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How do the affective and symbolic factors of private car driving influence car users' travel behavior in a car restriction policy scenario?

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ABSTRACT

The number of private car trips a person makes is usually linked to external factors such as economic incentives or disincentives, legislation, infrastructure, and the quality of transport systems, among others. The impact of these options are typically analyzed to evaluate urban transport policies and projects. However, internal factors related to an individuals' attitudes and perceptions also play an essential role in the amount of private car driving they do and on urban mobility as well. Therefore, insight into private car driving's affective and symbolic aspects is important in order to formulate appropriate transport policies and strategies to reduce car-use dependency and encourage private car drivers to use public transport. Congestion charging schemes make drivers pay the full social cost of driving, they achieve congestion reduction, pollution reduction, they make cities more attractive for pedestrians and cyclists, and help improve quality of life. Congestion charging schemes are often difficult to implement and expensive to administer. As a result of these reasons, several cities worldwide have adopted a variety of car restriction schemes that try to reduce air pollution and congestion as well, instead of establishing congestion charges. The effects of driving restrictions in the short term are positive, but in the medium and long term, there are unwanted consequences. However, by giving private car drivers the option to pay a toll so that their cars are exempted from the restriction, these perverse incentives could be eliminated. This paper analyzes the impacts of internal factors related to individuals' attitudes and perceptions about the travel behavior of car users affected by car restriction policies in urban areas. We designed a stated preference survey conducted among car owners in Cali, Colombia, where a License Plate Restriction Charging (LPRC) policy has been in place since January 2017. Through hybrid discrete choice modeling, we demonstrated that latent variables, such as the feelings of being in control, independence, and higher social status, positively influence the decision to use cars for daily trips, thus impacting the urban modal split. The heterogeneity captured through these latent variables allowed us to understand more deeply how individuals deal with the LPRC policy in order to travel to their destination.

1. Introduction

Public authorities worldwide have been working to improve air quality and traffic conditions in urban centers with the aim of improving the health and well-being of citizens. In some cities, such as London, Milan, or Stockholm, local governments have established congestion charges (Percoco, 2013; Börjesson and Kristoffersson, 2018; Green et al., 2020). Congestion charging schemes make drivers pay the full social cost of driving, they achieve congestion reduction, pollution reduction, they make cities more attractive for pedestrians and cyclists, and help improve quality of life. However, congestion charge schemes are difficult to implement and expensive to administer. As a result of these reasons, several cities worldwide have adopted a variety of car restriction schemes that try to reduce air pollution and congestion as well, instead of establishing congestion charges. These schemes are mainly low emission zones, license plate-based driving restrictions, and license plate lottery, or auction, among others (R. Ramos et al., 2017; Zhang et al., 2020; Basso et al., 2021; Jain et al., 2021; Guerra and Reyes, 2022).

Typically, such restrictions have been implemented according to day of the week, city sectors, vehicle characteristics, or a combination of them. For example, in Athens, authorities limit private vehicles in the

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city center based on an alternating license-plate scheme (Sorensen et al., 2008). The program in Mexico City prohibits drivers from using their vehicles one weekday per week based on the last digit of the vehicle's license plate. In Manila, authorities restrict large trucks, long pickup trucks, and wing vans from driving on certain roads. There is also a total truck ban along certain avenues every day except Sundays, and holidays. In China, for example, a one day a week scheme has been adopted by most cities, and odd-even numbered systems are used for temporary traffic regulation when necessary, particularly for important events (Ye, 2017). In the case of Bogota, car use rationing based on license plate numbering began in August 1998, restricting driving during peak hours. In February 2009, the restriction was extended to 14 h per day to further reduce congestion and traffic emissions (Bonilla, 2019). Currently, the measure is even stricter and is also applied on some holidays.

Although the effects of driving restrictions in the short term are positive, in the medium and long term there are unwanted consequences. For example, when restrictions are set by city sectors, traffic conditions in the areas immediately adjacent to the restricted area worsen (Sorensen et al., 2008). In fact, the literature has demonstrated that prohibiting the circulation of a proportion of private cars based on their license plate numbers is a policy that produces a net loss to society (Cantillo and Ortúzar, 2014). Consequently, in the long-term (and because of the social loss), a large number of car users express a willingness to pay to use their cars, which is evidenced in the purchase of additional cars that can bypass the policy (Nie, 2017; Sorensen et al., 2008). In some cities, authorities are considering replacing this policy with a congestion charge (Ramos et al., 2017). However, an appropriate transition from license plate rationing to a congestion charging policy involves a great challenge for some local authorities, which is why they could consider practical approaches for curbing congestion and air pollution. By giving private car drivers the option to pay a toll to get their cars exempt from the restriction, these perverse incentives could be eliminated (Basso et al., 2021). A good example of this is the License Plate Restriction Charging (LPRC) policy.

The LPRC is a gradual transition policy towards pricing schemes closer to the social optimum that allows payment for permission to drive during an established period of vehicle restriction based on the last digit of the vehicle's license plate (Soto et al., 2023). This policy was first implemented in Cali and Bogotá, Colombia, to raise funds to subsidize the public transport system and manage the demand for private cars. According to its price and schedule, those who usually use their car to commute to their destination would prefer to keep using their cars rather than switch to other modes of transportation. In this sense, some car users would be willing to pay the charge to keep using their vehicle or would switch their travel schedule. Others would prefer purchasing a second vehicle with a different license plate (especially higher-income ones). Under such scenarios, affective and symbolic factors associated with private car driving play an essential role in the travel decision-making process and allows for personalized policy-making by getting time valuations for different user categories.

Not considering affective and symbolic factors in restrictive transport policies may reduce their effectiveness, especially if they are believed to threaten the freedom of choice or significantly reduce quality of life (Steg and Gifford, 2005). For many people, the benefits of car use are not only related to meeting the demands of everyday life, such as commuting to work or places of study, driving children to school, or bringing groceries home. They are also related to affective and symbolic values, such as the enjoyment of travel by car, freedom, independence, power, higher social status, privacy, and lifestyle, as developed in affect theories (Goldberg, 1981; Steg et al., 2001; Russell, 2003; Steg, 2005; Lois and López-Sáez, 2009; Bergstad et al., 2011b; É. M. S. Ramos et al., 2020; Gatersleben, 2021). Thus, affective factors are not separate aspects in the decision-making process (Mann and Abraham, 2006). Owning a car also has social and psychological benefits beyond traveling since it may contribute to life satisfaction and subjective well-being (Bergstad et al., 2011; Deka, 2017; Makarewicz and Németh, 2018). Car users living in places with poor access to public transport, walking and cycling infrastructure, or those who routinely drive children to school, may perceive some restrictive transport policies as a threat to their individual quality of life (Steg and Gifford, 2005). Therefore, the evaluation process of transportation infrastructure, services, and policies has been encouraged to include travelers' cognitive and affective experiences as a new criterion in recent years (Li et al., 2022).

Depending on the situation and purpose of the trip, affective and symbolic motives for car use may be more or less important. According to Anable and Gatersleben (2005), affective factors are more relevant for leisure trips. Instrumental factors such as convenience and flexibility are more important for daily trips. These last factors are especially relevant when there is limited time for activities, or a lack of transportation alternatives to commuting. On the other hand, Stokes & Hallett† (1992) indicated that affective and symbolic motives are even more important than instrumental factors. As Ramos et al. (2020) discovered, they are more relevant for shopping and commuting trips. In the West of Scotland, Hiscock et al., (2002) provide empirical evidence that suggests that people's attachment to cars can be explained by the psycho-social benefits provided by the car, such as protection, autonomy, and prestige. In Sydney, Lupton, (2002) revealed that driving was a potent source of autonomy, pleasure, and self-expression among motorists. Ellaway et al. (2003) found that car users gain more self-esteem and feelings of autonomy, protection, and prestige than public transport users in the UK. In the UK, Mann and Abraham (2006) also found that control and freedom over departure time, route, and vehicle management are essential attributes individuals consider when they travel. They even found that owning a car is seen as a symbol of success. These results align with previous developments presented by Jensen (1999), but in contrast with results by Gatersleben and Uzzell (2007) in the case of control. Van et al. (2014) found that instrumental, symbolic, and affective factors significantly influence commuting by car in Japan, China, and Vietnam. They also found that, wealth, luxury, superiority, and coolness were tagged as symbolic factors. Comfort, excitement, and relaxation were also assumed to be affective factors.

Most recent studies analyze how car use influences travel satisfaction (Chatterjee et al., 2020; Gärling and Connolly, 2021; Li et al., 2022) and how social-symbolic factors influence private car driving and ownership (Zhao and Zhao, 2020; Moody and Zhao, 2020; Gatersleben, 2021; Meena et al., 2021; Benleulmi and Ramdani, 2022). For instance, Gatersleben (2021) found that status, driving pleasure, and control can firmly attach people to their cars, thus affecting the effectiveness of travel demand management strategies. In the US, Benleulmi and Ramdani (2022) found that symbolic motives, such as personal innovativeness and social influence, positively affect the intention to use autonomous vehicles. In Shanghai, China, Zhao and Zhao (2020), saw that car pride was significantly and positively correlated with car use and owning newer, more expensive, and luxurious cars. Subsequently, Moody and Zhao (2020) confirmed these results in two cities in the US and demonstrated that pride in owning and using a car increases the more it is used. These results are also aligned with Meena et al. (2021), who found a similar pattern in young adults.

