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Analysing a license plate-based vehicle restriction policy with optional exemption charge: The case in Cali, Colombia

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ABSTRACT

Several cities have restricted the use of private vehicles based on the last digit of a vehicle's license plate to reduce traffic congestion and pollution. However, the effectiveness of this measure has been questioned. In 2017, a hybrid scheme, License Plate Restriction Charging (LPRC), was implemented in Cali, Colombia. With this scheme, drivers can pay a charge (monthly, quarterly, or yearly) to circumvent the restriction, while the revenue is used to subsidise the BRT System. Cali was the first city in Latin America to implement such a scheme, while Colombia's capital, Bogota, adopted a similar policy in 2020. This article analyses the evolution of the measure using official information. In addition, we conducted a stated preferences survey and estimated a choice model to evaluate the behaviour of car owners to policy variables. Results show that LPRC price is the most relevant attribute in decision-making. Increasing the number of days with traffic restrictions and extending the hours of vehicle use restriction increases drivers' probability of paying for the LPRC. As currently implemented in Cali, the LPRC is a fixed cost that does not vary according to the car use level, encouraging users who pay for the exemption to use their car as much as possible to make the most out of the payment. Furthermore, the revenue from the charge contributes only marginally to financing the BRT. Finally, we propose several changes in the policy to improve its efficiency. Among them, consider a daily payment and hardening the current driving restriction.

1. Introduction

Private car use has become a major issue for cities worldwide due to its externalities, primarily in congestion and environmental pollution (Rizzi and De la Maza, 2017). Part of the problem is that drivers are only aware of the personal costs of using their vehicle in most cases and not the broader social, economic, and environmental costs that private cars generate for society. Road pricing schemes have emerged to counteract this phenomenon, which consist of shifting part of the marginal cost to the user and internalising some of the externalities to reach a social optimum (Small and Verhoef, 2007).

Traditionally, these policies—labelled as 'first best'—have been categorised as theoretical, given the difficulty of their practical application (Small and Verhoef, 2007). Among the main reasons are the impossibility—due to its very high cost—of charging for all road users (Verhoef, 2002); the inability to vary the charges freely over time; the difficulty of differentiating between types of users

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(Koster et al., 2018), and the stochastic nature of congestion (Small and Verhoef, 2007). However, recent technological advances have enabled planners to overcome most of these difficulties (Ghio et al., 2018).

Other measures, known as 'second best', facilitate the practical implementation of road pricing mechanisms by imposing restrictions. These include toll lanes and restricted access zoning (Small and Verhoef, 2007). In this context, Ortuzar et al. (2021) analysed different road pricing schemes in Chile, considering variables related to the extension of the tolled area, the hour of the day charged, and the potential use of revenues. They also analysed the effect of individual attitudes towards road pricing to determine which road pricing scheme could be more palatable to people travelling by car to Santiago CBD, at least once a week, for work purposes. However, few cases have been implemented, given *drivers' ex-ante dislike of these measures* (Börjesson et al., 2012) and their high political cost (De Borger and Proost, 2015). Nevertheless, there are cases where citizen support has grown post-implementation, such as in Stockholm (Eliasson and Jonsson, 2011).

A popular measure in Latin America has restricted vehicle movement based on the vehicle's license plate number. This measure prohibits the circulation of vehicles on certain days of the week and specific hours of the day, depending on the last number of their license plate. It has been applied in Mexico (Davis, 2008), Colombia (Ramos et al., 2017), and Chile (De Grange and Troncoso, 2011), among others. This measure has been implemented temporarily in Santiago de Chile on days of environmental emergency, and permanently in Mexico City and several cities in Colombia.

The rationing measure was implemented in the 1980 s to address congestion and pollution problems, rationalising car use on public roads. The measure showed notable success in its early stages due to its effectiveness, easy implementation, low costs, and flexibility. Although policies that impose driving and parking restrictions have low public and political acceptance (Mattioli et al., 2020), this measure was adopted by many Latin American cities since it was less unpopular than congestion charging.

