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E-scooters: how do latent and socioeconomic factors affect their usage in the global south? Implications for policy planning

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ABSTRACT

Electric scooters have been a rapidly growing mode of transport in recent years. This massive proliferation has brought issues frequently addressed without sufficient technical or scientific support, especially in cities of the Global South. This study seeks to identify latent and socioeconomic factors influencing e-scooter usage and their implications for policy planning. For this purpose, we applied a survey ($n = 1073$) to users and non-users in Bogota, Colombia. We estimated MIMIC model to assess the influence of individuals' perceptions. The results show that perceptions of crash risk and fear of crime negatively influence usage, while environmental awareness and pro-technology attitudes have a positive influence. On the other hand, e-scooter use decreases with the age of individuals, while it is higher in men, car owners, high-income and college-educated individuals. Finally, using the modelling results, we study the implications for policy planning and propose measures to reduce concerns related to e-scooter usage.

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Electric micromobility; e-scooter rider's behaviour; latent variables; MIMIC Model; e-scooter acceptance

1. Introduction

Micromobility is travelling short distances in a low-range human or electric traction vehicle, which can be lifted by a person without much effort and operates at maximum speeds similar to that of a bicycle (Eccarius and Lu 2020; ITDP 2019). It is considered a sustainable and versatile transportation mode that allows users to reach their destination, avoiding congestion (Dias, Arsenio, and Ribeiro 2021). While the conventional bicycle is the default vehicle, micromobility is frequently associated with the e-scooter. These are electric two-wheeled vehicles with handlebars and no seats. Although some people have purchased their e-scooters, renting them per trip is the most common way of usage, a service known as dockless-share e-scooters. To access the service, users must use an app to locate and unlock the vehicle. Shared e-scooters have grown thanks to their business model and potential for reducing pollution in cities, decreasing dependence on fossil fuels for passenger mobility while reducing congestion.

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The widespread adoption of e-scooters and their operational model has brought significant challenges to the mobility landscape. Its growth has been accompanied by various issues, including conflicts with other road users such as cyclists and pedestrians; instances of reckless driving; public space invasion; incidents of vandalism; violation of speed limits; environmental concerns (short service life), social division (proponents and opponents e-scooters), drivers without helmets, social gap and a notable absence of adequate infrastructure for its usage (Gössling 2020; Lanza, Burford, and Ganzar 2022). These issues have become common worldwide (Orozco-Fontalvo, Llerena, and Cantillo 2022).however, the literature regarding this is scarce in the global south. Moreover, to the best of our knowledge, there are no studies analysing users' perceptions of these vehicles in Latin America.

E-scooters started operating in Latin America in early 2018 as a transport alternative in congested capitals and overcrowded public transport. That year, e-scooter companies started deploying their e-scooters on the streets of Mexico City; later the same year, other companies started their operation in Brazil, Colombia, Peru, and Chile. Just like in Europe and the USA, e-scooter trips grew fast, reaching their peak in late 2019, just before being hit by the Covid-19 pandemic (Orozco-Fontalvo, Llerena, and Cantillo 2022). Similar to other regions, several issues arose immediately after its introduction. Issues related to the introduction of e-scooters led to protests and rejection from other road users. However, these issues were amplified by the distinct socio-cultural conditions in Latin America.

This study assesses the influence of attitudes and perceptions of different profiles of e-scooter users and non-users through latent factors, estimated through a structural equation model (SEM), from a survey (n = 1073) applied in Bogotá, Colombia. Four latent factors were defined: *Safety perception (crash risk)*, *Fear of crime*, *Environmental Awareness* and *Pro-technology attitudes*. These variables were defined based on previous related research, such as Kopplin, Brand, and Reichenberger (2021). We assess the effect of these latent constructs, attitudes, and perceptions to differentiate users from non-users of e-scooters, controlling for the socioeconomic characteristics of the individuals.

The contributions of this paper are twofold. First, to the best of our knowledge, this is the first study regarding user perceptions of shared e-scooters conducted in Latin America, a global south region with a high economic potential but also high social inequalities. Second, in addition to perceptions of safety, security and attitudes related to environmental awareness, this research considers pro-technology attitudes as determinants of using or not using e-scooters, given that to access this service, users need a certain level of digital literacy. The modelling approach controls for the sociodemographic characteristics of the individuals.

The structure of the article is as follows. The second section presents a literature review. Then, we explain the methodology and modelling framework. After that, we offer the results, discussion, and conclusion.

2. Literature review

Users perceive e-scooters as a fun and versatile transport mode (Christoforou et al. 2021). However, the accelerated growth in the use of e-scooters in cities generated different issues, such as invasion and blocking of public space, conflicts with other road users, vandalism, short service life and safety and environmental concerns (Orozco-Fontalvo, Llerena, and Cantillo 2022). These concerns have motivated researchers to study e-scooter characteristics and their impacts on urban mobility. Nevertheless, the scant information available from the recent mode focused the research mainly on the analysis of the type of injuries caused by crashes (Dhillon et al. 2020), analysis of modal changes (Christoforou et al. 2021), environmental impacts (Hollingsworth, Copeland, and Johnson 2019), life cycle analysis of vehicles (de Bortoli 2021) and interaction with other users (Fitt and Curl 2020), relegating the studies regarding user's perception and public policy formulation.

