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Research paper

Gender dynamics in electric bike-sharing: Insights on usage and fare structures

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ABSTRACT

Bike-sharing systems offer an efficient urban mobility solution by reducing traffic congestion, improving health, reducing pollution and promoting intermodality. Designing a pricing strategy for urban electric bicycle rental systems is an important issue to guarantee the desired levels of system adoption. This research explores gender differences in willingness to pay for and use electric bike-sharing services through two case studies, Santander (Spain) and Cartagena (Colombia). The methodology involved creating a survey to collect data on the socio-economic characteristics of participants, their current patterns of bicycle use, and their future use of the electric bike-sharing system. Additionally, the survey explores preferences for e-bike system prices through a stated preference experiment.

Various discrete choice models were estimated to evaluate willingness to pay and elasticities based on different pricing scenarios, including per-use tariffs and annual subscriptions. The results provide variations in context and gender in the perceived value and willingness to pay for bike-sharing services. The study of elasticities reveals that users in Santander are more sensitive to changes in subscription costs and pay-per-use fees than users in Cartagena. Also, women are more sensitive to price changes in both contexts, with higher sensitivity in Santander. This research contributes to an understanding of the factors that influence the acceptance and use of e-bike systems, highlighting the influence of gender when designing and assessing the suitability of rental bike systems in different cities.

1. Introduction

Bicycle-sharing systems aim to replace short car trips and long walking trips, improving urban mobility by offering an efficient transport option (Samet et al., 2018; Shaheen et al., 2010). The interest in this urban transport system is particularly focused on sustainability, as these systems allow for faster and more flexible mobility, reducing traffic congestion and thus reducing travel times. Additionally, implementing this transport system brings cities other positive factors, such as improvements in public health, pollution reduction, and the promotion of intermodality and multimodality (Braun et al., 2016; Galatoulas et al., 2020; Qiu & He, 2018). It has also been documented that bike sharing can influence urban configuration, modify traffic patterns and promote a more cyclist-friendly environment (Vallez et al., 2021).

Research on the effectiveness of bike-sharing systems addresses different aspects, including accessibility, infrastructure, safety and fares. Accessibility refers to the ease users can access bicycles and docking stations. In recent years, the introduction of electric bicycles has increased their use because it favours greater accessibility. Users can overcome geographical barriers, such as steep slopes, thus favouring their use for a wider public, including those with physical limitations (He et al., 2019; MacArthur et al., 2020).

Moreover, the diffusion of this transport system, whether with conventional or electric bikes, is directly related to the infrastructure; if it is adequate, including safe, well-maintained bike lanes and bicycle parking facilities, it is likely to encourage cycling while ensuring the safety of cyclists (Bakogiannis et al., 2019; Nikitas, 2018; Żochowska et al., 2021). Indeed, the perception of safety on bike lanes plays an important role; studies have shown that road safety education and segregation from motorised traffic are effective strategies to increase users' confidence, making citizens more likely to use shared bicycles if they feel safe on the roads (Bakogiannis et al., 2019).

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Finally, studies on fares have shown that users are sensitive to system prices, which establishes the need for a good fare structure (Guo et al., 2017). Some studies relate the sensitivity to payment and fare limits in bike-sharing systems, concluding that it is important to create a dynamic or incentive system to positively influence the use of this transport alternative by building user reliability (Jurdak, 2013). This has led to the joint exploration of establishing a usage fee linked to infrastructure and security improvements to maximise the uptake and use of bike sharing in urban environments (Chen et al., 2020; MacArthur et al., 2020).

Despite the increasing attention to different variables that influence the adoption of electric bike-sharing systems, no studies have been found that analyse the fare structure and its relationship with the use of the system according to the gender of the users. This study aims to fill this gap in the literature by analysing the influence of gender on the use of bike-sharing systems, considering a fare structure consisting of usage and subscription rates. For this purpose, a comparative analysis is carried out between two cities with different socio-demographic characteristics: Santander (Spain) and Cartagena (Colombia).

The article is structured as follows: after this introduction, a review of the literature covering studies on bike sharing with a focus on gender and the fare structure of these systems is presented and directly connected to the research objectives. This is followed by a description of the methodology employed, including details of the data collection instruments and modelling approach used. The results are then presented and discussed.

2. Literature review

Several factors, such as perceived safety, spatial accessibility, socio-economic conditions and users' particular needs, influence the interaction between gender and the use of shared bicycles, whether electric or conventional (Nikitas, 2018; Pelechrinis et al., 2017). Considering and addressing these aspects could contribute to greater equity in access to and use of this type of transport. For example, recent studies have analysed disparities in mobility patterns between genders and how this affects mode choice, including bike sharing, and have identified different behaviour patterns between men and women (Montero et al., 2023). In cities such as New York or Paris, this differentiation shows a lower propensity of women to subscribe to bike-sharing programmes than men, reflecting broader gender inequalities in urban settings (Crossa et al., 2022; Gorrini et al., 2021). Both studies conclude that addressing women's specific needs and expectations is important to improve their participation.

Other researchers have found gender differences in factors such as station location, travel time or safety (Guo et al., 2017; Zhang et al., 2017). These studies also show that cultural and social factors influence gender differences in bike-sharing. This analysis suggests that the uptake of bike sharing can vary significantly between men and women, depending on the urban context and the policies implemented. At the spatial level, studies have also been conducted on the sensitivity of use, with the case of New York revealing gender-differentiated patterns of use, possibly related to the location and availability of bicycles (Blanford, 2020). This finding suggests that bike-sharing infrastructure should be designed considering the specific needs of different demographic groups, including gender. Disparities in mobility patterns between genders have also been investigated, analysing how demographic characteristics such as age and resident or tourist status influence the perception and willingness to pay for bike-sharing (Macioszek et al., 2020; Schultz Peña Rodrigues et al., 2021). Another factor studied was acceptance according to frequency of use and gender (Mooney et al., 2019; Pellicer-Chenoll et al., 2021).

