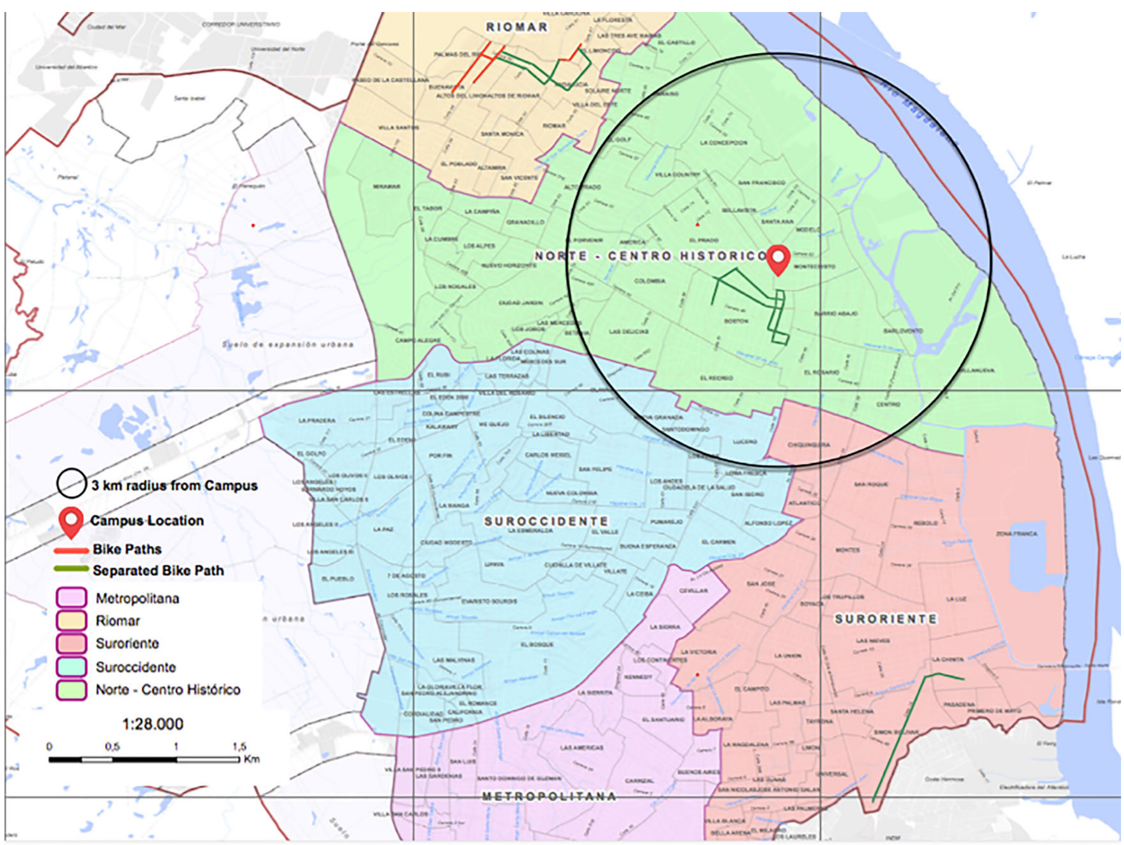

Figure 3. Map of current cycling infrastructure in Barranquilla. (Source: POT, 2014).

criminals on motorcycles cause *active mode* users to feel insecure. Security is one of the main concerns of Barranquilla's citizens (Universidad del Norte, 2018).

In summary, the behavior of drivers of motorized vehicles, the lack of facilities for cyclists, the unfavorable weather conditions and the high accident rate, together with a lack of road safety education by motorized users, creates such an aggressive environment in the city that even the school and college communities do not choose bicycles for their daily commutes.

Table 2. Satisfaction levels toward the bicycle and perceptual indicators.