Since the emergence of electric scooters, characterising the users' profiles has been of interest. E-scooters are used mainly by young high-income men in different cities worldwide (62-bureau de recherche 2019; Christoforou et al. 2021; City of Santa Monica 2019; Murray et al. 2020). On the other hand, when investigating the motivations for using this mode, many people perceive riding e-scooters as fun, making this a relevant reason for use (Bieliński and Ważna 2020; City of Austin 2019; City of Santa Monica 2019). In some cities, such as Portland, e-scooters are primarily used for daily trips (Portland Bureau of Transportation 2019).

Regarding modal change, there are also differences between cities. In the USA, e-scooter trips primarily displaced private vehicles and individual transportation services such as Uber and Lyft, and secondly, from walking (City of Santa Monica 2019; Murray et al. 2020). Meanwhile, in Canadian and Australian cities, such trips come mainly from walking and, in second place, from private vehicles (City of Calgary 2020; Fitt and Curl 2019). In French cities, trips come from walking, followed by trips by collective public transport (62-bureau de recherche 2019). In sum, the e-scooter mainly replaces trips on foot (Reck, Martin, and Axhausen 2022; Wang et al. 2022).

Most e-scooter studies focus on travel and user characteristics, pilot program results, and geographic analysis, but few employ modelling tools to assess perception and latent factors affecting adoption (Orozco-Fontalvo, Llerena, and Cantillo 2022). The issues previously mentioned may affect citizens' perception of e-scooters; however, evaluating these requires more detailed analyses since they cannot be measured directly. Subjective variables such as attitudes, norms, motivations, and desires have been studied in psychology and social sciences. For example, it has been found that private vehicle has extensive use because it provides a sense of independence, power, prestige and freedom, which has been proven in studies (Ben-Akiva et al. 2002; Paulssen et al. 2014; Vredin Johansson, Heldt, and Johansson 2006; Yáñez, Raveau, and Ortúzar 2010). In the context of active modes, previous research demonstrated that risk and safety concerns affect biking (Gutiérrez et al. 2021; Márquez, Cantillo, and Arellana 2021; Rodriguez-Valencia et al. 2021) and walking (Arellana et al. 2022; Cantillo, Arellana, and Rolong 2015; Vallejo-Borda, Cantillo, and Rodriguez-Valencia 2020).

Several researchers demonstrated that users' perceptions influence modal choice (Blazanin et al. 2022; Buehler et al. 2021; Loo et al. 2015; Qin et al. 2018; Sarkar and Mallikarjuna 2018). For e-scooters, subjective factors such as safety and environmental perception, digitalisation barriers, fear of crime, and hedonic motivation are relevant. Knowing these factors and their effect could provide a better insight into e-scooter adoption and user experience while becoming a valuable tool for policymaking.

Integrating subjective variables into econometric models has represented challenges, such as redesigning the collection of information, adjusting the analysis methods, and looking for ways of verifying predictions (McFadden 1986). Nevertheless, researchers have worked to incorporate into the 'black box' the explicit analysis of subjective factors, which has been achieved by integrating models of latent variables and measurement of psychometric factors, previously used in the measurement of unobservable attributes (Ben-Akiva et al. 2002).

Including latent variables in modelling allows for the visualisation of the existing relationship between the variables that cannot be measured directly, as well as the impact of individuals' socioeconomic characteristics. Moreover, it has been found that models including latent variables better represent user behaviour and have better goodness of fit indicators (Ben-Akiva et al. 2002; Vij and Walker 2016; Yáñez, Raveau, and Ortúzar 2010).

Table 1 summarises the advances in modelling e-scooter usage several conclusions can be drawn from this review. The first is that studies are recent, mainly in the USA, Europe, Asia, and Australia. The second is that, except for the investigation by Rodriguez-Roman et al. (2022) in Puerto Rico, a lack of studies in the global south, including Latin America, is evident. Conversely, the influence of latent factors has not been studied in the region.

Various modelling frameworks have been used, including discrete choice, count, and structural equation models. The latent variables involved include environmental sensitivity and perceptions of risk and safety. In some cases, the authors used the Theory of Planned Behaviour and the Unified Theory of Acceptance and Use of Technology (Kopplin, Brand, and Reichenberger 2021). Also noteworthy is the inclusion of socioeconomic characteristics of the individual and the household (age, gender, education, income, household size, children in the home and ownership of a vehicle, among others) and the environment (residential location, population density, accessibility to modes of transportation and land use, among others).

Based on this literature review and the main issues identified in different cities, we hypothesise that four latent variables influence e-scooter usage in the global south, being (1) *safety perception* due to evidence of the high number of crashes and falls in these vehicles (Che, Lum, and Wong 2020; Félix, Orozco-Fontalvo, and Moura 2023; Haworth, Schramm, and Twisk 2021; Rix et al. 2021; Sanders, Branion-Calles, and Nelson 2020); (2)*fear of crime* due to the rates of thefts in the city and its influence when choosing a mode of transport (Chadee et al. 2019; Chataway and Hart 2016; Cozens et al. 2003; J. Soto, Orozco-Fontalvo, and Useche 2022); (3) *environmental awareness* because the e-scooter was introduced as environmentally friendly (de Bortoli and Christoforou 2020; Hollingsworth, Copeland, and Johnson 2019), Öztaş Karlı, Karlı, and Çelikyay 2022, Kopplin, Brand, and Reichenberger (2021); and (4) being *pro-technology* since e-scooters are a technological innovation on their own, and rental services operate through digital platforms, which may be attractive to one sector of the population or a barrier to another (Chen 2019; Kopplin, Brand, and Reichenberger 2021). The hypothesised model is presented in Figure 1.