The restriction by plate number policy has been questioned. Research on the subject emphasises that the measure is perverse in the long term because, under certain circumstances, it can encourage the purchase of a second vehicle, in many cases a second-hand one, which is often more polluting. This response may exacerbate the very problems for which the measure was initially imposed (Cantillo and Ortúzar, 2014). According to Davis (2008), no significant reduction in the concentration of pollutants was achieved in the long run in Mexico City. Bonilla (2019) indicates that this measure is ineffective in improving air quality. Instead, it induces more driving and increases gasoline consumption, vehicle stock, and CO concentrations when the restriction is more drastic.

Moreover, in the long term, car users in different countries tend to adapt to the measure differently (Gallego et al., 2013). The most common forms are: (i) purchasing electric vehicles, which usually are exempted from the measure (Lu et al., 2020; Rao, 2020; Diao et al., 2016; Wang et al., 2017); (ii) purchasing a second car with a different license plate (Bonilla, 2019; Chen et al., 2020; Moncada et al., 2018); (iii) sharing car journeys (Gu et al., 2017); (iv) switching to transit or taxi (Yang et al., 2018; Mohan et al., 2017; Gu et al., 2017); (v) switching to bicycle and bike share (Gu et al., 2017; de Buen Kalman, 2021)); (vi) using the restricted vehicle outside of restricted hours (De Grange and Troncoso, 2011; Guerra and Millard-Ball 2017); (vii) transgressing the restriction rules (Viard and Fu, 2015; Wang et al., 2014), and (viii) shifting the trip to unrestricted days (Guerra et al., 2021).

From the perspective of public policy, local governments in Colombia face challenges because they do not have the legal powers that permit direct control over the automotive market, which is the opposite of China, where a license-plate-based driving restrictions policy was implemented in Beijing and other cities, but the authority has set a quota system for the entry of new vehicles. (Chen et al., 2020). Colombian authorities can only act by implementing travel demand management measures, favouring more sustainable modes of transport and to the detriment of private transport. In addition, they are increasingly concerned about the continued growth of the vehicle fleet, which has been used as a justification to adopt restriction measures based on the vehicle's license plate number.

In the cities where restriction by license plate number has been applied, abolishing the policy is complex due to the significant impact that would happen on traffic conditions and the multiplication of other collateral effects, which become evident on days when there are no vehicle restrictions (Cantillo and Ortúzar, 2014). Consequently, it is necessary to evaluate restrictions that allow for a gradual transition towards pricing schemes closer to the social optimum, such as congestion pricing. The last is one of the best-documented ways to reduce excessive traffic on public roads during rush hours since it allows drivers to internalise the external effect induced by private cars (Pigou, 1920; Beckman et al., 1956). This way, car users have incentives to prioritise their trips or switch to other transportation modes, among other decisions, thereby reducing delays (Hau, 2021).

This article studies the implementation of charging to use private vehicles during a license plate restriction policy to circumvent the restriction in Cali, Colombia, referred to in this paper as License Plate Restriction Charging (LPRC). The revenue is used to subsidise the Bus Rapid Transit (BRT) system called SITM-MIO. The results presented here will be of interest to transport planners and decision-makers. Cali is the first city in Latin America where this hybrid measure was implemented. After Cali, Bogotá implemented a similar policy. The results presented are drawn from the first three years of implementation of the measure.

The article is organised as follows: Section 2 examines the vehicle restriction measure based on the vehicle's license plate number and the "daily pass" policy. Section 3 presents the context and results in terms of the revenue of the LPRC. Section 4 describes the experimental design, the modelling, and analyses car owner behaviour towards the policy. Finally, Section 5 brings together the main conclusions of this study.

