Landscape and Urban Planning 214 (2021) 104174

Contents lists available at ScienceDirect

Landscape and Urban Planning

journal homepage: www.elsevier.com/locate/landurbplan

The role of bike sharing stations in the perception of public spaces: A stated preferences analysis

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HIGHLIGHTS

- The impact of bike sharing stations on the perception of public spaces is analysed.
- Presence of bike sharing has a positive impact on urban landscape perception.
- Positive perception of stations is more likely in compact urban contexts.
- Disorganised dockless bikes on sidewalks produce a negative perception.

ARTICLE INFO

Keywords:
Bike sharing
Neighbourhood image
Stated preferences
Perception
Public Space

ABSTRACT

The pervasiveness of bike sharing schemes around the world has the potential to bring important benefits in terms of public health and reduction of congestion and emissions. However, there can be negative externalities associated to these systems, especially in terms of misuse and degradation of public spaces. This paper explores how the presence of different shared bicycle systems and their stations affect peoplés perceptions of public spaces and neighbourhoods. For this, a stated preferences experiment was created and applied in Santiago de Chile, depicting two main scenarios (downtown and residential) with various configurations of public bicycle stations (dock-based and dockless), along other cycling facilities on a street. Survey results were used to estimate a choice model, measuring the impact of the scenario attributes on the probability of being chosen as a preferred public space. Attitudes about bikesharing, the environment and mobility in general were also measured and used to estimate latent variables and their role in public space perception. Results show bike sharing stations are overall positively perceived in terms of their capacity to improve a neighbourhood's image, safety and accessibility, although this is more likely in compact urban contexts and for users of bikesharing. Disorganized (dockless) bicycles left on sidewalks are perceived negatively, although not enough to make individuals prefer a situation without public bicycles. The previous findings indicate that bike sharing schemes could have positive effects on the image of neighbourhoods by making them look more attractive and modern.

1. Introduction

The number of bike-sharing systems (BSS) has grown significantly in the last two decades, now present in more than 1000 cities, most of them in China and the Global North (Meddin et al., 2020). There is abundant literature discussing the impacts of BSS, in terms of their capacity to improve health, to modify a citýs mobility patterns, and to bring environmental and economic benefits (for a review see Ricci, 2015). However, so far, little attention has been paid to the potential impact they may have on the perception of urban landscape, that is, on a citýs public spaces and its neighbourhoods.

The prospect of potential bike-sharing benefits has prompted multiple cities to implement BSS, with an especially important role played by the companies offering these services (Parkes et al., 2013; Tironi,

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https://doi.org/10.1016/j.landurbplan.2021.104174
Received 9 November 2020; Received in revised form 17 June 2021; Accepted 20 June 2021
Available online 30 June 2021
0169-2046/

2015), which often lobby for the adoption of BBS or directly deploy them without collaboration with city authorities. In many cases, this has resulted in a progressive (sometimes chaotic) diversification of BSS in cities, which often compete in the same territory for customers. For example, the city of Dallas had up to five bike-sharing systems at the same time (in 2017–2018), even though bike trips accounted for less than 1% of the modal split. Similarly, some Chinese cities have reported an excess of shared bikes (Gu et al., 2019) which often end abandoned, causing environmental issues and raising concerns about the business model of bike-sharing companies (Bieliński and Ważna, 2018). Other issues associated with BSS and public spaces are the increase of inexperienced cyclists riding on sidewalks, the misuse of urban equipment, blockage of pedestrian infrastructure (Chang et al., 2018; Shi et al., 2018), and the overall degradation of public space (Yin et al., 2019), especially when BSS are dockless (Chen et al, 2020). Further, even dock-based BSS might produce negative perceptions for some city-dwellers, especially when stations occupy public spaces that have other potential uses. The literature has paid little attention to these implications and their impact on the urban landscape.

The present study analyses how the presence of different types of BSS affects individual perception of urban environments. For this, a stated preferences survey, showing different scenarios of bike-sharing stations in public spaces, was designed and applied in Santiago de Chile. This city is a good laboratory for this purpose since it has three operating BSS (one of them being dockless) and, therefore, respondents will be familiar with the presented alternatives. Survey results are analysed and used to estimate an integrated choice and latent variable model. The choice model measures the role played by observable attributes in the individual's preferences for public spaces while the latent variable model captures subjective attitudes towards BSS and complements the choice model.

To the extent of our knowledge and literature review, this is the first study addressing the impact of bike-sharing schemes on the perception of public spaces and urban landscape, and the first one to measure the role played by BSS stations, and dockless bicycles, in this regard.

After this introduction, the article is organized as follows: Section 2 presents a brief review of BSS and their impacts while Section 3 covers studies dealing with measurements of the perception of urban spaces. Section 4 describes the case study of Santiago de Chile and its BSS. Section 5 presents the modelling methods while Section 6 describes the survey design and data collection process. Section 7 shows results while section 8 discusses them. Finally, Section 9 concludes the paper.

2. Impacts of bike-sharing schemes

Bike-sharing can be the source of several benefits, with abundant literature exploring them (Ricci, 2015). For example, it has been reported that the presence of BSS increases overall cycling usage (Vogel et al., 2014; DeMaio, 2009), helps reducing carbon emissions (Otero et al., 2018; Rojas-Rueda et al., 2011), and congestion (Wang and Zhou, 2017). Moreover, bike-sharing can bring relevant health benefits due to more active commuting (Otero, et al, 2018, Woodcock et al., 2014).

BSS can also be a good complement for public transport systems, helping to solve the "last mile problem" and, therefore, reducing car use (Fishman et al., 2013; Yang et al., 2016), although this depends on the proportion of trips made by car in the city (Fishman 2016). It has also been found that BSS can reduce the use of public transport (Shaheen et al., 2013) which could be positive or negative, depending on the level of crowding and the fare scheme of the system.

The literature also reports direct and wider economic benefits of BSS. For example, Sobolevsky et al. (2018) showed that subscribers of New Yorḱs bike-sharing program saved between 340 and 500 dollars per year in transportation, while El-Geneidy et al. (2016) showed that being close to a bike-sharing station increases property values. BSS have also been associated with an increase in sales for commerce located near its stations (Buehler and Hamre, 2015).

However, some literature indicates these benefits are not significant overall and are unequally distributed over the population, favouring the privileged and therefore exacerbating urban inequality (Duran et al., 2018; Médard de Chardon, 2019). Indeed, various studies have shown that bike-sharing users tend to be male, wealthy, and with higher education (Caspi and Noland, 2019; Fishman, 2016; Winters, Hosford and Javaheri, 2019).

