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Integrating perceptions of safety and bicycle theft risk in the analysis of cycling infrastructure preferences

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ABSTRACT

Cycling infrastructure development is an effective but expensive urban policy to encourage people to use bicycles. Although people usually prefer infrastructure with high cycling priority, authorities in some cities have focused policies on adapting part of current motor vehicle infrastructure to increase the length and coverage of bicycle infrastructure at the road level, which can help to lower infrastructure investment costs. Perceptions are also important in developing programs to promote cycling and they may even be more important for cyclists than the reality itself. In this research, we integrated the perceptions of cycling safety and theft risk into a hybrid discrete choice model in order to better understand cycling infrastructure preferences, using Bogota, a bike-friendly city with security concerns, as a case study. We found that concerns about safety are a significant deterrent to using bike lanes at the road level in the city while perceptions of theft risk affect the value or importance that bicyclists place on travel time. Based on modeling findings we proposed hard and soft measures to encourage bicyclists to use bike lanes at the road level.

1. Introduction

Benefits offered by cycling have been widely recognized in the literature. Cyclists do not pollute the environment and benefit from the positive health effects of cycling (Cavill et al., 2008; Mueller et al., 2015; Pucher & Dijkstra, 2003), diminishing the risk of cardiovascular illnesses and obesity (Oja et al., 2011). Cycling also has the potential to relieve overcrowded public transportation systems, especially for short duration trips in which the willingness to use the bicycle may be higher (Sun & Zacharias, 2017). Cycling makes cities more pleasant places to live by serving as a way for people to meet new people beyond their usual social group (Zander et al., 2013), cyclists also enjoy nature moving in silence and enjoying the pleasure of landscapes (Etminani-Ghasrodashti et al., 2018). Furthermore, bicycles are a more affordable transportation mode, use less space on the road, and need less parking space than cars (Litman, 2017). However, despite these demonstrated benefits, a limited number of people make the decision to bicycle in cities.

From the point of view of engineering, cycling infrastructure focuses on keeping cyclists safe (Thompson et al., 2017) and enabling the uninterrupted mobility of cyclists. Although cycling infrastructure is the most expensive element of urban cycling policy, there is a positive relationship between some characteristics of cycling infrastructure and cycling levels. The availability and continuity of cycling infrastructure, together with parking places, and other trip end facilities have a positive effect on the intention to use bicycles (Buehler & Dill, 2016; Heinen et al., 2010; Hunt & Abraham, 2007; Menghini et al., 2010; Rossetti et al., 2018; Tilahun et al., 2007).

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Bicycle parking supply and quality, which should convey a feeling of security, also appear to be a determinant of bicycling (Heinen & Buehler, 2019). The absence of secure parking is a crucial and often ignored problem that deterrents bicyclists (Chen et al., 2018) because they are normally reluctant to park in public places (Kang et al., 2019).

Safety concerns could be one of the most important barriers to more people deciding to use bicycles (Fishman, 2016). That is why cycling safety has been recognized as an issue playing an important role in choosing the bicycle as a transportation mode (Muñoz et al., 2016). Several studies have shown that safety is one of the most significant features of bicycle infrastructure (Liu & Marker, 2020; Götschi et al., 2018; Ng et al., 2017; Thompson et al., 2017; Wang & Akar, 2018) and is relevant in deciding whether to bicycle. To ensure cycling safety, a well-maintained, and connected infrastructure free of obstacles is needed. In addition to the infrastructure itself, interactions with other traffic are also important (Dozza et al., 2020; Gossling, 2013; Prato et al., 2016; Pu et al., 2017).

Although less studied (Sidebottom & Johnson, 2014), bicycle theft risk is also regarded as an important impediment to cycling adoption and a common problem worldwide (Li et al., 2019; Zhang et al., 2007). In general, bicycles are attractive targets for theft and in consequence, bicycle theft is a high-volume crime. Previous research shows that bicycle owners are more prone to be robbed than are owners of cars and motorcycles (Sidebottom et al., 2009; Zhang et al., 2007). Literature also shows that in addition to the presence of likely offenders, bike thefts are positively influenced by the number of bikes in an area (Levy et al., 2018), which suggests that urban policies aimed at promoting cycling could be increase chances for bicycle theft (Mburu & Helbich, 2016).

The general public's perceptions are important in increasing the effectiveness of programs and strategies to promote cycling (Habib et al., 2014). Today, it is currently acknowledged that people' perceptions are key factors to comprehend bicycle use (Fernández-Heredia et al., 2016). Previous research has shown that an important discouragement to use bicycles is the level of danger perceived (Tilahun et al.; 2007; Wardman et al., 2007). As a matter of fact, safety perception may be more significant than objective reality in deciding to use bicycles (Heinen et al., 2010) and it may even be more decisive for some people than the bicycle infrastructure (Damant-Sirois & El-Geneidy, 2015). Although it may be affected by the statistics people have of crashes, it is their own subjectivity in safety perception that really influences people when they choose a means of transportation (Sælensminde, 2004). Consistent with the above, not only theft but also the fear of bicycle theft is a major disincentive to bicycle use and may jeopardize efforts to increase the use of bicycles (Rietveld & Koetse, 2003).

Bogota is a bike-friendly city but remains at a high risk of bicycle theft and traffic fatalities. A qualitative study about the barriers and facilitators of cycling in the city showed that people fear of bike theft (Mosquera et al., 2012). However, we did not find in the literature a study dealing with perceptions of safety and bicycle theft risk in the analysis of cycling infrastructure preferences in Bogota. Indeed, to the best of our knowledge, ours is the first study to specifically incorporate these two perceptions in the context of a bike-friendly city with security concerns, such as Bogota. Some studies have addressed parking policies to reduce private cars use and increase the share for bicycling and other sustainable transportation modes in the city (Guzmán et al., 2020). Impacts of household proximity to bicycle infrastructure on bicycle ridership have also been studied, showing that the proximity to cycling infrastructure in Bogota has a positive impact on people choosing a bicycle as their main means of transportation (Rodriguez-Valencia et al., 2019). The story behind cycling development in the city has been carefully studied and analyzed to produce results that could be relevant to other cities (Rosas-Satizábal & Rodriguez-Valencia, 2019). The latest research into bicycling in Bogota has focused more on exploring the stress resulting from commuting by bicycle in Bogota (Jimenez-Vaca et al., 2020) and defining the total trips that could be supported by bicycle paths (Olmos, et al., 2020).

In our research, in addition to travel time, adjacent motor vehicle traffic, separation from motor vehicles, and trip end facilities, we integrated the perceptions of cycling safety and bicycle theft risk into a hybrid discrete choice model (HDC) in order to better understand cycling infrastructure preferences in Bogota, which is important to evaluating improvement of the current infrastructure or the development of new infrastructure (Hardinghaus & Papantoniou, 2020). Our work contributes significantly to the existing literature on the analysis of the bicycle infrastructure preferences, by integrating two perceptions that are deterrents to cycling in a robust modeling approach.

In summary, the literature has amply shown that both socioeconomic characteristics and infrastructure features affect people's cycling infrastructure preferences. Furthermore, with the recent development of discrete hybrid modeling, it has been possible to incorporate and analyze the effect of latent variables on preferences. However, there are still several gaps to close. First of all, there are not many studies that focus on perceptions of theft risk while biking, so our research contributes to broadening the basis of existing knowledge on this topic, especially on global south cities, were security issues are more important and there are fewer studies accounting its effect. Second, our research produces new empirical insights that could help authorities adapt existing vehicle infrastructure to increase the length of bike lanes. In third place, we demonstrated that bicycle theft fear increases the importance that bicyclists place on travel time, which implies that improving crime rates and reassuring users' confidence could encourage longer bicycle trips.