2. The license plate number restriction and daily pass policies

A relevant issue of any restriction policy based on the vehicle's license plate number is the incentive for a household to purchase or hire an alternative vehicle (Basso et al., 2021; Cantillo and Ortúzar, 2014; Ye, 2017; Moncada et al., 2018; Chen et al., 2020). Indeed, many Chinese cities have experienced a significant increase in electric vehicle sales after implementing a license-plate-based driving restrictions policy that exempts low-emission vehicles (Wang et al., 2017; Rao, 2020; Lu et al., 2020). However, in the long term,

congestion and pollution will return to the levels experienced before implementing the measure. According to Huang et al. (2017), the restriction is effective in the short but not the long run. Furthermore, it has been found that there are null or only slight effects on pollution levels due to this overall increase in the motor vehicle fleet (Bonilla, 2019; Davis, 2008; Cantillo and Ortúzar, 2014; Chen et al., 2020; Chen et al., 2021). Hence, it is frequently cited that the measure increases the motor vehicle fleet and causes greater commercialisation of older vehicles, both of which diminish air quality (Davis, 2008; Cantillo and Ortúzar, 2014; Bonilla, 2019).

The 'daily pass' is a payment for permission to drive during an established period of vehicle restriction. This measure was initially proposed by Daganzo and García (2000) and recently by Basso et al. (2021) as a hybrid of pricing and rationing scheme that includes a toll rate, a finite time window (usually the rush hour), and the fraction of free commuters (a fraction of the population that is not tolled). These two papers developed the basic theoretical foundations for the policy.

Daganzo and Garcìa (2000) used a bottleneck congestion problem to evaluate this scheme considering a homogeneous population and a fixed restriction time. Then, when divided into two classes – the ones having to pay on that day and those who are not- both will benefit from a lower level of congestion by the trips that switch to public transportation or the ones that are cancelled. The cost paid for circulating is balanced when the number of restriction days between groups is the same. Basso et al. (2021) extended this approach by considering a heterogeneous population with different income levels, two transport modes (car and public transportation) and adding a restriction to vintage cars to tackle pollution, using a static congestion model. Daganzo and Garcia (2000) stated that the scheme is a Pareto-improving measure. However, Basso et al. (2021) explained that this Pareto premise does not hold for low-income car-owning households, and revenue used to improve public transportation is needed.

This strategy can be implemented by assigning a toll rate proportional to the time window of the restriction, which is also dynamic according to the vehicle's license plate, which allows people to have more options than pure pricing or pure rationing. According to Montero et al. (2018), this scheme emerges as a complementary measure that offers the option of exemption from the restriction and can potentially reduce—or eliminate—the incentive to purchase a second car. Additionally, preventing access to the daily pass for vehicles with older, more polluting technologies in times of poor air quality addresses this environmental problem.

In sum, the use of vehicle restriction coupled with a daily pass option could mitigate the effects of pollution and congestion, but only if the setting of the price and the schedule are carefully considered. If the price is too high, the incentive to buy a second vehicle will rise, and if, on the contrary, it is too low, the reduction in congestion and pollution may not be significant, as most users will pay the fixed cost. Charging more for daily passes for older vehicles—or not permitting daily passes at all—is an essential aspect of this policy, embedding the environmental pollution factor in its design, something not addressed directly in measures where an equal restriction is applied to all vehicles, regardless of their emission levels. Such a measure can indirectly incentivise and accelerate the renewal of the motor vehicle fleet (Barahona et al., 2018) and the transition to cleaner automotive technologies.

Several researchers have questioned the benefit of the vehicle restriction measure. As the policy generates social loss (Cantillo and Ortúzar, 2014), it cannot be considered a 'second best' measure for road pricing (Nie, 2017). With the implementation of the daily pass, there are possible scenarios in which all users could be strictly better off than before the measure was applied. Since higher-income users are financially able to pay for the daily pass (or already have a second car), they would benefit from taking advantage of shorter travel times. Meanwhile, users who cannot afford the daily pass or do not have a car will also be benefited from a better service on public transport systems, assuming the service adapts to the higher demand and yields a Mohring effect. The revenues received from the daily pass can—or should—be used in full to improve public transport or active modes. Thus, reinvesting in the daily pass would allow for a scenario in which all users are better off than before (Basso et al., 2021), becoming a Pareto optimum congestion reduction scheme (Daganzo, 1995). According to Basso et al. (2021), the vehicle restriction cannot be limited to only one day but must be a minimum of two days per week to bring about notable benefits.