Statements	Perceptual Indicators
Riding abicycle, I can move easily even with congestion	Congestion
Cycling contributes to a healthy lifestyle	Health
Cycling generates economic savings	Savings
Riding a bicycle in Barranquilla is dangerous	Danger
When riding a bike, I feel uneasy due to possible robberies	Robbery
When riding a bike, I feel uneasy due to the possibility of an accident	Accident

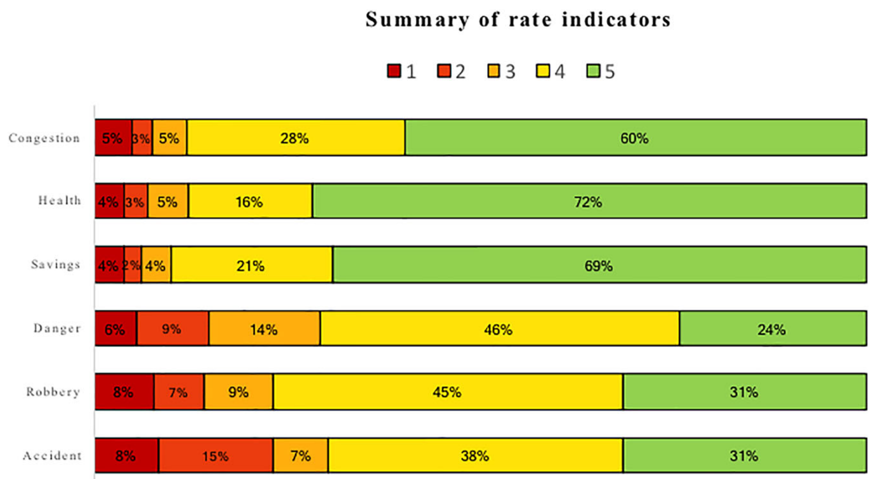

Figure 4. Summary of rating for indicators.

4.2. Data collection

To better understand the influence of Barranquilla's aggressive environment on bicycle demand, we applied a stated choice (SC) survey to the college community in the downtown part of the city. In the study area, there are two nearby universities, which among staff and students have a total population of 25,000 individuals. Students are about 90% of that population.

The survey form was designed using the Qualtrics software, which also allowed applying the SC questionnaires face-to-face, using tablets or smartphones connected to the internet. Respondents were randomly selected inside the campuses. Data collection was carried out during two weeks, at the end of the semester, when the students had already defined their travel patterns and schedules.

There is a new bicycle path which ends at walking distance from the main entrance of the university campuses. Taking advantage of this new project and the possibility of encouraging the use of bicycles in the college community, the SC experiment was geared to students and staff living in an area of 3 km around the campuses (see Figure 3). The objective was to analyze the potential use of the bicycle for daily trips to both universities during the morning rush hour.

The survey contained four sections. The first asked for gender, age, socioeconomic (SE) status[1], academic degree and household characteristics of the respondent. For modeling purposes, each of these variables was treated as a dummy: 1 for female and 0 for male, 1 for younger individuals (less than 24 years) and 0 for others, 1 for undergraduates and 0 for others, and 1 for individuals with low SE status (1 and 2) and 0 for the others.

In the second section, respondents were asked about the origin of their trips, their available alternatives, chosen mode and the main attributes of each mode available: travel time (min), access time (min), and cost (Colombian pesos, COP[2]).

In the third section, we measured satisfaction levels associated with the use of bicycles (Paulssen, Temme, Vij, & Walker, 2014). At this stage, we presented six different statements (see Table 2) with which individuals had to agree or disagree, rating them on a five-point Likert scale (1 representing total disagreement and 5 total agreement).

Figure 4 shows the percentage of responses for each indicator. Indicators associated with *convenience* (Congestion, Health and Savings) were rated higher, with more than 80% of respondents indicating high agreement. The other indicators had a more even distribution.

Finally, the last section contained the SC experiment that was only applied to public transport users. We used an efficient design with two blocks, where respondents had to choose between using bus and bicycle in nine hypothetical situations (Bliemer, Rose, & Hess, 2008; Rose & Bliemer, 2009). The attributes and their levels (three in each case) were defined as a

[1]The SE status is used in Colombia for public service taxation and subsidies. The SE status goes from 1 to 6: 1 representing the lowest income level and 6 the highest level. Socioeconomic levels 5 and 6 subsidize lower income people, belonging to levels 1 and 2. Usually, the medium income people are categorized into levels 3 and 4, while the wealthiest people in the population are categorized in levels 5 and 6 (Cantillo-García, Guzman, & Arellana, 2019).