2. Literature review

The literature has shown that objective and perceived risk, danger, and safety concerns are deterrents to cycling and, therefore, they could be considered in the analysis of users' preferences for cycling infrastructure. For example, the study of Ravensbergen et al. (2020), which discussed many different types of fear, showed that fears related to bicycle theft, among others, are experienced or described differently by different people. In general, the theft problem is considered one of the main obstacles for private bicycle use (Li et al., 2019). This implies that in addition to studying the perception of theft risk, it is necessary to consider heterogeneity from the user's perspective.

The literature on bike-share programs, which exhibits considerable interest in studying the problems related to bicycle theft, has also shown how problems related to bicycle theft affect users' decisions. For example, Ji et al. (2017) demonstrated that people with bicycle theft experience are more likely to use public bicycles. Overall, a substantial number of studies show how users make decisions to deal with bicycle theft (Fuller et al., 2013; Fan et al., 2019), also showing that some latent variables, such as being "less worried about being stolen or damaged", have differential impacts on people's behavior (Ma et al., 2020). Hence the importance of studying how cycling infrastructure preferences are affected by perceptions of safety and bicycle theft risk.

The existing literature has also shown that some bicycle programs succumbed to a number of problems such as theft and vandalism, forcing both operators and authorities to take steps to mitigate the problem (Shaheen et al., 2011). In fact, some authors have focused on the analysis of problems such as theft and vandalism (Xiao, et al., 2020) that are seen as obstacles to overcome for the long-term sustainability of bicycle systems (Hirsch et al., 2019) and that, from our point of view, may have implications in the decisions made by the authorities in relation to the provision of bicycle infrastructure in cities.

Despite the significant number of cases that are filed, bike theft still tends to be overlooked by police and authorities in most cities (Sidebottom & Johnson, 2014). Possibly, for this reason, many victims of bike theft do not even bother to report it. In addition to the obvious underreporting, the lack of attention of the authorities can lead to the perception of the bicycle theft risk in a city not being correctly reflected in the official figures. Although bicycle theft generates relatively small impacts on communities (Chen et al., 2018), we considered that authorities should not be overlooked its negative effects on bicycle use because theft and the fear of cycle theft are barriers to cycle use (Sidebottom & Johnson, 2014). In this way, understanding how the perception of bicycle theft risk affects the preferences for infrastructure in a city can help authorities to adopt better programs and strategies to promote cycling, keeping pace with the shift to active transportation. This is even more important on cities belonging to the global south, especially in Latin America, which has issues like sidewalk invasion, security issues, mixed traffic and poor planning (Arellana et al., 2020). Moreover, the security factor seems to be more relevant in the global south cities, and there is a need for more studies accounting its effect (Arellana et al., 2020b). Security has been rated among the most important aspects to care about by commuters and non-frequent cyclists, even above infrastructure presence (Arellana et al., 2020a), which shows the importance of this aspect in global south cities, where mugging -sometimes life threatening- is a common way of theft.

3. Cycling in Bogota: Thefts and traffic fatalities

Bogota is the capital city of Colombia. With an area of approximately 380 km^2 and a population of 7,412,566 inhabitants, it is the largest and most inhabited city of the country (DANE, 2018). In relation to distribution by income groups, the city has 2,514,482 households, of which 47.6% are low-income households; 46.9% mid-income households and the remaining 5.4% are high-income households (SDM, 2017). The city is the principal market in the country, with 25.6% of the Colombian GDP and over 29% of the registered companies in Colombia (CCB, 2019), making Bogota the Colombian administrative, economic and industrial center of the country and an attractive city for business and investments.

On an average day, there are 13,359,728 trips in Bogota, of which 14.9% are made in cars; 36.9% in public transportation and

Table 1
Modal split (%) in some cities worldwide.

City	C.I.	Year	Cycling	Walking	P.T.	Car	Motorcycle	Taxi	Other
Antwerp	73.2 (04)	2010	23	20	16	41			
Belo Horizonte		2016	0	33	28	35	4		
Belgrade		2015	1	24	49	26			
Berlin	56.3 (15)	2018	18	31	27	24			
Bremen	58.9 (11)	2018	27	26	15	32			
Bogota	58.1 (12)	2019	7	24	37	15	6	5	6
Cape Town		2016	1	8	26	53		12	
Copenhagen	90.2 (01)	2014	30	17	20	33			
Curitiba		2016	5	20	45	22	5		3
Helsinki	59.8 (10)	2013	11	32	34	21	2		
Kochi		2016	3	12	49	10	26		
Leipzig		2015	17	25	18	40			
Ljubljana	57.1 (14)	2003	10	19	13	58			
Mexico city		2017	1	26	50	23			
Montreal	53.6 (18)	2013	2	10	16	72			
New York		2018	3	28	31	32		3	3
Oslo	62.5 (07)	2014	5	32	26	37			
Taipei	54.5 (17)	2015	6	15	37	42			
Tokyo	55.4 (16)	2015	14	23	51	12			
Utrecht	88.4 (03)	2012	26	17	16	41			
Warsaw		2015	3	18	47	32			
Wien	60.7 (09)	2016	7	27	39	27			
Zürich		2015	8	26	41	25			

Notes: C.I.: Copenhagenize Index 2019 (The number in parentheses is 2019 rank); P.T.: Public transportation
Source: https://copenhagenizeindex.eu/; https://www.movilidadbogota.gov.co/web/encuesta_de_movilidad_2019; https://ecomobility.org/our-impact/; http://www.epomm.eu/tems/cities.phtml; http://www.nyc.gov/html/dot/downloads/pdf/mobility-report-2018-print.pdf; https://www.clc.gov.sg/docs/default-source/books/mobile-friendly-10-cities.pdf;

30.5% are non-motorized trips. Trips made in bicycle account for 6.6%, with a total of 880,367 trips. This number has increased two-fold since 2011 and 38% from 635,431 trips in 2015, with noticeable increases on all income bands (SDM, 2019). The total number of trips in all means of transportation is split almost evenly between genders, with 51.4% of the total trips made by women. However, 75.8% of trips made by bicycle are from men and 24.2% from women, revealing a gender gap in this mode of transportation. Stated briefly, 10.3% of men's trips and 3.1% of women's trips are made by bicycle (SDM, 2019).

Although cycling has been gaining ground in Bogota, the mobility of the city is based mainly on public transportation and the car. Overall, despite being two very different cities, in terms of the modal split, Bogota exhibits similar figures to that of Wien, where about 7% of trips are made by bicycle, as can be seen in Table 1. As in other cities such as Belgrade, Leipzig, Mexico City, and Zürich, walking accounts for about a quarter of total daily trips. In Bogota, the proportion of trips in sustainable modes of transportation (68%) is almost at the same level as Curitiba, Bremen, Warsaw, and Copenhagen, which is the most bicycle-friendly city in 2019, but it is still far from reaching the share of Asian cities like Tokyo.

The motorization rate in Bogota is 237.9 vehicles per 1000 inhabitants, on average. However, among low-income users, the motorization rate ranges between 127 and 184 vehicles per 1000 inhabitants. Meanwhile, for high-income users, the rate varies between 550 and 600 vehicles per 1000 inhabitants. In relation to the bicycle rate, the average in the city is 210 bicycles per 1000 inhabitants and it also increases with income. The rate ranges between 111 and 321 bicycles per 1000 inhabitants for low-income and high-income users, respectively (SDM, 2019).

