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The role of habit and the built environment in the willingness to commute by bicycle

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ABSTRACT

We study the willingness of citizens to change from their habitual mode of transport to cycling, in the case of routine trips to work or study during the morning peak in Santiago, Chile. For this, we designed a relatively complex survey, including information about the current mode, preferences of respondents, indicators of perception, habits, and a question about their willingness to change mode. We used a sample of 805 individuals to estimate a hybrid ordinal logit model. This model included individuals' socio-demographic variables, characteristics of the built environment, and the trip, as well as three latent constructs: *spontaneity* towards changing mode of transport; perception of *risk* regarding bicycle use; and *availability of cycling-related facilities* when using bicycles. The model confirms previous expectations; for example, the willingness to change to cycling diminishes with the length of the trip and with the age of the individual; also, people more habituated to their current mode are less willing to change it. In terms of public policy, the model provides several insights regarding incentives for using bicycles, including the need for structural changes to diminish the latent perception of insecurity held by less experienced cyclists.

1. Introduction

Bicycle use for daily travelling has taken on increasing interest in recent years. The advantages of using a bicycle instead of a car, such as economic savings, time savings (especially in highly congested cities), health improvement (as a result of an increase in daily physical activity), among others, make cycling an increasingly attractive option for urban trips. Despite these advantages, most journeys in Latin American cities are made by motorized modes, although some cities are showing an increasing trend in bicycle usage. For example, Bogotá is the city with the highest percentage of bicycle trips with almost 7% (Alcaldía de Bogota, 2019), followed by Santiago de Chile 4% in 2012 (SECTRA, 2015) but increasing strongly, while Buenos Aires and Rio de Janeiro have about 3% of their trips made by bicycle. The rest of the capital cities in Latin America have percentages of less than 2% as of 2015 (Rios et al., 2015) and there are no official statistics available for their current situations.

For the case of Santiago, although 4% of the total trips per day (in 2012) may appear as a rather small amount, it is still a significant number of journeys (around 750,000), practically the same as those made by car along the tolled urban highways within the city in the same year. On the other hand, the number of trips by bicycle doubled between 2001 and 2012, making cycling the fastest growing transport mode in that period (Muñoz et al., 2016). Finally, a recent report by a company that counts bicycle trips along cycleways in several countries around the world highlights Chile as one of the countries that have experienced the highest increase in the number of cyclists between 2017 and 2018 (Eco-Counter, 2019). The latter is coherent with some preliminary estimates indicating cycling currently represents about 8% of daily trips in Santiago (Ministerio del Medio Ambiente de Chile, 2018). This increase could be the result of various factors, including:

1) Changes in cycling-inclusive infrastructure within the city over the past five years (Sagaris and Ortúzar, 2015), including more kilometres of cycleways (although of questionable quality), bicycle parking in central areas of the city, and the introduction of public (shared) bicycle services, among others;
2) Increase in vehicular congestion (mainly due to higher car usage), even though, according to the latest travel survey (SECTRA, 2015), more than half of all trips by car have a length below 5 km, a nearly

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perfect distance to cycle.

3) Overcrowding in public transport, primarily in the Metro services, during peak traffic hours (Batarce et al., 2016; Tirachini et al., 2017);
4) Location of most job centres (i.e., trip destinations during the morning peak) along approximately 9 km of the city's main avenue (known as Alameda-Providencia), making Santiago a relatively monocentric city (Suazo-Vecino et al., 2020); and
5) Growth in food delivery services using motorcycles and bicycles, which among the four applications currently used in Santiago, employ over 3,000 delivery drivers, of which a significant number are immigrants[1] (Riveros, 2018).

Although attractive for many reasons, the shift towards active modes of transport such as the bicycle is complex from an individual perspective (de Vos et al., 2019). Bicycles are more exposed to the elements, are perceived as more vulnerable to traffic accidents, and require a non-negligible degree of physical effort. These are apparent barriers towards attracting new users (Fernández-Heredia et al., 2014; Handy et al., 2014) but even stronger in highly motorized cities that can be hostile to non-motorized modes (Loo and Tsui, 2019; Loo et al., 2019). The latter is the case for most Latin American cities, although some of them (like Santiago) have been able to increase the number of bicycle trips, despite relatively poor conditions. Understanding why users switch to cycling in those conditions is relevant to inform public policy, especially for cities where cycling infrastructure often comes late and with a standard far from those observed in more cycling-friendly cities.

In this paper, we explore the hypothesis that developing adequate conditions is necessary, but not enough to make motorized transport users switch to bicycle usage. Instead, there must also be a willingness to at least explore this alternative, and break the habit associated with using the current transport modes (Ogilvie et al., 2004; Cantillo et al., 2007). As habit formation reinforces over time, especially within a context of overall stability (Gardner, 2009), daily work-related trips (taken at similar times on every workday) tend to be considered habitual behaviour (Cherchi and Cirillo, 2014; Cherchi et al., 2017). In this context, the transport mode used daily tends to become the most attractive alternative, requiring nothing more than an automatic decision-making process (Verplanken et al., 1997; de Bruijn et al., 2009). Thus, the willingness to explore alternatives may be measured by differing levels of the perceived feasibility of commuting by bicycle. This willingness (or lack thereof) could be affected by personal, perceptual, or attitudinal factors, along with those related to the built environment and of the trip itself (Sottile et al., 2019; Janke and Handy, 2019; Stefansdottir et al., 2019).

We conducted a survey in Santiago de Chile, where, among other questions, we asked respondents about their current trip to work or study, and their willingness to do it by bicycle. We used 805 responses of current non-bicycle users to estimate a hybrid choice model for the willingness to commute by bicycle, as a function of built environment and socioeconomic attributes, as well as three latent variables: one related to spontaneity/habit, another related to cycling perceived safety and the last one related to the perceived relevance of cycling-related facilities. Our paper contributes to the literature by exploring the role played by current mobility habits in the willingness to explore cycling as an option.

The rest of the paper is organized as follows. Section 2 presents a state-of-the-art summary in terms of the use of latent variables in choice modelling, mainly attitudes, perception, and the role of habit. Section 3 describes the methodology used for designing the instrument and its posterior implementation, followed by a brief explanation of the theoretical basis underpinning the models used. A brief context of the case study and the main characteristics of Santiago is given in Section 4, while section 5 contains a description of the data gathered. Section 6 presents the model estimation and our main results. Finally, we discuss the principal conclusions and public policy recommendations of our research in Section 7.

2. Literature review

In recent years there has been a plethora of research on bicycle use as a sustainable mode of transport. For example, studies on how to provide incentives for and increase bicycle use through policies and interventions in infrastructure and the built environment (Cervero et al., 2009; Aarts et al., 2013; Muhs and Clifton, 2014; Oliva et al., 2018; Orozco-Fontalvo et al., 2018), and or legal interventions such as programs with incentives for cycling to work, reducing the speed limits of motorized vehicles (Bauman et al., 2008), applications involving the recreational use of bicycles on weekends (Cervero et al., 2009), and for discouraging the use of cars for daily trips (Graham-Rowe et al., 2011).

On the other hand, the importance of non-observed constructs, typically formulated as latent variables, has been increasingly mentioned in the bicycle choice literature. Some of the most frequently used factors cited as having significant roles in choice behaviour fall in the categories of attitudes and perceptions. *Attitudes* are defined as latent (non-measurable) characteristics that are specific to each individual, and *perceptions* are associated with latent attributes specific to a particular alternative (Bahamonde-Birke et al., 2017).