Several Latin American countries have attempted to address congestion in major cities by adopting measures commonly known as the License Plate Restriction (LPR), which regulates private car driving on certain days of the week and at specific times during the day. It has been implemented in Brasil, Mexico, Colombia, Chile, Argentina, Nicaragua, and Venezuela, and some countries in Asia such as China, Philippines, South Korea, and India. Its effectiveness has been questioned since car users use different ways to avoid the restriction in order to continue using their cars (Cantillo and Ortúzar, 2014; R. Ramos et al., 2017), which in part is considered to be related to affective and symbolic factors. Some of the documented ways car users do this are by (i) switching their travel schedule (de Grange and Troncoso, 2011; Guerra and Millard-Ball, 2017); (ii) paying for using the banned car during restricted hours; (iii) using a second car with a different license plate (Moncada et al., 2018; Bonilla, 2019; Chen et al., 2020); (iv) purchasing exempted vehicles, usually electric vehicles (Diao et al., 2016; N. Wang et al., 2017; Lu et al., 2020; Rao, 2020); (vii) disobeying the restriction rules (L. Wang et al., 2014; Viard and Fu, 2015), and by (vii) car sharing (Gu et al., 2017).

It has been demonstrated that positive feelings related to car use could significantly explain car users' behaviors in daily travel after implementing car restriction policies (Bergstad et al., 2011a). Symbolic and affective factors for car driving and ownership have been widely studied, still, most studies are limited to developed countries (Meena et al., 2021), but in emerging economies where populations are growing and disposable incomes are on the increase, this has not been studied as extensively. In this context, one of the most popular car restriction policies in Latin American countries, in which the role of affective and symbolic factors has not been analyzed, is based on the last digit of a vehicle's license plate. In order to bridge this gap, we have posed the following research question: How do the affective and symbolic factors of private car driving influence car users' travel behavior in a car restriction policy scenario such as the LPRC? In this order of ideas, we want to find a hybrid Discrete Choice Model that allows policymakers to understand how affective and symbolic factors linked to car driving influence the decision to use cars for daily trips in a car restriction policy scenario.

This work is important for different reasons: First, affective and symbolic factors of private car driving play an essential role in mode choice and travel behavior. Considering such internal factors in analyzing a car restriction policy scenario is a crucial element yet to be considered in the literature, which usually relies on complex behavioral models involving various interactions (Golias et al., 2002).

Second, some novel findings in the literature suggest moving the analysis of the LPRC policy into the terrain of the hybrid modeling approach. According to Soto et al. (2023), it is necessary to analyze the impact of intangible variables on the willingness of car users to pay for driving on restricted days, especially in developing countries. Such latent constructs could help policymakers to understand more deeply how individuals deal with the LPRC policy. Moreover, decision-makers can define measures to improve the effectiveness of any travel demand management strategy.

Third, from the methodology point of view, the transportation literature reflects that no study has implemented hybrid Discrete Choice Models (DCMs) to investigate the influence of affective and symbolic factors linked to private car driving under a car restriction policy scenario. Therefore, this is the first study in emerging countries to consider affective and symbolic car driving factors in a hybrid DCM. To the best of our knowledge, this is also the first study to examine how "a feeling of being in control", "a feeling of independence", and "a feeling of higher social status" impact the decision to use cars for daily trips under the LPRC policy. In this sense, this paper demonstrates that including such factors and their interactions in the analysis significantly improves the model's goodness-of-fit and better explains the car-user behavior under changes in their characteristics, such as cost, number of days per week, and hours per day. Moreover, these three latent variables play an important role capturing heterogeneity and providing much better predictive power.

The remainder of this paper is structured as follows. Section 2 summarizes the research context. Section 3 describes the methodology implemented including the data source and profile of the respondents, a description of the affective and symbolic variables analyzed, a description of the conducted stated preference experiment that was developed, and, the model framework of the research. Section 4 provides the modeling results and discusses research findings, including a sensitivity analysis of the latent variables and a market share simulation that considers heterogeneity. A brief subsection about implications for policy was also included to explain potential impacts. Section 5 highlights the main conclusions.

2. The research context and its car restriction policy

Cali is the third most populated city in Colombia, with approximately 2.2 million inhabitants, of which 98.5% are in its urban area and 1.5% in the city's rural outskirts (DAPM, 2019a; DANE, 2018). Around 700,000 motor vehicles are registered in Cali, of which 64% are private cars and 31% are motorcycles; the remainder are buses, taxis, and lorries.

To reduce traffic congestion, traffic accident rates, and air pollution, the Cali municipal council approved the restriction based on the last digit of the vehicle's license plate numbers in 2005 (Decree 0722, 2005). The measure was applied to private cars, public transport vehicles, and taxis (Decree 0434, 2017) from Monday to Friday during rush hours. The ban was set for two different numbers per day on a rotating schedule.

Currently, the measure allows car users to pay for using their car during restricted hours (from 06:00 to 10:00 and from 16:00 to 20:00) (Agreement 0401, 2016; Decree 0001, 2017), which is known in this paper as the LPRC policy. This new change happened in 2017 in response to the fiscal deficit on the operational costs of public transport, which affected service quality and coverage. Car users can pay the LPRC annually, per semester, or per month. The annual charge was set in 2020 at USD 495.70 (USD 1 ≈ COP 3614) (Decree 0034, 2020).

The LPRC was easy to implement because of its flexibility and low political cost since it does not force all car users to pay for driving on public roads when the measure is applied. As a result, no more than 20% of the total car users are restricted daily.

According to this context, a Stated Preference (SP) survey was conducted in Cali to analyze the influence of affective and symbolic factors on the travel behavior of car users affected by this car restriction policy.

3. Methodology

3.1. Sample and profile of the respondents

The SP survey was organized into the following three parts: (i) socioeconomic characteristics of respondents; (ii) measurement of individual attitudes and perceptions; and (iii) a discrete choice experiment.

The SP survey was carried out among 450 randomly selected respondents aged between 19 and 72 years old, out of which 63% were men and 37% were women. The respondents were self-employed people and private car owners, many of them heads of households from different areas in Cali.

Several important aspects were considered for minimizing bias in this study. The first one was designing an experiment that would be credible and reliable for the interviewee. In this sense, it was essential to conduct intensive individual interviews with a small number of respondents to explore and understand the decisions made by car users about the LPRC policy. Additionally, several pilot tests were conducted as part of the questionnaire design process, which showed that it needed to be easy to interpret and understand. Another equally important aspect was interviewer training, because interviewers needed to be familiar with the application of stated choice techniques. Finally, it was decided to survey representative areas with the highest rates of vehicle ownership in the city. After the conducting the survey, the data was post-processed, coded as an electronic data set, cleaned, and reviewed to ensure that it represented respondents' answers.

The socioeconomic information at household and individual levels are shown in Table 1, which shows a broad range of conditions. The proportion of households on low-incomes was 11%, while medium- and high-incomes represented 39% and 50% of the sample, respectively. The proportion of respondents with one car per household was 39%, two cars was 43%, and three or more cars was 18%. The individual's level of education in the sample corresponds to middle- and high-income individuals who are car owners. 57% have a college degree, while 29% have a graduate degree. The remaining 14% have a secondary or technical qualification. Since our sample exclusively comprised car owners,

Table 1
Profile of the respondents.

Characteristic	Level	Our sample	Cali mobility survey 2015[a]
Gender	Male	63%	62%
	Female	37%	38%
Household Size	2 or less people	31%	28%
	3–4	59%	53%
	5 or more people	10%	19%
Age	24 or less	4%	9%
	25–34	29%	19%
	35–44	35%	21%
	45–54	20%	22%
	55–64	10%	17%
	65 or more	2%	13%
Occupation	Employee	57%	37%
	Self-employed	30%	31%
	Other	13%	32%

[a] The population distribution is based only on the car users' characteristics identified in Cali' mobility survey 2015.

we compared the demographic composition of our sample with the car-user subsample from the city's most recent travel survey conducted in2015.[1] Table 1 shows that our sample distribution closely aligns with the population in terms of demographics, including gender, age, and household size. However, it is worth noting that our sample over-represents employees, primarily due to our sampling proximity to downtown and consolidated office and commercial zones. These findings indicate that our data consistently represents the population of car users in the city.

3.2. Affective and symbolic variables

As is widely known in random utility theory, in addition to the observable factors of the alternatives and individuals, attitudes and perceptions play an essential role in choosing an alternative from a set of available options (Walker, 2001). Both are underlying constructs developed over time, depending on the individual's socio-economic context, experiences, and opportunities.