[2]At the time of the survey, 1 US$ = 2800 COP.

result of discussions in two focus groups (for students and staff), and from our literature review, as follows:

a. *Bus cost*: current (reported) fare and two increases of 12.5% each, for a 25% total increase compared to the first level.
b. *Bicycle cost*: of using bike parking facilities on campus: no payment, 500 COP/day, or 1,000 COP/day.
c. *Travel time by public transport*: considering only time on board (min), calculated on the basis of a 3-km trip with three different bus speeds: 18, 23 and 36 km/h.
d. *Travel time by bicycle*: calculated assuming bike speeds of 10, 12 and 18 km/h for the same trip length.
e. *Access time to public transport*: calculated as the sum of waiting and walking times expressed in min. The reference level was 4 min, and the other two levels considered successive increases of 25%.
f. *Public transport comfort*: three different pictures were shown to respondents: one of an almost empty bus, another of a bus with the possibility of seating at some point, and finally one of a clearly overcrowded bus (Figure 5).
g. *Bicycle facilities*: the three levels were: a cycle-lane separated from the rest of the traffic (by only painted lines), the presence of on-campus bicycle parking lots and the availability of showers/lockers. These were treated as dummy variables (two levels each), 1 representing the existence of the facility, and 0 its absence. Further, in the case of the bike parking lots, their existence determined the cost of the bicycle alternative (i.e., when not available, the cost was zero).

The survey was applied during a typical working week, between 7 am and 8 pm, to capture students and staff during their working time. In total, 205 individuals answered the survey, but after data cleaning, we ended up with 181 usable forms.

The distribution of individuals and their socioeconomic characteristics is presented in Table 3. As can be seen, respondents are equally represented by gender. The income distribution, defined by the individual's SE stratum, shows that medium-income individuals comprise almost 50% of the sample. Finally, considering that most respondents are students, it is no surprise that 69% are less than 23 years old; this can also explain why only 19% are of the highest income level.

According to information obtained from the universities' administrations, about 60% of the students belong to the low SE stratum. This includes students who reside in towns near the city of Barranquilla, but who live near the campuses as boarders during the week. Most trips to the campuses are made by public transport (59%), 18% of the trips are made by car, 6% by taxi, 6% by motorcycle, 2% are a combination of public transport and other modes, 7% are

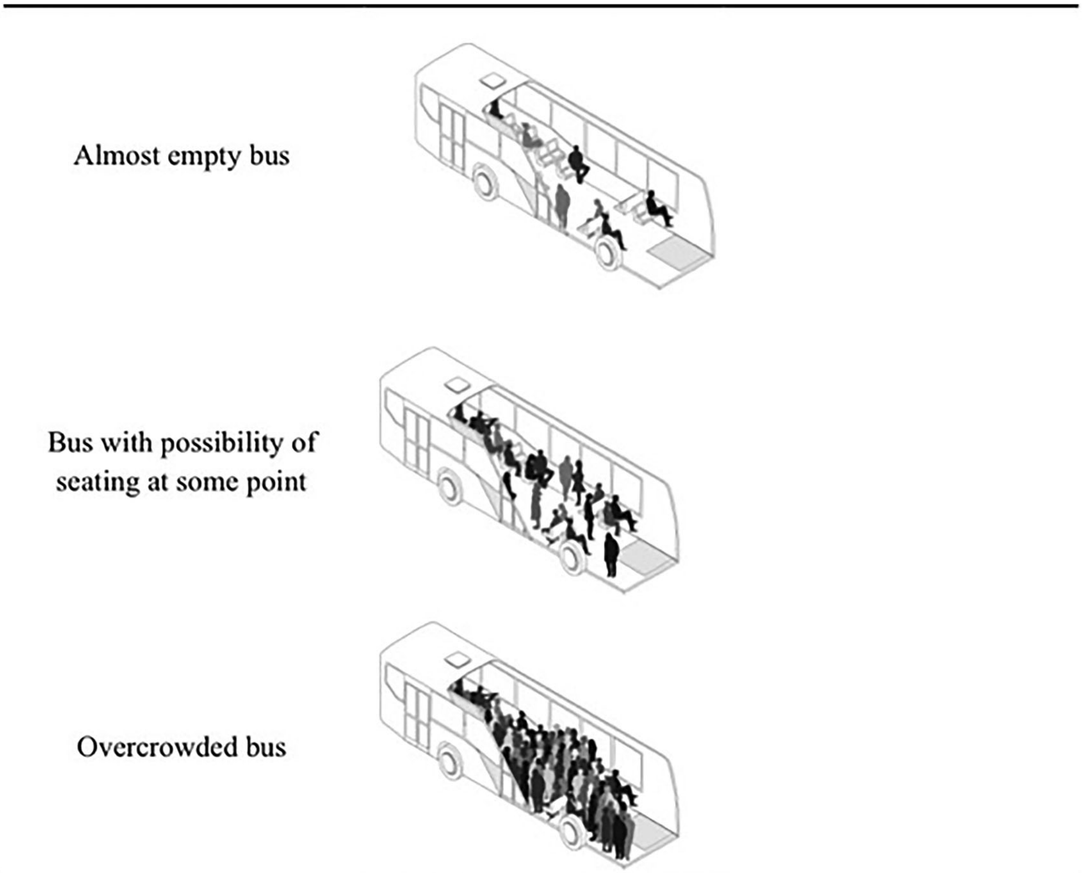

Figure 5. Level of crowding representations.