3. Methodology and data

This research was carried out in Bogotá, the capital city of Colombia, with a population of 7.2 million inhabitants and an estimated 13.4 million daily trips, of which 70% are made on sustainable modes (Secretaría de Movilidad 2019). However, Bogotá has been ranked as one of the most congested cities in the world (TomTom, 2020). E-scooters appeared at the end of 2018 and rapidly grew during 2019 until their operation stopped due to the

Table 1. Literature review. Modelling e-scooter usage and perceptions

Autor and year	Location	Analytical Method	Latent Variables	Socioeconomic and other variables
Bai and Jiao (2020)	Austin and Minneapolis, USA	GIS hotspot spatial analysis and negative binomial regression models		Population density, gender, age, education, land use, transit accessibility, distance to CBD
Caspi, Noland, and Smart (2020)	Austin, Texas, USA.	Analysis of trip patterns and spatial regression		Land use, bikeways in cell, bus stop in cell, employment density, intersection density, student ratio, distance to CBD
Eccarius and Lu (2020)	Taiwan	Theory of planned behaviour. Factor analysis and structural equation modelling	Attitudes toward e-scooters, Behavioral control over use, Social norms regarding use, Usage intention, Perceived compatibility, Environmental values, Subjective norms, Awareness-knowledge.	
Sanders, Branion-Calles, and Nelson (2020)	Tempe, Arizona, USA.	Chi-squared and Kruskal Wallis tests		Age, gender, ethnicity, income, children in the household, trip purpose, replacement mode
Younes et al. (2020)	Washington, D.C. USA	Negative-binomial regression model		Weather, time of the day, day of the week, special events, gas price
Almannaa et al. (2021)	Riyadh, Saudi Arabia	Logistic regression model		Marriage status, age, gender, occupation, income, education, sports activity, car ownership, ride-hailing system usage, bike usage, motorcycle usage, previous e-scooter usage
Baek et al. (2021)	Seoul, South Korea	Stated Preference experiment and Mixed Logit model		Age, gender, income, e-scooter experience, moving time for bus, moving time for e-scooter, moving time for walking,
Cao et al. (2021)	Singapore	Mixed logit models		Mass rapid transit stop, mass rapid transit transfer, mass rapid transit walking, fare, gender, age, income.
Christoforou et al. (2021)	Paris, France.	Binary logit model		Public transit use, frequency of e-scooter use, frequency of taxi use, e-scooter playfulness
Gioldasis, Christoforou, and Seidowsky (2021)	Paris, France	Logit, mixed logit, SEM	Risk	Age, gender, household, distance, trip duration, walking time, alcohol and drug consumption
Guo and Zhang (2021)	Florida, USA	Random parameter models		Gender, ethnicity, income, education, vehicle ownership,

(*Continued*)

Table 1. Continued.

Autor and year	Location	Analytical Method	Latent Variables	Socioeconomic and other variables
				household structure, e-scooter ownership, access, riding behaviours, trip purposes, health indicators, usage frequency, last trip motivation factor, mode substitution.
Ham et al. (2021)	Seoul, South Korea	Demand and unmet demand prediction using latent features and deep learning		Total e-scooter trips, trips e-scooter location, total of e-scooter users, total general trips and location
Haworth, Schramm, and Twisk (2021)	Brisbane, Australia	Logistic regression		Gender, age, mode, location on the street, time period, site
Hosseinzadeh et al. (2021a)	Kentucky, USA.	Geographical Weighted Regression		Age, land use, density of intersection, density of local roads, walk score, bike score, transit score
Hosseinzadeh et al. (2021b)	Kentucky, USA.	Geographical Weighted Regression in Traffic Analysis Zones		Age, gender, land use, density of intersections, density of bike lanes, average elevation, walk score, park score, job proximity index
Kopplin, Brand, and Reichenberger (2021)	Bayreuth, Germany	Unified Theory of Acceptance and Use of Technology	Performance expectancy, Effort expectancy, Perceived safety, Hedonic motivation, Environmental concerns, Social influence	
Lee et al. (2021)	South Korea	Latent class adjacent-category ordinal logit model	Satisfaction with the Town bus	Gender, age, income, trip type, trip purpose, trip time.
Li et al. (2021)	USA	Antecedent-privacy concern-outcome (APCO) macro model	Privacy experiences, Privacy awareness, Usage regularity, Geographical regularity, Privacy concerns for Payment Information, Privacy concerns for location information, Information privacy-protective responses	Gender, age, education, occupation, use frequency, use per time, use purpose
Mitra and Hess (2021)	Ontario, Canada.	Weighted logistic regression model	Quick and predictable; Active, flexible, and cost-effective	Age, gender, living situation, bike ownership, usual commute model, residential location, other people walking and cycling, streets are safe for all road users
Nikiforiadis et al. (2021)	Greece	Classification tree model and a latent variable logit model	Engagement	Age, gender, Area of living, traffic congestion, education.
Reck and Axhausen (2021)	Zurich, Switzerland	Multivariate probit model		Age, gender, income, driver's license, vehicle ownership, education,

(*Continued*)

Table 1. Continued.