These latent constructs can be gathered through attitudinal and perceptual questions designed and presented on a Likert scale in a survey, as shown in Table 2**.** Such a set of indicators was established based on results from focus groups performed previously. Each Likert item presents a general statement regarding the everyday travel experience in the city. Respondents were asked to select the category that best reflected their reaction to the statement, ranging between strongly disagree and strongly agree. Sixteen statements were given, and their pattern response (Mean (M), Standard Deviation (SD)), and internal consistency measure are shown in Table 2**.**

Based on the collected data, an exploratory analysis was conducted. As a result, the latent constructs Z1, Z2, and Z3 were identified using a minimum residual factor analysis, that's relative amount of variance explained were 0.44, 0.36, and 0.20, respectively. Their corresponding indicators were also grouped to show how closely related they are as a group. The Kaiser-Meyer-Oklin measure exceeded 0.80, and the Bartlett's test of sphericity was statistically significant ($p < 0.001$) (Hair et al., 2006).

The first construct was identified as a "*feeling of being in control*", since the general statements presented to the respondents express the need to control their travel time, mode, and route. In this sense, those car users who feel in control of their travel experience in their cars score the statements better. The second construct was identified as a "*feeling of independence*", because the related indicators express convenience, comfort, and flexibility. Finally, the third construct was identified as a "*feeling of higher social status*", since the indicators given express personal identity, social status, and confidence. In some cases, they pride themselves on owning a car (Gatersleben, 2021).

In Table 2 (legend), we presented the main fit statistics from the analysis developed, which according to Hu and Bentler (1999), shows a reasonable fit to the observed data.

Based on these identified latent constructs, a Hybrid Discrete Choice Model (HDCM) was developed, presented in Section 3.4. The following section presents the stated preference experiment conducted for this purpose.

3.3. Stated preference experiment

To build an appropriate representation of the choices people have when the driving restriction is applied, we interviewed sixty-eight self-employed and heads of families from different areas of Cali and socio-economic conditions. The unique condition required to participate in the focus groups was to be a car owner who usually uses their car to commute to their destination. As a result, it was possible to identify the following frequent decisions.

i. Using the restricted vehicle leaving home and returning during the allowed hours. That means that they have to leave very early in the morning (before the first restriction hours 06:00–10:00) and come back at night (after the second set of restriction hours 16:00–20:00), since the traditional working hours in Cali are Monday to Friday from 8:00 to 18:00, with 2 h for lunch. Despite the uncomfortable situation, it is the preferred alternative for the interviewees (31%). Under this alternative, they have the flexibility to use their car during the permitted hours. They also can avoid rush hour congestion, increasing confidence in being on time at the destination.
ii. Using a taxi or individual informal modes of transport was the second preferred alternative chosen by interviewees (29%). As stated by them, this alternative offers almost the same condition as using their cars, both in terms of comfort levels and travel costs.
iii. Using public transport (BRT) was preferred by 15% of the interviewees. Some indicated that using this alternative implies considerable discomfort and delays (especially in rush hour) due to overcrowding on buses and the long waiting times. However, they only have to tolerate this situation once a week, which is bearable. Other reasons given were appropriate accessibility conditions to public transport infrastructure and attitudes to support solving environmental and congestion problems through personal contributions.
iv. Using a second car with a different license plate (9%). As expected, those interviewees with two or more cars in a household selected this alternative.
v. Using other less preferred options such as car sharing, switching to bicycles, and breaking the restriction rules (16%).

With this information, a discrete choice experiment was designed and given to respondents, that considered nine hypothetical choice scenarios for traveling from their homes during the morning rush hours. They had four options to travel in each Stated Preference (SP) survey scenario as shown in Table 3: (i) car paying the LPRC monthly to drive during the restricted hours; (ii) car switching their travel schedule; (iii) switching to taxi; (iv) switching to BRT. The alternative of purchasing a second car with a different license plate was not considered because it is usually a long-term decision (Ma and He, 2016), and the experiment could be distorted if such an alternative were considered. The

[1] The Cali Travel Survey (Encuesta de Movilidad de Cali in Spanish) is an extensive household-based travel survey conducted to assess the mobility patterns, demographic variables, and factors influencing travel within Cali and its neighbouring towns. Its aim is to provide a comprehensive understanding of the region's transportation dynamics.

Table 2
Latent variable indicators and levels.

Latent variable (Type)	Ind	Description	Fom strongly disagree to strongly agree					M	SD
			1	2	3	4	5		
Feeling of being in control Z1* (affective)	I_1	I feel anxious when my means of transport is not immediately available.	6%	8%	14%	20%	52%	4.02	1.25
	I_2	I need to use my means of transport spontaneously and without planning.	2%	3%	10%	20%	64%	4.39	0.97
	I_3	I need to know how long my trip will take.	3%	3%	10%	21%	64%	4.38	0.99
	I_4	I do not like deviating from my usual route to get to my destination.	6%	7%	13%	20%	55%	4.13	1.20
Feeling of independence Z2* (affective)	I_5	I can always fulfill my study or work schedules using my car.	2%	4%	15%	19%	60%	4.32	0.98
	I_6	The car allows me to travel at any time.	1%	4%	9%	22%	64%	4.44	0.89
	I_7	The car allows me to save time traveling.	2%	4%	10%	21%	63%	4.40	0.94
	I_8	My life is easier having a car.	3%	7%	16%	23%	52%	4.15	1.08
	I_{14}	I feel comfortable traveling by car.	0%	1%	3%	24%	73%	4.68	0.58
	I_{15}	I feel safe traveling by car.	1%	2%	6%	25%	66%	4.54	0.77
	I_{16}	The car allows me to be independent.	2%	1%	7%	20%	70%	4.57	0.80
Feeling of higher social status Z3* (symbolic)	I_9	I am content to have any car if it fulfills its function of taking me to my destination.	12%	15%	24%	23%	26%	3.36	1.33
	I_{10}	Having a car is synonymous with economic well-being.	10%	11%	23%	28%	28%	3.51	1.28
	I_{11}	For me, the car is the best.	6%	11%	28%	24%	32%	3.65	1.20
	I_{12}	It is expensive to own and maintain a car.	3%	5%	14%	29%	50%	4.18	1.02
	I_{13}	Having a car is being fashionable.	30%	17%	24%	12%	18%	2.71	1.45

Fit statistics: TLI = 0.80; GFI = 0.94; RMSEA = 0.065; RMSR = 0.05.

Table 3
Stated Preference survey example.

Attributes	Options			
	Car paying the LPRC	Car switching travel schedule	Taxi	BRT
Travel time	30 min	25 min	40 min	40 min
LPRC cost/Fare	USD $ 83.17/ month	–	USD $ 3.49	USD $ 0.63
Days with license plate restriction per week	2 days	–	–	–
Time windows of the restriction measure	–	Rush hours [06:00 to 10:00] [16:00 to 20:00]	–	–

Table 4
Variables and values used in the experimental design.

Variables	Values
Travel time by car paying the LPRC [TT_1] (min)	15, 20, 30, 40, 50, 60
Travel time by car switching travel schedule [TT_2] (min)	10, 15, 25, 35, 45, 55
Travel time by taxi [TT_3] (min)	15, 20, 30, 40, 50, 60
Travel time by BRT [TT_4] (min)	20, 25, 40, 50, 65, 75
Taxi fare [F_3] (USD)	1.83; 2.16; 3.49; 4.16; 6.65; 7.32
BRT fare [F_4] (USD)	0.63
Days with the license plate restriction per week [D]	1 day, 2 days, every other day
Time window for the restriction measure [TW]	Rush Hours: [06:00 to 10:00] and [16:00 to 20:00]; Almost all-day: [06:00 to 20:00]
Monthly cost of the policy [LPRC] (USD)	33.27; 49.90; 66.53; 82.20

experimental attributes and levels included travel time, the fare for using transport services, the number of weekdays with a restriction, the restriction period, and the LPRC charge.

Travel time had two levels according to the length of trips usually made by respondents, to make it more realistic. The number of weekdays with restrictions had three levels, and the time window for restricted driving had two levels. The transport service cost was managed with one level for public transport, equivalent to the fare when the survey was applied, and two levels for taxis according to the length of trips usually made by respondents. The monthly cost of the LPRC had four levels. The attribute values used in the experimental design are presented in Table 4.

Finally, all the main effects and interactions of the attributes with their corresponding levels of variation require 36 choice situations following an orthogonal block design with level balance, minimum overlap, and profit balance (Zwerina et al., 1996). This massive number of choice scenarios cannot be responded to feasibly without the risk of losing the respondent's attention, so a fractional factorial design was used. Hence, the orthogonal design was divided into four blocks using the software Ngene® (ChoiceMetrics, 2012), allowing each respondent to consider nine choice situations.