Moreover, rates in non-electric bike-sharing systems influence the participation of different genders, showing that women are more sensitive to cost and accessibility (Nikitas, 2018; Xin et al., 2019). Along the same lines, other authors have perceived the influence of different socioeconomic factors (including gender), showing that bike sharing often disproportionately serves higher-income areas, which could exclude women with lower socio-economic levels (Winters et al., 2019). To model gender differences, the literature has employed various techniques to understand user preferences. The most employed method is stated preference (SP) surveys (Chen et al., 2018; Félix et al., 2022), being also used to design fares that are attractive and sustainable (Qiu & He, 2018; Samet et al., 2018). Regarding the treatment of this type of data, different types of discrete choice models have been used to measure how users perceive variables, such as the price of subscriptions or the cost per use (Ashraf et al., 2021; Du et al., 2019).

As can be seen, there are still important gaps in the research on the interaction between gender, fares, and electric bike-sharing, especially regarding the differential impact of fare structures on men and women. This study addresses these gaps.

3. Methodology

Surveys were designed for Santander (Spain) and Cartagena (Colombia), adapting an instrument to the characteristics of each city. The questionnaire was structured into a socio-economic characterisation section and a section for stated preferences (SP) exercise. This allows information to be collected on the demographic and behavioural characteristics of the participants, as well as their willingness to use electric bicycles in different fare scenarios. Structural equation modelling approaches have usually been used to study how socio-economic variables influence individuals' disposition towards certain transport attributes (Allen et al., 2020; Eboli et al., 2018). However, this study opted for an approach based on discrete choice models since the main objective was to analyse how individual decisions vary according to different fare combinations. To this end, a user characterisation form was designed that includes the essential variables recommended in previous literature (Hensher, 1994; Ortúzar & Willumsen, 2024) thus making it possible to link observable attributes with the choices made in the stated preferences exercise as well as in other studies focused on bike-sharing (dell'Olio et al., 2011; Song et al., 2022)

The first section of the questionnaire includes information on age, educational level, employment status, place of residence, and previous experience with bike-sharing systems (i.e., frequency of use and travel purpose), as well as their willingness to use them if a system with electric bicycles were to be implemented. In Santander, special emphasis was placed on data collection using the existing system in the city (which did not have an e-bike service at the time of data collection). In Cartagena, however, these questions were omitted because there is no bike-sharing system. Furthermore, questions were included to distinguish between resident and visitor users, which is relevant in both cities due to their tourist attractions.

The second section focused on an SP experiment. This method, widely used in transport and economic studies, allows us to analyse how participants value specific service attributes that have yet to be implemented or for which no market data is available, and then it is possible to study user heterogeneity (dell'Olio et al., 2025). As shown in Table 1, nine scenarios were presented to participants, combining annual subscription fares with prices per 30-min use, which allowed for an evaluation of adoption under different conditions.

In Santander, the scenarios were designed based on fare data from more than 20 Spanish cities with bike-sharing systems. The fare structure for single use ranged from €0.5 to €1.5 per half hour of use, and annual subscriptions between €20 and €50 plus usage fees of €0 to €0.5 for recurrent users. In Cartagena, SP scenarios were designed considering fare combinations based on experiences in cities such as Medellín and Bogotá. The scenarios included annual subscription options with fares between COP 50,00 and COP 200,000 and per-trip fares between COP 0 and COP 4000 per 30 min of usage. Non-subscription options were also incorporated, where trip rates ranged from COP 2000 to COP 6000. At the data collection date, 4500 COP equals approximately €1.

Table 1
Scenario configurations.

Scenario	Fare Category	Subscription fare (€)	Price per 30 min (€)	Subscription fare (COP)	Price per 30 min (COP)
		Santander		Cartagena	
1	Annual subscription + Price per 30 min	35	0.5	100,000	4000
2		20	0.25	50,000	2000
3		50	0	200,000	0
4		50	0.25	200,000	2000
5		20	0.5	50,000	4000
6		35	0	100,000	0
7	Price per 30 min	0	1.5	0	6000
8		0	1	0	4000
9		0	0.5	0	2000

The SP scenarios in both cities were designed using an efficient d-error optimised design (Rose & Bliemer, 2009). The design was carried out using the NGENE software (ChoiceMetrics, 2018), and preliminary data was obtained from a pilot sample of 20 participants (Hensher et al., 2015). The initial values for the experimental variables were determined based on a multinomial logit model applied to this sample. This allowed us to generate an efficient design, balancing the scenarios to avoid biases in the experiment.

Logit Mixed (ML) models were estimated based on the data collected in Santander and Cartagena to study gender differences in the willingness to use an electric bike-sharing system considering different fare structures. This approach, based on the work of Ben-Akiva et al. (2002) and Train (2009), allows us to analyse how individual preferences vary across genders by including interactions with fare parameters, to consider unobserved heterogeneity by including random fare parameters, and to quantify the characteristic panel effect of an SP experiment (McFadden & Train, 2000). This model was chosen for its ability to address the abovementioned issues, overcoming the limitations of other approaches that do not allow for heterogeneity and randomness in preferences. This approach provides a more detailed representation of gender differences in our case studies.

Train (2009) explains that, in an ML, the panel effect, which accounts for correlations of responses of the same individual due to unobserved characteristics that are constant over time or choices made, can be modelled by incorporating an additional error term. This term captures the unobserved individual-specific heterogeneity and allows for correlated within-panel choices, as Equation (1) shows.

$$U_{nj} = \alpha' x_{nj} + \mu'_{nj} z_{nj} + \varepsilon_{nj} + \eta_n \quad (1)$$

Where.

- U_{nj} = Utility function associated with alternative j for individual n.
- α' = Vector of fixed parameters.
- μ'_{nj} = Vector of random parameters.
- x_{nj} and z_{nj} = vectors of the variables respectively associated with fixed and random parameters.
- ε_{nj} = Extreme value identically distributed independent error term.
- η_n = Panel effect modelled as a random error that remains constant for each individual n across all observed choices.