Autor and year	Location	Analytical Method	Latent Variables	Socioeconomic and other variables
				employment, public transit ticket, travel time, travel flexibility, travel priority: environment
Reck et al. (2021)	Zurich, Switzerland	Mode choice model estimation		Distance, price, vehicle density, day period, battery
Zhang et al. (2021)	Virginia, USA.	Recursive logit route choice model		Slope, bikeway, multi-use path, pedestrian way, stairs, road hierarchy, interception, link size
Blazanin et al. (2022)	Autin, Texas, USA	Generalised Heterogeneous Data Model (GHDM)	Safety concerns, Time consciousness, Green-lifestyle propensity	Age, gender, education level, employment status, driver status, vehicle ownership, household size, land use, population density
Javadinasr et al. (2022)	Chicago, USA	SEM. Technology Acceptance Model	Perceived reliability, Perceived usefulness, Perceived ease of use, Social influence, Variety-Seeking, Perceived Enjoyment	
Öztaş Karlı, Karlı, and Çelikyay (2022)	Turkey	SEM. Unified Theory of Acceptance and Use of Technology	Performance expectance, Effort expectancy, Social Influence, Facilitating conditions, Hedonic motivation, Price sensitivity, Environmental awareness	
Rodriguez-Roman et al. (2022)	Mayaguez, Puerto Rico	Exploratory data analysis, Spatial analysis, binary logit		Age, gender, vehicle ownership

pandemic situation in 2020. According to the mobility survey conducted in 2019, around 13 thousand daily trips were made by e-scooters in the city (Secretaría de Movilidad 2019).

A stated preferences survey was designed and applied to users and non-users of e-scooters in 2021. The survey was conducted randomly among city dwellers and took approximately 15 minutes to complete. Some surveys were conducted online (28%), using social networks like Facebook, Twitter, and Instagram. However, most were completed in person (72%) in zones with a high presence of riders. This involved the sharing of a QR code but with the assistance of a trained pollster to guarantee an accurate completion.

We obtained a total of $n = 1073$ valid surveys. The form used for the study consists of two sections. The first focused on the socioeconomic information and travel characteristics of respondents. The second section collected perceptions of different aspects of e-scooter usage through a Likert scale from 19 previously defined indicators.

3.1. Socioeconomic profile of the respondents

Given the purpose of the study, we decided to have a significant sample of e-scooter users (over non-users). The total number of valid surveys was 46% ($n_1 = 490$) of e-scooter users and 54% of non-e-scooter users ($n_2 = 583$).

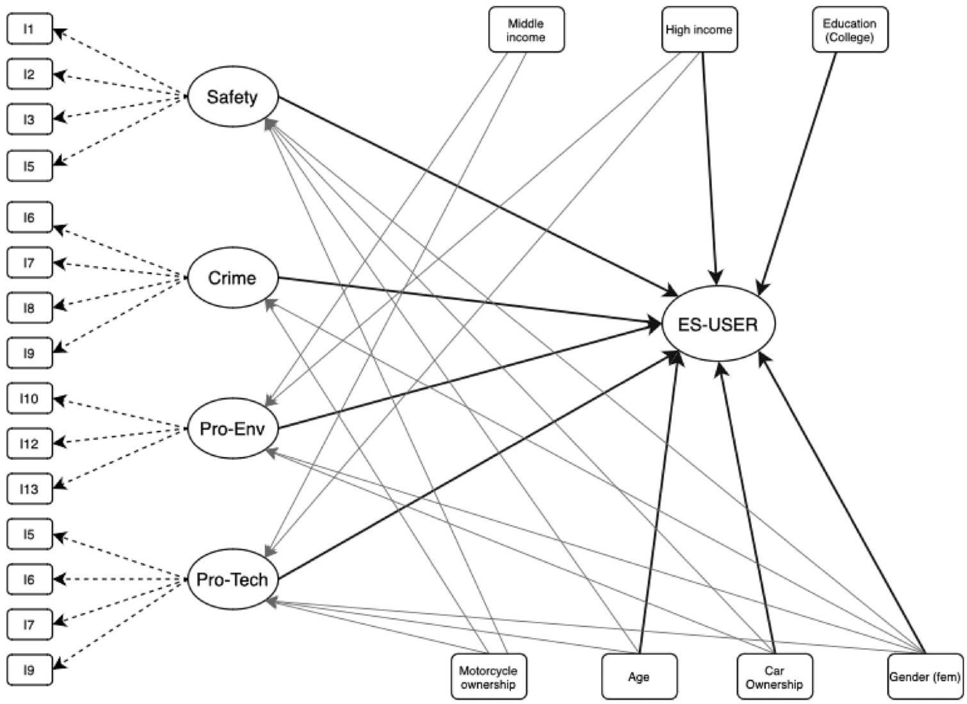

Figure 1. Hypothesised model

Table 2 presents the socioeconomic profile of the sample. For the income data, we used socioeconomic strata as a proxy (Cantillo-García, Guzman, and Arellana 2019). In terms of the representativeness of the sample, it matches the population in terms of gender, but some characteristics differ from the overall demographic. This was intentional in order to follow the profile of ES users presented in the literature, such as the over-representation of young adults. In the case of income, we deliberately focused on medium – and high-income individuals, deciding based on the scarcity or absence of e-scooter services in low-income areas, thus ensuring a more contextually relevant sample.