As a result of the stated preference experiment, 20% of the respondents chose to pay the LPRC monthly to drive during restricted hours, 34% to use the restricted vehicle outside restricted hours, 22% to switch to a taxi, and the remaining 23% to switch to BRT. Concerning the first alternative, 59% of males and 41% of females chose to pay the LPRC charge. As can be seen, there was an outstanding balance between individual preferences. The HDCM given in the next section was developed using the data obtained from this stated choice experiment.

3.4. Model framework

The latent variables were modeled using a structural equations model (Eq. (1)) and a measurement equations model (Eq. (2)). The structural equations model relates an individual's socioeconomic characteristics (Sn) with latent variables (Zn), while the measurement equations model relates the indicators (In) with latent variables. Both equations lead to the Multiple Indicators Multiple Causes (MIMIC) model.

The model included sixteen (16) measurement equations, one for each indicator presented in Table 1 (m = 1, …, 16), and one more for the chosen alternative in the discrete choice model. The measurement equations were specified following ordered logit type models considering five categories for the indicators, following Eqs. (2) and (3) (Greene and Hensher, 2010). As each indicator has k categories, then k-1 thresholds ($\boldsymbol{\tau}$) were specified, among which a continuous latent variable would take some value from the categorical indicator.

$$Z^*_{nl} = \lambda_{\mathbf{rl}} \mathbf{S_n} + \omega_{nl} \quad (1)$$

$$I_{nm} = \gamma_{\mathbf{lm}} \mathbf{Z^*_{nl}} + \upsilon_{nm} \quad (2)$$

$$I^*_{nm} = \begin{cases} 1 & \text{if } \tau_{0m} < I_{nm} < \tau_{1m} \\ 2 & \text{if } \tau_{1m} < I_{nm} < \tau_{2m} \\ \dots & \\ K & \text{if } \tau_{K-1m} < I_n < \tau_{Km} \end{cases} \quad (3)$$

where.

I_{nm} is the continuous indicator m.

I^*_{nm} is the categorical indicator m.

The set of thresholds $\boldsymbol{\tau}$ must be estimated. For identification $\tau_{0m} = -\infty$ and $\tau_{Km} = +\infty$ are fixed.

A general diagram of the hybrid discrete choice model developed in this paper is illustrated in.

Fig. 1, where ellipses represent unobservable factors to the analyst. In contrast, rectangles represent observable explanatory variables, both from the alternatives and individuals. The relationships between the latent variables Z1, Z2, and Z3 and their observable variables and indicators are explained in the latent variable model. The chosen alternative is explained in the discrete choice model.

Y_{nj}: Choice indicator. 1 for the chosen alternative, 0 otherwise.

TT, D, TW, LPRC, F: Variables according to the experiment design (Table 4).

λ are parameters of the structural equations model; γ are parameters of the measurement equations model.

Four systematic utilities were included in the choice model, one for each transportation mode, as shown in Eq. (4) and according to the number indicated in Table 3 for each alternative. The functional form of the utility function was specified as linear in parameters. A panel effect term was included to capture the correlation among the multiple responses gathered per individual. The proposed latent variables Z1, Z2, and Z3 were included in the utility function.

The latent variable "feeling of being in control" (Z1) was included in interaction with the travel time to obtain marginal substitution rates

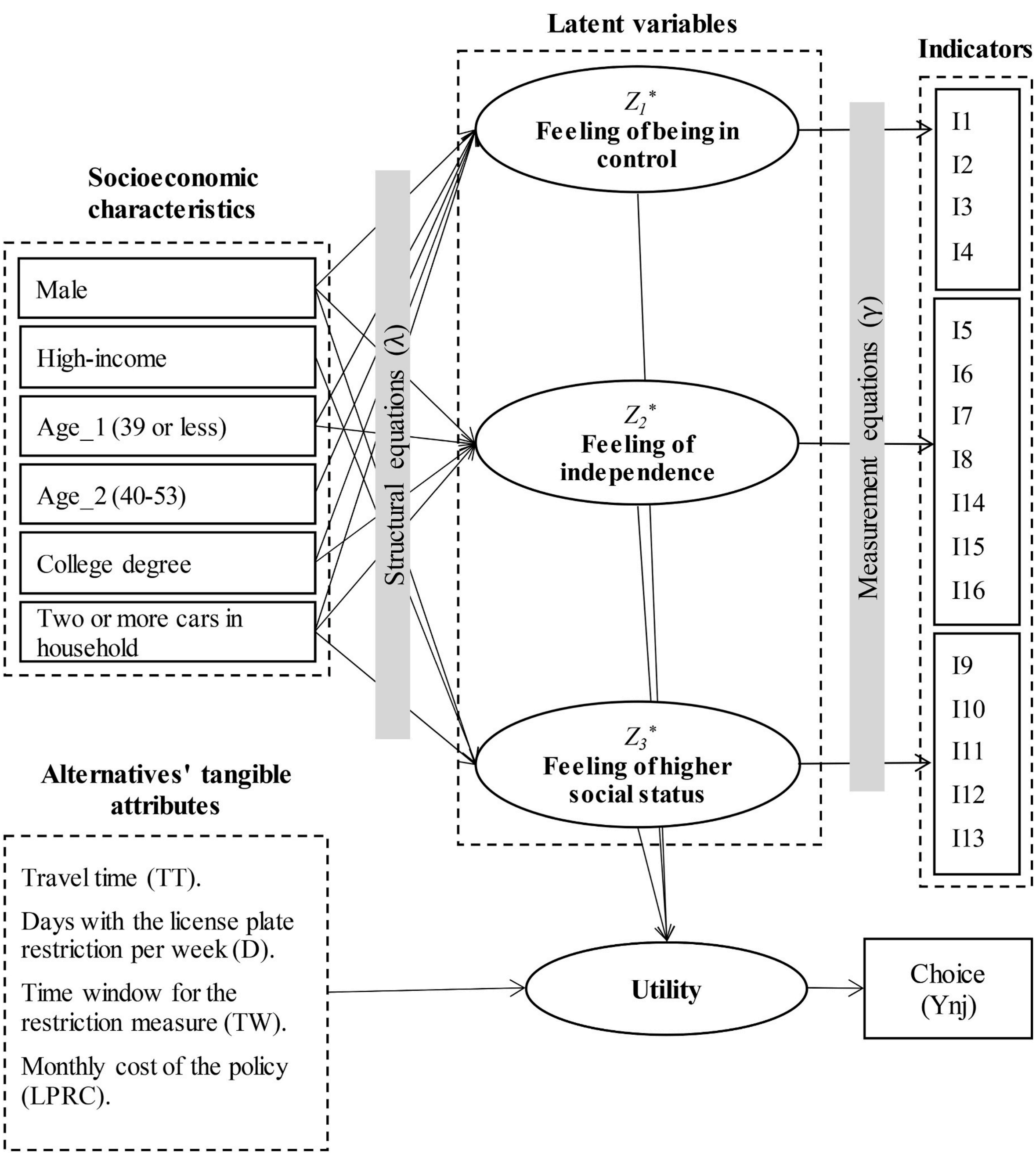


Fig. 1. Structure of the HDCM.

between travel time and cost for different population segments. We hypothesized that individuals are less willing to pay to reduce their travel time by 1 min when they maximize their feeling of being in control of their travel experiences.

On the other hand, the latent variable related to the feeling of independence (Z2) was specified in interaction with the time window of the restriction measure, which is related to using the restricted vehicle outside restricted hours. In that case, those car users motivated by a feeling of independence could decide on such an alternative when the restriction applies during rush hours.

Finally, the latent variable feeling of higher social status (Z3) was indicated in interaction with the LPRC cost, which is an attribute of using the restricted vehicle after paying the LPRC. In that case, we hypothesized that those car users who experience a feeling of higher social status would be willing to pay more for using their cars.

$$V_{(n\{1\})} = Asc1 + (\beta_{TT} + \beta_{TT\_Z1}\, Z_{n1})TT_1 + (\beta_{LPRC} + \beta_{LPRC\_Z3}\, Z_{n3})LPRC + \beta_D D + \varepsilon_{n1} \quad (4a)$$

$$V_{(n\{2\})} = Asc2 + (\beta_{TT} + \beta_{TT\_Z1}\, Z_{n1})TT_2 + (\beta_{TW} + \beta_{TW\_Z2}\, Z_{n2})TW + \varepsilon_{n2} \quad (4b)$$

$$V_{(n\{3\})} = Asc3 + (\beta_{TT} + \beta_{TT\_Z1}\, Z_{n1})TT_3 + \beta_F F_3 + \varepsilon_{n3} \quad (4c)$$

$$V_{(n\{4\})} = Asc4 + (\beta_{TT} + \beta_{TT\_Z1}\, Z_{n1})TT_4 + \beta_F F_4 + \varepsilon_{n4} \quad (4d)$$

β are parameters of the utility function of the choice model.