Table 3. Socio-economic characteristics of the sample.

Variable	Sample (%)	Variable	Sample (%)
Sex		*Income*	
Female	50	Low	37
Male	50	Medium	44
Age		High	19
<21	40	*Trip purpose*	
21-23	29	Study	57
24-30	20	Work	43
>30	11	*Transport mode*	
Education level		Public transport	59%
Basic	16	Car	18%
Technical or Technologic	12	Taxi	6%
Professional	57	Bicycle	2%
Postgraduate	15	Walking	7%
		Other	8%

walking trips and only 2% use bicycle. As less than 18% of students travel by private car (as a consequence of the lack of parking lots available for students in and around the campuses), the survey only considered public transport as an alternative to the bike.

5. Model estimation results and implications

5.1. Model results

Different Mixed Logit (ML) structures were specified to construct two baseline models without considering the latent variables (LV). The first baseline model (ML Panel Model in Table 5) included an error component to consider the *pseudo panel effect* associated with the fact that the nine responses declared by a given individual are not independent of each other (Ortúzar & Willumsen, 2011). The second baseline model (ML RP Model in Table 5) included a random parameter for the travel time variable to capture random taste heterogeneity.

Then, following the model framework described earlier, a hybrid discrete choice (HDC in Table 5) model was estimated using the simultaneous method to ensure consistent and unbiased parameters associated with the LV[3] (Bahamonde-Birke & Ortúzar, 2014). The specification of each LV derived, as usual, from a Principal Component Analysis (PCA) of the perceptual indicators. This analysis allowed us to identify two principal components with an eigenvalue greater than one, which could explain 72% of the variance. The first LV was labeled *convenience* and was correlated with the perceptual indicators: *savings*, *health* and *congestion*. The second LV, *unsafety/insecurity*, was associated with *robbery*, *accident* and *danger* (Table 4). So, the HDC model had two measurement equations with three indicators for each latent variable, and an ordinal logit model was used to represent the measurement component of the MIMIC model (Daly, Hess, Patruni, Potoglou, & Rohr, 2012). This approach recognizes the ordinal nature of the observed indicators.

[3]The model was estimated using a code written in Ox Metrics™ (Doornik, 2007; Arellana, 2012).

Table 4. Factorial matrix of the PCA with an orthogonal rotation.

Perceptual indicators	Unsafety/insecurity	Convenience
Savings	−0.037	**−0.480**
Health	0.027	**−0.494**
Congestion	−0.067	**−0.522**
Robbery	**0.507**	−0.043
Accident	**0.486**	−0.008
Danger	**0.524**	−0.027

The next step involved the construction of a Multiple Indicator Multiple Cause (MIMIC) model and its simultaneous estimation with the discrete choice model component (see Figure 6). During the specification searches, several HDC models were proposed considering various utility specifications and different structures of the MIMIC model. For example, in the structural equations, we tried to incorporate socioeconomic characteristics of the individuals and/or attributes of the modes, but only the former were finally included as explanatory variables (i.e., the only significant ones in the estimated models).

Finally, we chose the model that exhibited better microeconomic and statistical consistency, which had the following structure:

$$\begin{aligned}U_{bike} = {} & (\theta_{Time} + \theta_{T_P} \cdot Professional) \cdot TravelTime \\ & + (\theta_{Cost} + \theta_{C_{In}} \cdot HighIncome) \cdot Cost \\ & + \left(\theta_{Shower} + \theta_{S_{Age}} \cdot Young + \theta_{S_{Fem}} \cdot Female\right) \cdot Shower \\ & + \theta_{Bikelane} \cdot Bikelane + \beta_{Uns} \cdot Unsafety/Insecurity \\ & + \beta_{Conv} \cdot Convenience + \varepsilon_{bk} \\ U_{bus} = {} & \theta_{Bus} + \theta_{Time} \cdot TravelTime + \theta_{Cost} \cdot Cost + \theta_{Comfort} \\ & \cdot Overcrowed + \varepsilon_{bus}\end{aligned} \tag{7}$$

The two alternatives included in the model considered level-of-service attributes, socioeconomic status, bicycle facilities' variables, and the two LV (*convenience* and *unsafety/insecurity*), each measured by three indicators.