Drivers can take the risk of using the vehicle on restriction days. In this case, the risk level depends on enforcement and the fine's value. Clearly, there is more incentive for driving on restriction days if enforcement levels and the fine are low. On the other hand, illegal trips have been shown to increase when restrictions are tighter (Liu et al., 2018, Lin et al., 2022), even reaching levels of 8% to 18% of "restricted vehicles", for one day per week and odd–even restriction, respectively (Liu et al., 2018). Illegal commuting decreases the effectiveness of the measure.

Although a fine is a monetary charge that must be paid if the user travels with a restricted vehicle, it is not comparable with LPRC for two main reasons. First and foremost, the nature of the fine is to punish behaviour that goes against a law, with the aim of discouraging potential offenders. On the other hand, a restriction charge is implemented to allow for behaviour paying external costs. The opposed nature of payment to punish versus a payment to allow a behaviour could greatly (although not measured yet) distort i) willingness to pay, as losses might be valued differently than gains (Loss Aversion – Tversky and Kahneman, 1991) ii) travel demand, by changes in travel behaviour, such as mode change on work trips and mode and day/time for nonwork trips (Blackman et al., 2020), and iii) people with the potential or capacity to pay, but not willing to break the law or be fined.

Secondly, the fine is more expensive than the charge. Most of the time, it is not only a monetary charge, and includes penalties like driver's license point decreases (Lin et al., 2022), increasing fines for multiple violations (Liu et al., 2018; Blackman et al., 2020), request to return to the place of origin (Blackman et al., 2020) or car towing (Law 769, 2002). Besides, fines are charged per event, with the possibility of more than one fine per day, which increases the costs even more.

In this context, although the application of the daily pass would not have the same impact as road pricing, it can be seen as an intermediate step, given the ease of application and lower political cost. In the meantime, this measure may be a starting point and expand its coverage in days until a road pricing scheme is reached, which would correspond to paying exemption passes regularly or a complete migration to a daily congestion charge scheme. The latter is the desired condition because its application internalises the cost generated for road use and is applied proportionally to the level of vehicle use.

In January 2017, Cali became the first city in Latin America to implement a payment scheme for using a private vehicle during the

license plate restriction policy to manage demand for private cars and as a potential source of funding to subsidise the public transport system. However, users pay yearly, quarterly, or monthly rather than making daily payments. The payment of the charge permits drivers to use their vehicle on all restricted days of the period paid. Since 2020, Bogotá has applied the measure under different price and coverage time conditions. The following section presents the context which led to the implementation of this public policy in Cali.

3. Context

Cali is Colombia's third most populated city, with approximately 2.2 million inhabitants (DANE, 2018; DAPM. , 2019a). Around 700.000 motor vehicles are registered in Cali, of which 64% are private cars and 31% motorcycles; the remaining are buses, taxis, and lorries. On a typical day, city inhabitants generate 3.7 million trips, of which 62.3% correspond to motorised modes (including public transport) and 37.7% to non-motorised modes (walking and cycling).

The following sections briefly present the historical development of the driving restriction measure based on a vehicle's license plate number in Cali and its subsequent migration to the LPRC.

3.1. Transition to the exemption charge in Cali

The restriction based on vehicle license plate number (locally known as "Pico y Placa") was first applied in Cali in 2005 (Decree No. 0722, 2005). The measure established a ban on the circulation of private vehicles in the urban area, from Monday to Friday between 07:00–09:00 am and 17:30–19:00 pm, based on the last digit of the vehicle's license plate. On a rotating schedule, the restriction was set for two different last numbers per day (20%).

The initial objective of the measure was to reduce the levels of traffic congestion, air pollution and incidence of traffic accidents caused by the growth of the motor vehicle fleet. Although the restriction was initially aimed at private vehicles, public transport vehicles (buses, microbuses and minivans) and taxis were also included, given their oversupply in the city (Decree No 4112.010.20.0434, 2017). Even though motorcycles have had greater participation and growth than cars, they have no restrictions.