3.2. Indicators

The indicators were defined based on the different studies cited in the literature review. For instance, indicators about being pro-technology were inspired by the structure of the technology acceptance model (Venkatesh and Davis 2000). On the other hand, other indicators were based on Kopplin, Brand, and Reichenberger (2021), but considering the context of our case study.

The indicators section included 19 statements, where respondents selected whether they agreed or not using a five-point Likert scale (1. Strongly disagree, 2. Disagree, 3. Neutral, 4. Agree, 5. Totally agree). In this section, four relevant aspects of e-scooter usage were inquired about safety perception (crash risk), fear of crime, environmental awareness, and the willingness to use and adapt to new technologies.

Table 2. Sample characteristics.

Variables		Study sample ($n = 1073$)		Population
		e-scooter users ($n = 490$)	Non-e-scooter users ($n = 583$)	
Gender	Man	64.7%	45.3%	47%
	Woman	34.7%	54.5%	53%
Age range	16–24	36.1%	28.1%	19.3%
	25–39	48.2%	38.3%	35.4%
	40–59	15.3%	30.4%	33.5%
	≥60	0.4%	3.3%	20.3%
Income	Low	14.9%	26.4%	61%
	Middle	75.3%	69.1%	30%
	High	9.8%	4.5%	9%
Occupation	Employee	68.2%	70.0%	–
	Student	27.3%	19.0%	–
	Pensioner	0.2%	3.4%	–
	Housewife	0.6%	3.3%	–
	Unemployed	3.7%	4.3%	3.4%

3.3. Modelling

The procedure consisted of two main steps. Initially, we carried out an exploratory factor analysis to identify the relationship between the different indicators., which helped define the latent variables. It was followed by the model estimation using a Multiple Indicators Multiple Causes (MIMIC) model for modelling latent variables. The MIMIC has two submodels. The structural equation submodel uses socioeconomic characteristics to explain latent variables. The measurement sub-model expresses the relationship between latent variables and indicators. The structural equations were estimated as a function of socioeconomic characteristics as follows:

$$\eta_{lq} = \sum_{r} \alpha_{lr} S_{rq} + \upsilon_{lq} \tag{1}$$

Where η_{lq} is the latent variable l for respondent q, α_{lr} are coefficients to be estimated, S_{rq} is the socioeconomic variable r for respondent q and υ_{lq} is the term representing error. The error term was assumed to follow a normal distribution with a mean of 0 and a standard deviation of 1.

For the measurement equations, ordered logit models were applied using categorical indicators. In this case, each discrete response $(1, 2, \ldots, m)$ observed within each indicator is obtained from the latent variables through a censorship mechanism that defines different response categories as presented in equations (2) and (3) (Daly et al. 2012).

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

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

Where η_{lq} represents the latent variable l for respondent q, C_{pq} denotes the response of each individual q for the indicator p, while $\gamma_{lp}$and the threshold τ_{pm} are parameters to be estimated. ζ_{pq} is introduced as the error term.

The binary variable defining e-scooter usage was modelled using logistic regression. Table 3 presents the variables included in our model. We used Lavaan R package to estimate the structural equation model (Rosseel 2012).

4. Results and discussion

A descriptive analysis shows that users are mainly young adults and adult men, employees, or university students with medium to high incomes, similar to other studies found in the literature. E-scooter usage started decreasing in adults older than 40, while few low-income respondents used them. Among the respondents, 44% stated they used shared e-scooters, while 22% already owned one.

Regarding gender, there is a wide gap similar to the one found in bicycles (Moscoso et al. 2020), suggesting a barrier between women and two-wheelers (electric or not). Finally, the occupation of users is (as expected) mainly employees and students, showing them as the leading niche market for these vehicles.

This demonstrates a strong interest in technology and the anticipated preference for electronic payments over cash since they are presumably more practical, which would make user adoption easier as all shared scooter services are paid through an app. As a relevant result, respondents agreed with most of the environmental awareness statements, except the one comparing it with economic development, meaning they value the latter more. The results show a rightward tilt for the security and safety factors, meaning they are both concerned about crashing and falling and their safety (Figure 2).

The exploratory factor analysis showed that the four latent variables are strongly related to the indicators of the study, except for some indicators (I4, I11 and I18),

Table 3. Description of the variables included in the model.