2.1. Attitudes and perceptions

Muñoz et al. (2016a) present a detailed review of different ways to incorporate perceptual indicators and latent variables into models of bicycle use, including the type of model. Several studies show that the most significant latent variables include: *safety/risk*, *comfort*, *convenience,* and *bicycle riding skills* (Paige-Willis et al., 2013; Maldonado-Hinarejos et al., 2014; Muñoz et al., 2016b). Notwithstanding, only five from 54 studies use a hybrid latent variable mode choice model (Kamargianni & Polydoropoulou, 2013; Fernández-Heredia et al., 2014; Habib et al., 2014; Maldonado-Hinarejos et al., 2014; Kamargianni et al., 2015).

Research on the effects of the *perceived risks* associated with using bicycles in cities shows different ways in which this variable may affect choice decisions. Most studies confirm the obvious: sharing roads with motorized vehicles is perceived as riskier than using bicycle-exclusive or protected lanes (Chataway et al., 2014; Maldonado-Hinarejos et al., 2014; Sottile et al., 2019). Further, Rossetti et al., 2018 show the vital role played by the design of adequate bicycle infrastructure and that perceived risk is relatively heterogeneous across individuals. Finally, Habib et al. (2014) explore how improved levels of perceived safety can increase the "bikeability" of a city and the perception of comfort when using bicycles; they show that it can also heighten awareness about the positive effects of choosing a bicycle for compulsory trips. These studies have not identified whether women are less risk-prone than men, which is something we attempt to do in this work.

On the other hand, research based on measures adopted to provide incentives for bicycle use (or diminish car usage) and evaluate their effectiveness over time, has shown that just implementing structural changes (i.e., better infrastructure for bicycles) is not enough to increase bicycle use significantly (Wilmink and Hartman, 1987; Ogilvie et al, 2004). For this, it would be necessary to complement such measures with behavioural change strategies, which can be better informed by models accounting for attitudes and perceptions. In this line, research on health, seeking to increase daily exercise to improve physical and general health and wellbeing, has identified behavioural changing techniques that appear to be effective over time (Graham-Rowe et al., 2011; Bird et al., 2013; Arnott et al., 2014). Such research also shows

[1] According to statistics of the Department of Immigration, over 800,000 visas have been granted recently to foreigners living in Chile.

that structural changes can indeed encourage the use of the bicycle. However, it also shows that coordinated actions to promote organizational changes, changes in individual and social behaviour, and the implementation of environmental measures, together with the structural improvements (Wardman et al., 1997), can provide a solid basis for developing pro bicycle use policies (Department for Transport, 2011). We consider the importance of structural improvements under the light of its variance concerning genre and the socioeconomic characteristics of the potential bicycle users.

2.2. Habit

The role of *habit* in bicycle choice has certainly been less explored. In the field of health psychology, habit is defined as "*a process by which a stimulus automatically generates an impulse towards action, based on learned stimulus-response associations*" (Gardner, 2015). We take this definition to formulate and estimate models that allow for detecting habit in a latent variable modelling framework.

Paige-Willis et al. (2013) review research that includes the social environment related to choosing the bicycle, in addition to the perceptions, attitudes and even the habit or inertia associated with using bicycles (de Bruijn et al., 2009; Heinen et al., 2011; Ducheyne et al., 2012; Muñoz et al., 2013; Cabral et al., 2018). However, these studies do not consider the effect of the inertia associated with using other transport modes (Cantillo et al., 2007), and how this might affect a potential change to bicycle usage. In this investigation, we try to incorporate habit as a measure of the resistance to change towards the bicycle.

Measuring habit varies with the field of study, and the theory underpinning the phenomenon (Verplanken et al., 1997; Schwanen et al., 2012; Hagger et al., 2015). Here we adapt a sub-scale of the *Self-Report Habit Index* (SRHI) proposed by Verplanken & Orbell (2003) and studied by Gardner et al. (2012). We present four of the 12 items of the SRHI, to capture elements related to the automaticity of habit, in addition to context (daily trips to work/study) and time of day (Gardner, 2015). We are aware that measuring habit is not a simple task and that it is undoubtedly a more complicated process than what we can replicate in the context of our research. For this reason, we approach habit (in this case associated with the mode currently used by each individual) as a latent construct integrated into the utility function, in a way similar to how we treat individual attitudes and perceptions.

3. Methodology

We performed an in-depth literature review to identify psychological, social, economic, environment-related, and trip-related factors that might affect the choice of bicycle as a transport mode. An initial draft of our survey form was developed based on these factors and presented to a focus group. Based on the information from the focus group, a second draft was designed and applied in two pilot surveys to test the clarity of the questionnaire and to ensure that it adequately captured the information that we would use later for model estimation. We applied the final survey instrument via the web. Fig. 1 presents a flow chart of our complete methodology.

3.1. Focus group

A focus group was held with nine participants with varying profiles, including an immigrant (to consider the perceptions of this growing segment of the population), and conducted by an expert psychologist. The group attempted to represent the diversity of potential bicycle users, considering: frequency of use (non-users, occasional users, and frequent users), age, gender, the alternative used (car, Metro, bus, shared taxi), and total distance travelled (round trip). After applying the questionnaire, we asked participants about their general understanding of the survey. Finally, we asked them about the perception of "habituality" towards their current mode and the definition of habit from their viewpoint.

Among the reasons provided for not regularly using a bicycle, the most relevant variables included the fear of being robbed, the need to transport children, the risk of being in an accident due to lack of cycleways (safety concerns related to sharing the road with cars), lack of secure bicycle parking areas near their destinations, and the inexistence of showers or comfortable places to change clothes at their places of work/study. It is interesting to point out that the low economic cost of cycling, which is far less costly than other transport modes in Santiago, was not mentioned as a relevant variable.

Another critical issue explored in the focus group was the concept of "habituality" associated with the participants' current transport mode. Respondents expressed that they did indeed feel habituated to their usual transport mode. Habit appeared as a behaviour that occurred almost automatically or unconsciously. All participants responded affirmatively to a statement indicating that sometimes they made their trips without thinking about it and that they tended to take the same route by mistake, even when going to a different destination. The information collected in this focus group served to design psychometric indicators and to validate the questionnaire regarding the characteristics of the trip.

3.2. Survey design

The survey instrument considered three stages. In the first, we characterized the respondents, including trips to work or study, and willingness to use a bicycle for those trips. The second stage consisted of a stated choice (SC) survey, which was only presented to users who declared using car, bus, metro or taxi. The third stage included psychometric indicators associated with the potential habit associated with their current transport mode, perceptions regarding bicycle use, and attitudes towards the environment. In this paper, we explore the results obtained from data related to the first and third parts of the survey. Annex 1 shows the 29 indicators presented (on a 5-point Likert scale) to participants in the study grouped by habit, attitudes, perceptions, and obstacles against bicycle use.