The parameters μ'_{nj} are modelled as a combination of a population mean value and a random variation term shown in Equation (2).

$$\mu_{nj} = \overline{\beta_j} + \sigma_j \cdot \nu_{nj} \quad (2)$$

Where.

- $\overline{\beta_j}$ is the average parameter in the population.
- σ_j is the standard deviation that captures the variability between individuals.
- ν_{nj} is a random term that follows a known normal distribution in the case of this article.

The terms z_{nj} represent an error component, which, together with the ε_{nj}, comprises the random part of the utility in discrete choice models. If z_{nj} takes a value of zero, the model reduces to a Multinomial Logit (MNL), which assumes independence between alternatives, which generates the Independence of Irrelevant Alternatives (IIA) problem.

4. Results and discussion

Data were collected from 390 participants in Santander and 529 in Cartagena. Table 2 shows the socioeconomic characterisation of the sample (partially discussed in Rodriguez et al. (2024), which allows us to know the different types of users whose sociocultural and geographical differences might influence their usage patterns and preferences for bike sharing.

Firstly, regarding gender distribution, the focus of this study, in Santander, 43.85 % of respondents identified as male, 53.59 % as female, and 2.56 % chose not to specify. In contrast, in Cartagena, a higher percentage identified as male (53.12 %) compared to female (45.75 %), with only 1.13 % opting not to disclose their gender. Differences were also observed in age groups, where respondents in Cartagena were primarily young, with 24.01 % under 25 years of age, compared to 17.18 % in Santander. Santander had a higher proportion of older respondents, especially in the 55–64 (16.92 %) and 65–74 (10.51 %) age groups.

Secondly, regarding the employment situation, the percentage of salaried employees surveyed was significantly higher in Santander (42.05 %) than in Cartagena (23.25 %). In contrast, the percentage of self-employed was higher in Cartagena (7.75 % compared to 3.85 %), as was the percentage of unemployed (23.25 % compared to 9.74 %). In terms of educational level, in Santander, 48.97 % of respondents had a university degree, compared to only 16.45 % in Cartagena, where the proportion of people with secondary education (38.94 %) or no formal education (13.61 %) was higher. Moreover, most respondents in Cartagena (94.10 %) resided within the city, compared to 60.52 % in Santander.

Finally, current bicycle use is more than double in Cartagena (58.98 %) than in Santander (26.87 %). The frequency of use also shows differences, with daily use being significantly higher in Cartagena (67.37 %) than in Santander (9.26 %), where occasional use predominates (73.15 %). As for the trip purpose, in Santander, trips are mainly for leisure (57.94 %), while in Cartagena, trips for work (25.34 %) and study (29.39 %) are the most common. On the other hand, the possible use of electric bicycles aroused interest in both cities, with 56.67 % in Santander and 51.98 % in Cartagena. In Cartagena, 58.05 % reported daily use, while in Santander, 55.80 % reported occasional use. Furthermore, the most declared use in Cartagena was for study or work purposes, while in Santander, it was for Leisure.

These data reveal different cycling patterns in cities. In Santander, users are characterised by leisure trips and occasional use. On the other hand, Cartagena has younger users and higher rates of daily use for work and study trips. It is worth mentioning that there is currently no public bike-sharing system in Cartagena, whereas there is in Santander.

Fig. 1 shows the responses to the scenarios of the SP exercise. In Fig. 1 (a) (Santander), scenarios 1 to 6, which combine pay-per-use and subscription, show a similar proportion of 'Travel' responses to 'No travel'. Scenarios 7 to 9, single-pay-per-use, show an increased willingness to travel, especially in the latter scenarios where the fare decreases. In Fig. 1 (b) (Cartagena), scenarios 1 to 6 have a higher proportion of 'Travel' responses than 'No Travel'. Also, the 'travel' response is more frequent in Cartagena in the single-use payment scenarios than in Santander, especially in the lower fares (scenarios 8 and

Table 2
Survey responses for each city.

Variable	Santander	Cartagena	Variable	Santander	Cartagena
	% Over 390 responses	% Over 529 responses		% Over 390 responses	% Over 529 responses
Gender			**Frequency of cycling**		
Male	43,85 %	53,12 %	Daily	9,26 %	67,37 %
Female	53,59 %	45,75 %	Weekly	14,81 %	8,07 %
Not specified	2,56 %	1,13 %	Monthly	2,78 %	3,51 %
Age			Occasionally	73,15 %	21,05 %
Under 25	17,18 %	24,01 %	**Where did I rent a bike?**		
25–34	15,64 %	22,68 %	Santander	63.74 %	–
35–44	15,90 %	20,42 %	Other	36.26 %	–
45–54	17,95 %	16,07 %	**Trip purpose**		
55–64	16,92 %	5,86 %	Leisure	57,94 %	7,43 %
65–74	10,51 %	3,78 %	Work	13,08 %	25,34 %
75 and over	5,90 %	7,18 %	Studies	6,54 %	29,39 %
Employment Status			Health	2,80 %	8,45 %
Housework	1,54 %	3,02 %	Shopping	0,93 %	3,38 %
Self-employed	3,85 %	7,75 %	Administrative	3,74 %	19,26 %
Employee	42,05 %	17,96 %	Sport	5,61 %	6,08 %
Unemployed	9,74 %	23,25 %	**Use E-Bike if available**		
Student	8,21 %	7,37 %	Yes	51,98 %	56,67 %
Retired	16,15 %	30,62 %	No	22,31 %	27,43 %
Education level			Not sure/Depends	25,71 %	15,90 %
None	1,79 %	13,61 %	**E-Bike Frequency Use (if available)**		
School grad.	8,72 %	15,88 %	Daily	15,94 %	58,05 %
High School	7,44 %	38,94 %	Weekly	18,84 %	11,87 %
H. School Dipl.	33,08 %	15,12 %	Monthly	9,42 %	1,32 %
University	48,97 %	16,45 %	Occasionally	55,80 %	28,76 %
Residence			**E-Bike Trip purpose (if available)**		
Within the city	60,52 %	94,10 %	Leisure	53,45 %	5,74 %
Within the region	19,74 %	4,95 %	Work	16,00 %	29,77 %
Within the country	15,32 %	0,95 %	Studies	6,91 %	22,72 %
Outside the country	4,42 %	0,00 %	Health	4,00 %	6,27 %
Bike use?			Shopping	2,91 %	6,27 %
Yes	26,87 %	58,98 %	Administrative	5,82 %	25,07 %
No	73,13 %	41,02 %	Sport	5,09 %	1,83 %
			Other	5,82 %	2,35 %