ε are random error terms, which are supposed to be independent and identically distributed Gumbel.

Based on previously proposed systematic utility functions, the final choice probability (P) of replicating an individual's choices observed in the SP survey is given by Eq. (5), where x_{njk} is the measurable explanatory attribute k of the alternative j for the individual n. At the same time, Y_{nj} is equal to one if individual n chooses alternative j. The simulated maximum likelihood technique was used to estimate the unknown parameters with simultaneous estimation, building a joint likelihood function that includes the MIMIC model and the Discrete Choice Model (DCM).

$$P\left(Y_{nj}, I^*_{nm} \middle| x_{jkn}, s_n, \beta_{kj}, \beta_{kjl}, \gamma_{jlm}, \upsilon_{nm}, \tau_{km}, \lambda_{rl}, \omega_{nl}, \varepsilon_{nj}\right) = \int_{Z^*_{nl}} P\left(Y_{nj} \middle| x_{njk}, Z^*_{njl}, \beta_{kj}, \beta_{kjl}\right) \bullet f\left(I^*_{nm} \middle| Z^*_{njl}, \gamma_{jlm}, \upsilon_{nm}, \tau_{km}\right) \bullet h\left(Z^*_{njl} \middle| s_n, \lambda_{rl}, \omega_{nl}\right) \bullet dZ^*_{nl} \quad (5)$$

The description of each alternative and estimated parameters are shown in detail in the next section.

4. Results and analysis

Table 5, Table 6, and Table 7 show the HDCM results estimated by the simulated maximum likelihood technique (Train, 2009) based on 4050 observations gathered from 450 respondents, as indicated in section 3.1. The estimation process included 1000 draws of Modified Latin Hypercube Sampling type for each respondent (Hess et al., 2006) and the effect of repeated observations in a panel context. The model was estimated using Apollo (Hess and Palma, 2019). A total of 105 parameters were estimated: 12 parameters in the choice model (β, σ, and Asc), 12 parameters in the structural model (λ), 16 parameters in the measurement model (γ), and 65 thresholds in the ordered models (τ). The last set of results is not provided in this paper since they are not required to use the HDCM in a predictive way. However, they displayed statistical significance with at least 95% confidence, indicating that the individual's opinions expressed through the indicators presented in Table 2 were appropriately represented with the proposed ordered models.

Table 5
The choice model results.

Variables		Description	Coefficients	T-test
Alternative Specific Constants	Asc1	Car paying the LPRC {1}	0.000	Fixed
	Asc2	Car switching travel schedule {2}	−2.694	−6.51
	Asc3	Taxi {3}	−0.229	−0.42
	Asc4	BRT {4}	−1.420	−3.32
Attributes	β_{TT}	Travel time (min) {1, 2, 3, 4}	−0.074	−5.16
	β_{LPRC}	LPRC cost (10^5 COP) {1}	−5.908	−12.81
	β_D	Number of restricted days per week {1}	7.839	11.85
	β_{TW}	Dummy for restriction during the rush hours {2}	2.750	10.05
	β_F	Fare (10^3 COP) {3, 4}	−0.118	−3.74
Interactions	$\beta_{TT\_Z1^*}$	Travel time – Latent variable "Feeling of being in control"	0.051	4.87
	$\beta_{TW\_Z2^*}$	Dummy for restriction during the rush hours – Latent variable "Feeling of independence"	1.599	7.92
	$\beta_{LPRC\_Z3^*}$	LPRC cost – Latent variable "Feeling of higher social status"	1.956	11.28
Standard Deviation - σ (Panel Effect)			−3.040	−21.73
Parameters				104
Parameters in choice model				12
Observations				4050
Draws				1000
Loglikelihood (0)				−5614.49
Loglikelihood (Final)				−3052.80

4.1. The choice model

Table 5 shows the estimated coefficients of the DCM, including their corresponding *t*-test (in parenthesis) and the value of the Loglikelihood at convergence. All estimated parameters show an excellent fit to the data, displaying at least 95% statistical significance. According to microeconomic theory, the signs of the parameters are consistent, because when the time, fare, or the LPRC cost goes up, the utility function goes down. The travel time parameter is in minutes, while the fare and the LPRC cost parameters are in thousands and hundreds of thousands of Colombian pesos.

As suggested by the model's specific constants, paying the LPRC cost for using the car during the restricted hours is ceteris paribus, the individuals' preferred alternative, followed by Taxi and the BRT system. The parameter of the dummy variable TW, which applies to restriction during rush hours (06:00 to 10:00 and 16:00 to 20:00), positively impacts the alternative of traveling by car during the non-restricted hours. This result is consistent with the expected result, since extending the restriction period to almost all day (6:00 to 20:00) reduces the flexibility and probability of the car being used. Therefore, the more restricted the hours are per day, the higher the chance of paying the LPRC charge, especially for those car users that experience a feeling of higher social status.

On the other hand, increasing the number of restricted days per week also increases the probability of paying the LPRC charge. This result is also aligned with the previous one, since it limits the flexibility of car use. Furthermore, as the LPRC is a fixed monthly value that does not depend on car use, an increase in the number of restricted days per week benefits those who pay the charge since the number of cars on the road decreases reducing delays.

The proposed interactions with the latent variables Z1 and Z2 are statistically significant and positive, indicating that the higher the

Table 6
The measurement model results.

Variables		Description	Coefficients	T-test
Feeling of being in control (Z_1*)	$\gamma_{1,1}$	I feel anxious when my means of transport is not immediately available.	2.097	7.67
	$\gamma_{1,2}$	I need to use my means of transport spontaneously and without planning.	2.170	8.06
	$\gamma_{1,3}$	I need to know how long my trip will take.	1.507	7.64
	$\gamma_{1,4}$	I do not like deviating from my usual route to get to my destination.	1.367	7.97
Feeling of independence (Z_2*)	$\gamma_{2,5}$	I can always fulfill my study or work schedules using my car.	1.510	8.08
	$\gamma_{2,6}$	The car allows me to travel at any time.	1.354	7.80
	$\gamma_{2,7}$	The car allows me to save time traveling.	1.174	7.51
	$\gamma_{2,8}$	My life is easier having a car.	1.199	7.79
	$\gamma_{2,14}$	I feel comfortable traveling by car.	1.694	7.74
	$\gamma_{2,15}$	I feel safe traveling by car.	1.386	7.68
	$\gamma_{2,16}$	The car allows me to be independent.	1.824	8.09
Feeling of higher social status (Z_3*)	$\gamma_{3,9}$	I am content to have any car if it fulfills its function of taking me to my destination.	−0.453	−4.67
	$\gamma_{3,10}$	Having a car is synonymous with economic well-being.	0.476	4.73
	$\gamma_{3,11}$	For me, the car is the best.	0.539	4.96
	$\gamma_{3,12}$	It is expensive to own and maintain a car.	−0.446	−4.40
	$\gamma_{3,13}$	For me, having a car is being fashionable.	0.390	4.05

Table 7
The structural model results.

Variables		Description	Coefficients	T-test
Feeling of being in control (Z_1*)	$\lambda_{1,1}$	Gender (male)	0.162	1.47
	$\lambda_{3,1}$	Age1 (39 or less)	0.619	4.02
	$\lambda_{4,1}$	Age2 (40–53)	0.298	1.79
	$\lambda_{5,1}$	High level of education	0.308	2.22
	$\lambda_{6,1}$	Number cars per household (more than 1)	0.176	1.38
Feeling of independence (Z_2*)	$\lambda_{1,2}$	Gender (male)	0.166	1.59
	$\lambda_{3,2}$	Age1 (39 or less)	0.132	1.23
	$\lambda_{5,2}$	High level of education	0.217	1.53
	$\lambda_{6,2}$	Number cars per household (more than 1)	0.418	3.23
Feeling of higher social status (Z_3*)	$\lambda_{1,3}$	Gender (male)	0.251	2.06
	$\lambda_{2,3}$	High-income	1.149	8.34
	$\lambda_{6,3}$	Number cars per household (more than 1)	0.837	6.09

perceived feeling of being in control of all travel elements, the higher the willingness to choose the alternative. Similarly, the fewer restrictions there are on private car driving, the lower the dependence on public transport, thus increasing the feeling of independence. As Z1 interacts with the travel time in all alternatives, travelers will prefer those transportation modes with a better feeling of being in control of their travel plans. Travelers will experience a feeling of independence using their cars when they can switch their travel schedule to avoid the restriction. In such a case, the latent variable Z2 positively impacts this decision. Lastly, the proposed interaction between the latent variable Z3 and the LPRC cost is positive and significant, suggesting that a feeling of higher social status positively influences the decision to pay the LPRC charge to continue using the car, even when the restriction is extended.

Overall, All latent variables contribute positively and differently to the utility function based on the attribute value explained and the individuals' socioeconomic characteristics. These results are consistent with the supposed rationality expressed in the random utility theory. In this sense, the expected behavior of the individual is that their utility increases as their feelings of being in control and of independence improve. These results also show that a feeling of higher social status will incentivize private car driving.