To characterize respondents, we enquired for their household

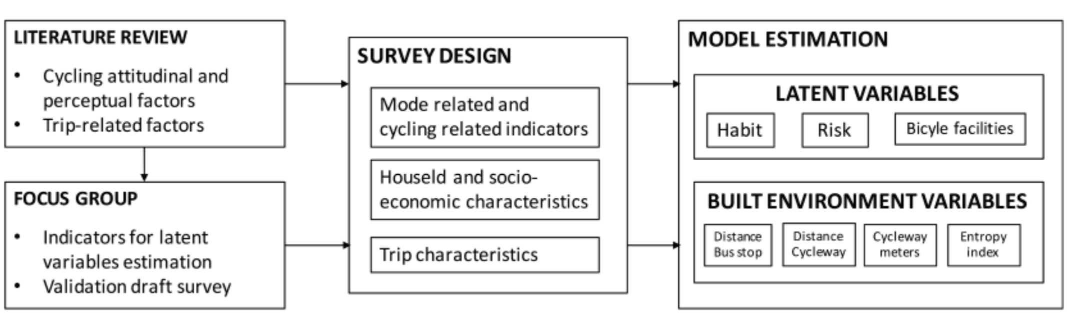

Fig. 1. Methodological flow chart.

characteristics, socio-economic information, and, finally, if they knew how to ride a bicycle. Afterwards, we asked them about the basic features of their daily trips to work or study. A map of Santiago (based on an interactive map API by Google) was displayed, and respondents asked to mark the points of origin and destination of their trips, to obtain the coordinates for both locations. We also asked the time their trip began, the time of arrival at the destination, and the transport mode (s) used along the way. This was followed by questions regarding relevant characteristics of the trip, such as time spent walking and/or waiting, and associated costs. Finally, if the individuals knew how to ride a bicycle, they were redirected to the SC survey; otherwise, they proceeded to the final stage involving the psychometric indicators.

Before the SC survey, two filter questions allowed to define the SC design presented to each respondent. (i) Do you have a bicycle available for this trip? If the answer was affirmative, respondents were asked: (ii) Would you be willing to use it for this trip? If the response was again affirmative, they proceeded to the SC survey where they had to choose between their current transport mode and using their bicycle under varying conditions. In the case of a negative response to either of the two questions, respondents proceeded to the final stage involving the psychometric indicators. If respondents did not own a bicycle, they were asked if they knew about or had used any of the public bicycle services available in the city. In the case of an affirmative response, they were redirected to the SC survey asking them to choose between their current transport mode and using a shared bicycle. In the case of a negative response, they had to proceed to the psychometric indicator stage.

Although the survey involved a sophisticated design and was relatively long, it only took about 10 min on average to complete. It was carried out in Santiago between March and May of 2018. Note that the academic year, for both high school and college in Chile, begins in March, and transport patterns are fairly regular during this period.

The surveys were applied via web, to two clearly defined groups:

i) Academics and administrative staff from all departments of the four campuses of the Pontificia Universidad Catolica de Chile in Santiago (in this case, the survey was sent to the respondents by the Dean of each respective faculty);
ii) People who use social networks, understanding that this would lead to a bias towards respondents who have access to platforms such as Facebook, Instagram, and Twitter.

This data collection methodology was defined based on the results of the focus group, expert opinion, and the implementation of the two pilot surveys, to achieve a higher level of variability regarding socio-economic strata and transportation patterns from the social networks' component. Besides, both ways to contact respondents had already been used (separately) in successful previous research (Yañez et al., 2010; Navarrete et al., 2013; Oliva et al., 2018; Rossetti et al., 2018).

3.3. Proposed model

A hybrid ordinal logit model, with latent variables, for the probability of answering in a positive way to the question about the willingness to commute by bicycle is proposed. The latent variables $\boldsymbol{Z}$ are defined as a function of explanatory variables $\boldsymbol{X}$ (including trip attributes, built environment descriptors and socioeconomic characteristics) through *structural equations*, and they are assumed to explain certain indicators $\boldsymbol{I}$ through *measurement equations*. Individual utility is modelled as a function of both the observable variables $\boldsymbol{X}$ and the latent variables $\boldsymbol{Z}$ (Walker and Ben-Akiva, 2002). For individual q, latent variable l, alternative i and indicator p, the model requires simultaneously specifying and estimating the structural (1) and measurement (2) equations, as follows:

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

where the random error term ω_{lq} takes on unitary variance to make the model identifiable (Díaz et al., 2015). In (2) the indicators I_{pq} are a function of the latent variables Z_{lq}, with a random error term ν_{pq} that is assumed to follow a logistic distribution:

$$I_{pq} = m(Z_{lq}; \alpha) + \upsilon_{pq} \tag{2}$$

and the indicator is modelled, discretely, through an ordinal logit model (Greene, 2012):

$$\begin{aligned} I_{pq}^{*} &= 1 if -\infty < I_{pq} \le \mu_{p1}, \\ &= 2 if \mu_{p1} < I_{pq} \le \mu_{p2}, \\ &= \cdots \\ &= J if \mu_{p(J-1)} < I_{pq} \le \infty \end{aligned} \tag{3}$$

In (3), I_{pq}^{*} denotes the indicator associated with the latent variable Z_{lq}, and the parameters μ_{pj} define the thresholds for the indicator's values.

Finally, in the hybrid discrete choice model component, it is assumed that the individual has a certain utility U_{iq} associated with the question, "Would you be willing to make this trip by bicycle?", with three possible answers: ***No, Maybe*** and ***Yes***:

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

where θ and β are sets of parameters to be estimated, and the errors ε distribute logistics, with a cumulative distribution function given by:

$$F(\varepsilon) = \exp(\varepsilon)/(1 + \exp(\varepsilon)) \tag{5}$$

If U_i is lower than a threshold γ_1, the individual will choose the answer "No". If U_i is higher than γ_1, but lower than γ_2, the individual will choose "Maybe", and if it is higher than γ_2, the individual will choose "Yes". This can be represented as follows:

$$\begin{aligned} U_{iq} &= \text{"No"} if U_{iq} \le \gamma_1, \\ &= \text{"}Maybe\text{"} if \gamma_1 < U_{iq} \le \gamma_2, \\ &= \text{"Yes"}\ if U_{iq} > \gamma_2 \end{aligned} \tag{6}$$

The parameters α, β, γ and λ must be estimated jointly, using simulated maximum likelihood (Train, 2009; Bahamonde-Birke et al., 2014). Several software packages are now available to do this. We used Ox Metrics™ (Doornik, 2007; Arellana et al., 2012).

4. Case study

Santiago is the capital city of Chile and had approximately 6,5 million inhabitants in 2017. It has 32 municipalities with independent budgets and administrative autonomy. Households of higher income (strongly correlated with higher education) tend to locate in the northeast areas of the city (see Fig. 2). These areas also concentrate an essential part of the job opportunities (see Fig. 3), making Santiago a somewhat monocentric city, but with a centre that extends towards the east, along the Alameda-Providencia-Apoquindo axis (Suazo-Vecino et al., 2020). Residential density closely follows the spatial distribution of the job density.

According to the latest mobility survey for Santiago (SECTRA, 2015), in 2012, 4% of the 18 million total daily trips were made by bicycle, 27% by car, 28% by public transport, 34% by foot, and 6% used other transport modes. The bicycle has been the fastest growing mode in the city, with a uniform modal share across income levels (see Fig. 4).

Santiago had approximately 350 km of cycleways by 2018, a rather low value considering its extension and bicycle modal shares. It has three public bicycle systems: one dock-less and two station-based, with most of the stations located in the highest income area.