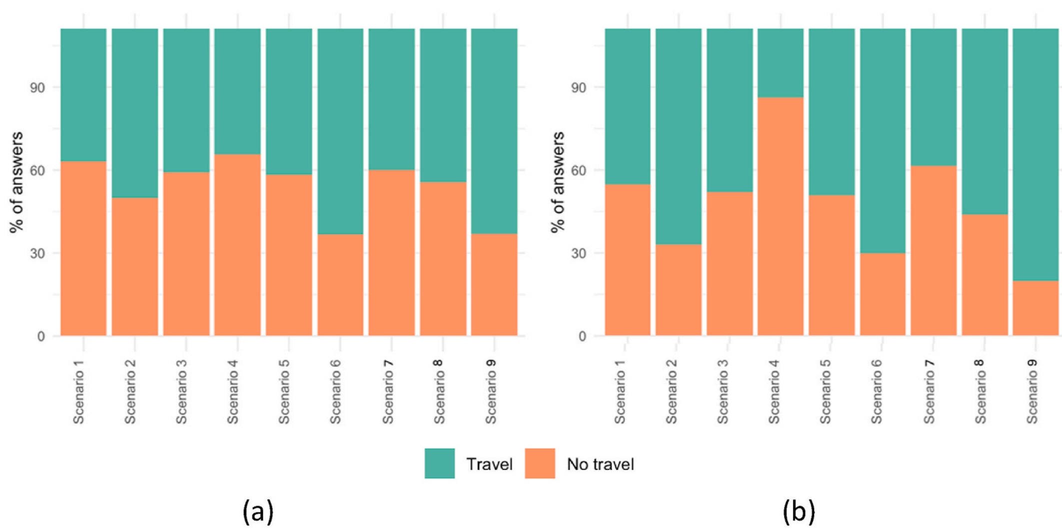


Fig. 1. Decision taken in the scenarios presented (a) Santander (b) Cartagena.

9).

Different model configurations were tested from the survey data, and only statistically significant ones were included in the final model specification. First, an MNL model was estimated as a starting point for the more complex model estimation (equations (3) and (4)). Second, two ML models (equations (5)–(8)) have also been estimated (ML1 and ML2). Both ML models capture the unobserved correlation between choices made by the same individual (panel effect). However, ML2 incorporates random parameters in the pay-per-use and subscription (Equations (7) and (8)). When random parameters were used, both models were estimated using the simulated maximum likelihood method using an MHLS sequence with 2000 draws (v) (Hess et al., 2006). Finally, another modelling approach, such as the Probit model (equations a.1 a.2 in Appendix 1), was used as an extension to verify the robustness of the proposed approach.

MNL:

$$U_{USE} = SUBSCRIPTION \cdot (\beta_{Subscription} + \beta_{Gender} \cdot FEMALE) + RATE \cdot (\beta_{Rate} + \beta_{Gender} \cdot FEMALE) + \varepsilon \quad (3)$$

$$U_{NOUSE} = \alpha_{NOUSE} + \varepsilon \quad (4)$$

ML1:

$$U_{USE} = SUBSCRIPTION \cdot (\beta_{Subscription} + \beta_{Gender} \cdot FEMALE) + RATE \cdot (\beta_{Rate} + \beta_{Gender} \cdot FEMALE) + \eta_{panel} + \varepsilon \quad (5)$$

$$U_{NOUSE} = \alpha_{NOUSE} + \eta_{panel} + \varepsilon \quad (6)$$

ML2:

$$U_{USE} = \left(\left(\overline{\beta}_{Subscription} + \sigma_{Subscription} \cdot \nu\right) + \beta_{Gender} \cdot FEMALE\right) \cdot SUBSCRIPTION + \left(\left(\overline{\beta}_{Rate} + \sigma_{Rate} \cdot \nu\right) + \beta_{Gender} \cdot FEMALE\right) \cdot RATE + \eta_{panel} + \varepsilon \quad (7)$$

$$U_{NOUSE} = \alpha_{NOUSE} + \eta_{panel} + \varepsilon \quad (8)$$

The results of the probit model are presented in Table a.1 of Appendix 1, which shows the significance of all variables. Table 3 shows the modelling results of the logit models. It is observed that the MNL model presents lower statistical significance for the gender parameter, which is resolved by incorporating unobserved heterogeneity in preferences in the ML models. However, to select the best model, a likelihood ratio test was performed between the MNL and the ML1 (restricted model), and finally between ML1 and ML2 (full model). The first comparison between the MNL and ML1 models shows that ML1 provides a better fit. In both Santander and Cartagena, the likelihood ratio test yields a log-likelihood greater than 1000. Since this value is far above the critical value of $-\chi^2$ with 4 degrees of freedom (9.49), the MNL model can be quickly disregarded.

The second comparison between ML1 and ML2 models shows that ML2 is better adjusted. In the Santander models, the log-likelihood of the ML1 model was −1774.34, while the log-likelihood of the ML2 model was −1619.91. Applying the likelihood ratio test formula, 308.86 was obtained. This exceeds the critical value of the χ^2 distribution with 4 degrees of freedom at the 5 % significance level (9.49), indicating that the ML2 model provides a better fit to the data than ML1. Similarly, for the Cartagena models, the test produced a value of 107.86, again above the critical threshold, supporting ML2 specification as the best option. Therefore, while all models show an adequate fit, ML2 outperforms ML1 in both case studies. The significant improvement from ML1 to ML2 is attributed to the inclusion of unobserved heterogeneity in the fare-related parameters.