3. Measuring the perception of urban space

The debate on how humans make sense of their urban environment can be traced back to the work of Kevin Lynch (1960), who argued that cities imprint certain "images" on individuals. Many scholars have followed Lynch́s footsteps, attempting to decode the psychological and implications of visual perception. A highly influential one is Kaplan's theory of mystery (1995) , which postulates that two main principles guide people's movement: the need to explore and the need to understand their environments. To Kaplan, these principles shape how people perceive natural and built environments and make sense of them. In a similar thread Gibson (1979) and Benedikt (1979) attempted to disentangle the role of visual fields in human navigation, a line of research that has been further explored by Turner et al. (2001), Wiener and Franz (2004) , Culagovski et al (2014) and recently Emo (2014). These studies, however, have paid little attention to the role played by specific elements in the landscape, something that has been usually approached through much more direct and quantitative methods (Clifton et al., 2008), usually with an emphasis on measuring the relation between objective attributes of landscapes, subjective perceptions and behaviour (Ewing et al., 2006). Such measurements are usually of high cost due to the need of intercepting and interviewing respondents in the location under analysis, and the need to measure several different locations in order to have enough variance in attributes to generalize conclusions. Using stated preference (SP) surveys reduces these costs by portraying the scenarios under analysis through modified photographs, synthetic images, videos, or even virtual reality (Rossetti and Hurtubia, 2020).

SP surveys are widely used, often combined with discrete choice models (McFadden, 1974), to understand peoplés preferences when facing a hypothetical situation with two or more competing alternatives. One of the main advantages of this technique is the capacity to assess the trade-offs between attributes. In landscape evaluation, SP surveys often display pictorial choice sets in which each alternative's attributes are presented graphically for individuals to compare. For example, SP surveys have been employed to measure design preferences for new public spaces (Strazzera et al., 2010), to assess the role of trees, fences and transparency of facades in the perception of safety (Sillano et al., 2006; Iglesias et al., 2013; Hurtubia et al., 2015), to understand residential location preferences (Torres et al., 2013), to measure the willingness to pay for trees (Giergiczny and Groneberg, 2014), to assess the value assigned to a public transport corridor (Navarro et al., 2018) or urban elements related to walking (Ewing and Handy, 2009), or to measure how crowding in public transport affects mobility preferences (Tirachini et al., 2017).

In the case of cycling infrastructure, image-based SP surveys have been used to investigate how cyclists value different types of facilities (e.g. bike lanes) and other environmental attributes, and their trade-off with travel time or route decisions (Tilahun et al., 2007; Motoaki and Daziano, 2015; Rossetti et al., 2019a). The role of attitudes or perceptions has also been explored, for example by measuring how attributes of presented scenarios influence safety perception and, consequently, affect route choice (Rossetti et al., 2018). Nevertheless, no studies found in this literature review have investigated how BSS schemes affect a citýs landscape.

4. Case study

Santiago is the largest city of Chile (with almost seven million inhabitants in 2017), concentrating most of the economic activity and administrative power of the country. Formed by 34 municipalities with autonomous budgets and administrations, the city lacks a central authority in charge of integrated land use and transport planning. It is also a very segregated city, with important spatial disparities in public infrastructure (Borsdorf et al., 2016) and accessibility (Tiznado-Aitken et al., 2018; 2021). Fig. 1 depicts the income distribution in Santiago, where high-income groups are concentrated in the northeast.

To date, cycling infrastructure covers almost 500 km and presents quite different qualities depending on the municipality, with most of it being far from the standards observed in the cities of the Global North that are usually cited as good practice examples. Since most of the cycling infrastructure is funded by local governments, which themselves have substantial disparities in terms of budgetary resources, bike lanes are highly concentrated in well-off, central areas (Mora et al., 2021). Despite this, according to the last Origin-Destination Survey (Sectra 2014), bicycle trips account for 4% of all daily trips (not necessarily concentrated in the zones with better infrastructure), and more recent official estimates put this figure up to 7% (MMA, 2018).

The first BSS of Santiago began in 2014 in the district of Providencia, and was managed by this municipality. The system required residents to pay a modest annual fee and gave them the possibility of picking up bicycles (from human-operated stations) and use them for thirty minutes. In 2014, BikeSantiago (administered by B-Cycle) started operating in the wealthy district of Vitacura—adjacent to the district of Providencia (see Fig. 2)— moving to other districts over time until reaching 17 districts by 2017, including some of the lower-income ones (although with a notably smaller number of stations). In 2015 “Bici Las Condes” (BiciLC), managed by Clear Channel, started functioning in the affluent district of Las Condes (adjacent to Vitacura and Providencia). Unlike BikeSantiago, BiciLC operates exclusively in the district Las Condes and its business model is based on advertising. It is worth noticing that the municipality of Las Condes made a call for bids and selected this system, which also implied excluding BikeSantiago from operating in its territory, producing an unnecessary (and quite irrational) fracture in the overall system. Finally, in 2018 the dockless BSS Mobike arrived in Santiago and started operating in the districts of Las Condes and La Reina.

At the moment of this study, Santiago had these three BSS with partially overlapping operational territories (Fig. 2), mainly covering high-income areas of the city. The systems are diverse in terms of their hardware and operational characteristics, but most notably in their stations, as shown in Fig. 3. BikeSantiago stations are characterized by their robust and high-standard outlook, with bicycles being parked between a series of solid pillars made of steel with a large information panel located at one side. BiciLC’ stations are also a dock-based scheme, but its stations are less prominent than Bikesantiagós, with a relatively light structure that resembles a standard bike rack. As a dockless system, Mobike does not have traditional “stations” but sometimes defines areas where bikes are daily repositioned.

5. Modelling methods

To measure the impact of public bicycle systems on public space, we combine a stated preferences survey (see the Survey designs and data collection section) with discrete choice models (McFadden, 1974) and latent variables (Walker and Ben-Akiva, 2002). The survey presents pairs of scenarios depicting –through images– different configurations for public bicycle stations and other elements of an urban landscape. Respondents are asked to choose their preferred scenario in several choice experiments. These results are used to estimate a binary choice