5. Data

Out of 1432 survey forms received, 1398 were completed by individuals of 18 years old or more. Of these, 47% of respondents were

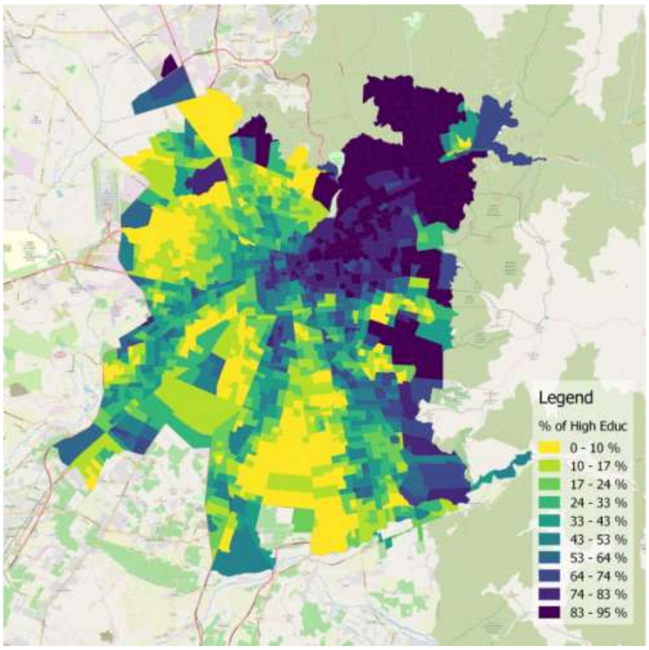

Fig 2. Percentage of households with head of households with higher education Source: own ellaboration with data from INE (2017).

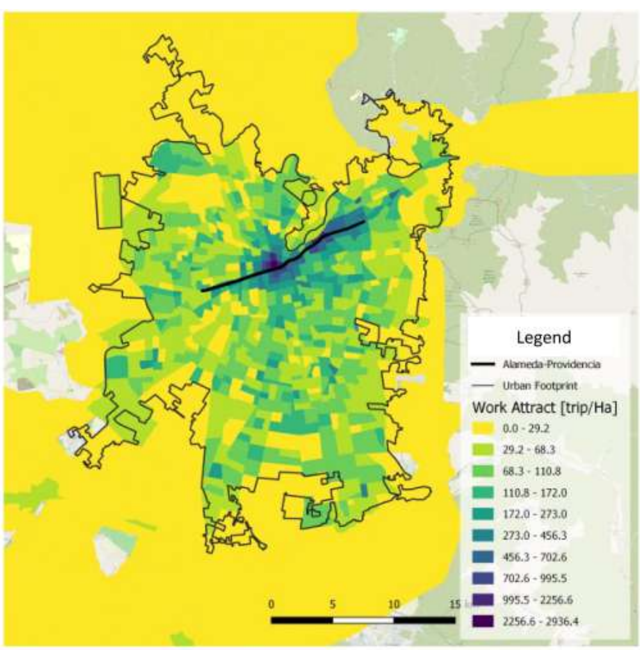

Fig 3. Density of jobs, estimated as attracted tripw per hectare with work purpose Source: own elaboration with data from SECTRA (2015).

female, 47% had completed university education, and 40% had also obtained a post-graduate degree. In terms of occupation, 13% of the sample were students and 87% workers. Although the sample had a high level of education, monthly income levels varied considerably. 10% declared income below the legal minimum wage (USD 463), 11% had income 1–2 times over the minimum wage, 15% earned 2–3 times the minimum wage, and 58% declared income three times or higher than the minimum wage (only 6% of respondents refused to answer this question).

Out of the total sample, 77% had trips involving only one stage, 20% involving two, and 3% involving three or more (each stage represents a change of vehicle or transport mode). Approximately 2% of

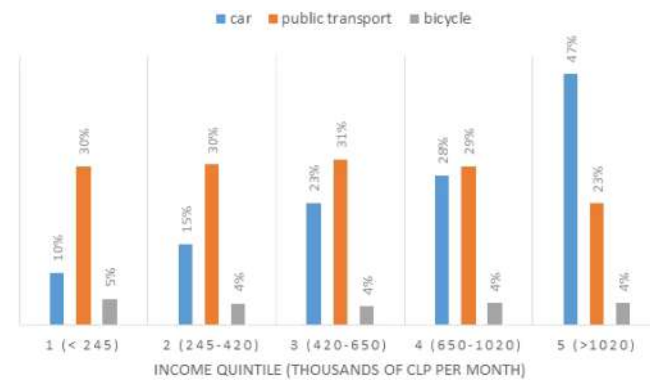

Fig 4. Modal split by income quintile in 2012 ("walking" and "other" are not shown) Source: own elaboration with data from SECTRA (2015).

the sample (34 people) declared not knowing how to ride a bicycle; so, they only reported the characteristics of their daily trips and then proceeded to answer the psychometric indicators.

Fig. 5 shows the geographical distribution of the origins (blue) and destinations (green) of trips declared in the survey. As expected, the highest concentration of destinations is along the Alameda-Providencia-Apoquindo axis, which represents a central hub of business centres and offices in the city. Our main concern was the risk of not achieving a sufficiently varied spatial distribution of trips, given how we contacted the sample population (27% of the responses came from people contacted via social networks); however, the images show that the survey did capture respondents from a significant portion of the city.

Additional data of interest include that 28% of the sample made their trips by car, either as a driver or passenger, 26% used a bicycle, 30% used Metro, bus or a combination of both, and 8% walked to their destination. The rest used motorcycles, taxi or shared taxi (each at percentages lower than 2%). This modal-split distribution is similar to the one observed in the city for car and public transport, but bicycle and walking are heavily over and underrepresented, respectively. The journeys analysed were frequent: 67% of the sample made their trips five times or more per week.

We calculated several variables describing the built environment within a buffer radius of 500 m around each point, based on data from the Chilean Internal Revenue Service, the Ministry of Transportation, and the coordinates obtained for the origin and destination of all trips. This buffer size had already proven to be adequate to measure the influence of the built environment on cycling behaviour (Oliva et al., 2018).

Respondents who reported using a car, bus, Metro, taxi, or any combination of these (805 individuals, excluding those who had reported not knowing how to ride a bicycle), were asked if they would be willing to make these trips by bicycle. Of these participants, 39% answered negatively, 40% answered "maybe" (or that it depends), and 21% responded that they would be willing to change and use a bicycle for the trip. The models presented in the next section were estimated using this sub-sample.

6. Estimation results

To model the willingness to use a bike for the trip under consideration, we estimated ordinal logit models. The choice alternatives were: **Yes**, I would use a bicycle; **Maybe** (it depends), and **No**, I would not use a bike. The attributes associated with the utility function included individual socio-demographic characteristics, variables related to the built environment (around both the trip origin and destination), and the primary characteristics of the trip (in addition to the previously described latent variables). Table 1 describes the variables that ended up being significant in some of the estimated models.