4.2. The measurement model

Concerning the measurement model presented in Table 6, the grouped indicators are explained by the latent variables Z1, Z2, and Z3 with a 99% significance. Their signs are valid and conceptually consistent with what is expected and with microeconomic theory. This paper does not provide the threshold parameters; however, they display statistical significance with at least 95% confidence, showing that the ordered models sufficiently represent the responder's views. Although these results are not required to use the hybrid choice model in a predictive way, they validate the exploratory analysis presented in **section 3.2**.

Interestingly, in the specific case of Z3, the parameters $\gamma_{3,9}$ and $\gamma_{3,12}$ are negative, suggesting that individuals with a feeling of higher social status do not have a car just to satisfy their travel requirements. Additionally, they do not consider it expensive to own and maintain a car, which is aligned with the structural model result since status is a symbolic characteristic of people with a high-income level. In contrast, results show that a feeling of higher social status is expressed when car users consider their car a fantastic and fashionable possession that generates economic well-being.

4.3. The structural equations model

As shown in Table 7, some of the parameters associated with the structural model are significant at 95%, while others are at 90%. They all have positive signs, indicating that different socioeconomic segments assign different values to the latent variables Z1, Z2, and Z3.

According to the results, men are more sensitive to being in control and independent in their travel experiences, and are more likel to feel a higher social status when using their cars, which is consistent with findings in previous studies (Belk, 2004; Ellaway et al., 2003). This sensitivity is also identified in young adults and individuals with a higher level of education, which is the level of education more relevant in the case of independence and age in the case of control, as indicated in the recent literature. (Belgiawan et al., 2016; Dėdelė et al., 2020).

Being in control, being independent, and feeling a higher social status are more significant in individuals with two or more cars in their household, where car ownership is seen more as a desirable goal than an essential tool (Clark, 2009). In this population segment, it is interesting to note that the feeling of higher social status is higher than the others are, especially in individuals with a high-income level, as indicated by Moody and Zhao (2019). Furthermore, independence is more valuable than a sense of control. However, having more than one car per household increases independence and control since there are more substitute alternatives to travel to the destination. All these results align with what is expected, considering that a car is the preferred mode of transportation for high-income travelers (Gao et al., 2014; Gonzalez et al., 2021).

4.4. The influence of the latent variables on the modal split

One of the most potent applications of including the three latent variables considered in this paper is the possibility of capturing how different population segments respond to the LPRC policy. Through the structural model, it is possible to describe the heterogeneity that is not provided by regular analysis. In this case, different population segments can be established as the individuals' socioeconomic characteristics explain the latent variables. Then, using the sample enumeration technique, a base scenario in the modal split is identified, which would change if everyone's attitudes were similar to those of a given population segment. Thus a sensitivity analysis of the latent variables was conducted using the HDCM through different what-if scenario tests, as explained by Hess et al. (2018). The analysis included 4050 pseudo-individuals, and the comparison was ceteris paribus. As a result, different impacts in the expected modal split were estimated according to the population segments identified in the structural model. Fig. 2, Fig. 3, and Fig. 4 show such impacts for each latent variable.

As observed in Fig. 2, the most significant impacts in the modal split occur when everyone's attitudes are similar to those over 54 years old, with an increase in demand for using the car within permitted driving times by 1.4%. At the same time, the BRT would decrease by 1.7%. Although the demand for Taxi and Car paying the LPRC charge would increase, it would be less than 0.05%. This pattern is repeated with a lower proportion when everyone's attitudes are similar to respondents with low and middle levels of education (0.9% for car and 1.0% for BRT), respondents aged between 40 and 53 years old (0.46% for car and 0.53% for BRT), women, and individuals with one car in their household. The opposite pattern occurs by adopting the attitude of young adults (persons 39 years old or less), individuals with two or more cars in their household, men, and individuals with a high level of education. It is interesting to note that the feeling of being in control more significatively impacts those transportation modes where such characteristic is less perceived when the LPRC policy is applied. Individuals who pay the LPRC charge are less impacted than the rest of the alternatives, since such a decision allows them to maximize the feeling of being in control of their travel experience.

The behavior of the latent variable Z2 is presented in Fig. 3, where the most significant variation in demand is obtained by observing the attitudes of the population segment with two or more cars in their household. In this case, demand for using the car within the permitted driving periods increases by 2.2%, while demand for taxis and BRT decrease by 0.91% and 0.82%, respectively. Similarly, the demand for paying the LPRC charge for using the car during the measure decreases by 0.47% since owning additional cars allows travelers to get around the restriction by using the non-restricted car when the measure is applied, thus maximizing independence. This pattern is similarly observed but with a lower proportion by adopting the attitude of men, young adults, and individuals with a high level of education, which are generally known for their independence (Holdsworth, 2009; Howard, 2021). Men and young adults are even better known for their willingness to take risks (Eckel and Grossman, 2008), which explains why they would use the restricted car during the permitted period.

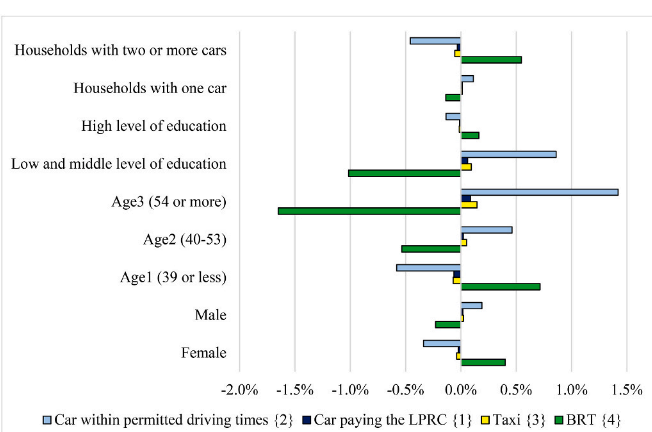


Fig. 2. Feeling of being in control (Z1).

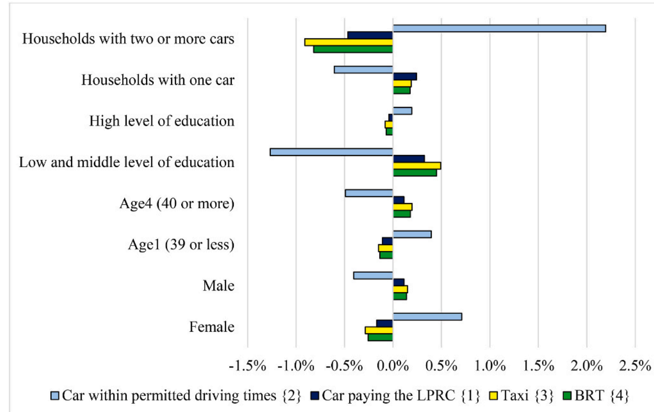


Fig. 3. Feeling of independence (Z2).

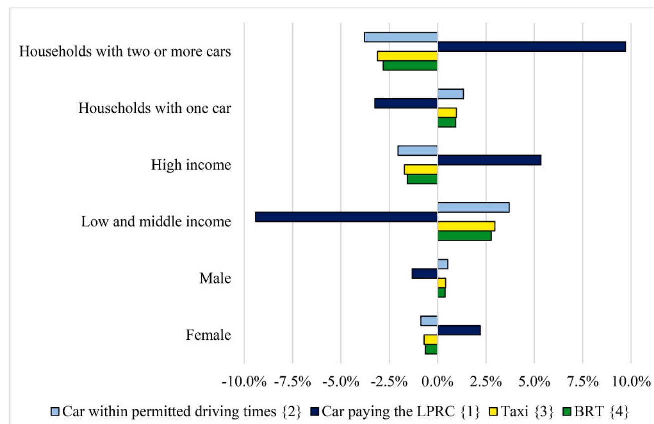


Fig. 4. Feeling of higher social status (Z3).

Interestingly, the rest of the population segments behave differently. For example, individuals with one car in their household are more willing to pay the LPRC charge to keep their independence. Thus, embracing such behavior increases its demand by 0.24% and the demand for public transport by about 0.19%. In contrast, private car driving during the scheme reduces its participation by 0.61%. Although assuming the attitudes of older people, women, or individuals with low and middle levels of education have the same pattern, in such cases, public transport has better use, especially in this last population segment.

Fig. 4 presents the impacts of the latent variable Z3 in the modal split. As can be seen, this latent variable has the most substantial impact in the modal split compared to the others. Interestingly, in addition to men, individuals with a high level of income or more than one car in their household would significantly increase their participation in the Car paying the LPRC charge, leading to a feeling of higher social status. The behavior of these two last population segments is consistent with microeconomic theory. Thus individuals with two or more cars experience more life satisfaction, aligned with the recent literature (Li et al., 2022). If all respondent's attitudes are similar to those with two or more cars in their household, the demand for using the car after paying the LPRC charge will increase by 9.7%. In contrast, the demand for using the car within the permitted periods would decrease by 3.8%, and the demand for Taxi and BRT would also decrease by 3.1% and 2.8%, respectively.