Considering the ML2 models, the heterogeneity in the valuation of per-use of the service fares (RATE) and subscription fares (SUBSCRIPTION) was modelled using a normal distribution, with deviations significantly different from zero and the effect of the gender variable accounted for. The estimated parameters were negative and statistically significant in both case studies. These results indicate that the valuation of both per-use and subscription fares influences the probability of using the shared bicycle system, with the per-use fare having a greater impact than the subscription fare. Additionally, the valuation of these variables is heterogeneous, partly explained by gender. Specifically, women exhibit a more negative valuation of the rates, meaning that an increase in fares reduces their utility from using electric bike sharing to a greater extent. Consequently, women are less likely to use the service when rates increase. In addition, the error component specified to capture unobserved heterogeneity at the panel level yields significant and similar deviations in both cases: $\sigma_{Panel} = 2.103$ in Santander and $\sigma_{Panel} = 2.014$ in Cartagena.

As for the evolution of market share as a function of the subscription price and gender (Fig. 2), in both cities, it shows a common trend that is consistent with the increase in prices. As the subscription price increases, the participation in the e-bike system decreases. However, in both cases, this decrease is more pronounced for women than men. In Santander, men show less sensitivity to price, with a less steep drop in usage as the subscription fee increases than women. Compared to Cartagena, it is more sensitive to tariff increases (as they started with a higher initial fee). In Cartagena, both men and women show this decline less markedly, suggesting a lower elasticity to price changes, although it is still higher for women. These differences reflect a greater female sensitivity to the price of the service, especially in Santander, where the

Table 3
ML models estimations.

Variable Name	Base MNL				Mixed Logit with panel effect (ML1)				Mixed Logit with panel effect and random parameters (ML2)			
	param	Robust *t*-test	param	Robust *t*-test	param	Robust *t*-test	param	Robust *t*-test	param	Robust *t*-test	param	Robust *t*-test
	Santander		Cartagena		Santander		Cartagena		Santander		Cartagena	
	Non-random parameters				Non-random parameters				Non-random parameters			
ASC (NO USE)	−1.182	−9.41	−0.337	−3.77	−2.023	−9.26	−0.662	−3.68	−3.513	−11.83	−0.913	−4.60
GENDER (1 = Female)	−0.008	−1.93	−0.007	−1.61	−0.020	−2.85	−0.013	−2.00	−0.024	−2.41	−0.016	−1.93
									Random parameters mean			
RATE	−1.355	−13.42	−0.805	−10.45	−2.419	−14.21	−1.516	−10.66	−4.807	−11.27	−1.935	−9.63
SUBSCRIPTION	−0.032	−10.00	−0.016	−5.44	−0.055	−9.98	−0.031	−6.08	−0.096	−10.64	−0.042	−6.13
									Random parameters deviation			
σ RATE (Normal)									4.414	9.54	1.568	6.04
σ SUBSCRIPTION (Normal)									0.059	6.04	0.026	9.28
					Panel effects deviation				**Panel effects deviation**			
σ Panel					1.704	15.58	1.870	16.07	2.103	11.69	2.014	12.85
Log-likelihood	−2288.11		−2989.12		−1774.34		−2232.73		−1619.91		−2178.8	
Log-likelihood (Constants only)	−2432.95		−3162.83		−2432.95		−3162.83		−2432.95		−3162.83	
Number of observations	3510		4563		3510		4563		3510		4563	

*All models were calculated using euros with an exchange rate of 1€ equals 4500COP.

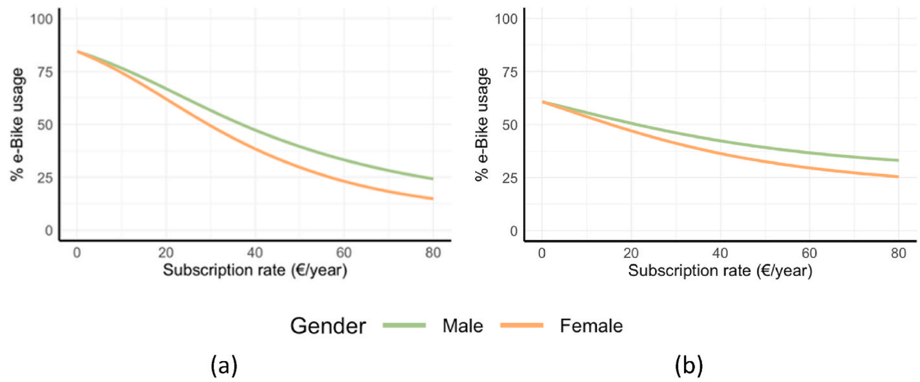


Fig. 2. Simulation of market share for e-bike system with a fixed rate of 0€ per 30-min usage. (a) Santander (b) Cartagena.

main use is for leisure activities, which are more dispensable than the use in Cartagena related to the possible commuting use of the service (if available).

On the other hand, Fig. 3 shows the impact of the increase in pay-per-use in both cities for a 30-min rental. In this case, no notable gender differences are observed in either city, suggesting that it cannot be concluded that gender influences the willingness to pay for the use of the system. However, different sensitivities are perceived in each city. In Santander, the drop in usage is more pronounced between the €0 and €1 fare, where the percentage of usage decreases by more than 50 %, while in Cartagena, the decrease is more moderate (approximately 30 % for the fare increase from €0 to €3), showing less elasticity to the fare increase in the Colombian city.