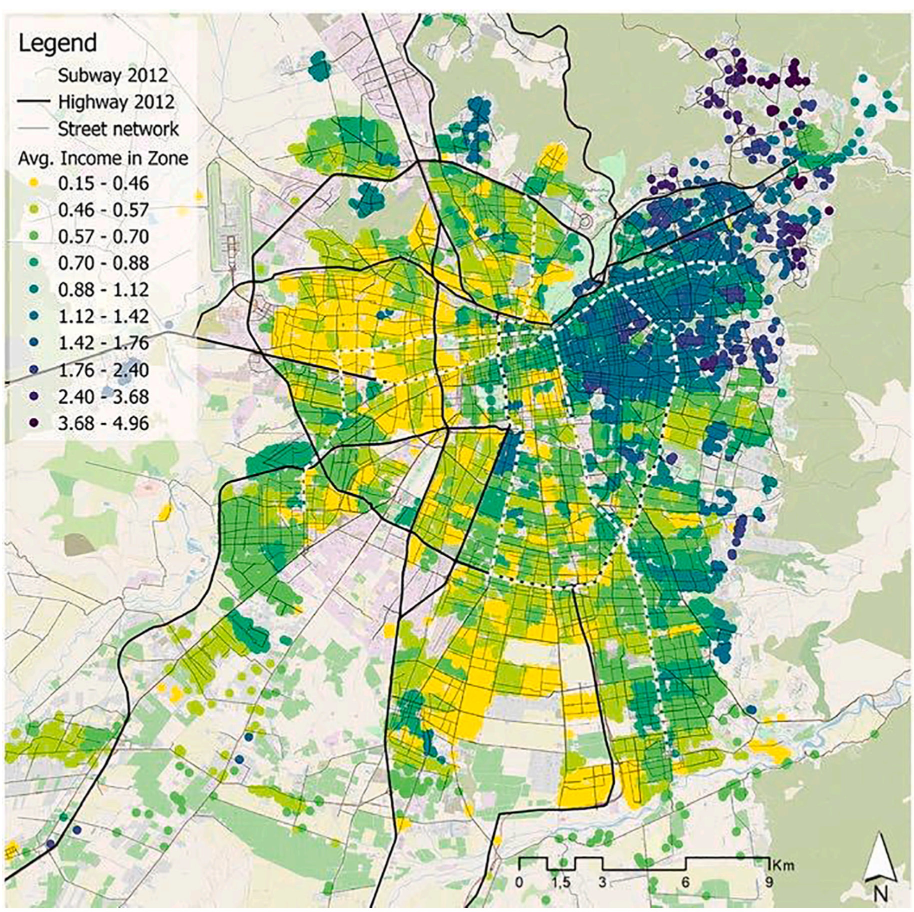

Fig. 1. Income distribution in Santiago according to Sectra (2014), in millions of Chilean Pesos per month. Adapted from Cox and Hurtubia (2021).

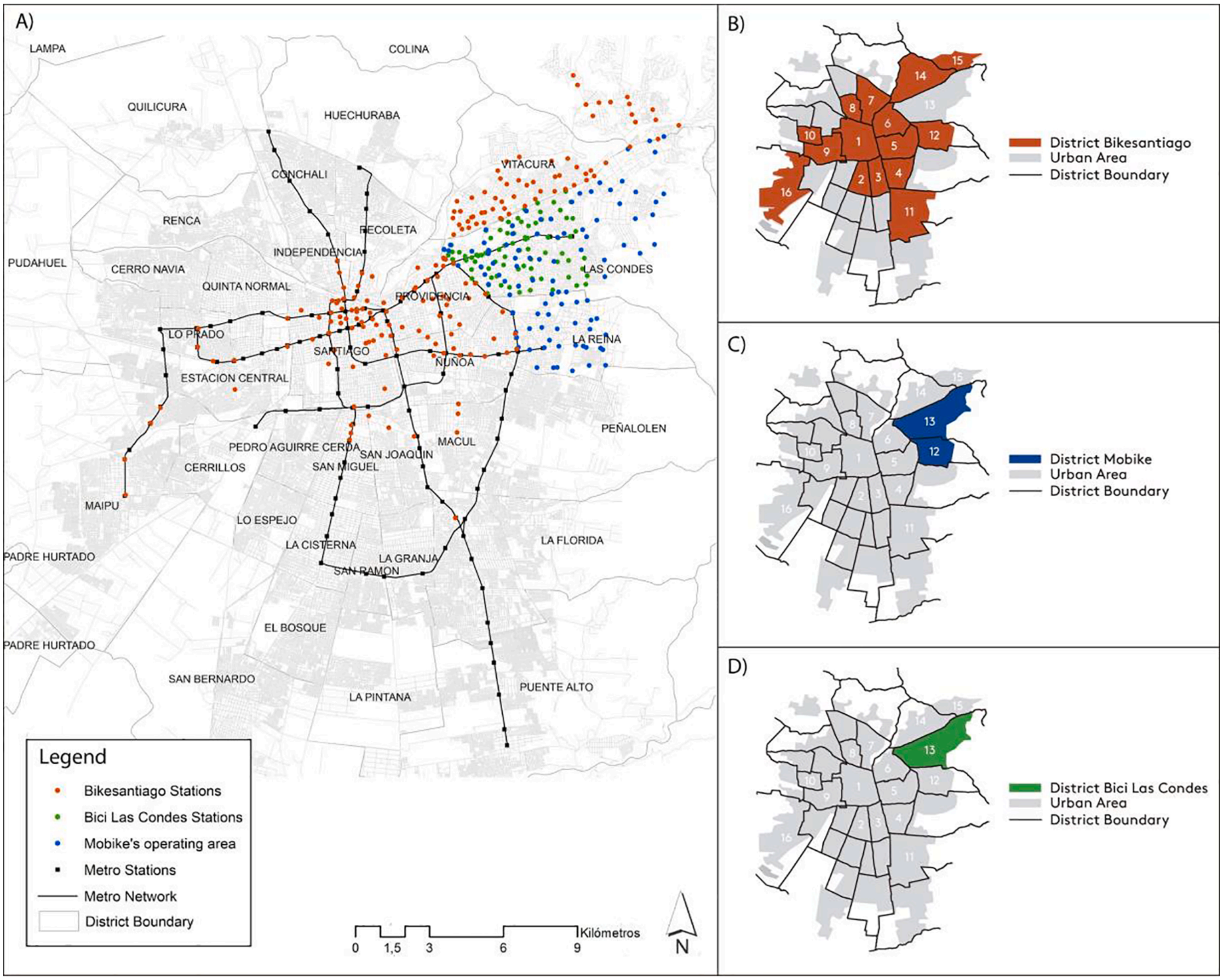

Fig. 2. Metro lines and location of bike-sharing stations in Santiago in 2019. Source, Prepared by the authors.

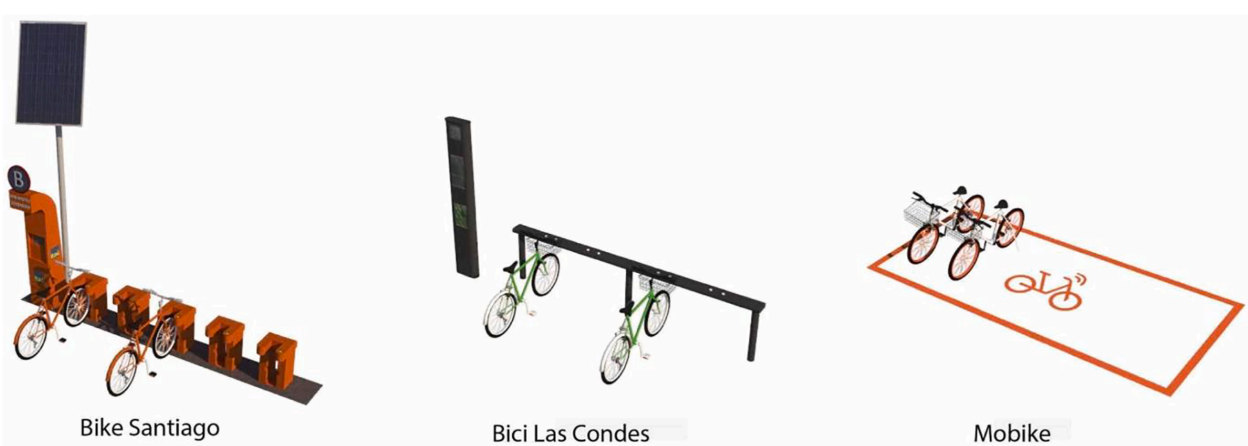

Fig. 3. Stations of the three types of bike-sharing systems in Santiago. Source: Prepared by the authors.