On the other hand, adopting the attitudes of those respondents with low- and middle-income would significantly decrease the demand for paying the LPRC charge by 9.4%, which is expected. At the same time, the demand for cars switching their travel schedule would increase by 3.7%, and the demand for Taxi and BRT would also increase by 3.0% and 2.8%, respectively.

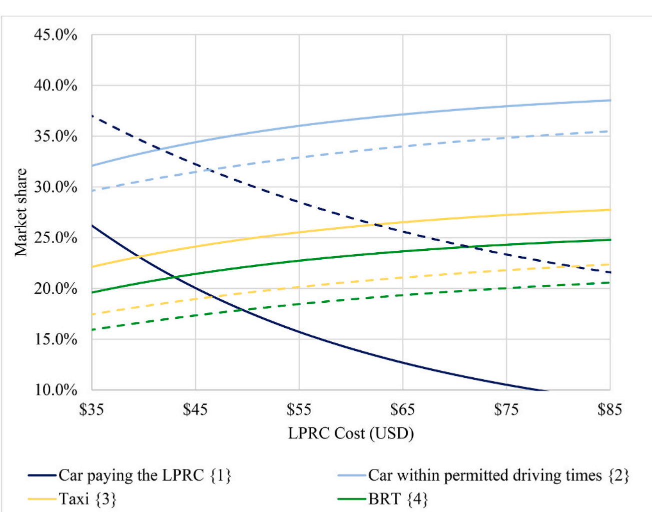
These results are significantly informative and allow us to deeply understand individuals' heterogeneity and the role of affective and symbolic aspects of car use in the context of the LPRC policy.

4.5. Market share simulation considering heterogeneity

Considering the influence of the three latent variables, a more profound look at the impacts in the modal split was made based on a market share simulation of scenarios with different car ownership levels and gender. The model was applied to estimate the aggregate market using simulated probabilities in such cases. The sample enumeration technique was used to perform a sensitivity analysis of the modal split variation for different LPRC costs.

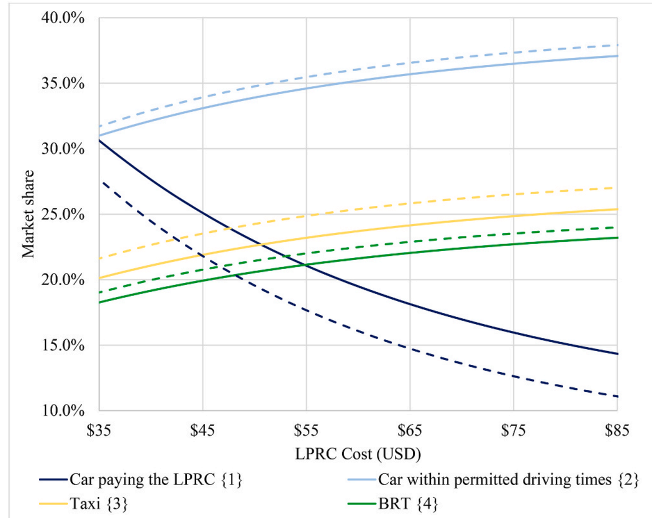
The results for different car ownership levels are illustrated in Fig. 5, where households with one car are depicted with solid lines in all alternatives. In contrast, dashed lines represent households with two or more cars in all alternatives. As expected, the market share of cars paying the LPRC charge is more significant in households with two or more cars than with one car. The difference is about 12.4%, and it remains relatively constant for different cost levels. In contrast, such a population segment has less participation in the other transportation modes, whose difference concerning households with one car is approximately 5.3% for Taxi, 4.1 for BRT, and 3.0% for cars switching their travel schedule. Although the market share of Taxi and BRT increases as the LPRC charge increases, car switching their travel schedule increases the most, especially in population segments with one vehicle in their household, which is related to the effect of the latent variables Z1, Z2, and Z3.

On the other hand, the market share result by gender is presented in Fig. 6, where women are depicted with solid lines in all alternatives and men are represented with dashed lines. As expected, the shift between men and women in the market share for different cost levels is less sensitive than between different levels of car ownership. In contrast to the latter, the difference between men and women is about 3.3%. In the other alternatives, this difference is less significant, about 0.8% for cars switching their travel schedule, 1.6% for Taxi, and 0.8% for BRT. Contrary to women, men are less likely to pay the LPRC charge for using their cars during the restriction and more likely to use the other alternatives.



*Households with one car (solid lines) - Households with two or more cars (dashed lines).

Fig. 5. Market share for households with different motorization rate.



*Female (solid lines) - Male (dashed lines).

Fig. 6. Market share by gender.

Concerning the direct and cross elasticities for the attributes considered in the experimental design, Table 8 shows the results estimated by sample enumeration for all population segments. The elasticities related to the LPRC cost, fare, and travel time are in the inelastic range, indicating that car users are unwilling to change their transportation modes due to marginal changes in those attributes. However, car users are sensitive to changes in the number of days per week when the restriction is applied and the number of restricted hours per day. These attributes are in the elastic range; therefore, changing the number of restricted days per week from one to two leads to a 6.64% increase in the demand for car users paying the LPRC charge. At the same time, the demand for cars switching their travel schedule would decrease by 2.58%, and the demand for Taxi and BRT would also decrease by 2.10% and 1.96%, respectively. Similarly, changing the number of restricted

Table 8
Direct and cross elasticities.

Attribute	Alternative	Car paying the LPRC {1}	Car within permitted driving times {2}	Taxi {3}	BRT {4}
LPRC Cost	Car paying the LPRC {1}	−0.17	0.07	0.06	0.05
Fare	Taxi {3}	0.02	0.04	−0.09	0.03
	BRT {4}	0.00	0.01	0.01	−0.01
Travel time	Car paying the LPRC {1}	−0.05	0.02	0.02	0.01
	Car within permitted driving times {2}	0.02	−0.08	0.03	0.02
	Taxi {3}	0.02	0.04	−0.08	0.02
	BRT {4}	0.02	0.04	0.03	−0.08
Number of restricted days per week (from one day to two days)	Car paying the LPRC {1}	6.64	−2.58	−2.10	−1.96
Restriction during the rush hours (from rush hours to almost all-day)	Car within permitted driving times {2}	6.80	−27.48	10.82	9.86

hours per day from both rush hours (06:00–10:00 and 16:00–20:00) to almost all day (06:00–20:00) would increase the demand for car users paying the LPRC charge by 6.8%, as well as the demand for Taxi and BRT by 10.82% and 9.86% respectively. As expected, this scenario would substantially reduce the demand for cars circulating during the permitted driving times by 27.48%, maximizing revenue for BRT both via fare and cross-subsidy.

The heterogeneity captured by the latent variables Z1, Z2, and Z3 gives us an insight into how different population segments respond to the last two scenarios (when the number of days per week changes and when the number of restricted hours per day changes). For instance, in the first scenario, the direct elasticity of the demand for car users paying the LPRC charge would increase to 8.55% when the households have two or more cars and would reduce to 6.08% if the households have only one car. Similarly, in the second scenario, the direct elasticity of the demand for car users switching their travel schedules would decrease to 30.13% for individuals with two or more cars and also reduce to 26.84% for individuals with only one car in their household. In both scenarios, the impact on demand for all alternatives is more significant for the population segment with two or more available cars in their household than with one car. The same assessment showed that women are more sensitive to the changes in both scenarios than men, but with a much lower proportion compared to the previous analysis. In the first scenario, the elasticity of the demand for car users paying the LPRC charge would increase to 7.08% for women, while it would decrease to 6.39% for men. In the second scenario, the demand for car users switching their travel schedules would increase to 28.47% for women, whereas it would decrease to 26.92% for men.

Another essential issue captured through the HDCM is the marginal substitution rates between travel time and cost for different population segments, which were evaluated using the estimated parameters. Table 9 [WTP, Z1] shows the willingness to pay, taking into account the influence of the feeling of being in control (Z1) on the users' travel experience. The WTP to reduce travel time by 1 min is valued differently by car users from different population segments, as previously hypothesized. When a user's socioeconomic conditions allow them to maximize their feeling of being in control of their travel experiences, they are willing to pay less, USD 0.054, to reduce their travel time by a minute. In the opposite case, they are willing to pay up to USD 0.415 to reduce their travel time by 1 min. As shown in Table 9, being in control is at its maximum level when the individual is a young adult man with two or more cars in their household and has a high level of education. However, when the car user is an older woman with just one car in her household and a low or middle level of education, the feeling of being in control of the travel experience is minimum.