In terms of bicycle infrastructure, early investment efforts were to build bike paths at the sidewalk level, especially between 1998 and 2014, while the first bike lane at the road level was opened in 2013 (Rosas-Satizábal & Rodriguez-Valencia, 2019). Recently, investment has been focused on bike lanes at the road level as well as the relocation of the busiest bike paths from the sidewalk to the road, to increase cycling speed (Clarry et al., 2019), avoid conflicts between cyclists and pedestrians (Rosas-Satizábal & Rodriguez-Valencia, 2019), and impact positively on the perceptions of pedestrians as shown in other geographical contexts (Nikiforiadis &

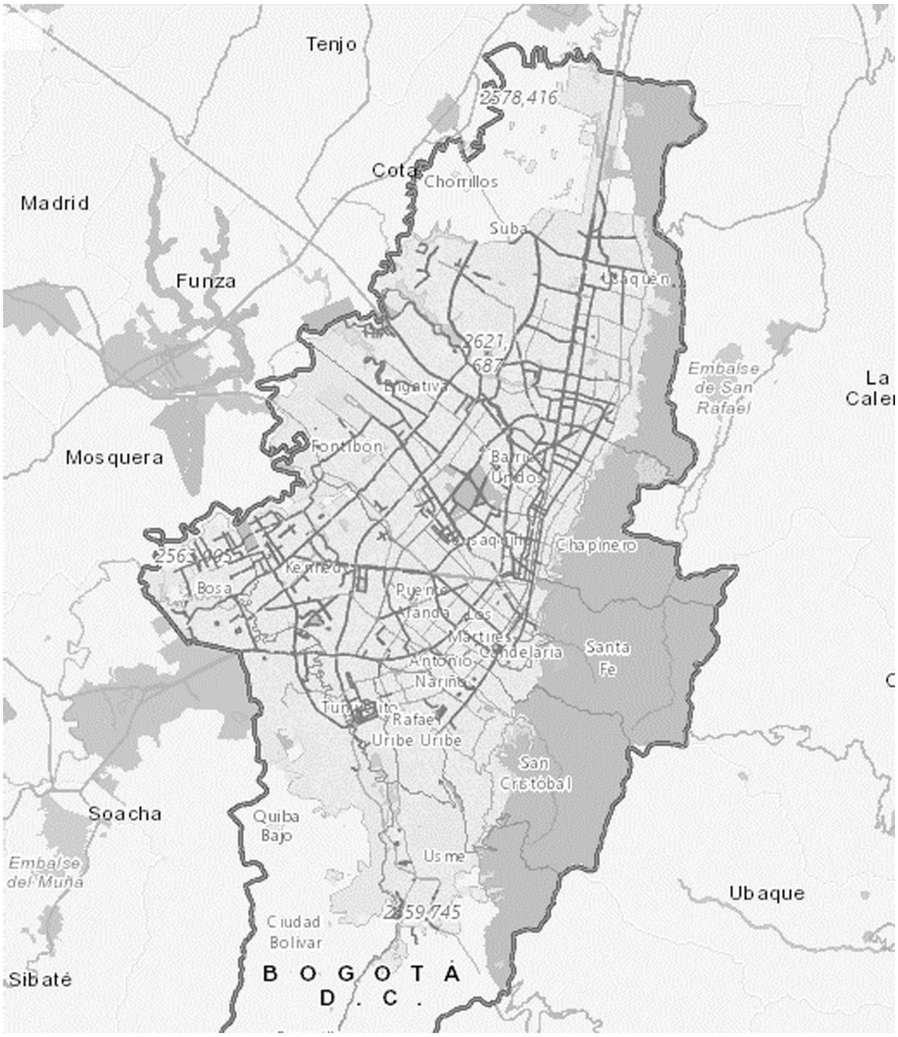

Fig. 1. Bicycle network in Bogota.

Basbas, 2019). The city has 523 km of bicycle infrastructure, of which 400 km belongs to sidewalk level paths and 123 are road level lanes. Several corridors have over 5000 cyclists per day, and a maximum of slightly over 7000 cyclists per day (Bogota Como Vamos, 2019). In addition, Bogota opened more than 100 km of bike lanes at the road level to promote the use of bicycles during the COVID-19 crisis (Arellana et al., 2020). Fig. 1 shows the network of available bike lanes on a map of the city, where it can be observed that there is wide coverage with connected networks that encourage bicycle use.

Traffic fatalities in Bogota have been declining in the last few years, from 606 in 2014 to 514 in 2018. This decrease is more noticeable when mortality rates are compared in considering vehicle growth. In this case, 2014 had a rate of 8.6 victims per 100,000 inhabitants and 2018 had a rate of 7.2 (Bogota Como Vamos, 2019). Despite the effort made in reducing traffic crash victims, the vast majority comes from vulnerable, non-motorized actors. Average pedestrian and cyclists' deaths in the last 5 years are 51% and 11% of the total number of deaths by traffic accidents, respectively (SDM, 2019); with a participation of 47.6% for pedestrians and 12.4% for cyclists in 2018 (Bogota Como Vamos, 2019).

Table 2 shows the number of cyclists injured or dead from traffic crashes in 2018 per mode involved in the event. It can be seen that collisions with cars and motorcycles produced the most injured. However, most victims came from collisions with buses and trucks, as expected for the higher weight difference between actors involved. Another category that has a high percentage of cyclist deaths corresponds to collision with an object or fall from the bicycle, with 14.1% of victims.

On a general note, it could be said that Bogota is a bike-friendly city, with the largest bike lane network and the highest modal share in a Latin American city. In fact, it is the only Latin American city that is among the 20 most bike-friendly cities worldwide, where Bogota making 12th place, according to the 2019 Copenhagenize index. This holistic index considers infrastructure culture and ambition parameters, showing that Bogota is making things right when it comes to encouraging bicycle use, especially for the ambition parameter, which includes the advocacy of cycling organizations and the presence of bicycling among the main priorities in the urban planning and policies. However, cyclist security is an important issue in Bogota as bicycle theft is a growing problem in the city. In fact, after cash and cellphones, the bicycle is next among the most stolen personal goods (Bogota Como Vamos, 2017).

Security in Bogota is still a major concern for bicyclists. In 2019 there were 5213 bicycle thefts, which is an increase of 5.8% in relation to 2018 (Secretaria Distrital de Seguridad, Convivencia y Justicia, 2019). However, it should be noticed that there is a clear underrepresentation of all the thefts since only about 41% of them are reported in official records (Bogota Como Vamos, 2019). The profile of bicycle thefts by victim and theft characteristics in 2019 is depicted in Table 3, which also includes the Pearson's chi-squared test in order to evaluate whether the observed frequency distributions differ from a discrete uniform distribution. It can be observed that most victims are male, as expected by the gender gap on bicycle use. Also, the majority of victims are between 18 and 39 years old, probably because of a higher share of cyclists in that age range.

According to the theft characteristics, although statistically there is no uniformity, there is also no clear pattern when it comes to the day of the week and hour of the day, as thefts during daytime are a little over the half, with 53.5%. In relation to the days of the week, percentages among days are similar, with a little peak on Friday and a low point on Sunday, but it should be noticed that they are only 2.5% apart. This could imply that bicycle theft is a problem for both utilitarian users and recreational or sports users, as there is a high theft risk each day of the week. Finally, almost half of the thefts include weapons, with the prevalence of knives.