As the sample included two kinds of clearly identified users, people

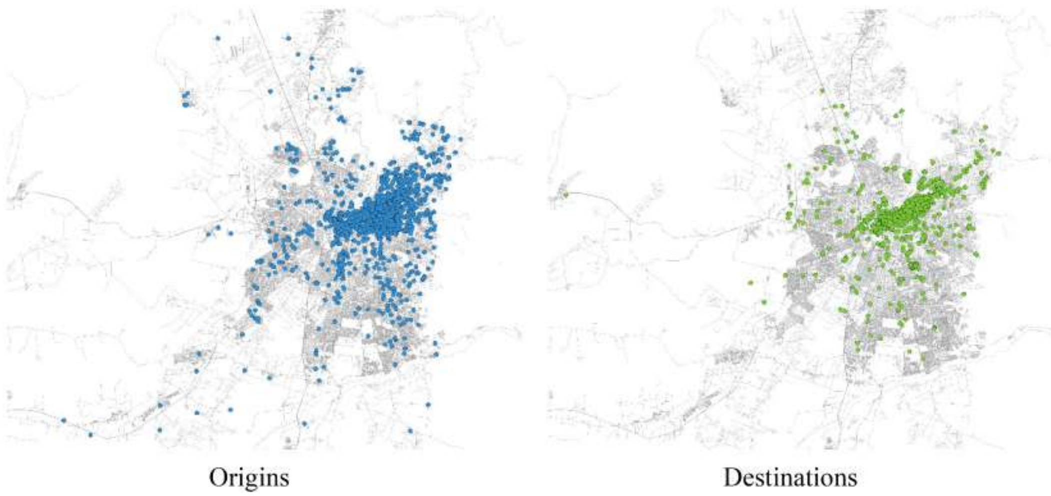

Fig. 5. Points of origin and destination of daily trips to work/study by survey respondents.

Table 1
Description of the variables used in the models.

	Mean	Std. Dev.	N
Socio-demographic			
Female (1.0)	0.47	0.49	378
Age (years)	37.13	10.45	—
Low income level (1.0): I < USD 663[1]	0.21	0.41	173
Medium income level (1.0): USD 663 < I < USD1456	0.19	0.39	154
Number of cars at home	1.54	1.11	—
Number of bicycles at home	1.97	1.45	—
Household size	3.29	1.27	—
Children at home (1.0)	0.68	0.46	549
Trip characteristics			
Trip distance (km)	9.46	7.69	—
Trip frequency (days of the week when trip was made in the same way)	4.4	1.03	—
Car user (1.0)	0.46	0.49	373
Social and built environment variables			
Mean income, zone of residence (thousands of CL$)	500.6	271.7	—
Number of metro stations within a buffer area (500 m)	0.33	0.59	—
Destination Entropy Index	0.52	0.15	—
Length of cycleways passing through buffer (500 m)	0.54	0.64	—

[1]USD was equivalent to approximately Ch$ 680 on the date of the survey application.

Table 2
Model estimation results.

Parameters	SOL Model Value (*t*-test)	HOL Model Value (*t*-test)
θ_{Age} (Age)	−0.027 (−3.77)	−0.027 (−2.58)
θ_C (Number of cars)	−0.140 (−1.84)	——
θ_F (Female)	−0.335 (−2.43)	——
θ_{BK} (Number of bicycles)	0.191 (3.45)	0.103 (1.15)
θ_{HS} (Household size)	−0.104 (−1.63)	−0.132 (−1.52)
θ_C (Car users)	−0.676 (−4.25)	−0.948 (−3.65)
θ_{TL} (Trip length)	−0.078 (−5.66)	−0.086 (−2.33)
θ_{inc} (Zone of residence mean income)	−0.095 (−3.33)	−0.132 (−3.00)
θ_{LM} (Origin cycleway length)	0.180 (1.50)	——
θ_E (Destination land use entropy)	−1.034 (−2.13)	−1.295 (−1.80)
β_1 (Spontaneity: Z_1)	——	0.093 (3.00)
λ_f (Frequency)	——	−0.157 (−4.51)
λ_k (Kids at home)	——	−0.158 (−1.84)
λ_C (Number of cars)	——	−0.045 (−1.26)
λ_{SE} (Origin metro stations)	——	−0.100 (−1.54)
β_2 (Risk: Z_2)	——	−0.876 (−1.92)
λ_{Sex} (Female)	——	0.578 (7.18)
λ_{BK} (No. of bicycles)	——	−0.085 (−3.02)
λ_{Age} (Age)	——	0.009 (2.39)
λ_{LM} (Origin cycleway length)	——	−0.129 (−2.11)
β_3 (Bicycle facilities: Z_3)	——	1.122 (1.38)
λ_C (Number of cars)	——	−0.111 (−3.06)
λ_{BK} (Number of bicycles)	——	0.103 (3.59)
λ_{Low} (Low income)	——	0.314 (3.26)
λ_{Medium} (Medium income)	——	0.476 (4.00)
Final log-likelihood	−785.67	−776.76
Sample size	805	805

who owned a bicycle and those who did not (but who would be willing to use a public bicycle service for their trip), we thought that the model parameters could vary by user. Therefore, we estimated different models for each type of user, in addition to a model with a dummy variable associated with owning a bicycle or not. However, we did not find a significant difference. Therefore, we only present here two models for all users: (i) a simple ordinal logit (SOL) model, used as a reference, and (ii) a hybrid ordinal logit model (HOL) with the latent variables described earlier.

6.1. Simple ordinal logit model (SOL)

The SOL model results (Table 2) show that age correlates with a lower willingness to change to use the bicycle. In the same way, being female, having a larger household size, a more extended trip, and being a car user, reduces the probability of being willing to change. These results were expected since larger households with children choose their transport mode influenced by the complexity of their trips (e.g., taking their kids to school by car and then continuing to work).

Besides, as we applied the survey to people not accustomed to cycling, the longer the trip, the harder it was for them to perceive the trip's distance as a feasible or reasonable cycling distance. The latter was especially the case if they were inexperienced or lacked the physical ability required to make a relatively long journey by bike. On the other hand, individuals with more bicycles at home are more likely to be familiar with using one, and thus more open to change to use bicycles for their trips to work/study. We explored if there were differences in behaviour between students and workers but found no significant results in this regard.

Some social and built environment variables are significant as well. Individuals living in higher-income parts of the city are less likely to be willing to change. Mixed land use at the destination negatively affects the willingness to use the bicycle, a result consistent with the findings of Oliva et al. (2018), where the entropy index appeared as a factor that correlated with lower cycling frequency. The latter is probably because the highest entropy index is found in central parts of Santiago, where it is possible to find several good public transport alternatives (Metro and bus). The presence of bicycle infrastructure (length of cycleways within a 500-meter buffer around the origin of the trip) shows a positive but not highly significant effect. We kept this variable in the SOL model due to its relevance in terms of public policy and for comparison purposes with the HOL model.

6.2. Principal component analysis

Before estimating the hybrid discrete choice model (HOL), we performed an exploratory principal component analysis (PCA) with oblique rotation[2]. We did not know *a priori* the latent constructs to be considered, except for *habit* which was based on the survey designed especially for this purpose, as we described in Section 2.2. We based the PCA on the 29 indicators summarized in Annex 1. We ended up with eight principal components (i.e., with an eigenvalue higher than 1), which – together – explained almost 60% of the data variance. In performing an oblique rotation and evaluating the reliability of the constructs (Cronbach's α) three latent variables were finally identified: *habit* ($\alpha = 0.86$), *risk* ($\alpha = 0.74$), and *cycle facilities* ($\alpha = 0.78$). Note that these are in close agreement with the opinions expressed by the focus group participants, as described in Section 3.1.

Table 3 summarizes the questions asked for each psychometric indicator, and the latent variable developed from this analysis.

The three latent variables may be defined as *perceptual* (i.e., they consider the characteristics of the transport alternative). For example, *habit* is associated with the mode currently used by the individual, while *risk* and *cycle facilities* are related to perceptions regarding bike use.