model, measuring the impact of the scenario attributes on the observer's satisfaction and, therefore, on the probability of being chosen. The survey also asks about attitudes regarding public bicycle systems, mobility in general, public space, and the environment. These attitudinal indicators are used to identify and estimate latent variables, which help to understand the influence of socioeconomic characteristics on the perception of public bicycle systems. These latent attitudes are also included as explanatory variables in the choice model. Fig. 4 provides a diagram describing the model structure, where the elements to the left correspond to a choice model while the ones to the right refer to the

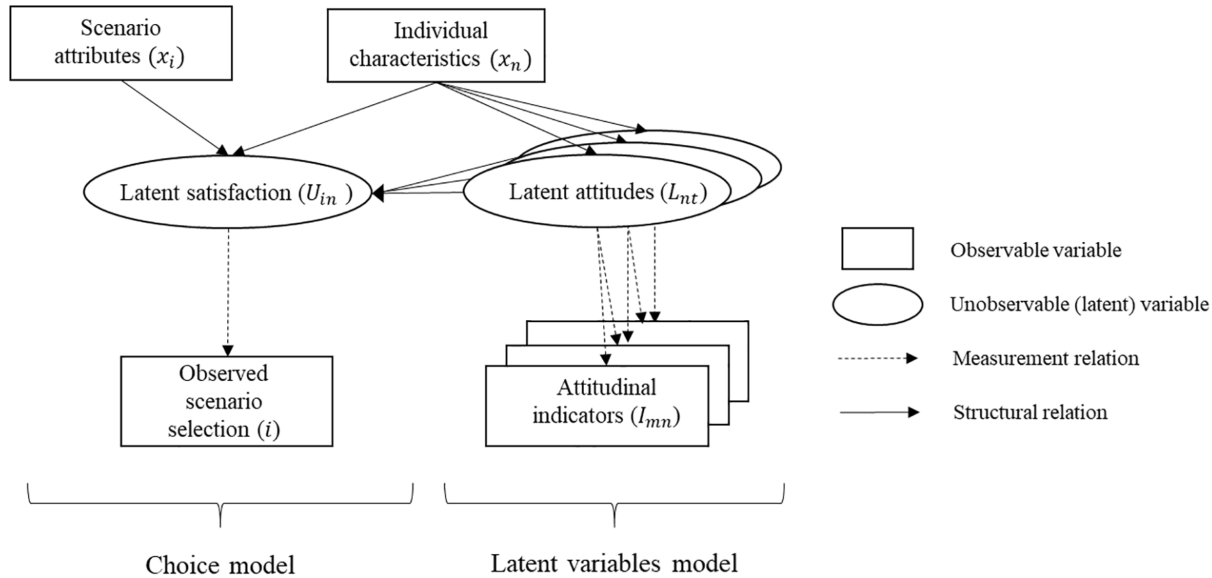

Fig. 4. Integrated choice and latent variable modelling framework. Source: Prepared by the authors.

latent variables model. Each of these models is explained in detail in the following subsections.

5.1. *Choice model*

We assume an individual's preference for a streetscape scenario is the result of that scenario providing a higher satisfaction (or utility) than the alternative. Each scenario i is described by attributes (x_i) which can include, for example, the presence of certain types of bike-sharing stations or other relevant elements such as cycle lanes. Some attributes can be introduced interacting with individual characteristics x_n (e.g. age or gender), in which case we denote them by x_{in}. We define a utility function (U_{in}) to measure the satisfaction an individual n perceives from scenario i, as a function of scenario attributes. We assume this function follows a linear-in-parameters specification, with preference parameters β:

$$U_{in} = \sum_k \beta^k \cdot x_{in}^k + \varepsilon_{in} \tag{1}$$

The preference parameter β^k represents the marginal increase in satisfaction the individual perceives if the k-th attribute of scenario i increases in one unit. The ε_{in} term is a stochastic error component, accounting for unobserved attributes, errors in measurement and non-systematic taste heterogeneity across individuals. Following Random Utility Theory (Ben-Akiva and Lerman, 1985; McFadden, 1974), if the error term follows an IID Gumbel distribution, the probability of an individual n preferring scenario i over a set of alternative scenarios is a Multinomial Logit model. However, since the choice experiment used in this work presented only two alternatives to respondents, the model is a Binary Logit and the probability of choosing alternative i over j is:

$$P_n(i) = \frac{1}{1 + \exp\left(-\mu \sum_k \beta_n^k \cdot \left(x_{in}^k - x_{jn}^k\right)\right)} \tag{2}$$

If an attribute has a positive impact in perceived satisfaction, the choice probability will increase as the difference in the attribute between i and j grows. The opposite happens if the valuation of an attribute is negative (i.e., is not desired, or $\beta < 0$). The preference parameters β can be estimated via likelihood maximization. The scale parameter (μ) cannot be directly identified and it is estimated confounded with the preference parameters (β).

5.2. *Latent variables model*

Following Walker and Ben-Akiva (2002) we assume that (unobservable) latent attitudes are a function of observable individual characteristics (x_n) and a set of parameters (ρ). This relationship can be described by the following structural equation for each latent variable t:

$$L_{nt} = \sum_k \rho_t^k \cdot x_n^k \tag{3}$$

The observer's answer to the m-th attitudinal question can be treated as a psychometric indicator (I_{mn}) which provides information that can be used to measure the latent variable. For this, a measurement equation must be defined:

$$Y_{mn} = \alpha_m + \gamma_m L_{nt} + \epsilon_{mn} \tag{4}$$

where ϵ_{mn} is an error term. Since indicators are ordered and discrete responses (level of agreement, from 1 to 5, with a statement), it is convenient to assume there is the following discrete relation between the measurement equation (Y_{mn}) and the observed response (I_{mn}):

$$\begin{aligned} I_{mn} &= 1 \quad \text{if} \quad Y_{mn} \leq \omega_{m1} \\ I_{mn} &= 2 \quad \text{if} \quad \omega_{m2} < Y_{mn} \leq \omega_{m2} \\ &\ \ \ldots \\ I_{mn} &= 5 \quad \text{if} \quad \omega_{m4} < Y_{mn} \end{aligned} \tag{5}$$