Gender-differentiated sensitivities to using the system in both cities have also been analysed, considering different annual subscription fares. Fig. 4 illustrates a common trend shared by both cities. For all subscription values analysed, the willingness to use the e-bike sharing system in Cartagena remains below 50 %. In both cities, a higher willingness to use the system is observed when the usage charges are lower than 1€. In Santander, the willingness to use the system is higher for different subscription values than in Cartagena, when the usage fee is zero. However, when the usage fee reaches 1€, the willingness to use the system is higher in Cartagena.

On the other hand, although demand follows similar patterns between men and women, women are less willing to use the system than men. Furthermore, the difference in sensitivity between men and women increases as the subscription fare increases but gradually evens out as the pay-per-use fares increase in the different fare ranges, showing a tendency to stabilise.

The estimated ML2 model was also used to calculate the elasticities of the different attributes related to the two payment variables (pay per subscription and pay per use) for e-bikes in Santander and Cartagena. These elasticities were obtained by weighted enumeration of probabilities in the sample. Concerning the direct elasticities (all of them inelastic), a 1 % increase in the subscription cost resulted in a larger decrease in the probability of using this mode in Santander (−0.465) compared to Cartagena (−0.169). This indicates that users in Santander are more sensitive to changes in subscription cost than users in Cartagena. Similarly, the sensitivity to increases in pay-per-use is higher, although to a lesser extent, in Santander (−0.351) than in Cartagena (−0.262).

The difference in elasticities between the two cities reflects variations in the demographic characteristics and urban context. In Santander, where the infrastructure is more prepared but with higher economic levels and vehicle rates per capita, users are more price-sensitive. In Cartagena, where bicycle users are more oriented towards commuting trips, demand for the service is more inelastic.

Additionally, simulations of disaggregated elasticities have been carried out according to the characteristics of the service for each city. On the one hand, Fig. 5 shows the elasticities for Santander and Cartagena considering variation in the price of a 30-min use of the service and different scenarios of annual subscriptions of €20, €35, and €50, respectively. In both cities, demand is inelastic to the price per use when considering the different genders and subscription prices. In Santander (Fig. 5a), decrescent elasticity is observed up to a specific value, which varies between €0.5 and €1 depending on the subscription price. Then, there is a inflexion point where the trend increases. There may be an unidentified factor in this study influencing this segment of demand, which causes elasticity to rise above a certain price, rather than decrease. As for gender, the differential effect on elasticities becomes evident as the subscription price increases. The higher the subscription price, the trend shows that men have a more negative elasticity value

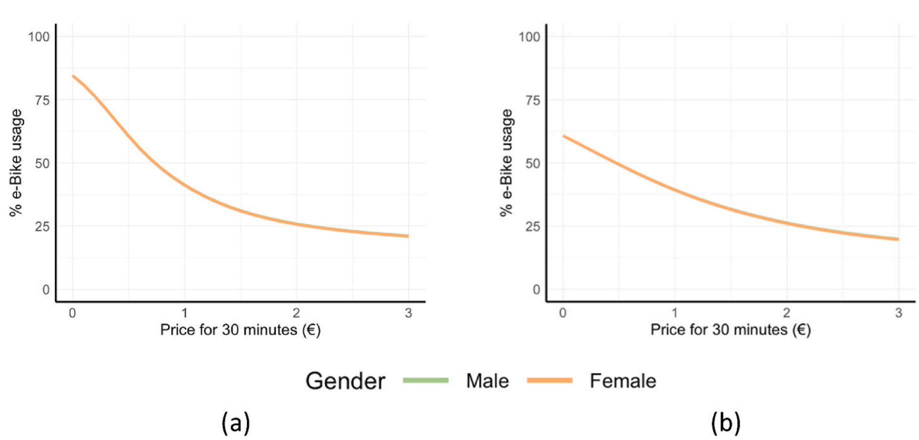


Fig. 3. Simulation of market share for e-bike system with a fixed subscription of 0€ per year. (a) Santander (b) Cartagena.