Summarizing, Bogota is clearly a bike-friendly city, as appears from its bike lane network, modal share, and policies encouraging bicycle use. However, there are some aspects that need to be evaluated to further encourage bicycle use. First, the recent switch on bicycle infrastructure investments, prioritizing bike lanes at road level rather than sidewalk level, and its effects on users' perception should be taken into account. Furthermore, there are some safety and security issues that need to be addressed in order to understand how to further incentivize the use of the bicycle as means of transportation, since cyclists are in the second category with most traffic crash victims. Last but not least, bicycle theft has been increasing over recent years, which may have had an impact on bicyclists' perceptions.

Although authorities are looking to understand the problem of bicycle theft through statistics, which for them would represent the true state of things, the perception of bicycle theft risk can become people's reality. Overall, perceptions act as a lens through which people view reality and influence how people understand, decide about, and act on reality. It is for this reason that it is interesting and useful for better decision making to incorporate the perception of bicycle theft risk in the analysis of cycling infrastructure preferences

Table 2
Cyclist victims in traffic crashes in 2018 per mode involved.

Involved mode	Victims		Injured	
	Number	%	Number	%
Pedestrian	0	0.0	25	1.2
Bicycle	0	0.0	32	1.5
Motorcycle	6	9.4	469	22.2
Car	8	12.%	667	31.6
Bus	16	25.0	347	16.5
Taxi	4	6.3	231	11.0
Truck	13	20.3	96	4.6
Object or Fall	9	14.1	116	5.5
+2 Actors	8	12.5	125	5.9
Total	64	100	2108	100

Table 3
Victim and theft characteristics.

Characteristic		Category	Frequency	%	Differences with Uniform distribution	
					χ^2	p
Victim	Gender	Female	975	18.7	2042.43	0.0000
		Male	4238	81.3		
	Age	Under 18	94	1.8	4107.72	0.0000
		18–29	2674	51.3		
		30–39	1418	27.2		
		40–49	615	11.8		
		Older than 50	412	7.9		
Theft	Day of the week	Monday	725	13.9	16.32	0.0122
		Tuesday	766	14.7		
		Wednesday	714	13.7		
		Thursday	772	14.8		
		Friday	824	15.8		
		Saturday	719	13.8		
		Sunday	693	13.3		
	Hour of the day	Daytime	2789	53.5	25.56	0.0000
		Nighttime	2424	46.5		
	Weapon	Knife	1866	35.8	3688.46	0.0000
		Firearm	381	7.3		
		No Weapon	2820	54.1		
		Other	146	2.8		

Table 4
Fractional factorial design.

Choice games	Blocks	Bike path at the sidewalk level		Bike lane at the road level			
		Travel time (min)	Adjacent motor vehicle traffic	Separation from motor vehicles	Travel time (min)	Trip end facilities	Adjacent motor vehicle traffic
1	1	20	Buses and trucks	Separators	20	None	Buses and trucks
2	1	30	Buses and trucks	Marked with a line	30	None	Only cars
3	1	20	Only cars	Marked with a line	30	Secure parking and lockers	Buses and trucks
4	1	20	Only cars	Separators	20	Secure parking	Only cars
5	1	30	Only cars	Marked with a line	30	Secure parking	Buses and trucks
6	1	30	Buses and trucks	Separators	20	Secure parking and lockers	Only cars
7	2	20	Only cars	Marked with a line	20	Secure parking	Buses and trucks
8	2	30	Buses and trucks	Separators	30	Secure parking and lockers	Only cars
9	2	20	Only cars	Marked with a line	20	Secure parking and lockers	Only cars
10	2	20	Buses and trucks	Separators	20	None	Buses and trucks
11	2	30	Buses and trucks	Marked with a line	30	None	Buses and trucks
12	2	30	Only cars	Separators	30	Secure parking	Only cars
13	3	20	Only cars	Separators	30	None	Only cars
14	3	30	Only cars	Marked with a line	20	None	Only cars
15	3	30	Buses and trucks	Separators	20	Secure parking	Buses and trucks
16	3	20	Buses and trucks	Marked with a line	30	Secure parking	Only cars
17	3	30	Only cars	Separators	20	Secure parking and lockers	Buses and trucks
18	3	20	Buses and trucks	Marked with a line	30	Secure parking and lockers	Buses and trucks
19	4	20	Buses and trucks	Separators	30	Secure parking	Buses and trucks
20	4	30	Buses and trucks	Marked with a line	20	Secure parking	Only cars
21	4	30	Only cars	Separators	30	Secure parking and lockers	Buses and trucks
22	4	20	Only cars	Separators	30	None	Only cars
23	4	30	Only cars	Marked with a line	20	None	Buses and trucks
24	4	20	Buses and trucks	Marked with a line	20	Secure parking and lockers	Only cars

and determine whether different individuals develop different perceptions, in order to enhance policy formulation.

4. Methodology

In order to better understand cycling infrastructure preferences, we integrated perceptions of cycling safety and bicycle theft risk into a hybrid discrete choice model. For this purpose, we constructed a face-to-face questionnaire, targeted at bicyclists in Bogota.

4.1. Survey

In 2018 we collected the data, contacting bicyclists in four city districts, namely Engativa, Kennedy, Puente Aranda y Suba. Respondents were selected randomly, in order to get a representative sample, by two researchers on each point. Surveys were conducted over the course of a normal week -no holidays-, at the end of October. After obtaining consent from each individual, we collected the following data: (1) stated preference data to estimate a discrete choice model in order to analyze the respondents' preferences of bicycle infrastructure, (2) a set of indicators regarding perceptions of cycling safety and bicycle theft risk in order to identify the latent variables, and (3) a set of socioeconomic variables, including gender, age, occupation, education level, socioeconomic strata, main transportation mode used to commute, number of cars and bicycles in the household, use of the bicycle, and bicycle price. These socioeconomic variables were used to account for the heterogeneity of individuals through the latent variables.

Our experimental design was developed based on the city policy, which focuses on adapting part of current motor vehicle infrastructure to increase the length and coverage of bicycle infrastructure at the road level. In line with the city objectives, through a binary stated preference experiment, respondents faced the typical bike path at the sidewalk level and the proposed bike lane at the road level. Underlying this experiment was the notion that the development of the new bicycle infrastructure at road level could be accompanied by secure parking and some trip end facilities.

Taking into consideration the individual expectations declared in focus groups, we selected the following attributes to design the stated preference experiment: travel time, adjacent motor vehicle traffic, separation from motor vehicles, and trip end facilities. Except for the trip end facilities, which were presented at three levels, all other attributes were designed at two levels. Specifically, separation from motor vehicles and trip end facilities were only considered for the bike lane at the road level. Finally, as shown in Table 4, the experiment consisted of six choice games per respondent, arranged in three blocks by using a minsum search in Ngene software (ChoiceMetrics, 2018). An example of a choice situation is shown in Fig. 2.

After facing the stated preference experiment, respondents rated the latent variables' indicators. As seen in Table 5, this part of the survey involved two sets of statements to measure the perceptions of cycling safety and bicycle theft risk. The statements were originally written in Spanish using short sentences so that respondents could easily understand them. Following the recommendations of Márquez et al. (2020), with the aim of estimating ordered models for measurement equations, we used an odd-numbered Likert scale ranged from "Strongly disagree" to "Strongly agree" on a 5-point scale.