Gender, age, level of study and income were the only significant socioeconomic variables left in the structural equations. We decided to estimate a parameter for total travel time, that is, adding travel time and access time because these were not significantly different from each other (the cost value was divided by 100 for modeling purposes).

Table 5 shows the estimated parameters for the ML and HDC models (in parenthesis, robust t-test are presented). In all cases, the parameter signs are consistent with microeconomic theory (Ortúzar & Willumsen, 2011) and most are significant at the 90% confidence level ($t > 1.64$), except for the parameter of an interaction term (θ_{S_Female} (Shower_Female)) in the HDC model. However, we decided to maintain it in the HDC model to compare the log-likelihood among all choice models. Interestingly, the model fit of the ML Panel model was better than that of the ML RP model, but still lower than that of the HDC model; this is in line with previous studies in the Latin American context

Table 5. Relevant attributes in the mixed logit models and hybrid choice model.

		ML Panel model	ML RP Model	HDC model
Attribute	Alternative	Parameter (t-value)	Parameter (t-value)	Parameter (t-value)
Bus Constant	1	1.305 (2.48)	1.982 (4.51)	1.226 (2.75)
θ_T (Travel Time)	1,2	−0.069 (−4.62)	−0.072 (−5.29)	−0.062 (−4.00)
θ_{TT} (Travel Time_Professional)	2	−0.054 (−2.79)	——	−0.065 (−2.93)
σ_{TT}	2	——	−0.118 (−10.58)	——
θ_C (Cost)	1,2	−0.085 (−5.44)	−0.079 (−5.28)	−0.094 (−6.40)
θ_{C_LI} (Cost_LowIncome)	1	−0.048 (−1.86)	−0.049 (−2.20)	——
θ_O (Overcrowed)	1	−1.214 (−7.18)	−1.208 (−7.33)	−1.129 (−6.97)
θ_{SHOWER} (Shower)	2	0.885 (3.76)	1.026 (4.30)	0.771 (3.21)
θ_{S_Age} (Shower_Young)	2	−0.486 (−1.80)	−0.526 (−2.05)	−0.365 (−1.38)
θ_{S_Female} (Shower_Female)	2	−0.524 (−2.03)	−0.569 (−2.21)	−0.515 (−1.92)
θ_{CL} (Cycle-lane)	2	0.755 (5.17)	0.811 (5.50)	0.702 (4.89)
β_{Conv} (Convenience: Z_1)	2	——		1.593 (7.57)
β_{Sec} (Unsafety/insecurity: Z_2)	2	——	——	−0.831 (−2.68)
μ (Panel Effect)		1.812 (10.73)	——	——
LL choice model		*−814.46*	*−821.56*	*−810.65*
$\bar{\rho}^2$		*0.202*	*0.196*	*0.207*
AIC		*1650.92*	*1663.12*	*1643.3*
Number of individuals		*181*	*181*	*181*
Number of observations		*1629*	*1629*	*1629*