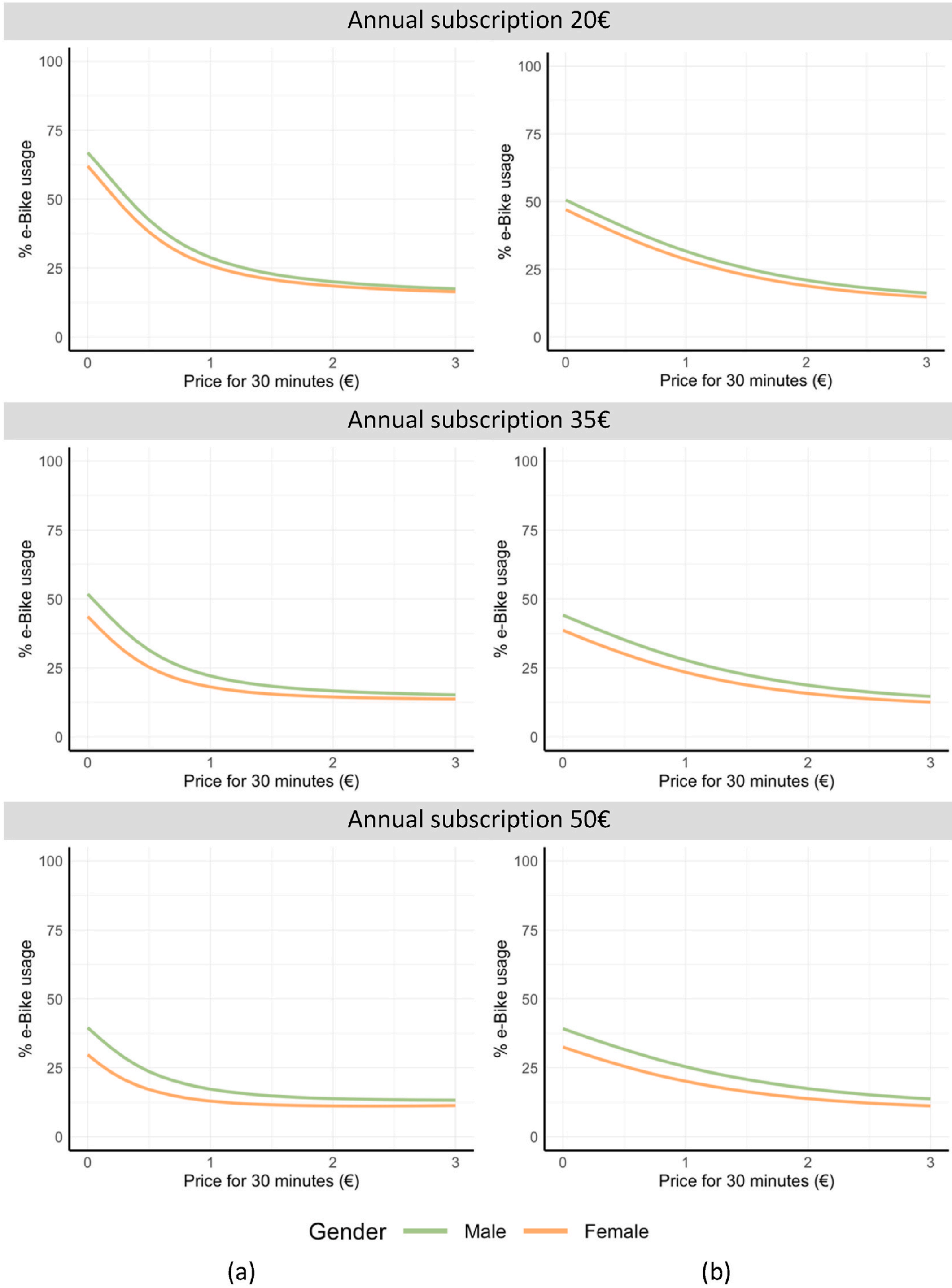


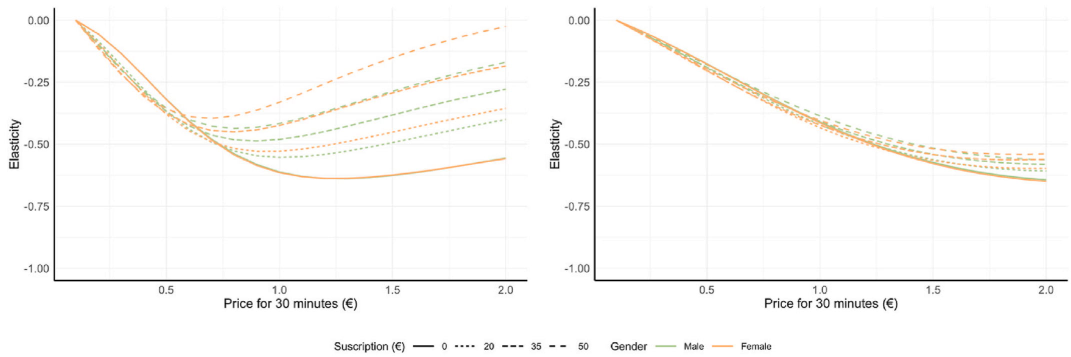
Fig. 4. Simulation of market share for e-bike system with different annual subscription rates and per-use fares. (a) Santander (b) Cartagena.

than women.

In Cartagena (Fig. 5b), elasticity drops to a point where the curve stabilises, tending to be asymptotic. The asymptotic behaviour suggests that, once a certain price has been reached (around 40 euros), users do not perceive significant differences in the cost of the service. Moreover, the differences by gender and subscription price in the figure are small through pay-per-use increases. This behaviour could be influenced by the activities that users state they would carry out with the electric bicycle system, that is, compulsory activities such as work, study and administration, rather than the recreational and leisure activities that are predominant in users of Santander. The system in Cartagena would be more indispensable in daily life, making them less sensitive to price changes and gender dependency in contrast to the use of the system in Santander.

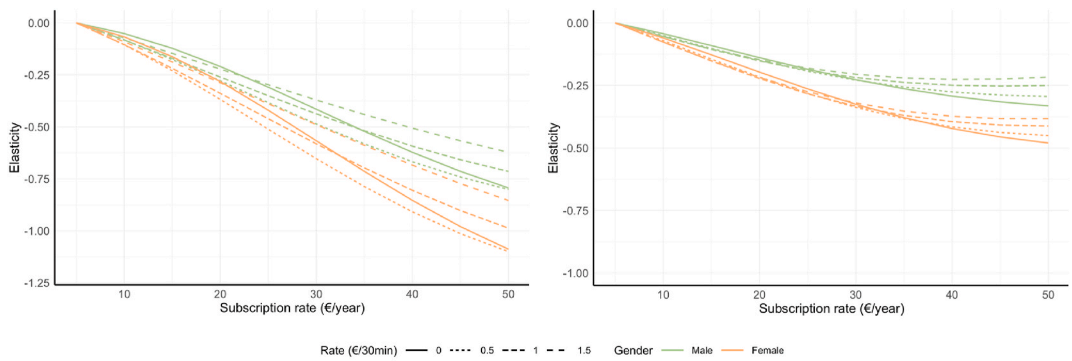
Fig. 6 illustrates the elasticities as a function of changes in subscription prices, considering four rates that range from €0 to € 1.50 for every 30 min of bicycle use. Considering the two different cases, Santander (Fig. 6a) and Cartagena (Fig. 6b), significant differences in price elasticity between men and women are observed. In both cities, women exhibit more negative elasticity values, although the gender disparity is less pronounced in Cartagena than in Santander.

Additionally, the figures reveal a decreasing trend, indicating that as



(a) (b)

Fig. 5. Direct elasticities for e-bike system for different use fares. (a) Santander (b) Cartagena.