CATEGORY	NAME	TYPE	DESCRIPTION
Socioeconomic characteristics	Education Level College	Dummy	1: If the survey respondent has a college degree 0: Other educational levels
	Gender (Female)	Dummy	1: If the respondent is female 0: Otherwise
	Age	Continuous	Respondent's age between 16 and 80 years old
	Car Ownership	Dummy	0: The respondent does not own a car 1: The respondent owns 1 or more cars
	Motorcycle Ownership	Dummy	0: The respondent does not own a motorcycle 1: The respondent owns 1 or more motorcycles
	High Income	Dummy	1: If the respondent lives in a high-income zone 0: Otherwise
	Employee	Dummy	1: If the respondent is an employee 0: If the employee has another occupation
User	ES User	Dummy	1: The respondent uses e-scooters 0: The respondent did not use e-scooters
Latent factors	Safety perception (Crash risk)	Continuous	Unobserved variable
	Security concerns (Fear of crime)	Continuous	Unobserved variable
	Environmental awareness	Continuous	Unobserved variable
	Pro-technology (Tech savvy)	Continuous	Unobserved variable

which presented low load factors (Appendix). Furthermore, the four variables suggested in the exploratory analysis group indicators coherently: a group for safety perception indicators, another for theft and robbery, one for environmental indicators and a group of indicators for those associated with the use of technologies. The MIMIC model is presented in Figure 3, and the estimates are shown in Table 4. The goodness-of-fit indicators of the model (TLI > 0.9, CFI > 0.9, RMSEA < 0.05) show its robustness. The measurement equations are presented in Appendix.

The model suggests that high-income, male, car-owning, college-educated individuals are prone to use e-scooters. This is consistent with the existing literature regarding the influence of income on e-scooter usage. For instance, Ghaffar, Hyland, and Saphores (2023) found that areas with higher income generate significantly more ridership than low-income ones. The spatial connotation of this statement is particularly crucial for our case study, considering that the deployment and operation of e-scooters in the city was highly focused in high-income areas. In this context, a more equitable approach to the deployment of e-scooter services is needed (Villa-Zapata et al. 2024).

Conversely, usage decreases with age. According to the results, a higher perception of crash risk and fear of crime discourages using e-scooters, possibly improving the perception of safety once the individual becomes familiar with the vehicle. In contrast, similar to Kopplin, Brand, and Reichenberger (2021), pro-technology attitudes and environmental awareness encourage their use.

The MIMIC model makes it possible to assess the influence of individuals' socioeconomic characteristics on perceptions and attitudes. Regarding safety perception in e-scooters, women perceive these vehicles as dangerous, which aligns with the results of Sanders, Branion-Calles, and Nelson (2020). The positive sign of car ownership could be related to the road conflicts between car and e-scooter users. At the same time, motorcycle owners tend to perceive e-scooters as safer, which could be related to motorcycles' high severity and crash rates. It is noticeable that risk perception increases with age.

The fear of crime is mainly correlated to motorcycle ownership. Motorcyclists show less fear than other road users. According to the model, women tend to perceive more security concerns, although the effect was not significant.