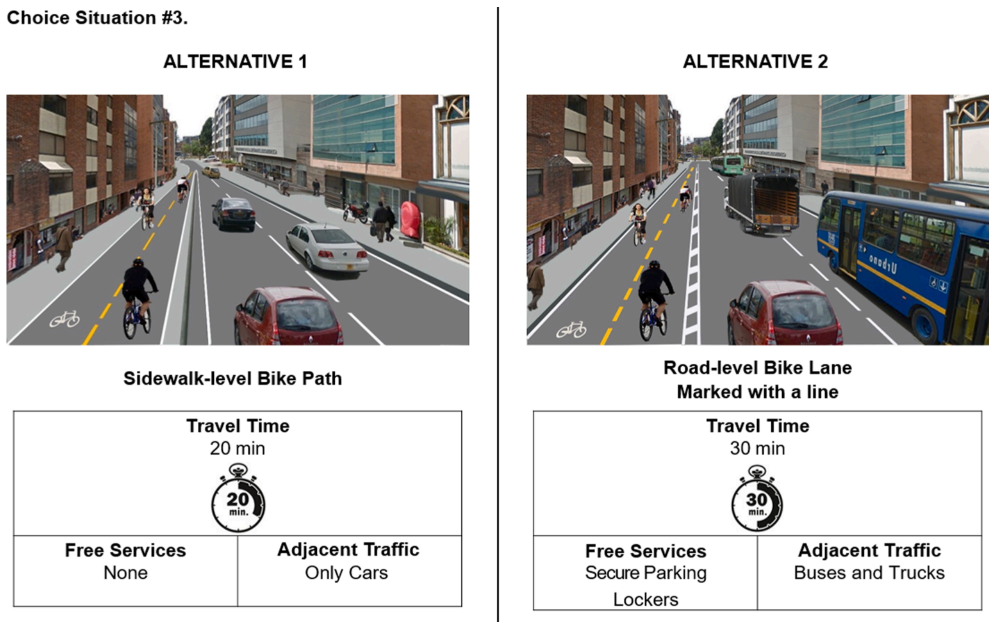

Fig. 2. Choice situation example.

Table 5
Latent variables and indicators.

Latent variable	Indicator	Statement
Cycling safety	CS1	Wearing safety equipment should be mandatory for cyclists
	CS2	I perceive motor vehicles as a safety risk for cyclists
	CS3	I perceive more safety when bicycle infrastructure is separated from traffic
Bicycle theft risk	BT1	I am at risk of bicycle theft when I travel alone
	BT2	Bicycle theft rates affect a greater use of the bicycle to commute
	BT3	I am at risk of bicycle theft when I travel in a group
	BT4	Cyclists are more exposed to theft than other users

Table 6
Profile of the sample and bicyclists' population in Bogota.

Variable	Category	Sample (%)	Population (%)
Gender	Male	79.7	75.8
	Female	20.3	24.2
Age	<25	37.7	34.2
	25–34	30.0	20.8
	35–44	12.7	16.7
	45–54	12.7	19.8
	55–64	4.7	9.1
	65>	2.2	2.4

4.2. Participants

The sample (N = 300) was compared with the bicyclist population in the city, in terms of gender and age, as can be seen in Table 6, in which the data from the official statistics were used as a reference (SDM, 2017). Our sample represents the existing gap between genders in relation to bicycling well enough. Likewise, the age of cyclists exhibited similar distributions both in the sample and population.

Additional characteristics of respondents are shown in Table 7. The distribution of the respondents' occupation is consistent with the main trip purposes in Bogota, where most daily trips are mandatory to work and study. Particularly, the importance of trips to work in Bogota is remarkable since they increased by about 1.5 million trips a year between 2011 and 2015 (SDM, 2019). The distribution of

Table 7
Additional characteristics of respondents.

Variable	Category	%
Occupation	Worker	52.00
	Student	21.50
	Other	26.50
Education level	Elementary or high school	43.33
	Technical	26.33
	Higher education	30.00
	Post-graduate	0.34
Main transportation mode used to commute	Public transportation user	16.32
	Car user	5.67
	Motorcycle user	3.67
	Bicycle user	73.67
	Other	0.67
Number of cars in household	0	61.67
	1	27.00
	2>	11.33
Number of bicycles in household	0	19.34
	1	40.33
	2>	40.33
Primary use of the bicycle	Daily use	59.66
	Tourist and recreational	27.67
	Sports	12.67
Bicycle price	Low cost	65.67
	Medium cost	24.00
	High cost	10.33

education level is representative of the four districts where we conducted the survey. The sample consisted mainly of bicycle users, as intended, with a share of 73.67%, followed by public transportation users with 16.33% and car users with 5.67%. The majority of households do not have cars, and a high percentage of households have one or more bicycles. In addition, 59.67% of the respondents use their bicycles daily, followed by tourist and recreational use with 27.6% and sports use with 12.67%.

4.3. Modeling approach

The study was based on the HDC modeling approach, which allows for the integration of latent variables into the systematic utility of alternatives. Recent international cycling research based on the HDC modeling approach has mainly studied the effect of safety perception and other latent variables (Ding et al., 2017; La Paix Puello & Geurs, 2015; Fernández-Heredia et al., 2016; Kamargianni & Polydoropoulou, 2013; Maldonado-Hinarejos et al., 2014; Rossetti et al., 2018). Some authors have also specified mixed latent variables including perceptions of safety and theft risk, such as comfort/safety (Yáñez et al., 2010) or concern about the risk of having a crash/ being robbed/ having a mechanical problem (Gutiérrez et al., 2020a), which behaved properly in the models.

We aimed at understanding the behavioral process that leads to the individual's choice among a bike path at the sidewalk level and another at the road level. Therefore, the outcome variable in our study is the individual's choice, which is not deterministic and cannot be predicted exactly. The preferences, which are represented by perceived utilities, are unobservable, but they are hypothesized to be a function of explanatory variables such as travel time, adjacent motor vehicle traffic, separation from motor vehicles, trip end facilities, and latent variables. In short, the individual's choice is the manifestation of the preferences.

When considering the HDC modeling framework, we postulated that individuals choose the alternative that maximizes their perceived utility. In addition to the previously mentioned experimental attributes, we considered two latent variables: perception of cycling safety and perception of bicycle theft risk, identified as important variables in our study context, providing a richer explanation of the choice process. Fig. 3 presents the overall structure of our model. As usual, model representation follows the convention that latent variables are shown in ovals, observable variables in rectangles, causal relationships by solid arrows, and measurement relationships by dashed arrows.

Our modeling approach assumes that latent variables are explained by people's socioeconomic characteristics, which do not vary between the alternatives so the latent variables cannot directly enter both utility functions due to identifiability issues. To deal with this, we tested different interactions among the latent variables and the experimental attributes, which do vary between the alternatives. After having tested several specifications we found that the interaction of the perception of bicycle theft risk and the alternatives' travel time was significant, as well as the interaction between the perception of cycling safety and the separation from motor vehicles. Consequently, the perception of cycling safety only entered the utility of bike lane at the road level because the separation