(a) (b)

Fig. 6. Direct elasticities for the e-bike system for different annual subscription prices. (a) Santander (b) Cartagena.

subscription prices increase, elasticity becomes more negative. This suggests a higher sensitivity to price changes at higher pricing levels. In Santander, the slope is steeper, with higher elasticity values than in Cartagena, reflecting greater price sensitivity, likely due to the system being primarily used for leisure purposes. Notably, within the analysed price range, female elasticity values in Santander exceed −1, indicating that demand reach elastic behaviour for certain pricing levels, specifically subscription fees above € 40 and per-use prices between € 0 and € 0.5.

In line with these results, it is recommended to consider complementary approaches that integrate advanced technological tools and intelligent planning systems, especially to better adapt to the specific needs of fare and urban context-sensitive groups, such as women in both cities analysed. One can take, for example, the recommendation of Caggiani et al. (2017, pp. 645–650) who have shown how fuzzy logic-based multi-objective models can be implemented in mobile bike-sharing applications. The model can be used to optimise routes considering critical aspects such as safety, pollution and real-time bicycle availability. Although this approach does not explicitly address gender, its methodology enables the integration of different variables, especially those relevant to women, such as perceptions of safety or exposure to pollution. Incorporating these variables into customised planning tools could encourage greater adoption of the system by different user profiles, thus reinforcing the benefits identified in this study.

5. Conclusions

This work has focused on filling a gap in the literature, looking for differences in the predisposition to use electric bike-sharing systems according to gender and fare structure (i.e., per-use and per-subscription fares). Two case studies, Santander (Spain) and Cartagena (Colombia), were used to implement a survey that explored socio-demographic differences and sensitivity to annual subscription prices and pay-per-use through an SP design. Models were then estimated that reflected user preferences and behaviours regarding the future implementation of an e-bike-sharing system in the city. The results of the study revealed differences between genders and between the two cities analysed, as in the previous study with data from conventional (non-electric) bicycles (Suomalainen et al., 2024). In both cities, women are more sensitive to subscription and per-use fares than men. Moreover, this sensitivity is more pronounced in Santander, where bicycle use is principally oriented towards leisure, a more indispensable activity, in contrast to Cartagena, where work and educational uses predominate.

The rate simulations show that, in both cities, changes in the annual subscription and usage tariffs affect women more pronouncedly, especially in Santander, where demand is more sensitive to price. Compared to Cartagena, elasticity in Santander is higher, suggesting that tariff changes have a more significant impact on users in this city. Elasticity analyses indicate that demand for the electric bicycle system in both Santander and Cartagena are predominantly inelastic, especially at low subscription and usage fees. However, as costs increase, elasticity varies in Santander, there is a transition to higher elasticities in certain price ranges. In contrast, Cartagena shows a trend towards stabilised elasticities at higher prices, indicating that the system may be perceived as more indispensable. These findings are useful for adjusting pricing strategies that encourage greater adoption of the system among different groups of users and social contexts. Therefore, differences in gender characteristics should be considered when designing a shared electric bicycle system.

Finally, several challenges and limitations have been encountered that open the way for future research. Although two geographically and socio-culturally separate cities have been included, more urban contexts could enrich the study results. Moreover, including cities with already established systems by combining the expectations of SP surveys with those of PR surveys that show existing realities could enrich the conclusions drawn.

CRediT authorship contribution statement

Andrés Rodríguez: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Maira Delgado-Lindeman:** Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Silvia Sipone:** Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Luigi dell'Olio:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization.

Disclosures and declarations

This research does not involve sensible and/or individual data regarding the human participants and does not involve the use of animals. The personal data in this paper are anonymous and/or presented in aggregate form. All the authors agree with the information provided and give their consent to the information provided.

Data availability statements

The data used in this article have been obtained from surveys of study participants.

Authors cannot share individual data but aggregate data included in the article tables.

Declaration of competing interest

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

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Appendix 1. Probit model

This appendix presents an additional analysis using a Probit model, with the aim of verifying the robustness of the results obtained from the Mixed Logit models presented in the main body of the paper. The Probit model has been estimated assuming a non-linear relationship between the explanatory variables and the choice probabilities. Both the Probit model approach (equations ap1 and ap.2) and the results obtained (Table ap.1) are detailed below, further validating the previous findings and allowing for a more complete analysis of the observed elections in both cities.

Probit:

$$U_{USE} = \text{SUBSCRIPTION} \cdot \left(\beta_{Subscription} + \beta_{Gender} \cdot \text{FEMALE}\right) + \text{RATE} \cdot \left(\beta_{Rate} + \beta_{Gender} \cdot \text{FEMALE}\right) \quad \text{(ap.1)}$$

$$U_{NOUSE} = \alpha_{NOUSE} \quad \text{(ap.2)}$$

Table ap.1
Probit models estimations

Variable Name	Probit			
	param	robust *t*-test	param	robust *t*-test
	Santander		Cartagena	
RATE	−1.188	−11.56	−0.702	−8.81
SUBSCRIPTION	−0.030	−10.56	−0.014	−6.36
ASC (NO USE)	−1.038	−9.81	−0.292	−3.76
GENDER (1 = Female)	−0.007	−3.28	−0.006	−2.72
Log- likelihood	−2287.85		−2989.21	
Log- likelihood (Constants only)	−2432.95		−3162.83	
Number of observations	3510		4563	

*All models were calculated using euros as the exchange rate 1€ equals 4500COP.

The results obtained (Table ap.1) reveal similar patterns to those obtained in the Mixed Logit models in both cities, although the Probit models do not include random parameters. In both cities, the variables 'RATE' and 'SUBSCRIPTION' have significant negative effects, suggesting that an increase in these variables decreases the probability of transport mode choice, with highly significant *t*-test parameter values supporting their statistical significance. Also, as in the ML models, the variable 'GENDER' shows significant effects, with a negative impact on women. This reinforces the idea that gender plays a relevant role in the decision-making process for electric bike-sharing systems. Regarding model fit, the Log-likelihood values show a higher likelihood in the Mixed Logit models (Table 3), suggesting that these models can better fit the data due to the inclusion of random parameters and the panel effect.

Data availability

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