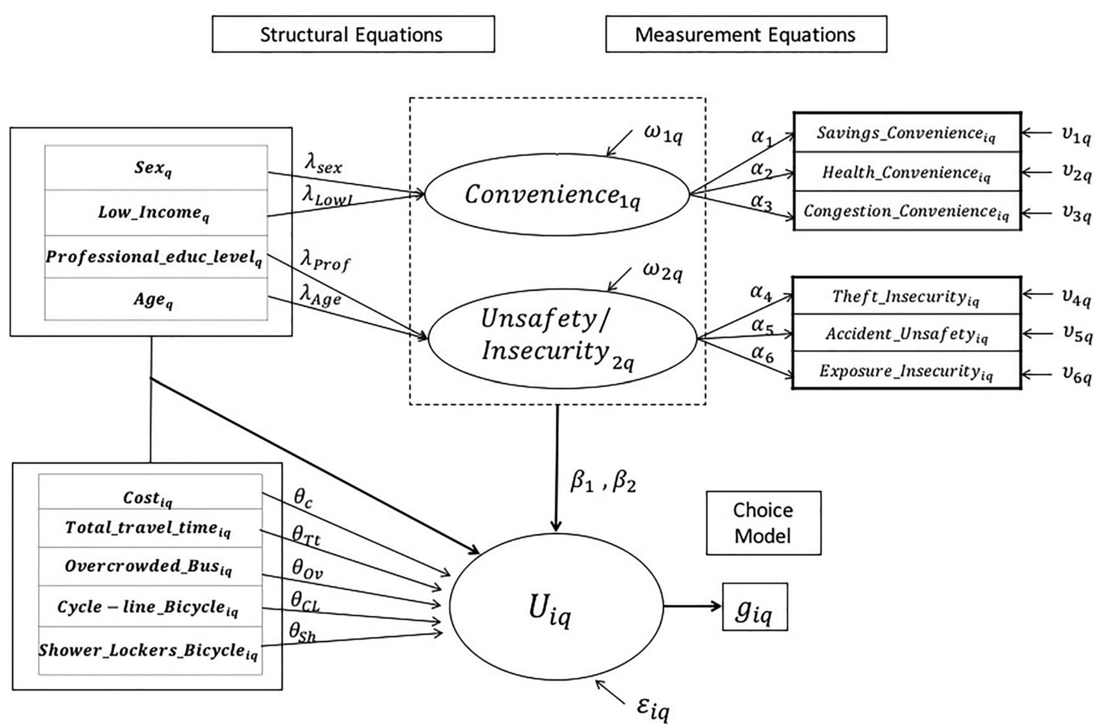

Figure 6. Diagram for the hybrid discrete choice model specification.

(Arellana, 2012). The three error terms included in the HDC model appear to help to capture this effect. Regarding the goodness of fit of the model, Table 5 presents the corrected rho-squared and the Akaike Information Criterion (AIC, Akaike, 1980). With the value of these two indices, we can infer that the HDC model has a better goodness of fit than the ML Panel model, and this, in turn, has better goodness of fit than the ML RP model.

Table 6 shows that the HDC model has also strong structural equations, since the observable attributes: gender, age, education level and level of income, are good predictors of the LV *convenience* and *unsafety/insecurity*, have the expected sign and most t-tests indicate confidence levels greater than 90%.

The HDC model suggests that individuals with a high education level (i.e., professionals holding a university degree) weigh bicycle travel time almost twice as much as the rest of the sample. The subjective values of time (SVT), defined as the marginal rate of substitution between time and cost (Gaudry, Jara-Díaz, & Ortúzar, 1989), for bus users and bike users without a professional degree are around 66 COP/min (0.02 USD/min), which is in line with estimated SVT for public transport users in Colombia (Ramos, Cantillo, Arellana, & Sarmiento, 2017). Meanwhile, the SVT

Table 6. Relevant attributes in the MIMIC model.

	MIMIC model
Attribute	Parameter (t-value)
$\lambda_{F,Z1}$ (Female, Z1)	−0.152 (−1.14)
$\lambda_{LI,Z1}$ (Low Income, Z1)	0.627 (3.34)
$\lambda_{Y,Z2}$ (Young, Z2)	0.373 (2.41)
$\lambda_{U,Z2}$ (Professional, Z2)	−0.312 (−1.81)
α_S (Savings: Z1)	2.652 (5.14)
α_H (Health: Z1)	3.300 (4.24)
α_C (Congestion: Z1)	3.836 (3.57)
α_{Ac} (Accident: Z2)	2.622 (5.59)
α_{Rob} (Robbery: Z2)	3.309 (4.45)
α_D (Danger: Z2)	2.023 (6.19)

for bike users holding a professional degree is around 135 COP/min (0.04 USD/min).

The aggregate demand elasticity, calculated using the sample enumeration technique (Ben Akiva & Lerman, 1985), was around −0.7. This value indicates that individuals are highly sensitive to cost. In Barranquilla, students do not have a preferential fare for public transport use; therefore, from the point of view of savings, the bicycle is an attractive mode of transport.

As expected, the effect of traveling in an overcrowded bus is negative for the utility of public transport and it is an important attribute when choosing this mode. On the other hand, having bicycle-lanes and showers/lockers has a positive effect on the utility of bikes (Handy, van Wee, & Kroesen, 2014). We expected that the presence of bicycle-lanes would improve users' perception of safety; however, this was not the case probably because bicyclists do not have enough facilities that protect them from motorized vehicles in the whole city, which means that users do not perceive them as safe. Bike users must compete for road space and, in the case of a minor accident, the bike can be totally damaged and the cyclist can sustain severe injuries, compared with going by bus, for example, where the accident must be major to produce serious injuries.