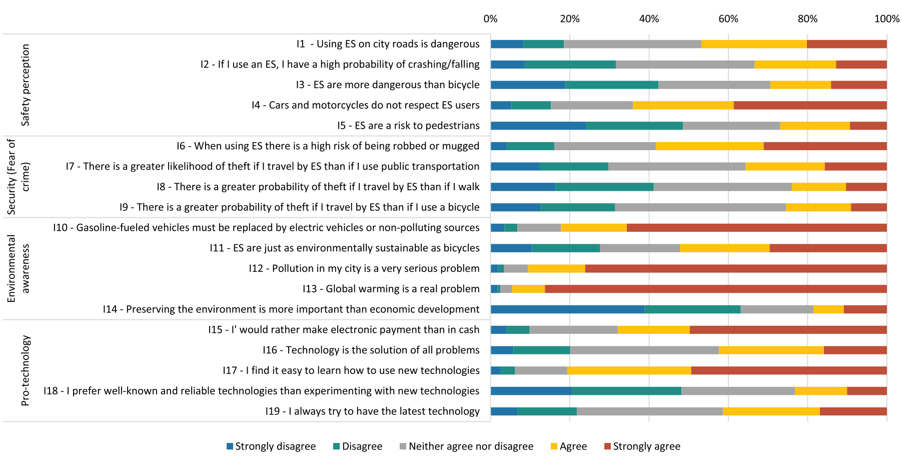

Figure 2. Indicators' results

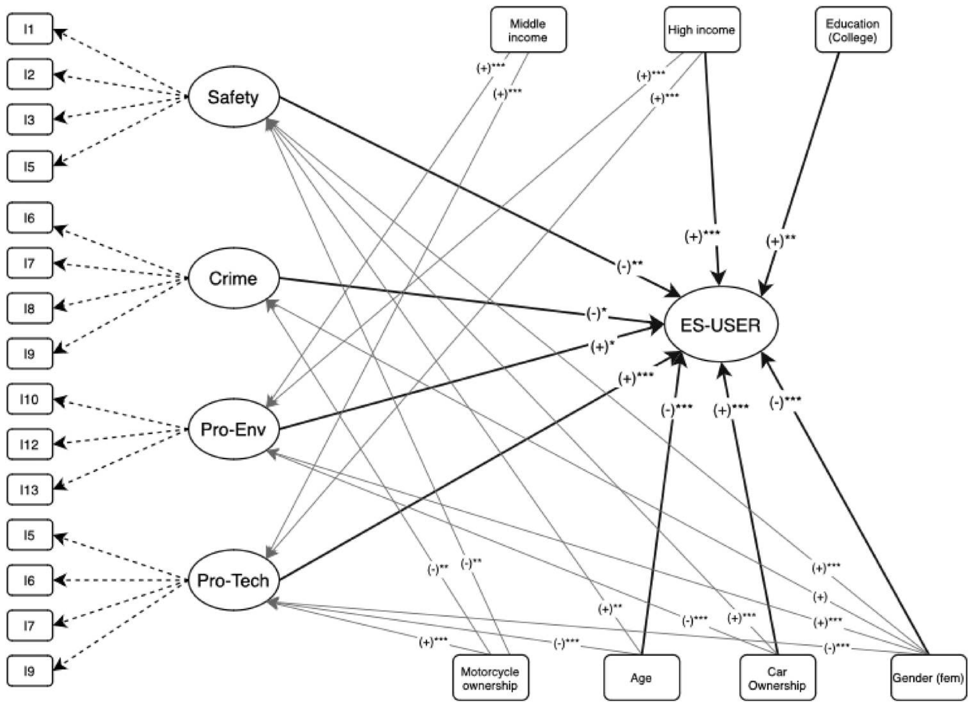

Figure 3. MIMIC model scheme

Women show greater environmental awareness but are less keen to try new technologies, which is coherent with other studies such as Nikiforiadis et al. (2021). On the contrary, private vehicle owners are less concerned about environmental issues but favour technological innovations, which could be used to incentivise. In addition, as expected, age had an inverse effect on being pro-technology.

The results indicate that the perceptions of fear of crime and safety are independent of an individual's income. This is an expected result, given the high crime rate in Bogotá. Despite this, this variable is a strong predictor of being pro-technology, which may be related to the purchasing power of this sector of the population regarding the acquisition of new devices and technological innovations.

Increasing safety perception for non-users is needed. The literature supports measures such as demanding a mandatory helmet (Tillemann & Feasley 2018), which would reduce crash severity (Trivedi et al. 2019), identified as the main externality of using e-scooters (Félix, Orozco-Fontalvo, and Moura 2023). A good example is the new 'Reckless rider score' feature developed by Bolt, which aims to improve e-scooter safety with a 3-step approach for reckless riders, first providing educational materials, second (if habits do not improve) their maximum scooter speed will be 15 km/h. Finally, if any of these measures works, the company will suspend the rider for a week. Moreover, considering that fear of crime in first or last-mile trips discourages public transport choice for home-based trips (Tilahun et al. 2016), our results show that e-scooter users feel less likely to be robbed while using this vehicle. Hence, this is another finding to support this integration within public transport, promoting a modal shift to decrease car use (Bozzi and Aguilera 2021).

Table 4. Modelling results

Variable	Coefficient	t-test	
ES – USER			
High Income	0.257	2.558	***
Car Ownership	0.097	2.281	***
Age	−0.008	−2.852	***
Gender (Female)	−0.166	−2.897	***
Education Level College	0.071	1.929	**
Safety perception (Crash risk)	−0.06	−1.749	**
Security concerns (Fear of crime)	−0.048	−1.468	*
Environmental Awareness	0.045	1.49	*
Pro-Technology	0.109	2.288	***
Intercept	0.667	8.656	***
Safety perception (Crash risk)			
Gender (Female)	0.162	3.307	***
Age	0.004	1.93	**
Car Ownership	0.122	2.324	***
Motorcycle Ownership	−0.09	−1.65	**
Security (Fear of Crime)			
Motorcycle Ownership	−0.098	−1.739	**
Gender (Female)	0.048	1.006	
Environmental Awareness			
Gender (Female)	0.146	2.597	***
Car Ownership	−0.23	−3.758	***
High Income	0.251	1.979	***
Middle Income	0.207	2.913	***
Pro-Technology			
Gender (Female)	−0.16	−3.765	***
Age	−0.007	−3.672	***
Middle Income	0.116	2.2	***
High Income	0.434	4.675	***
Motorcycle Ownership	0.128	2.715	***
Goodness of fit			
n	1073		
CFI	0.923		
TLI	0.952		
RMSEA	0.049		

Note: ****p*-value < 0.05; **p – value < 0.1; * *p*-value < 0.20.

People highly concerned about the environment and those attracted by technology are clear allies in using e-scooters. Since they are the closest potential market, the initial efforts to promote their use should be directed towards them, emphasising the system's benefits. The results obtained in this research allow the design of user segmentation strategies for marketing purposes, as Soto, Cantillo, and Arellana (2021) suggested. Companies providing e-scooter rental services are natural allies for promoting usage.

The built environment may also influence our findings. Over the last decade, there have been ongoing efforts to improve both pedestrian and bicycle infrastructure, transforming the mobility landscape of the city, with a significant growth in bicycle ridership. Nevertheless, a great portion of the infrastructure that could be used by e-scooters (in the areas where they operate) is not segregated, creating continuous conflicts with other road users, namely pedestrians. This may be true for non-users, given that according to Lang (2018), in Buenos Aires, bike lane availability did not guarantee a higher demand, and the number of riders using the dedicated infrastructure was almost the same as the ones not using it. We might expect a similar behaviour in our case (but for scooters), as both cities are Latin American capitals with several commonalities.