If we assume the error term ϵ follows a normal distribution $N(0,\sigma)$, the probability of an individual n answering $j \in [1,5]$ to attitudinal question m is:

$$P_{nmt}(I_{mn} = j) = F\left(\frac{\omega_{mj} - \alpha_m + \gamma_m L_{nt}}{\sigma_m}\right) - F\left(\frac{\omega_{mj-1} - \alpha_m + \gamma_m L_{nt}}{\sigma_m}\right) \tag{6}$$

where F is the cumulative distribution function for the standardized Normal distribution. The expression of equation (6) is commonly known as an Ordered Probit model. One particular latent variable t can be simultaneously measured against multiple indicators m, as long as they can be explained by the latent variable. Relationships between indicators and latent variables are usually identified through a factor analysis. After estimation, parameters ρ of eq. (3) can be interpreted as a measurement of the influence that socioeconomic characteristics have on the latent variable and, consequently, the likelihood of agreeing with each attitudinal question.

5.3. Integrated choice and latent variables model

The models described in the previous subsections can be estimated independently. However, if we want to understand the role played by latent attitudes in the preference for the presence and configuration of bike-sharing stations, they must be estimated simultaneously. Following Walker and Ben-Akiva (2002) and Bierlaire (2018), this can be done by including an additional, normal-distributed error term to the structural equation of the latent variable ($L^*_{nt} = L_{nt} + \tau_{nt}$, with τ_{nt} $N(0, \sigma_t)$) and inserting it as an explanatory variable in the satisfaction or utility function (1). Since in our case the latent variable is attitudinal (therefore specific to the individual and independent of the scenario under evaluation), the latent variable must interact with an attribute of the scenario:

$$U^*_{in} = \sum_k \beta^k \cdot x^k_{in} + \delta_t \cdot x^*_i \cdot L^*_{nt} + \varepsilon_{in} \tag{7}$$

This makes the choice probability of (2) and the probability of indicator-response of (6) conditional to the latent variable's error term: $P_n(i|\tau_{nt})$ and $P_{nmt}(I_{mn}=j|\tau_{nt})$, respectively. Therefore, to estimate parameters for both the choice and the latent variable model, the likelihood function to be maximized is the joint probability of the observed scenario-choice and response to the indicators, which must be integrated over the distribution of the latent variable's error term:

$$P_n = \int_{\tau_{nt}=-\infty}^{+\infty} P_n(i|\tau_{nt}) \prod_{m\in\Omega_t} P_{nmt}(I_{mn}=j|\tau_{nt}) f(\tau_{nt}) d\tau_{nt} \tag{10}$$

where f is the probability density function of the normal distribution. The simultaneous estimation process allows measuring the impact of attitudes in the valuation of scenario attributes without bias.

6. Survey design and data collection

Survey design considered several steps: First, choice contexts and relevant attributes were selected to define a preliminary set of alternatives. Then, a pilot survey was applied to test and improve the alternative's configuration and to collect preliminary observations. These observations were then used to build an efficient design for the choice experiments. Final renders of the alternatives considering this design were then included in the main survey, which was applied online. The following subsections explain these steps in detail.

6.1. Definition of alternatives

To present alternatives that are relatively familiar to respondents, two urban contexts were defined: a rather dense, mixed land-use area resembling central areas (hereafter called "Compact City"), and a more residential-looking environment, composed of two-story semi-detached houses (hereafter called "Residential District"). Besides fitting to the respondent's usual public spaces, the selection of these two contexts assumes that different urban morphologies (and presumably densities) will have different urban patterns of mobility (Cervero and Kockelman, 1997), therefore influencing perception of BSS and their stations. These two urban contexts loosely resembled typical streetscapes of Santiago (the central areas and the -more peripheral- residential districts, respectively). Fig. 5 shows these two contexts. In each, three attributes were surveyed:

1) **Type of station** (present or not) considering each of the BSS schemes of Santiago (see Fig. 3) but including a fourth category with dockless bicycles positioned in a disorganized array. To prevent respondents from associating the systems on display to the ones currently existing in the city of Santiago, the official colours of the three bike-sharing systems being tested were changed.

2) **Presence of bike lane** (yes or no). The presence of segregated bike lanes has been reported as a fundamental factor for (perceived) cycling safety by numerous studies (Pucher and Buehler, 2016; Reynolds et al., 2009)

3) **Position of station** (sidewalk or street level). It was assumed that bike-sharing stations positioned on sidewalks would encourage sidewalk cycling, a common (yet unpopular among pedestrians) behaviour in Santiago. Conversely, positioning a bike-sharing station near roads might imply that cycling should occur on streets only. The different positions were applied only to the three "formal" types of BSS stations described above, excluding the disorganized dockless bicycles and the case where no station is present at all.

The construction of the scenarios sought to emphasize the type of bike-sharing facility being tested. This meant that trees, cars, presence of people and other attributes were left constant in all scenarios, and their presence was rather limited. Likewise, both the Compact City and Residential District contexts aimed to give few cues about the socio-economic characteristics of the area.

6.2. Experiment design

Generating scenarios with all possible combinations of levels of attributes would render 16 versions for each context, a rather manageable number. However, while these scenarios have combinations of attributes that could be more or less appealing to different individuals, no variables are forcing a trade-off (especially if all attributes can be perceived as something positive). This can be solved by associating a cost to each scenario, therefore forcing respondents to choose scenarios with desired attributes only if the cost justifies it. Since there is no fee for using public spaces, we associate the choice of scenario with the choice of residential location. For this, before the stated choice experiments, we ask the respondent for socioeconomic information including the municipality where his/her dwelling is located, and the rent paid (or, if the respondent is the owner of his dwelling, the expected rent). Considering this, it is possible to generate a cost attribute to combine with the ones

Fig. 5. The two contexts tested in this experiment: the Compact City (left) and Residential District (right). Source: Prepared by the authors.

discussed in the previous subsection. It is not important if the reported rent is accurate since, as we do not want to compute a willingness to pay, only a reference value that makes sense to the respondent is needed. We decided to use four levels for this attribute: current rent and 7%, 14% and 21% increases of it. The reason to use only larger than current values comes from the fact that scenarios (even the base one) already portray a rather idealistic situation when compared to the average street in Santiago.

To anchor responses as much as possible to the real context of respondents, they are first asked to select which context most resembles their current neighbourhood (Compact or Residential). All choice experiments are then shown with the selected context as a "canvas" (Fig. 6). When the choice experiment is presented, they are asked to assume they should pay the rent associated with each scenario, but that their current dwelling remains the same in all remaining regards.