In 2016, the LPRC was approved by the Municipal Council and implemented in January 2017 (Agreement 0401, 2016; Decree No. 4112.010.0001, 2017). Marketing campaigns were launched as a promotion strategy. The policy's purpose was to raise funds to subsidise the public transport system, which has a significant financial deficit affecting service quality and coverage.

The LPRC was initially set at COP 2,578,680 (USD 860)[1] per year, possibly paying per semester or per month. The price per day was not a result of a marginal cost and externality estimation nor based on a willingness to pay analysis for using a private vehicle during the license plate restriction. It was instead decreed as five (5) times the cost of the average ticket of the public transport system (Decree No. 4112.010.0001, 2017).

After the first year of implementation, the vehicle restriction hours were extended from 6:00 to 10:00 and 16:00 to 20:00. The LPRC charge remained constant. In December 2018, the local government modified the price of the measure, reducing it to COP 1,628,640 (USD 543) per year, equivalent to COP 135,720 per month, a reduction of 36.8%, while keeping the time window and the number of days of the restriction constant (Decree No. 4112.010.20.0805, 2018). From then on, the LPRC charge is updated at the beginning of each year in alignment with the annual increase in public transport fares. In 2020, bus fares increased by 10%, so the LPRC annual charge was set at COP 1,490,292 with no changes in the restriction details (Decree No. 4112.010.20.0034, 2020). Although the measure was well-intentioned, some aspects must be highlighted:

- Since its inception, the measure has been erroneously named a "Congestion Charge" or "Contamination Charge", a misnomer as it is a fixed charge rather than a variable marginal cost per vehicle use. Congestion charging aims to achieve an optimal equilibrium point by imposing a charge that increases personal travel costs for car users. The LPRC charge does not raise awareness among drivers of the social cost they generate by each journey they take, which depends on the time and place where the congestion occurs and the distance travelled by car in congestion areas, among other factors not included in the measure.
- As it is not a daily payment, the risk exists that individuals paying the charge per month will increase car use, as the perceived unitary cost per trip decreases as the car is used more. The policy generates an incentive towards car use when users have paid the monthly payment. This is the opposite of the congestion charge scheme, where the payment is directly proportional to car use. If the car is not used in a marginal charge scheme, the owner does not pay.
- The measure did not include motorcycles, potentially encouraging their use. Motorcycles in Cali are exempt from paying taxes, exempt from paying urban and interurban tolls and even exempt from the license plate restriction policy. As a result, this mode of transport has seen 38% more growth than the rise in private vehicles in Cali. Currently, trips in motorcycles are 26.6 % of the modal share (DAPM. , 2019b).
- This urban transport policy does not vary depending on the city sector (it applies to the whole city) nor the use of the busiest roads or zones where traffic congestion is heaviest. In consequence, its capacity to correct the congestion externality is diminished.
- Before its implementation in 2016, no analysis was carried out to address uncertainties about the measure's effects, nor were any economic or financial evaluations of the policy conducted to determine its viability.

[1] The exchange rate when the survey was applied was 1 USD = 3,000 COP.

- No technological plan for managing the measure was implemented. As a result, users who had paid the LPRC charge and were, in principle, exempt from restrictions continued to be identified by automatic plate detection cameras and penalised, reducing its adoption due to the multiple problems experienced by users.

3.2. Assessment of the LPRC charge in Cali

Table 1 presents key financial statistics after implementing the measure, from 2017 to 2019, including annual revenue, the number of months paid per year, the distribution of payments by vehicle use, type of vehicle, and month of the year. We excluded 2020 due to the COVID-19 pandemic. Data evidence an increase in annual revenue each year, with a jump much more pronounced between 2018 and 2019, when the price of the LPRC charge was dropped.

Regarding the total number of months paid per year, business vehicles were the majority at the beginning of the measure. In contrast, in 2019, private vehicles became the majority of LPRC users. While both types of vehicles increased the number of transactions annually, there was a bigger increase among private vehicles.