Fig. 6a and b summarizes the response percentages for each indicator. In the case of *habit*, the automaticity of this variable displays a higher rate of positive evaluations (Gardner 2009). That is, the survey respondents have a higher level of agreement with the phrase indicating that using their current mode is automatic.

On the other hand, the availability of protected bicycle lanes along the entire route taken by the respondent is the indicator with the highest percentage of positive responses (i.e., over 80% of respondents agreed with the idea that having such infrastructure was an incentive for using a bicycle). For the remaining indicators, there is a higher degree of variability among responses. However, there is a clear trend of agreement with the statements related to other facilities that would encourage cycling. Fear of accidents seems to be the main reason to avoid the bicycle; this is coherent with the general agreement with the importance of bicycle infrastructure, probably due to the improvement in perceived safety they provide.

6.3. Hybrid ordinal logit model

Fig. 7a presents the final structure of both models (note that the parameters corresponding to the measurement equations, $\underline{\alpha}$, are given in Annex 2). To facilitate the interpretation of these results, in the HOL model (Fig. 7b) we worked with the latent variable *spontaneity* (defined as the inverse of *habit*), which was specified as a systematic taste variation associated with trip length. However, our specification searches ended up with both *risk* and *bicycle facilities* integrated directly into the utility function.

The parameters for the attributes in the utility function are generally consistent with those of the reference SOL model; for example, older participants are less willing to change to bicycle use, as are people who use cars. However, the addition of the three latent variables allowed for a more in-depth analysis of some of the critical attributes that affect the willingness to use a bicycle, through the inclusion of parameters that are not in the model's utility function but are part of the structural equations of the latent variables.

For example, two variables that appeared in the reference SOL model lost significance (*gender* and *meters of cycleways at origin*) and did not appear directly in the utility function of HOL. However, as they make up part of the structural equation for the *risk* variable, their impact is preserved in the model. Further, this provides an exciting insight for public policy, suggesting that women are less likely to ride a bicycle more for perceived security (not only in terms of risk but also in terms of feeling less able to resolve any mechanical failure) than for other reasons (Abasahl et al., 2018), something that we could ameliorate with well-designed educational campaigns[3]. Similarly, the role of the length of nearby cycleways increases its significance but is now included through the *risk* latent variable, indicating that the importance of providing a well-connected network of cycling infrastructure has to do primarily with the increase in perceived safety that it generates.

The results of this model allow us to conclude that *spontaneity* has a significant effect: the more spontaneous the individual (i.e., less habituated to his/her current transport mode), the higher the willingness to change to bicycle use. People with children are less spontaneous when choosing transport mode, as they probably have a more structured daily routine, which often consists of taking the kids to school and then going to work. The availability of car and Metro near the residential location correlate with lower *spontaneity* (i.e., higher habit). The latter could be due to people becoming accustomed to these modes when they are easily accessed, although it could also be due to the residential choices of more habit-oriented people. These findings are also consistent with the results of the pioneering research by Ortúzar et al. (2000), showing that many individuals would be willing to use a bicycle as the first stage of a long trip if the nearest bus stop or Metro station was far from their point of origin. In a similar trend, the higher the frequency of the journey, the lower the degree of *spontaneity* (i.e., as individuals are accustomed to using a specific alternative, their behaviour becomes automatic). Note that the use of trip frequency as an explanatory variable is uncommon since, instead, we generally use it as an indicator of *habit/spontaneity* (Cherchi et al., 2013). We believe, however, that the causal relation (and direction) between habit and trip frequency is not well understood yet and as such, using frequency as an explanatory variable is a valid behavioural hypothesis.

Finally, in the case of the *bicycle facilities* latent variable, the higher the number of cars at home, the lower the relevance of such facilities for the respondents. On the other hand, individuals with low and medium-income levels and a higher number of bicycles at home are more likely to find these facilities relevant. The latent variable enters the utility with a positive parameter. Thus, the availability of cycle-inclusive facilities (such as protected bike lanes, secure bicycle parking areas, and the availability of showers and lockers at the point of destination) seems to be important in terms of encouraging individuals to consider changing to bicycle use. These results contradict those of previous studies on the subject in Chile, that suggested that cycling commuters do not assign value to elements such as showers and lockers at the destination (Waintrub et al., 2016). However, in our case, the responses used for estimation came from individuals who were not cycling commuters and, hence, believed they could need to shower and change clothes after the trip. In practice, frequent cyclists in Santiago are unlikely to need this thanks to the city's dry weather, differing with what usually happens in urban areas with more humid weather (Wardman et al., 2007; de Geus et al., 2008; Gutiérrez et al., 2019).

6.4. A quick model application

We applied the HOL choice model to a sample of 4546 observations from the last Mobility Survey in Santiago (SECTRA, 2015). These observations, when expanded, account for approximately 680,000 trips (40% of all morning rush hour journeys of a typical business day). We

[2] Using R Studio software.

[3] We are grateful to Prof. Becky Loo for having suggested this interpretation.

Table 3
Satisfaction levels towards bicycle use and perceptual indicators.

Statements	Indicators	Latent Variable (α)
What would encourage you to make this trip by bicycle?		
Protected bicycle lanes along the entire route	Protected bike-lanes (P1)	Bicycle facilities (0.78)
Bicycle parking areas near to my place of work/study	Near parking (P3)	
Guarded or enclosed bicycle parking areas	Guarded parking (P4)	
Availability of showers/lockers at my place of work/study	Showers and Lockers (P5)	
What stops or would stop you from making this trip by bicycle?		
I am concerned about the possibility of having an accident	Accident (B4)	Risk (0.74)
I am concerned about the possibility of being robbed	Robbery (B5)	
I am concerned about having a mechanical problem and not knowing what to do	Broken bike (B6)	
Using my "*Current Transport Mode*" for my daily trip to work or study, is something that		Habit (0.86)
I do automatically	Automatic (A1)	
I do without thinking	Without think (A2)	
I start doing before I realize I am doing it	Awareness (A3)	
I do without having to consciously remember	Without remember (A4)	

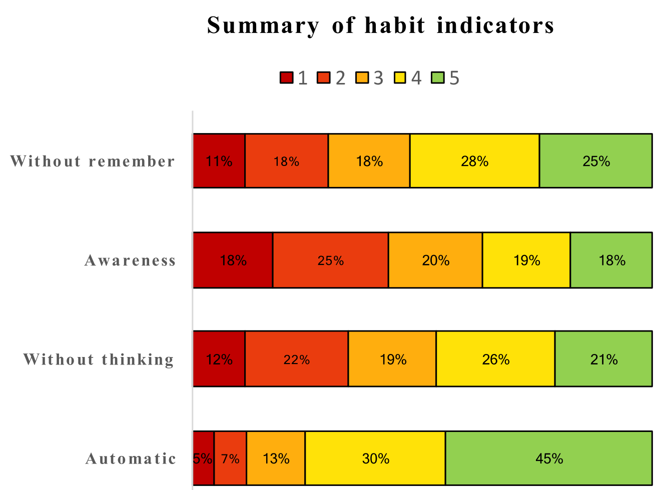

Fig. 6a. Rates for *habit* indicators.