The inclusion of the rent attribute makes the total number of possible combinations rather large (16x4 = 64), and a reduced experimental design becomes necessary. Using responses from the pilot survey, a preliminary choice model was estimated and used to calibrate a D-efficient experimental design (Rose et al., 2008) with the software NGene (ChoiceMetrics, 2012). This design (detailed in the appendix) was used to build the final renders of the alternatives to be included in the main survey.

6.3. Data collection

The main survey had four parts. The first part collected personal and household data, as well as rent paid. The second part presented the choice experiment described above. The third part included questions about awareness and usage of public bicycle systems, and the fourth part asked the level of agreement (using a 1 to 5 Likert scale) to a series of statements about public bicycle systems, mobility, public spaces, and the environment. Finally, respondents were asked to report their income level. The survey was implemented and executed online using the Qualtrics Research Suite platform.

A total of 949 individuals responded to the survey. After an internal revision of inconsistencies, the dataset was cleaned leaving a total of 744 valid responses. Subjects were contacted through social media (Facebook, Twitter and Instagram), using a snowball sampling technique (Biernacki and Waldorf, 1981) and offering the chance to win a gift card in a raffle among those forwarding the survey to their contacts.

Table 1 shows the main characteristics of the sample. Although biased towards the young and educated, and therefore not representative of the population, it does provide enough heterogeneity to measure how perceptions vary with relevant socioeconomic characteristics, by controlling for these variables in the modelling effort.

Table 1
Descriptive statistics of respondents.

Gender	Male	50,0%
Age	18–29 years	62,9%
	30 years and more	37,1%
Educational level	High school or lower	21,3%
	Technical/University / post-graduate	78,7%
Occupation	Student	38,0%
	employed, independent, unemployed, retired, other	62,0%
Bike ownership	One or more	80,5%
Living in a municipality with operational BSS		65,3%
Self-reports to live close to a bike-sharing station		39,9%
Is or was subscribed to any bike-sharing system		16,9%

7. Results

To streamline the presentation of results, we first show the estimation of the attitudinal latent variable models alone. Results for the integrated choice and latent variable models are shown together afterwards.

7.1. Identification and estimation of latent variables

Using the factor_analyzer package for Python (Biggs, 2017), a factor analysis was performed over the responses to the attitudinal questions included in the fourth part of the survey. Table 2 presents results for this analysis, showing only indicators with factor loadings higher than 0.5. Several indicators were not significant in this regard and are not reported. The factor variance indicator confirms the relevance of the presented factors while an exploratory analysis of more factors returned variances lower than one, suggesting additional factors can't explain enough variance in the data.

Each factor can be interpreted as a latent variable that is correlated to the observed answers. Factor 1 is related to the concern about the environment and improvement in accessibility at a city scale resulting from BSS operating in cities. We assign the name "sustainable mobility" to the latent variable associated with it. Following a similar logic, we assign the names "neighbourhood" and "safety" to the latent variables behind factors 2 and 3, respectively.

We model each latent variable as a function of socioeconomic characteristics of the respondent and measure them using the responses to questions that show strong factor loadings as psychometric indicators. Estimation was made using the statistical software Biogeme (Bierlaire, 2020), results are shown in Table 3. For the sake of brevity, we do not report the estimates for measurement parameters that do not have a behavioural interpretation (ω, α, γ and σ from eq (6)) and focus on the

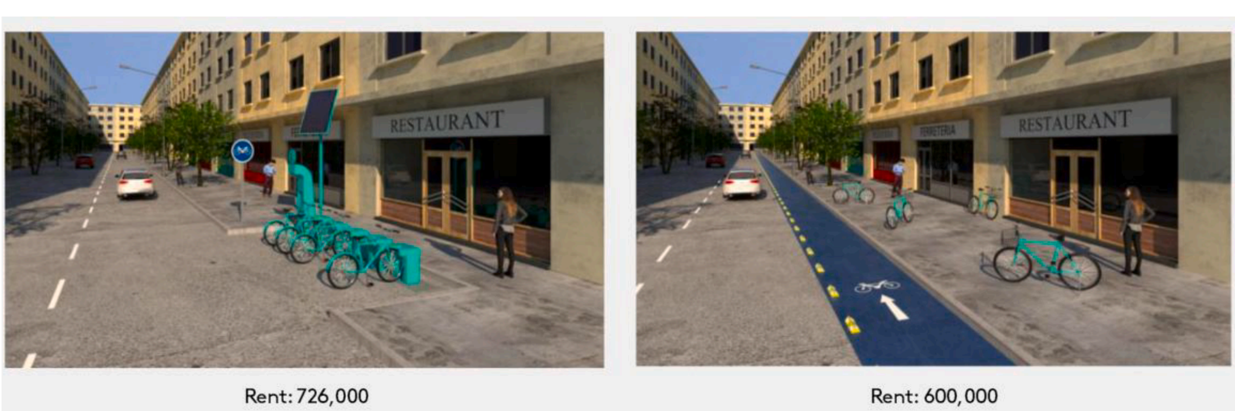

Fig. 6. Example of a choice situation presented to a respondent. The rent value presented below each alternative is based on previously reported rent (+0%, +7%, +14%, +21%). Source: Prepared by the authors.

Table 2
Factor analysis of responses to attitudinal questions.

Attitudinal indicator	factor 1	factor 2	factor 3
Bike-sharing schemes improve cycling safety	–	–	0.817
Bike-sharing stations improve the safety of neighbourhoods	–	–	0.611
Bike-sharing schemes improve a citýs connectivity and accessibility	0.600	–	–
Bike-sharing stations encourage cycling	0.671	–	–
Bike-sharing stations make neighbourhoods more attractive	–	0.661	–
Bike-sharing stations make neighbourhoods look more modern	–	0.688	–
Bike-sharing stations upgrade the status of neighbourhoods	–	0.789	–
Having a bike-sharing station nearby means that I live in a good neighbourhood	–	0.698	–
I believe climate change is something we should be concerned about	0.599	–	–
Bike-sharing systems provide an overall positive benefit to cities	0.790	–	–
Factor variance	2.984	2.578	1.437

Table 3
Estimation results for the latent variable models.

	sustainable mobility		neighbourhood		safety	
Parameter (ρ)	Value	t-stat	Value	t-stat	Value	t- stat
Intercept	1.69	37.3	0.898	20.6	0.323	5.23
Context is "Compact city"	0.182	7	0.0473	2.65	0.153	5.83
Respondent lives close to a BSS station	0.135	5.23	0.036	2.04	−0.144	−4.88
Respondent lives in a municipality with BSS	−0.091	−3.88	−0.271	−8.15	−0.098	−3.58
Income	–	–	−0.017	−1.81	−0.057	−3.55
Higher education studies	0.052	2.65	−0.034	−2.19	−0.05	−2.19
Age	−0.013	−9.64	−0.003	−2.89	0.0026	2.22
Female	–	–	0.0359	2.37	−0.038	−1.76
Household size	–	–	–	–	0.0275	2.56
Student	–	–	−0.081	−3.77	−0.086	−3.03
Respondent is a user of BSS	0.129	4.23	0.173	6.23	0.217	6.48
Final log-likelihood:	−15878		−23490		−13253	
Likelihood ratio test for the init. model:	15,770		13,950		9609.8	
Rho-square for the init. model:	0.332		0.229		0.266	

parameters of the latent variables' structural equations (ρ in eq (3)).