The "others" category consists mainly of commercial vehicles, such as lorries and private buses. During the first year, more than half of transactions were made by this category. They fell to 45% in 2018 and 29.8% in 2019, despite increasing the total number of paid months from 5,816 in 2017 to 9,958 in 2019. However, the annual increase for this category was lower compared to others. It is relevant to consider that commercial vehicles do not have the flexibility to make travel decisions, and a charge, such as a toll or LPRC, is assumed as a fixed cost in their operation (Holguin-Veras, 2008). Therefore, preference analysis was carried out only on non-commercial vehicles, mainly because they showed a larger increase over the years and their owners have flexibility and choice over transport mode.

Table 2 shows the frequency information regarding the percentage of vehicles by the number of months paid over the year and the most and least paid months, respectively. Half of the vehicles pay only one month of the year; meanwhile, three-quarters pay up to three months. Less than 10% of vehicles pay every month. Despite the price drop in 2019, the overall behaviour has been similar over the years, as the percentages show. Also, the similarities remain, with the most paid month of the year being December, probably due to the holiday season. This behaviour highlights a significant number of occasional users, paying according to their needs.

While revenues increased over time, the policy's effectiveness has been questioned in meeting the objective of funding the BRT system. Since its inception, total revenue from the LPRC was one hundred per cent destined to finance the city's public transport system (Decree No. 4112.010.0001, 2017; Decree No. 4112.010.20.0805, 2018; Agreement N° 0452, 2016). However, low uptake by users has meant the policy has not raised significant funds.

Taking year 2019 as a reference, the public transport system's operational sustainability contribution was only about 1.2% of the total operational costs and about 4% of the operational deficit. This effectiveness is also less if the administrative and implementation costs of the policy are considered, which correspond to 5% of the total policy revenue. The benefit transferred to passengers if fare reduction is 37 COP per passenger, 1.8% of a single-trip fare, clearly showing this measure's tiny contribution in subsidising the public transport system.

On the other hand, a hypothetical maximum of 20% of private vehicles could be released with the implementation of the restriction based on the vehicle's license plate number, which would mean that the maximum financial benefit of the LPRC would be 3.5% of the total operational costs of the public transport system and 5.1% of the user fare.

Under such circumstances and considering the administrative and implementation costs to ensure its correct policy application, it is not very hopeful that the total policy revenue outweighs the negative externalities generated by the released demand. Moreover, there is a risk that the LPRC is a misguided transport policy that requires rethinking in terms of financial efficiency and economic viability. Rethinking the policy means evaluating possible changes regarding the characteristics of the restriction in terms of price, the number of restricted days per week and the number of restricted hours per day. Other changes should include the proposed transition to a daily pass payment scheme (Basso et al., 2021).

Table 1
Descriptive statistics on the collection of LPRC.

LPRC		Year		
		2017	2018	2019
Vehicle Fleet		388,109	411,725	435,341
Total Paid Months		10,894	16,291	33,393
By Use	Business Vehicle	7,470 (68.6%)	10,350 (63.5%)	14,453 (43.3%)
	Private Vehicle	3,424 (31.4%)	5,941 (36.5%)	18,940 (56.7%)
By Type	Cars	1,450 (13.3%)	2,333 (14.3%)	7,296 (21.8%)
	SUV	3,628 (33.3%)	6,627 (40.7%)	16,139 (48.3%)
	Other	5,816 (53.4%)	7,331 (45.0%)	9,958 (29.8%)
Income (COP)		$2,341,011,660	$3,500,772,990	$4,897,230,000
Income (USD)		$780,337	$1,166,924	$1,632,410

Source: Cali Mayor's Office.

Table 2
LPRC Frequency information.

Payments		Year		
		2017	2018	2019
Number of months paid	1	56.2%	50.8%	49.9%
	2–3	22.6%	22.5%	23.5%
	4–6	12.0%	11.6%	13.8%
	7–9	5.0%	6.2%	6.6%
	10–12	4.3%	9.0%	6.2%
Most Paid Month		December (12.01%)	December (10.11%)	December (11.54%)
Least Paid Month		February (6.07%)	January (4.12%)	January (2.74%)

Source: Cali Mayor's Office.