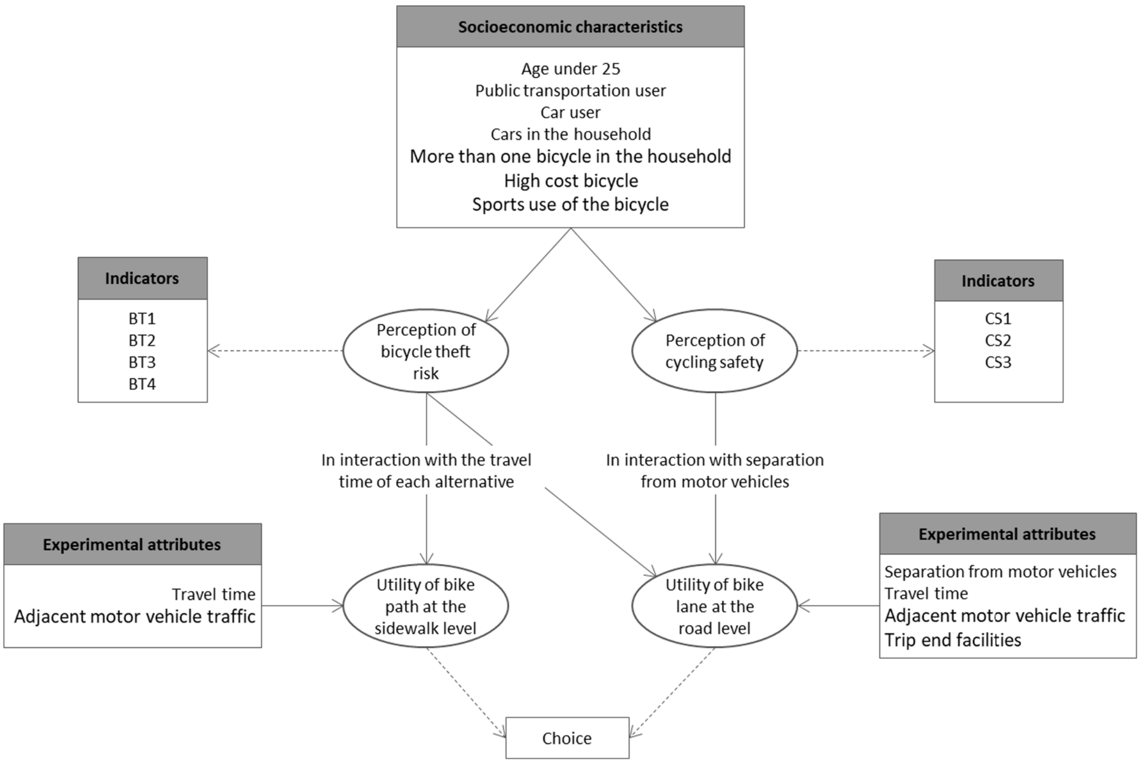

Fig. 3. HDC model specification.

from motor vehicles is an experimental attribute that was only present in the bike lane at the road level alternative.

We included the perceptions of cycling safety and bicycle theft risk into a multiple indicators multiple causes model (MIMIC), which is a singular case of structural equation model. The MIMIC is comprised of two sets of equations: measurement equations, which link the latent variables and their indicators; and structural equations, which relate the causal effects among explanatory variables and latent variables. Specifically, we defined two structural equations in which each latent variable is hypothesized to be a function of the socioeconomic characteristics of individuals and an error term, as seen in (1).

$$\eta_{lq} = \sum_r \alpha_{lr} \cdot S_{rq} + \upsilon_{lq} \tag{1}$$

Where,

η_{lq}: is the latent variable l for individual q.
S_{rq}: is the socioeconomic characteristic r for individual q.
α_{lr}: are parameters to be estimated.
υ_{lq}: are error terms normally distributed with mean zero.

The measurement equations were specified as ordered logit models (Daly et al., 2012), in which each response k observed is obtained from the latent variables plus an error term through a censoring mechanism according to (2) and (3).

$$C_{pq} = \begin{cases} 1 & if(-\infty) < C^*_{pq} \leq \tau_{p1} \\ 2 & if \tau_{p1} < C^*_{pq} \leq \tau_{p2} \\ \vdots & \vdots \\ K & if \tau_{p(K-1)} < C^*_{pq} \leq \infty \end{cases} \tag{2}$$

$$C^*_{pq} = \sum_l \gamma_{lp} \cdot \eta_{lq} + \zeta_{pq} \tag{3}$$

Where,

C_{pq}: is the categorical response in the indicator p for individual q.
τ: are the thresholds to be estimated.
γ_{lp}: parameters to be estimated
ζ_{pq}: are the error terms that follow a logistic distribution

The probability of observing C_{pq} within a response k, can be written as (4)

$$P\{C_{pq} \in k | \eta_q\} = \frac{1}{1 + e^{-\left(\tau_{pk} - \sum_l \gamma_{lp} \cdot \eta_{lq}\right)}} - \frac{1}{1 + e^{-\left(\tau_{p(k-1)} - \sum_l \gamma_{lp} \cdot \eta_{lq}\right)}} \tag{4}$$

Where,

$$\tau_{p0} = (-\infty)$$

$$\tau_{pK} = \infty$$

According to our stated preference experiment, we specified the experimental attributes and the latent variables in two utility functions, as indicated in (5) and (6).

$$U_{1qt} = ASC_1 + \sum_k \theta_k X_{k1qt} + \beta_{BT} \eta_{BTq} X_{TT1qt} + \varepsilon_{1q} \tag{5}$$

$$U_{2qt} = ASC_2 + \sum_k \theta_k X_{k2qt} + \beta_{BT} \eta_{BTq} X_{T2qt} + \beta_{CS,M} \eta_{CSq} X_{M2qt} + \beta_{CS,S} \eta_{CSq} X_{S2qt} + \varepsilon_{2q} \tag{6}$$

Where,

U_{1qt}: is the utility function for the bike path at the sidewalk level, for individual q, and situation t.
U_{2qt}: is the utility function for the bike lane at the road level, for individual q, and situation t.
ASC_1: is the specific constant for the bike path at the sidewalk level.
ASC_2: is the specific constant for the bike lane at the road level.
X_{kiqt}: is the experimental attribute k of alternative i, for individual q, and situation t.
X_{Tiqt}: is the travel time of alternative i, for individual q, and situation t.

X_{M2qt}: is the separation from motor vehicles marked with a line of the bike lane at the road level, for individual q, and situation t.
X_{S2qt}: is the separation from motor vehicles with separators of the bike lane at the road level, for individual q, and situation t.
η_{BTq}: is the perception of bicycle theft risk for individual q.
η_{CSq}: is the perception of cycling safety for individual q.
θ_k, β_l: are parameters of utility equations to be estimated.
ε_{iq}: are error terms, which are assumed to be independent and identically distributed extreme value type I.

The choices were expressed as a function of the utilities, according to (7).

$$y_{iqt} = \begin{cases} 1 & U_{iqt} \geq U_{jqt} \\ 0 & otherwise \end{cases} \tag{7}$$

Where,

y_{iqt}: is the choice of alternative i for individual q and situation t.
U_{iqt}: is the utility function of the alternative i, for individual q, and situation t.

5. Results and discussion

We estimated two models. The main model is an HDC model, in which the perception of cycling safety entered the utility function of the path at the road level directly and the perception of theft risk entered the two utility functions in interaction with the alternatives' travel time. Due to identification issues, the variance of the structural equations was set to one, and the specific constant for the bike path at the sidewalk level (ASC_1) was set to zero. For comparative purposes, we also estimated a mixed logit (ML) model, in which only experimental attributes and correlation among respondents' observations were considered. The parameters of the two models were estimated simultaneously in Ox 7.1 (Doornik, 2015), using maximum simulated likelihood with 1000 MLHS draws (Hess et al., 2006).

Although indicators are only helpful in model identification, we showed the estimated parameters of the measurement equations in the Appendix. In examining the results, only the evaluation of the adequacy of the approach can be done, as these equations show the relationship between the latent variable and the indicators. In that order, the orientation of the indicators is appropriate, as expected. Furthermore, between adjacent thresholds, the majority of them are significantly different from zero, which confirms that the proposed ordered model adequately represents the nature of the indicators' responses.