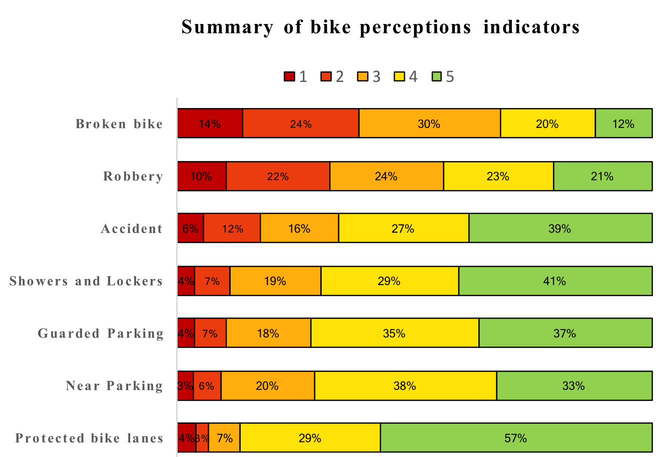

Fig. 6b. Rates for attitudes/perceptions indicators.

focused on trips that exhibited similar characteristics to those of our estimation sample; that is, trips in the morning rush hour, with work and study purposes, made by public transport or by car, and by people with an income distribution, level of education and chosen transport mode similar to the estimation sample. However, variables such as trip length are higher for this subsample than the average for the population

With this data, the aggregate probability of choosing the three alternatives (i.e., **No**, **Maybe**, and **Yes**, I would consider changing to

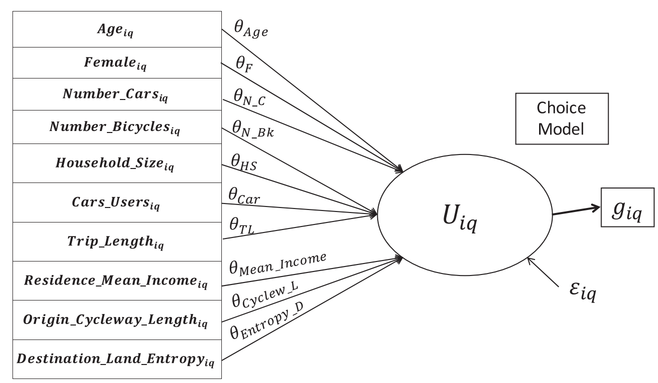

Fig. 7a. Simple Ordinal Logit specification.

bicycle) was estimated using sample enumeration (Ortúzar and Willumsen, 2011, Chapter 9). We obtained that 32% of individuals would not be willing to make the trip by bicycle, 41% might be willing to do it, and 21% would be ready to change to this transport mode. The latter means that, in 2012, about 142,800 commuting trips were potential cycling trips, a significant number equivalent to all bicycle trips in the morning peak period of a typical day in the same period.

Fig. 8 maps these probabilities for each municipality in Santiago. Note that the individuals who live in municipalities further from the city centre tend to have a smaller likelihood of being willing to change to bicycle. This result is most likely due to the concentration of jobs and educational establishments along the Alameda-Providencia-Apoquindo axis and a stronger presence of cycleways in the richer areas. Other zones that appear in blue tend to be near some of the (much smaller in scale) subcentres of Santiago.

Using the same data, we estimated aggregate elasticities for two variables in our model that could be modified through public policy and infrastructure investments: length of cycleways ($E_{yes} = 0.025$), and trip length ($E_{yes} = -0.467$). While the number and length of cycleways is clearly a decision of city officials and planners, the length of trips could be modified (in the long term) if, for example, land use regulations and incentives would induce a more polycentric city structure, reducing the average distance between origins and destinations. Considering the average values of these variables, a marginal increase of 1% in the number of trips willing to change to cycling would require (*ceteris paribus*) either to increase the average cycleway length from 385 to 539 m or to reduce the average trip length from 9.1 to 8.8 km.

7. Discussion

We explored the role of habit, perceptions, and the built

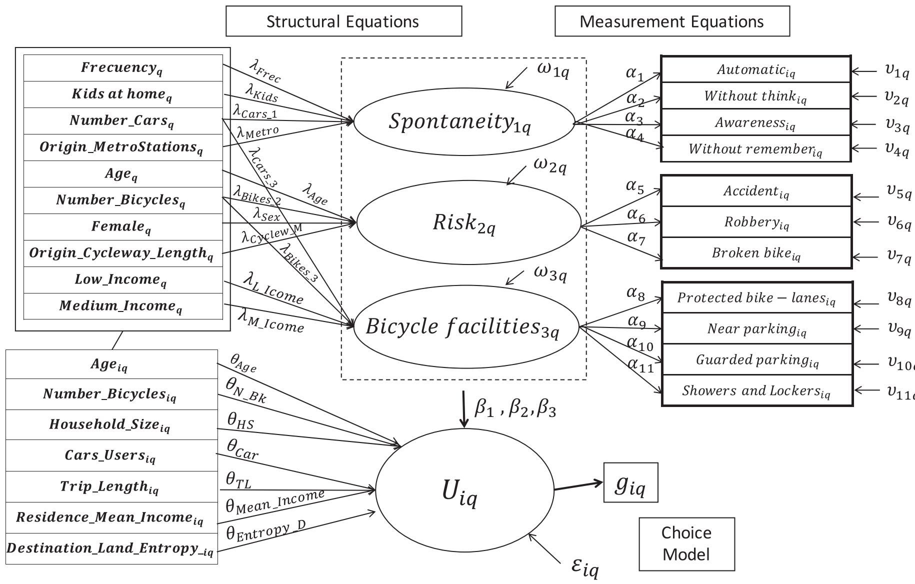

Fig. 7b. Hybrid discrete choice model specification.

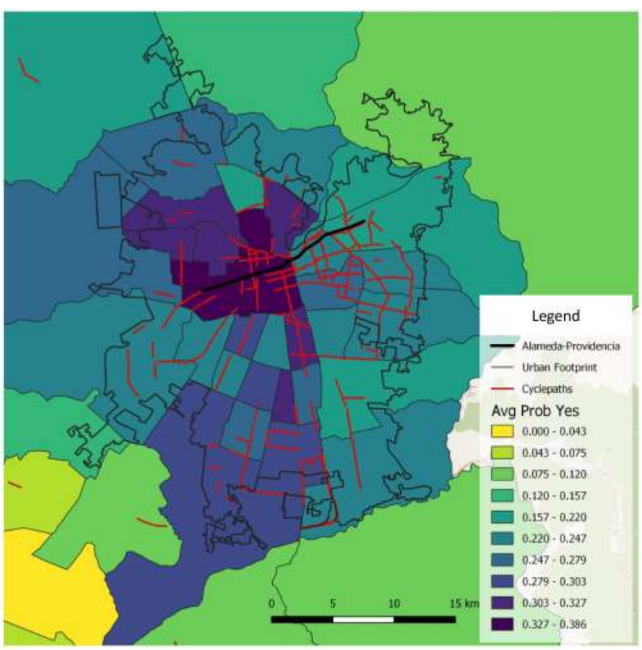

Fig. 8. Distribution of "yes" probabilities by municipality in the city of Santiago.

environment in the willingness to change to bicycle use on daily commuting trips. In particular, we focused on the potential effects of the following variables: the habit or inertia associated with using the current transport mode, the perception of risk towards bicycle use (fear of robbery, having an accident or a mechanical malfunction), and the availability of facilities such as bike lanes and bicycle parking areas. The target population included individuals that do not use a bicycle to commute in Santiago at present. These are mainly office workers and (older than 18) students that travel during the morning peak on public transport (Metro or bus) or by car (either as a driver or passenger), and who may potentially become bicycle users.