Individuals are more likely to have a positive perception of BSS as a contribution to sustainable mobility when they are bike-sharing users, when they have a university degree or when they live in compact areas of the city that are close to BSS stations. Older individuals are less likely to perceive a positive contribution to mobility and, surprisingly, also those living in municipalities that have access to BSS. The perception of bike-sharing stations improving neighbourhoods is more likely for young individuals and women living in compact areas, while higher income and education reduces this perception.

The perception of bike-sharing stations improving safety is more likely in males of lower-income, living far from stations and in municipalities lacking BSS. The latter suggests that this perception could be due to an idealization of such systems, as reported by recent research (Mora and Moran, 2020).

7.2. Integrated choice and latent variables model

Joint scenario-choice and latent variable models were estimated. Latent variables were included separately in the specification of the satisfaction function and three models were estimated. For comparison purposes, a simple choice-only model was also estimated. Results are shown in Table 4. The second column of the table indicates the variable (or interaction of variables) associated with each parameter. A positive value for β or δ can be interpreted as that variable (or attribute) having a positive impact on the probability of choosing a scenario and, therefore, a positive effect on perceived satisfaction; conversely, a negative value for β means that a variable (or attribute) is having a negative impact in the probability of choosing the aforementioned scenario. Most parameters were estimated interacted with both the compact and residential contexts.

Results indicate an overall positive valuation of the presence of bike-sharing stations of all types (these values are estimated with respect to the situation of not having any station or bicycles) with a slightly stronger effect in the Compact City context. Older individuals are more likely to dislike public bicycle systems in general, although the estimates for this attribute are not very significant.

The preference between different types of bike-sharing stations is more or less equal in the Compact City contexts, although in the residential context "light-weight" stations (BiciLC) are less preferred than the others. Other than the latter, there are no important differences in the perception of scenarios in each context. Higher-income males tend to prefer the presence of dockless bikes (Mobike). Dockless bikes are significantly less preferred when displayed in disorder, although not enough to make them something less liked than having no BSS station at all. Women show a slightly higher tolerance to this disorder.

The presence of bike lanes increases the overall likelihood of a scenario being chosen, with a significant decrease when they have bike-sharing station near them. This is an unexpected result since one would assume there are some synergies between stations and cycling infrastructure.

The inclusion of the latent variables improves the models, without triggering significant changes in the magnitude of the choice parameters compared to the basic model. The most significant outcome is for the attitude regarding safety improvements associated with the presence of bike-sharing stations. Since all the parameters for the latent variables are positive and interacted with a dummy variable for the presence of bike-sharing stations, an increase in these variables increases the likelihood of preferring scenarios with bike-sharing stations, and positive structural equation parameters (ρ) can be interpreted as those user-characteristics increasing the likelihood of preferring the presence of bike-sharing. These parameters do not vary much in magnitude and sign with respect to the stand-alone estimation of latent variables (Table 3), although their statistical significance is affected in some cases, such as the neighbourhood effects latent variable. Regardless of this issue, it is possible to see that some user characteristics affect the preference for bike-sharing which is mediated through latent variables, such as being a user and living in more compact municipalities with no access to BSS. This last result is interesting as it seems to indicate that the positive image of BSS declines when individuals become accustomed to them.

A model with all latent variables simultaneously included in the satisfaction function was also estimated, but produced poorer results, with lower significance for the latent variable (δ) and structural equation parameters (ρ). These results are included in the appendix (Table A2)

Table 4
Estimation results for the integrated choice and latent variables model.

		Choice only		Sust Mobility latent variable		Neighbourhood latent variable		Safety latent variable	
	Name	Value	t-stat	Value	t-stat	Value	t-stat	Value	t-stat
β	Intercept (image to the left)	0.0917	2.25	0.0918	2.25	0.0923	2.27	0.0925	2.27
	High-income • Mobike	0.241	2.94	0.24	2.92	0.244	2.97	0.246	2.99
	Female • Mobike	−0.191	−1.7	−0.189	−1.68	−0.191	−1.7	−0.187	−1.66
	Female • Disorder	0.257	1.92	0.257	1.92	0.258	1.93	0.257	1.92
	Age	−0.314	−1.65	−0.252	−1.3	−0.322	−1.69	−0.342	−1.79
βcompact context	Bikesantiago	2.48	3.66	2.02	2.78	2.42	3.54	2.47	3.62
	BiciLC	2.28	3.39	1.82	2.52	2.22	3.27	2.27	3.35
	Mobike	2.34	3.45	1.88	2.59	2.28	3.33	2.33	3.41
	Rent	−0.674	−7.53	−0.674	−7.53	−0.674	−7.53	−0.674	−7.52
	Station at street level	−0.346	−3.82	−0.346	−3.82	−0.346	−3.82	−0.345	−3.81
	Bikelane	1.91	6.44	1.91	6.45	1.92	6.47	1.92	6.46
	Bikelane • Presence of BSS	−1.03	−3.71	−1.04	−3.71	−1.04	−3.73	−1.04	−3.73
	Disorder	−0.856	−5.75	−0.857	−5.76	−0.858	−5.76	−0.859	−5.76
βresidential context	Bikesantiago	2.4	3.63	1.98	2.82	2.34	3.53	2.41	3.64
	BiciLC	1.94	2.95	1.52	2.17	1.88	2.84	1.95	2.95
	Mobike	2.16	3.26	1.74	2.47	2.09	3.15	2.16	3.25
	Rent	−0.613	−8.15	−0.613	−8.16	−0.614	−8.16	−0.614	−8.16
	High income • Rent	0.234	2.79	0.235	2.8	0.234	2.8	0.235	2.8
	Station at street level	−0.232	−3.65	−0.232	−3.66	−0.233	−3.67	−0.233	−3.67
	Bikelane	1.99	8.91	2	8.92	2	8.92	2.01	8.93
	Bikelane • Presence of BSS	−1.15	−5.38	−1.15	−5.39	−1.15	−5.39	−1.16	−5.42
	Disorder	−0.747	−6.49	−0.746	−6.47	−0.743	−6.45	−0.742	−6.44
δ	Sust Mobility • Presence of BSS	–	–	0.0695	1.76	–	–	–	–
	Neighbourhood •Presence of BSS	–	–	–	–	0.062	1.5	–	–
	Safety • Presence of BSS	–	–	–	–	–	–	0.222	2.93
ρ(latent variables)	Intercept	–	–	3.89	18.6	1.83	13.3	0.409	3.86
	Compact context	–	–	0.494	5.63	0.0615	0.966	0.203	3.7
	Lives close to a BSS station	–	–	0.335	3.66	0.0368	0.548	−0.137	−2.04
	Lives in a municipality with BSS	–	–	−0.234	−2.62	−0.584	−7.94	−0.166	−3.9
	Income	–	–	–	–	−0.0423	−1.22	−0.028	−0.737
	Higher education studies	–	–	0.111	1.45	−0.0893	−1.54	−0.0373	−0.962
	Age	–	–	−0.0317	−8.92	−0.0037	−1.19	0.00347	2
	Female	–	–	–	–	0.0513	0.893	−0.0636	−2.04
	Household size	–	–	–	–			0.0147	0.696
	Student	–	–	–	–	−0.209	−2.85	−0.11	−2.12
	User of BSS	–	–	0.46	4.2	0.358	4.51	0.262	3.34
	Final log-likelihood:	−2629.4	–	−16573		−21805		−14958	
	Likelihood ratio test for the init. model:	929.645	–	17000.9		23086.2		13,196	
	Rho-square for the init. model:	0.15	–	0.339		0.346		0.306	