The CS1 indicator produced the strongest weight estimate in the cycling safety perception measurement equation, confirming that it adequately reflects the latent variable. Although we worded the statement of this indicator as emerged from the focus groups, we consider that it could have been written using a personal and active statement, in the same way as for the rest of indicators with whom the latent variable was identified. We make this comment to the extent that wording could be adjusted in future research.

5.1. Relationships between explanatory variables and perceptions

Table 8 shows the results of the structural equations from the HDC model. According to the results of the perception of cycling safety, young people (<25) are less concerned about this latent variable. This is in line with literature findings which show that perception of risk in cyclists increases with age (Gutiérrez et al., 2020b), and younger cyclists have more likelihood of belonging to a segment who has low fear of traffic (Rossetti et al., 2018). This contributes to confirming that young people are less risk-averse in various contexts, like pedestrian crossing (Cantillo et al., 2015), choice of parking (Soto et al., 2018), given that they have a higher likelihood of transgression of road rules (Stefanova et al., 2018). In addition, modeling results showed that the higher the rate of vehicles per person in the household, the lower the concern for cycling safety of the respondent. This could be related to a lower willingness to use the bicycle as the number of cars in the household increases (Gutiérrez et al., 2020b).

In relation to the perception of bicycle theft risk, as the rate of cars per person increases, the latent variable decreases. This is also related to the lower use of bicycles among car users in Bogota (Cervero et al., 2009). Theft is such a widespread problem in the city that it is difficult to find significant differences in the perception of bicycle theft risk among population segments. However, when

Table 8
Estimated parameters of the MIMIC model.

Explanatory variables	Cycling safety		Bicycle theft risk	
	Estimate	Rob *t*-test	Estimate	Rob *t*-test
Age under 25	−0.306	−2.16	−0.105	−0.71
Public transportation user		0.303	1.64	
Car user	0.830	2.97		
Cars in the household	−0.967	−4.05	−0.570	−2.64
More than one bicycle in the household	0.127	0.76		
Sports use of the bicycle		0.488	1.89	
Daily use			0.277	1.60

controlling by bicycle usage, considering tourist and recreational use of the bicycle as the baseline, the results of the structural model show, with a confidence of 94.1%, that people who are sport users tend to be more concerned about bicycle theft. Furthermore, in comparison with users of other means of transportation, at a level of significance of 0.1, public transportation users are more concerned about bicycle theft risk, possibly because captive users (Márquez et al., 2018), being lower-income people, are more exposed to theft than other types of users.

Unlike the results presented by Mosquera et al. (2012), who had shown that females felt more vulnerable to theft while cycling than male participants, the estimated parameters of the MIMIC model do not show significant differences by gender, which suggests that, at the present time, both men and women perceive the risk of bicycle theft in the same way. This is an interesting finding because, although men take three times as many bicycle trips as women, perceptions of cycling safety and bicycle theft risk are now aligned by gender, which supports the idea that bicycle theft is such a widespread problem in the city.

5.2. Integrating perceptions into the choice model

Table 9 exhibits the estimates of the two discrete choice models, which considered a panel effect as the standard deviation of a normally distributed alternative specific constant, to incorporate the correlation among responses of each individual. As usually, the HDC model outperforms the ML model (Ding et al., 2017). The number in curly brackets indicates the utility function in which the variable was specified: {1} Bike path at the sidewalk level and {2} Bike lane at the road level. According to the estimated specific constant, it is suggested that *ceteris paribus,* the preferred alternative is bike lanes at the sidewalk level, which is in line with the findings of Caulfield et al. (2012) who showed that segregated facilities from traffic are the preferred form of cycling infrastructure. At the road level, bike lanes protected by separators are preferred against bike lanes marked with a painted line. This order of preferences also can be found in the literature by Rossetti et al. (2018), who showed that the bike lane at the sidewalk level has the highest utility among infrastructure options.

All of the experimental design attributes were highly significant in the utility functions, with appropriate signs according to the microeconomic theory and the literature (Heinen et al., 2010; Hunt & Abraham, 2007; Menghini et al., 2010; Tilahun et al., 2007; Wardman et al, 2007). In that sense, the travel time negatively affects the utility, as expected, and the absence of buses and heavy vehicles in the traffic has a positive impact. Furthermore, having trip end facilities positively impacts the utility, therefore, the lower preference for bike lanes at the road level could be compensated by implementing secure parking as well as secure parking and lockers as desirable trip end facilities.

As studies based on similar modeling approaches have shown (Soto et al., 2018), the interactions among latent variables and objective attributes imply that if individuals change their perceptions, they may perceive some alternatives' attributes differently. In our case, the negative sign of the interaction between the perception of theft risk and the alternatives' travel time reflects that a higher concern for theft gives more weight to the travel time on the utility function. In other words, if a bicyclist is highly concerned about theft risk and mugging while traveling on his/her bicycle, the travel time is much more important for him/her. This result is in line with the findings of Hardinghaus & Papantoniou (2020), who found that people in Greece are significantly more willing to accept longer travel times in return for better environment of the cycling infrastructure.

The specification of the perception of cycling safety in the model could be interpreted as an interaction with a dummy variable that represents the type of infrastructure. As well as we designed the experiment, one alternative is at sidewalk level and the other alternative is at road level separated by painted line or physically by separators. Then, the latent variable was estimated only on the alternative 2, which allowed the model to be identified, by setting to zero the interaction of sidewalk level. With this in mind, the greater cycling safety concerns, the lower the utility of road level bike lanes marked with a line, but greater utility for bike lanes at the road level with separators from traffic, which means that cyclists concerned about safety prefer more protected and physically

Table 9
Estimated parameters of the choice model.

Variable	ML		HDC	
	Estimate	Rob *t*-test	Estimate	Rob *t*-test
Specific constant for bike lane at the road level {2}	−0.804	−4.19	−0.860	−3.05
Separation marked with a line {2}	−1.941	−9.43	−2.498	−8.04
Travel time {1,2}	−0.053	−5.56	−0.040	−1.81
Absence of buses and heavy vehicles in the traffic {1,2}	0.312	3.33	0.362	3.21
Secure parking {2}	0.883	5.42	1.113	5.80
Secure parking and lockers {2}	1.101	6.64	1.380	6.92
ASC Standard Deviation {1,2}	−2.289	−12.85	−2.818	−11.47
Perception of cycling safety * Separation marked with a line{2}			−0.733	−1.60
Perception of cycling safety * Separation with separators {2}			1.016	2.02
Perception of bicycle theft risk * Travel time {1,2}			−0.104	−4.44
Number of estimated parameters	7		10	
Number of Observations	1800		1800	
Number of Respondents	300		300	
Log-likelihood			−3637.47	
Log-likelihood for choice component	−960.57		−940.01	
Likelihood ratio test with respect to ML			41.12	

separated paths from traffic and pedestrians, with infrastructure at the road level. This confirms studies that analyze cycling risk at sidewalk level, which show that risk is increased for cyclists (Reynolds et al., 2009; Aultman-Hall & Kaltenecker, 1999; Aultman-Hall & Hall, 1998) and that more experienced bicyclists prefer to cycle at road level (Rossetti et al., 2019).

5.3. Implications for policy

Although developing infrastructure with high cycling priority is an effective measure to promote bicycle use in cities (Meng et al., 2014), cycling infrastructure is the most expensive element of urban cycling policy and possibly, for this reason, the city policies focus on adapting part of current motor vehicle infrastructure to increase the length and coverage of bicycle infrastructure at the road level. However, if the main investments are made on bike lanes at the road level, as it has been lately, some hard and soft measures must be considered in order to motivate people to use this bicycle infrastructure. In this connection, the aforementioned results are valuable to authorities in order to motivate individuals to use this type of bicycle infrastructure. Clearly, encourage the use of bike lanes at the road level should go hand in hand with public policies and infrastructure investment.