To estimate the willingness to change to using a bicycle, considering the variables mentioned above, we calibrated a hybrid choice model with ordinal responses that were included both in the choice and measurement equations. The survey participants had to choose between saying, No, Maybe or Yes, to the question of whether they would change from their current transport mode to bicycle for their commuting trip. Besides, we applied the model to a sample of observations from the 2012 Santiago Mobility Survey.

Our results show that the willingness to change to bicycle use is primarily affected by the length of the trip and the length of cycleways near the origin of the trip, in addition to individual characteristics such as gender, age, and number of cars at home. Beyond these variables, results suggest that attitudinal and perceptual latent variables also affect the willingness to change mode. For example, *spontaneity* (i.e., the opposite of *habit*) of individuals increases the likelihood of willing to commute by bicycle. This spontaneity, however, is not correlated with any variable that could be modified by the authorities (people with habit living near Metro stations are more likely explained by location choices rather than by a causal phenomenon). Breaking habits is, therefore, not a straightforward task and, apparently, cannot be achieved by modifying the built environment. However, there are ways to induce changes in this regard that are mostly related to the application of incentives and educational campaigns, focusing on younger individuals and/or taking advantage of significant "life changes" (moving, changing jobs or even an economic or a climate crisis), that may induce people to revise their habits (Department for Transport, 2011).

In fact, Santiago recently experienced a series of demonstrations and social outbursts that, among other consequences, affected the operation of the public transport system. Several Metro stations were attacked and closed for long periods of time. This triggered a significant increase in cycling, especially during peak hours, where measurements in key cycleways showed up to a 100% increase in flow (Gotschlich, 2019). While the attacks to the Metro stations are certainly undesired, the resulting disruption creates an opportunity to break habits and (somewhat forcedly) expose individuals to new, previously ignored, alternatives for their daily commuting. This kind of system disruption has already proven to be a driver of changes in mobility patterns that may benefit individuals and improve the overall performance of the transport system (Larcom et al., 2017).

The availability of cycling facilities (i.e., appropriate parking, showers, protected bike lanes along the entire route) positively affects the willingness to commute by bicycle. However, since this is a perception by bike non-users, it may be that some of these elements would become less relevant once the individual becomes a frequent cycling commuter. In the case of Santiago, this has already been confirmed regarding showers (Waintrub et al., 2016) and sidewalk-level protected cycleways (Rossetti et al., 2019).

The perception of risk can create a barrier when deciding whether to commute by bicycle, that increases with age and affects women more. Having more bicycles at home, probably a proxy for cycling experience, correlates with a lower concern for safety. Longer cycleways available near the origin of the trip decrease the perception of risk, increasing at the same time the willingness to commute by bicycle. This is consistent with what has been reported in several studies in the literature and confirms the importance of providing abundant and well-connected infrastructure to encourage cycling.

When applying the model to data from a large travel survey, we estimated that, in 2012, there could be over 100,000 commuters likely to be willing to commute by bicycle. A relevant question here is: What was missing to achieve this change? While the strong increase in cycling in Santiago suggests that an important part of those potential trips eventually became bicycle commutes, there are several missing links that prevent further increases in cycling in the city. Therefore, based on the results of our model and our analysis, the best policies that can be suggested are:

1. Build more and better-quality cycling infrastructure, according to international standards and forming a well-connected network;
2. Provide safe bike-parking facilities in the zones of the city that attract most trips;
3. Generate land use regulations and incentives inducing (in the long term) the formation of sub-centres and a more compact city, to reduce the length of trips.

Most likely, beyond trip length, the main barrier for cycling today in Santiago is the lack of a high quality and well-connected network of cycleways. The quality of the cycleways is a variable that, unfortunately, could not be considered in this work, but will be explored in future research thanks to the inclusion of different types of cycling infrastructure in the stated choice experiment that was part of our survey. With this data, we intend to model the choice of mode between bicycle and the respondeńs current transport mode.

Finally, another possible explanation for the above's untapped potential is, as mentioned before, the strong habit developed by many commuters. Because of this and the previously discussed findings, it seems that providing adequate infrastructure and conditions for cycling is necessary, but not sufficient, to induce a significant increase in cycling commute. The role of habit, and how to break it, to allow for the adoption of more sustainable mobility patterns, is then a key question for further research.

CRediT authorship contribution statement

Margareth Gutiérrez: Conceptualization, Methodology, Investigation, Software, Data curation, Writing - original draft. **Ricardo Hurtubia:** Methodology, Writing - review & editing, Supervision. **Juan de Dios Ortúzar:** Methodology, Writing - review & editing, Supervision, Visualization.

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Annex 1

Using "*Current Mode of Transportation*" for my daily trip to work or school, is something that:

Indicator	Indicator Name
I do automatically	H1
I do without thinking	H2
I start doing before I realize I'm doing it	H3
I do without having to consciously remember	H4
I would find hard not to do	H5

When thinking about your daily trip to work/school, What would encourage you to make this trip by bicycle?

Indicator	Indicator Name
Protected bicycle lanes along my entire route	P1
Speed limit reduction for motorized traffic	P2
Bicycle parking areas closer to my place of work/school	P3
Guarded or enclosed bicycle parking area	P4
Availability of showers/lockers at my place of work/school	P5
Being able to bring by bike on the bus or metro	P6
Seeing more cyclists in the streets	P7
Feel in better shape thanks to my bicycle use	P8
Living closer to my place of work/school	P9

What stops or would stop you from making this trip by bicycle?

Indicator	Indicator Name
I live very far away	B1
I would need to change my clothes	B2
Lack of safe parking areas for my bicycle	B3
I am worried about being in an accident	B4
I am worried about the possibility of being robbed	B5
I am worried about experiencing a mechanical problem and not knowing what to do	B6
Lack of cycleways along my habitual route	B7
I have health issues	B8
I have to take kids or materials with me	B9

Annex 2

Attribute	Mimic model Value (*t*-test)
β_{Esp} (Spontaneity: Z_1)	0.093 (3.00)
α_{a1} (Automatic)	−1.691 (−13.78)
α_{a2} (Without think)	−3.795 (−14.18)
α_{a3} (Awareness)	−4.304 (−13.20)
α_{a4} (Without remember)	−3.357 (−14.87)
β_{Sec} (Risk: Z_2)	−0.876 (−1.92)
α_{b1} (Accident)	1.954 (11.13)
α_{b2} (Robbery)	2.704 (9.01)
α_{b3} (Broken Bike)	1.469 (12.54)
β_{Ciclof} (Cycle facilities: Z_3)	1.122 (1.38)
α_{p1} (Protected bike-lanes)	1.386 (11.80)
α_{p2} (Near parking)	3.703 (10.40)
α_{p3} (Guarded parking)	3.795 (9.97)
α_{p4} (Showers and lockers)	1.306 (12.42)

The study determines the willingness to change from their habitual mode of transport to cycling in the city of Santiago – Chile.

The willingness to change to bicycle diminishes with the length of the trip and with the age of the individual.

The perception of insecurity can create a barrier when deciding whether or not to commute by bicycle, that increases with age and affects women more.

People more habituated to their current mode are less willing to change it.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.tbs.2020.02.007.

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