Furthermore, having shower/lockers in the campus is less important for young people than for people over 24, probably because they are mostly students (a typical employee would normally need to change sweated clothes before starting a day of work). In fact, during the survey, we heard some individuals saying that having a shower/locker could be important for them due to the possibility of taking a shower and changing clothes after their commute. Recall that temperatures in the city contribute to ending the trip sweating always, which could make some bicycle users feel uncomfortable. However, it would require them to add more time to complete the trip and could mean arriving late to the campus or having to leave home earlier.

The importance of the latent variable *unsafety/insecurity* (Z_2), reflects the fear of having the bicycle or the individual belongings stolen on route. It is an important variable considering that the rate of robberies in the city was about 625 per 100,000 inhabitants in 2017, and that 31% of citizens felt insecure while walking on the city's streets (Universidad del Norte, 2018). As we can see in Table 6, young students (age < 23 years) have a higher perception of *unsafety/insecurity* discouraging their bicycle use. On the other hand, older and professional individuals are less sensitive to safety and security issues in the city. Even though this can appear counterintuitive, it could be due to those individuals being familiarized with safety and security issues in the area. Experience plays a significant role in shaping perceptions and attitudes, in line with previous research in the city (Arellana, Fuentes, Cantillo, & Alvarez, 2019)

In contrast to the *unsafety/insecurity* variable, a higher perception regarding the *convenience* variable should encourage cycling because of its significant effect in the HDC model. For low-income people, using a bicycle is more convenient than for medium and high-income people. The above result is expected, as using a bicycle implies a saving in monthly expenses (in comparison with paying the daily bus fare), and this is reinforced by the fact that students do not have a preferential fare in Barranquilla. Additionally, the ability to travel freely that the bicycle brings is attractive in a city where there has been increasing congestion in the last years, and where currently motorists spend an average of 40 hours a year in vehicular congestion (INRIX, 2018). Finally, the contributions to health that can be generated by using a bicycle every day are perceived as important (Deenihan & Caulfield, 2014; Doorley, Pakrashi, & Ghosh, 2017); this is interesting in a country with a recent increase in obesity rates and where more than 50% of the people currently suffer this condition (Ministerio de Salud, 2015).

The model also suggests that women find bicycle use less convenient. The literature on the role of gender in bicycle use, generally mentions that women prefer separated paths over bike lanes (Garrard et al., 2008; Waintrub, Peña, Niehaus, Vega, & Galilea, 2016; Frater & Kingham, 2018; Mitra & Nash, 2019); however our model did not support this claim.

5.2. Implications for policy

To encourage the use of the bicycle in aggressive environments would require the implementation of forceful policies and strategies regarding the provision of adequate bicycle infrastructure and facilities, that in turn improve the convenience perception of potential bicycle users and also achieve an improvement in the perception of their safety and security.

A first set of strategies that can be derived from our analysis, involves the design of incentive policies to make the bicycle more attractive and convenient for potential users. These policies should include the construction of exclusive bicycle lanes and the provision of facilities such as showers, lockers, and free parking lots for cyclists at main destinations. Furthermore, we think that these policies could also influence the unsafety/insecurity perception, as exclusive bicycle lanes should help diminishing crash rates involving bicycles in the city. In addition, we believe that the design of certain facilities should consider the weather conditions of the city; for example, facilities and infrastructure planning should consider the provision of shade, drinking fountains, and secure resting places. Finally, this first set of policies could be accompanied by the integration of bicycle infrastructure to the public transport network, to promote sustainable mixed-mode mobility in the city and favor long-distance trips by public transport rather than by car.

A second set of strategies could be developed toward influencing the perception of insecurity/unsafety in the use of bicycles in the city. Definitively, hard measures associated with the provision of surveillance cameras, the improvement of lighting during night hours, the presence of security or police officers, and the availability of panic buttons along the bicycle infrastructure could be considered. However, soft measures such as a high density and mixed land use developments in the surroundings of bicycle infrastructure could also favor higher pedestrian flows that could indeed provide higher social control to strengthen the security perception (Greene & Ortúzar, 2019). Regarding the safety perception, hard measures involving the provision of exclusive bicycle lanes, as discussed earlier, but together with the supply of adequate traffic signaling and safe crossing alternatives could also promote the use of the bicycle. Soft measures toward safety should consider education campaigns for both cyclists and motor vehicle drivers, to promote safer driving behavior.