According to our results, people would prefer bike paths at the sidewalk level over bike lanes at the road level. However, bicyclists would be more willing to use bike lanes at the road level if separators are provided and trip end facilities such as secure parking and lockers are implemented. Since most trips are made to study and work, collaborative measures can be adopted in which the authorities invest in bike lanes at the road level with separators and the educational centers and employers offer secure parking and lockers. Instead of continuing to invest in the main corridors, the authorities could also develop new bicycle infrastructure on minor roads, preferably where there is no presence of buses and heavy vehicles in the traffic.

Modeling results also showed that concerns about safety are a significant deterrent to using bike lanes at the road level in the city when separation from traffic is a painted line. Overall, bike paths are chosen by risk-averse people and bike lanes with separation from traffic by people with safety concerns. Therefore, in addition to providing bike lanes at the road level with separators, authorities should take action to diminish the number of traffic crashes involving cyclists to try to improve their perceptions of bicycle safety. Improving the perceptions of the risk posed by motor vehicles will further encourage bicyclists to use bike lanes at the road level. In this specific case, campaigns should consider people's age, which emerged as a socioeconomic characteristic that influences the willingness to use this type of bicycle infrastructure.

In order to encourage bike lane use, one set of hard measures needs to consider cycling safety, providing bike lanes with protection from traffic, especially on roads with the presence of heavy vehicles and buses. Painted separation from traffic would not encourage cycling and it is better to use separators, to avoid lane invasion and to provide a higher sense of safety on the road. Although not considered in this study, other types of separators could be used, in order to enhance the sensation of physical separation from the traffic, such as separated bike paths.

To promote cycling in the city, there is also a need to improve crime rates, to reassure users' confidence, and to lower fear of bicycle theft. This could have a direct impact on the willingness to use the bicycle for longer periods, which means lengthier trips and a higher reach for bicycle trips, potentially increasing the cycling share on the city's modal split. At the same time, although the perception of bicycle theft risk is general among the population, soft measures regarding fear of bicycle theft perception should be developed, mainly focused on people who are sport users as well as public transportation users, who tend to have a higher perception of bicycle theft risk.

Finally, there are two findings that calling on the authorities to take urgent measures regarding bicycle theft. In the first place, we showed that if a bicyclist is highly concerned about theft risk, the weighting of his / her travel time is higher, which implies a loss of well-being. Secondly, the fact that perceptions of bicycle theft risk did not show significant variations among different population segments, which implies that bicycle theft is a widespread problem in the city from the users' point of view. Most interestingly about this second finding is that people's perceptions are aligned, possibly close to reality, so the actions that authorities take to mitigate this problem will be well received by the majority of people, who apparently have a consensus regarding the perception of bicycle theft risk.

6. Conclusions

Brand new cycling infrastructure is a successful policy in order to encourage bicycle use. However, it is a relatively expensive policy in comparison to repurposing existing vehicle infrastructure to bicycle users. In Bogota, a bike-friendly city, where a high risk of bicycle theft and traffic crashes fatalities are a real concern, bicycle infrastructure investment has been recently focused on bike lanes at the road level as well as the relocation of the busiest bike paths from the sidewalk to the road. However, concerns over safety and bicycle theft, which can be highly important for people in deciding to bicycle, have not been researched enough. The present investigation integrated the perceptions of cycling safety and bicycle theft risk into an HDC model in order to better understand cycling infrastructure preferences in Bogota, accounting for attributes related to travel time, traffic type, and trip end facilities.

Integrating perceptions of cycling safety and bicycle theft risk in the analysis of cycling infrastructure preferences was useful to better understand bicyclists' decisions and enhances policy analysis. Our modeling approach also allowed us to propose hard and soft measures to encourage bicyclists to use bike lanes at the road level. According to the results, people would prefer bike paths at the sidewalk level over bike lanes at the road level. However, bicyclists would be more willing to use bike lanes at the road level if separators are used and trip end facilities are provided. In that order, in addition to providing bicycle infrastructure itself, collaborative measures can be adopted with educational centers and employers to offer trip end facilities and developing new bicycle infrastructure on minor roads, with no presence of heavy traffic.

The interaction between the perception of cycling safety and the type of separator from motor vehicles we specified in the utility function of bike lanes at the road level allowed us to consider the effect perception of cycling safety has on bicycle infrastructure's preferences. Modeling results showed that the greater bicycle safety concerns the greater the utility of the bike lanes with separators and the lower the utility of bike lanes with separation marked with a line. This confirms, in terms of safety, the preference for a physically separated bicycle infrastructure from traffic and pedestrians. Although the decision about which type of bicycle infrastructure to build is not evident, our findings suggest that bike lanes at the road level with separators have the potential to motivate car users to adopt bicycling as a mode of transportation since these users do have a positive perception of cycling safety.

Bicycle theft risk, although less studied in the literature, is a significant deterrent to cycling adoption and a common problem worldwide. In this study, we considered the effect of the perception of bicycle theft risk in interaction with infrastructure alternatives' travel time. Overall, we found that bicycle theft fear increases the value or importance that bicyclists place on travel time, which makes the use of the bicycle even less attractive, especially for long trips regardless of the type of infrastructure. In this sense, our final recommendation for authorities is to improve crime rates, to reassure users' confidence as needed, and, thereby, encourage longer bicycle trips.

Our findings are valuable to authorities in order to motivate people to use bicycle infrastructure at the road level. The methodological approach used in this study could be applied in other cities interested in developing bicycle infrastructure, especially if in such cities there are concerns regarding road safety and bicycle theft, which are two factors that discourage cycling. Although we do not study it in this paper, an important issue is the effect of the built environment on the perception of bicycle theft risk. We suggest further research on this area, especially in developing countries where the demand for transportation must be dealt with sustainably.

Data availability statement

The data used to support the findings of this study are available from the corresponding author upon request.

CRediT authorship contribution statement

Luis Márquez: Conceptualization, Writing - original draft, Methodology, Data curation. **Jose J. Soto:** Formal analysis, Writing - review & editing, Software.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix. Estimated parameters of the measurement equations

Latent variable	Indicator		Estimate	Threshold			
				1	2	3	4
Cycling safety	CS1	Coefficient	−4.407	−2.755	−1.674	0.277	−3.411
		Robust *t*-test	−7.13	−6.45	−4.83	1.01	−8.78
	CS2	Coefficient	−1.728	−0.975	1.009	1.878	0.865
		Robust *t*-test	−6.19	−4.08	4.63	3.57	4.12
	CS3	Coefficient	0.689	1.171	1.437	1.413	0.946
		Robust *t*-test	4.05	4.52	3.9	4.46	4.25
Bicycle theft risk	BT1	Coefficient	−4.176	−3.417	−2.575	0.004	−3.025
		Robust *t*-test	−6.3	−6.05	−5.5	0.01	−8.92
	BT2	Coefficient	−1.289	−0.196	1.344	−3.725	−2.342
		Robust *t*-test	−5.53	−1.02	7.04	−9.64	−10.14
	BT3	Coefficient	−1.619	0.329	−3.595	−1.864	−0.756
		Robust *t*-test	−8.45	1.95	−9.03	−6.76	−3.21
	BT4	Coefficient	1.007	−3.873	−2.882	−1.892	0.038
		Robust *t*-test	4.36	−7.63	−6.61	−5.29	0.14

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