8. Discussion

The employment of latent variables helps to better understand participantś underlying preconceptions affecting the perception of urban environments and BSS. Previous research has shown that pro-environmental latent attitudes, themselves dependant on certain socio-demographic characteristics of respondents, can explain to some degree mobility decisions (Hess, Shires and Jopson, 2013; Roberts et al., 2018). Concurrently, attitudes towards bike-sharing in general and its effects on neighbourhoods seemed less relevant in shaping individual perceptions and preferences, than attitudes regarding more general topics such as urban sustainable mobility, or those more related to the individuals themselves, such as perception of safety. Indeed, recent research using latent variables points in the same direction, showing the importance of safety as a key component when individuals assess cycling facilities (Rossetti et al., 2018).

The fact that all latent variables are more likely to have higher values when the respondent is a user and lives in compact areas could indicate the presence of a self-selection bias (James et al, 2015). It is however interesting to notice that higher income individuals are more likely to think that BSS are a positive contribution at a city-scale perspective, especially on their relation to environmental aspects, while lower-income individuals tend to associate bike-sharing stations to local positive effects. This might be due to the high segregation that characterises the city of Santiago, which is mirrored by the urban landscape and its infrastructure (Rossetti et al., 2019b).

Modelling results show that, regardless of their characteristics (dock-based or dockless), the presence of bike-sharing stations is positively evaluated by respondents not only because of their capacity to improve a citýs accessibility, but also because they can make neighbourhoods look more attractive and modern. This is consistent with previous studies that detected the same positive perception among urban planning officials, especially those working in poor districts (Mora and Moran, 2020). This aspect might be particularly relevant for highly unequal cities like Santiago, where the quality of public infrastructures such as cycle paths, sidewalks or green areas varies enormously across municipalities (Mora et al., 2021). The expansion of BSS to lower-income municipalities has already been identified as necessary due to both efficiency and equity issues in Santiago (Saud and Thomopoulos, 2021) and the results presented here provide additional evidence supporting this idea.

This research also shows that urban and demographic characteristics shape, to some extent, how individuals perceive BSS. Previous work has shown that bike-sharing users are usually younger, more affluent and educated than the general population (Fishman et al 2013), thereby the fact that older people perceived BSS less favourably is not surprising. In addition, the presence of unsupervised and disorganized bicycles in public space was disliked by most respondents, in line with previous research on the matter (Zhao and Wang 2019, Qianling et al 2019), a phenomenon that needs to be addressed by city officials. Peoplés dissatisfaction with disorganized bicycles left in public spaces might be linked to the perception of social unrest and the weakening of social norms in residential communities (Ross and Mirowsky, 1999). This suggests stricter regulations for the operation of dockless BSS might be necessary in the future. For example, assigning parking spaces that do not interrupt pedestrian movement, launching educational campaigns for new cyclists on how to ride and park their bicycles, or forcing the operators to generate incentives for users to park their bikes properly.

In line with previous research (Aldred et al., 2017; Garrard et al., 2008; Zacharias and Meng, 2021), cycle lanes were perceived as positive assets for all users, suggesting the need for secluded and safer infrastructure remains an important demand from citizens (regardless of being a bicycle user or not). Evidence shows that the poor quality of bike lanes in Santiago affects women mainly (Rossetti et al, 2019a; Echiburú et al., 2021), and represents an important barrier to the expansion of cycling in the capital (Gutierrez et al., 2020). This is a matter of concern in Santiago where modal split for cycling is relatively high (4% of daily trips in 2012 and increasing since then), despite the low number and quality of dedicated cycling infrastructure.

There are limitations to this study, though. First, although the bike-sharing systems were shown differently as they exist, people might have recognized them and therefore considered their operational attributes (bicycle quality, costs, etc.) when assessing each system. Second, images showing disorganized bicycles in open spaces were rather subtle, and our model could be underestimating the real negative effect in perception produced by the disarrayed placement of shared bicycles in public spaces and sidewalks. Third, the bias in the sample prevents generalizing results for the whole relevant population. However, since the survey includes enough observations of the sub-sampled segments of the population, and the model controls for several relevant sociodemographic variables, it is reasonable to assume that at least the sign (and therefore interpretation) of the estimated parameters is correct.

9. Conclusions

The results of this study indicate that, beyond perceived increases in accessibility and mobility options, BSS can have overall positive effects on the image of urban landscapes by helping them to be perceived as more attractive, modern and safe. These perceptions are shaped by socioeconomic characteristics and, to some degree, by large-scale properties of the urban areas in which respondents live. For example, BSS are more likely to be positively evaluated in compact urban contexts by younger individuals who are bike-sharing users. Higher-income individuals are more likely to associate BSS to city-wide benefits related to sustainable mobility, while lower-income individuals tend to associate them with local positive impacts.

The three BSS analyzed in this research were perceived as positive elements to be included in public spaces, although dockless systems seem to be preferred by higher-income males. The presence of disorganized dockless bicycles on the sidewalk has an overall negative effect, although not large enough to cancel the aforementioned positive perception. These results suggest that the impact on public spaces should be considered when assessing the convenience of implementing bike-sharing systems.

CRediT authorship contribution statement

Ricardo Hurtubia: Conceptualization, Methodology, Formal analysis, Writing - original draft, Writing - review & editing, Supervision. **Rodrigo Mora:** Conceptualization, Writing - original draft, Writing - review & editing, Supervision, Funding acquisition. **Felipe Moreno:** Investigation, Visualization.

Acknowledgments

We are grateful to ANID (Fondecyt projects N° 1180605 and 1171232) and to CEDEUS (ANID-FONDAP 15110020) for the financial support for this research. We also would like to thank Tomás Rossetti for his help with the experimental design.

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