In the particular case of Bogota, a program similar to the one favouring bicycle use can be extended to e-scooters, particularly as a feeder for the BRT, Transmilenio. However, any program must consider users' characteristics and perceptions, particularly those most reluctant to use them. When designing policies and strategies, stakeholders should focus their attention on the previously defined profiles and develop strategies to involve more women in its usage and close the gender gap that is already present in bicycle riding, for which the attitudes identified in this study are crucial.

In this sense, this study demonstrates the influence of perception on e-scooter use in Bogota, and as stated by several authors, perceptions can be as relevant as the level of service regarding the choice (Sarkar and Mallikarjuna 2018; Willis, Manaugh, and El-Geneidy 2015). For the Latin American context, certain latent variables, particularly those related to safety and security, could be more impactful than those in wealthier regions. For instance, fear of crime was disregarded in previous literature and was highly significant in our case study. Therefore, it is crucial to go beyond the objective parameters when attempting to understand the dynamics of e-scooter adoption in Latin America and consider context-specific characteristics for its implementation, operation, and regulation.

A limitation of this study is that it accounted only for latent variables, not considering other variables that may have a direct effect on e-scooter usage (like travel time and price); these are frequently considered in the likes of the Theory of Planned Behaviour. This limitation may mask some relevant insights and hinder the possibility of going beyond being a user or not, for example, estimating the intention to use. An additional limitation has to do with the temporal aspect of data collection, specifically the fact that they were collected in 2021, following the relaxation of COVID-19 restrictions, which warrants consideration in the interpretation of our findings.

5. Conclusions

This paper presented a structural equation model to explain the attitudes, perceptions and socioeconomic variables influencing e-scooter usage. These perceptions and attitudes were grouped into unobserved variables such as safety perception (crash risk), fear of crime, acceptance of new technologies and environmental awareness, which were evaluated through latent factors. The latent variables considered were significant, proving their importance for policy formulation.

The results show that income, gender, car and motorcycle ownership, education and age strongly predict perceptions. A reason for not using e-scooters is the fear of suffering a crash or fall. That is why the companies providing the e-scooter rental service should promote user training programs. In addition to explaining the operation and handling of vehicles, overcoming the barrier of negative perceptions in a controlled environment would be possible.

However, apprehensions surface in light of specific challenges that have become evident due to the operation of e-scooters, such as high accident rates, accessibility, life cycle (environmental) and digital barriers. These issues must be addressed through regulation and adequate policies. This entails the requirement of safety elements (e.g. helmets) and unambiguous legislation governing e-scooter circulation. Additionally, rental services ought to formulate explicit operational instructions for those with limited digital literacy.

The fear of crime may hinder these vehicles' adoption, highlighting an often disregarded issue in other contexts but essential in the Latin American context. Improving the built environment could be instrumental in mitigating this concern. When designing policies to promote the use of scooters (e.g. for the last mile to public transport systems), it is essential to consider individual differences and the role of perceptions in their willingness to use scooters. Regulation of the use of safety features and infrastructure may be determinants of changes in perceptions of risk and insecurity.

The results are helpful for planners in designing strategies for promoting e-scooter usage, including market segmentation. E-scooters have the opportunity to be integrated with public transport or MaaS platforms, as well as a tool to reduce the urban transport gender gap and the carbon footprint. Transport planners should consider such latent and socioeconomic factors to build sustainable mobility policy agendas involving e-scooters.

For future studies, research should focus efforts on evaluating the impact of different policies on the choice of this mode, providing governments with scientific support to define guidelines for use that mitigate the problems that have been generated around the use of e-scooters, without missing their potential and assessing the impact of new regulations.

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Appendix

Results of the exploratory analysis

Indicator	Latent variable 1	Latent variable 2	Latent variable 3	Latent variable 4
I1	–	–	0.613	–
I2	–	–	0.791	–
I3	–	–	0.607	–
I4	–	0.173	0.201	–
I5	0.165	–	0.45	–
I6	0.494	0.192	0.217	–
I7	0.664	–	–	–
I8	0.796	–	–	–
I9	0.64	–	–	–
I10	–	0.558	–	–
I11	–	0.169	–	0.158
I12	–	0.701	–	–
I13	–	0.784	–	–
I14	–	0.274	–	−0.244
I15	–	0.168	–	0.404
I16	–	–	–	0.578
I17	–	0.203	–	0.498
I18	0.155	−0.166	–	–
I19	–	−0.115	–	0.538

Measurement model

Indicator	Coefficient	*t*-test	
Safety			
I1	1.000		
I2	1.133	24.652	***
I3	0.960	24.644	***
I5	0.859	19.752	***
Crime			
I6	1.000		
I7	1.085	29.043	***
I8	1.112	30.781	***
I9	0.983	27.782	***
Environmental Awareness			
I10	1.000		
I12	1.201	20.991	***
I13	1.421	18.451	***
Pro-Technology			
I15	1.000		
I16	1.048	11.981	***
I17	1.273	11.874	***
I19	1.027	11.727	***