A third set of strategies involves highlighting the factors that make the bicycle a convenient and sustainable mode of transport. Educational and advertising campaigns focusing on the health and environmental benefits of using the bicycle for the university commute could be one option in this sense. Numerous studies demonstrate the health benefits associated with using the bicycle as the main mode of transport (Deenihan & Caulfield, 2014; Raustorpa & Koglin, 2019), by incorporating daily physical activity in the routines of those who do not practice any sport or physical exercise. In this sense, cycling could be an important step in preventing cardiovascular diseases and obesity, and even improving cholesterol, diabetes or blood pressure levels (Huy, Becker, Gomolinsky, Klein, & Thiel, 2008; Oja et al., 2011). Also, other studies demonstrate that traveling by bicycle is more environmentally friendly than traveling by any motorized vehicle (Mrkajic, Vukelic, & Mihajlov, 2015; Jain & Tiwari, 2016; Espinosa, Pacheco, & Franco, 2018). Particularly, the aforementioned campaigns could reinforce the message that the city of Barranquilla and its surrounding region have the lowest percentage of minimum compliance of daily physical activity (between transport and leisure time), with 46% compared to the average of Colombia that is 56%. At the country level, excess weight has increased by about 6% in the last 10 years, together with an increase in the time spent in front of screens in adolescence and adulthood, reducing the time for outdoor activities and sports. Physical daily activity times could be improved by adopting a bike for commuting (ICBF, 2015). Finally, regarding the environmental impact of using bicycles in the context of Barranquilla, the campaigns could socialize the fact that according to the European Environment Agency (2014), a bus emits approximately 68/gr/km/passenger of CO_2. Therefore, if we apply our model to the population of 25,000 individuals between the two universities, and considering that approximately 68% of them would be willing to travel by bicycle, a reduction of about 1 ton/km of CO_2 per day could be achieved.

Additionally, we propose educational and incentive campaigns for the daily use of bicycles across the university community, such as (i) creating recreational bike paths on weekends like *ciclovía-recreativa* in Bogotá (Cervero et al., 2009) or *CicloRecreovias* in Santiago de Chile (Mora, Greene, & Corado, 2018), but targeting students, staff and faculty of the two universities; (ii) restart a campus based bike rental systems subsidized by the university administration; and finally, (iii) design incentives for workers and students using programs like Bike-to-Work Days (Rose & Marfurt, 2007), where commuters can access free breakfast, giveaways, or commuter challenges encouraging to choose active modes of transport for their trips to and from work, with the chance to win an attractive prize (Castillo & Moreno, 2018).

6. Conclusions

We explored how the environment of a city can affect the choice of transport mode, focusing on bicycle use, for daily commutes by two college communities in the city of Barranquilla, Colombia. We estimated a hybrid binary choice model that allowed us to examine the importance of socioeconomics, trip level-of-service, bicycle facilities and non-measurable factors that can encourage/discourage bicycle use as a sustainable mode of transport. Our results suggest that the choice of commuting by bicycle depends not only on the level-of-service attributes, but also on the perception of safety/security on the route and the perception of the convenience of biking.

Our results support the hypothesis made regarding the influence of perception of an aggressive environment in the choice of the daily mode of transport. For example, the importance of having showers to change clothes before starting work can be related to the high temperatures and humidity in the city, which can cause discomfort due to sweating. The study also highlights the relevance of providing adequate and safe infrastructure (e.g., bike paths and parking lots), and of designing policies for influencing the perceptions of insecurity/unsafety and of the convenience of using the bicycle as a sustainable and healthy mode of transport for daily commuting trips to university campuses. Policies encouraging the use of bicycles by the college community may be developed by university administrators but also fostered by the local authorities.

A limitation of our study is that we did not consider car or motorcycle users in our sample, both modes clearly more environmentally damaging than bus. Thus, future research could involve the estimation of more complex models, incorporating other modes, as well as further latent variables and built environment attributes, to help designing more customized policy measures in the city. It could also be interesting to include parameters associated directly with the city weather (such as temperature, time of day when the trip was made, among others), to explore its effect in the choice of bicycle use. Finally, quantifying the environmental benefits achieved by the increase in the use of the bicycle and the reduction in the use of all types of motorized transport is another line to enrich the analysis.

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