Finally, Table 9 [WTP, Z1, Z3] shows the marginal substitution rates between travel time and cost for different population segments considering the combined effects of Z1 and Z3. Such WTP follows a similar trend to that obtained under the Z1 effect. This result suggests that some population segments that are more attached to their car that could experience a feeling of higher social status and therefore are less willing to pay to reduce their travel time by 1 min. Based on the heterogeneity analyzed, this WTP would range from USD 0.084 to USD 0.504. When individuals have two or more cars in their households (which indicates a high-income level), the WTP between travel time and cost increases since an income effect plays a factor. In other cases, the WTP between travel time and cost becomes very similar to those obtained under the effect of Z1.

4.6. Implications for policy

Cali is the first city that implemented this policy scheme in Latin America. Following Cali's lead, Bogotá in Colombia also implemented a similar policy, and several other cities have shown interest in studying the possibility of its implementation. This growing interest highlights the policy's potential as an effective congestion-tackling measure that generates revenue for investment in public transportation, while also being relatively low-cost to implement and enforce. Besides, the measure can be taken as an intermediate step towards a proper congestion charging scheme (Soto et al., 2023).

The implementation of this policy scheme can serve as a valuable source of insights for other cities in Latin America and Asia that already have license plate restriction policies in place or are considering their implementation. In developing countries where car ownership and disposable income are on the rise, car users might be willing to pay for the privilege of using their vehicles on restricted days. However, it is crucial to recognize the significance of affective and symbolic factors in influencing travel behavior choices when considering the introduction of a license plate restriction policy with an exemption charge. For car owners, their vehicles often represent a status symbol and a means of control and independence. As a result, the importance of travel time savings diminishes, making users less responsive to price changes.

Given the pricing and scheduling of the LPRC, individuals who rely on their cars for daily commuting would likely choose to continue using their vehicles instead of switching to alternative modes of transportation. As a result, some car owners, particularly those with higher incomes, may opt to purchase a second vehicle with a different license plate. Conversely, others might be willing to pay the charge to maintain the use of their existing vehicle or adjust their travel schedules accordingly.

Soto et al. (2023) indicate that tightening restrictions can lead to a higher willingness to pay for the exemption charge. However, despite the demand being relatively inelastic to price changes, finding the right balance in determining the charge amount is essential to prevent individuals from resorting to purchasing additional vehicles to circumvent the restriction and avoid payment altogether. Taking into account affective and symbolic factors when estimating demand and willingness to pay for a license plate restriction policy with an exemption charge can assist in understanding the heterogeneity among car users. By tailoring sustainable transport policies to accommodate preferences and attitudes within the population, policymakers can optimize the effectiveness of such measures (Soto et al., 2021).

Table 9
Marginal rate of substitution between travel time and cost for different population segments.

Socioeconomic characteristic	Population segments																	
Male	1	0	1	1	1	0	1	0	1	0	0	0	1	0	0	0	1	0
Age1 (39 or less)	1	1	1	1	0	1	1	0	0	1	0	0	0	0	0	0	0	0
Age2 (40–53)	0	0	0	0	1	0	0	1	0	0	1	0	0	0	1	0	0	0
High level of education	1	1	1	0	1	1	0	1	1	0	1	1	0	1	0	0	0	0
Households with two or more cars	1	1	0	1	1	0	0	1	1	0	0	1	1	0	0	1	0	0
[WTP, Z1] Travel time (USD/min)	0.05	0.10	0.10	0.14	0.15	0.15	0.19	0.19	0.23	0.24	0.24	0.28	0.32	0.33	0.33	0.36	0.37	0.41
[WTP, Z1, Z3] Travel time (USD/min)	0.08	0.14	0.11	0.22	0.23	0.15	0.21	0.27	0.36	0.24	0.24	0.38	0.50	0.33	0.33	0.50	0.40	0.41

In order to effectively implement the License Plate Restriction and Charging (LPRC) scheme, it is imperative to acquire a comprehensive understanding of the users who are willing to pay for the scheme. This necessitates the segmentation of the respondents, thereby facilitating the formulation of targeted strategies. To promote the LPRC policy successfully, a combination of hard measures (fiscal strategies) and soft measures (campaigns) is essential.

Price discrimination can be employed by considering key variables such as vehicle type, price, and age. This approach enables the inclusion of higher-income individuals and owners of vehicles with larger engines or higher levels of pollution. By incorporating these factors, the policy can be tailored to accommodate specific segments of vehicle owners more effectively.

Moreover, attitudes play a pivotal role in defining the segmentation of vehicle owners. By comprehending the attitudes held by individuals towards the LPRC scheme, it becomes possible to formulate campaigns that are customized to characteristics and preferences of each segment. These tailored campaigns serve to promote awareness of the LPRC policy and encourage greater participation and compliance among vehicle owners.

By employing a systematic approach that incorporates user segmentation and employs a combination of fiscal and campaign-based strategies, the LPRC scheme can be implemented in a targeted and efficient manner. This approach ensures that the policy is communicated effectively to diverse groups of vehicle owners, thereby increasing the likelihood of achieving its intended objectives.

5. Conclusions

This paper uses the simultaneous approach of the hybrid discrete choice modeling methodology to analyze the influence of affective and symbolic factors on the travel behavior of car users affected by the License Plate Restriction policy in urban areas. The methodology was used in city of Cali in Colombia, where the LPRC policy has been implemented since January 2017. As a result, a hybrid discrete choice model with 105 parameters (including three latent variables associated with affective and symbolic aspects), was estimated based on 4050 observations gathered from a stated preference survey. The model displayed statistical significance and consistency according to microeconomic theory.

The model allowed us to answer how the affective and symbolic factors of private car driving influence car users' travel behavior in a car restriction policy scenario. On the one hand, such affective and symbolic factors were identified as "a feeling of being in control", "a feeling of independence", and "a feeling of higher social status". On the other hand, these three latent variables positively influence the decision to use the car for daily trips, thus impacting the urban modal split differently. First, the higher the perceived feeling of being in control of all travel elements, the higher the willingness to choose the alternative. In this sense, travelers will prefer those transportation modes with a better feeling of being in control of their travel plans. Second, travelers will experience a feeling of independence using their cars when they can switch their travel schedules to avoid restrictions. Thus, the fewer restrictions there are on private car driving, the higher the feeling of independence. Third, the decision to pay a charge in a car restriction policy scenario to continue using the car is positively influenced by a feeling of higher social status. Finally, the heterogeneity captured through these three latent variables allowed us to understand more deeply how individuals deal with the LPRC policy in order to travel to their destination.

According to the model, men, young adults, individuals with a higher level of education, high-income level, and two or more cars in their household are more sensitive to those latent variables, thus increasing their probability of using their car. In this population segment, independence is more valuable than a sense of control, and the feeling of higher social status is above independence and sense of control.

For the purposes of policy-making, a sensitivity analysis of the latent variables was conducted using the HDCM through different what-if scenarios tests. We analyzed how modal splits change if everyone's attitudes are similar to those of a given population segment. On the one hand, the most optimistic scenario for public transport, (considering its operational sustainability through fares), is reached when car users adopt the attitudes of individuals from low- and middle-incomes. On the other hand, considering the LPRC policy contribution through cross-subsidy, the most optimistic scenario for public transport is achieved when everyone's attitudes are similar to the individual with a high level of income or more than one car in their household. If all respondent's attitudes are similar to those with two or more cars in their household, the demand for using the car after paying the LPRC charge will increase by 9.7%.

In line with the previous conclusion, the maximum benefit for public transport is achieved by changing the number of restricted hours per day from rush hours (06:00–10:00 and 16:00–20:00) to almost all day (06:00–20:00). In this scenario, the demand for car users paying the LPRC charge would increase by 6.8% and the demand for public transport would increase by 9.86%. At the same time, the demand for cars circulating during the permitted driving times would decrease by 27.48%, thus reducing congestion and other externalities, and maximizing revenue for public transport both via fare and cross-subsidy. The heterogeneity captured by the latent variables analyzed enabled us to identify that the impact on demand for all alternatives is more significant for the population segment with two or more available cars in their household, instead of just one. Similarly, women are more sensitive than men to changes in the LPRC policy.

Finally, the marginal substitution rates between travel time and cost for different population segments were estimated using the HDCM. We found that individuals are willing to pay a less (USD 0.053) to reduce their travel time by 1 min, when they feel in control of their travel plans. In the opposite case, they are willing to pay up to USD 0.41. Similarly, some population segments are more attached to their car than others. When individuals experience a feeling of higher social status, they are less willing to pay to reduce travel time by 1 min. Based on the heterogeneity analyzed, such as the WTP range from USD 0.083 to USD 0.41.

Declaration of competing interest

None.

Luis F. Macea: Conceptualization, Formal analysis, Writing- Original draft preparation, Methodology, Software, Data Curation, Writing - Review & Editing. **Luis Márquez:** Formal analysis, Writing- Original draft preparation, Writing - Review & Editing. **Jose J. Soto:** Conceptualization, Writing- Original draft preparation, Methodology, Writing - Review & Editing.

Data availability

The authors do not have permission to share data.

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