4. Analysis of car owner behaviour

We conducted a stated preferences experiment to evaluate the car-user behaviour under changes in characteristics of the measure, such as cost, number of days per week and hours per day. Data were used to estimate a discrete choice model to assess the willingness to pay for circumventing the restriction, estimate elasticities and evaluate different policy scenarios.

4.1. Experimental design

The instrument used for collecting data was structured into the following three parts:

(i) Socioeconomic information of respondents, including gender, age, social strata, level of education, occupation, household size, number of school-age children, and income.

(ii) Information on the last trip during the license plate restriction. It includes the mode of transport; departure and return times; flexibility in arriving before or after work/study hours; whether or not the respondent paid for parking at the destination, and willingness to purchase another vehicle if the restriction measure is reinforced, among others.

(iii) Stated preference scenarios. The experimental design for the stated choice survey includes four travel alternatives for private vehicle users travelling from their homes during the morning. The options were: 1) travel by car, paying the LPRC monthly to be allowed to drive during the restricted hours; 2) travel by car, limiting travel to within permitted driving times; 3) travel by Taxi/Uber; and 4) travel by Public Transport (BRT/Bus).

Although purchasing a second car with a different license plate could be an alternative for some people, it was not included in the experimental design because it is usually a long-term decision (Ma and He, 2016), so including such an alternative could distort the

Table 3
Variables used in the experimental design.

Variables	Levels	Values	Length of the trip
Travel time in private vehicle paying the LPRC monthly to permit driving during the restriction (min)	2	15 – 20	Short
		30 – 40	Medium
		50 – 60	Long
Travel time in private vehicle with driving restricted to the permitted hourly slots (min)	2	10 – 15	Short
		25 – 35	Medium
		45 – 55	Long
Travel time in Taxi/Uber (min)	2	15 – 20	Short
		30 – 40	Medium
		50–60	Long
Travel time in public transport – BRT/Bus (min)	2	20 – 25	Short
		40 – 50	Medium
		65–75	Long
Cost for Taxi/Uber (COP)	2	5,500 – 6,500	Short
		10,500 – 12,500	Medium
		20,000 – 22,000	Long
Cost for public transport - BRT/Bus (COP)	1	1,900	
Days with the license plate restriction per week	3	1 day	
		2 days	
		Every other day	
Time window of the restriction measure	2	06:00 – 10:00 and 16:00–20:00	
		06:00 – 20:00	
Monthly Cost of the LPRC (COP)	4	100,000	
		150,000	
		200,000	
		250,000	

Note: $1 USD = 3,000 COP when the survey was applied.

experiment. Furthermore, the realism of some stated choice scenarios cannot be entirely pertinent to some respondents due to their budget restrictions.

Table 3 shows the variables, values, and attribute levels used for the model estimation. This configuration gave a total of 384 treatments, of which 36 were chosen to be applied to the experiment based on an orthogonal block design with level balance, minimum overlap and profit balance (Zwerina et al., 1996). These 36 treatments were divided into four blocks using the software Ngene® (ChoiceMetrics, 2018). Consequently, each respondent faced nine choice situations. In each scenario, the respondent had to decide the mode to travel, considering the variations presented by the variables. Surveys were customised according to the trip length (short, medium and long).

4.2. Data

The sampling considered the population of private vehicle users, the location of the areas with the highest number of private vehicles within the city and the socioeconomic characterisation of the respondents. The survey was applied in November 2018. A total of 450 people were surveyed as private vehicle owners in Cali. The majority were from households composed of three members, with 44% of households having one or more school-age children. Table 4 presents the sample distribution across additional socioeconomic characteristics in contrast with Cali's mobility survey distribution, the most recent and available population distribution pattern.

As indicated in section 4.1 (ii), respondents were asked about their willingness to purchase another vehicle if the time window of Cali's current license plate restriction policy is extended. As a result, 39% stated they would consider buying another vehicle in response to the restrictions, 18% are indifferent to the measure, and 43% would not be willing to buy another car. As for the choice made by respondents to cope with the restriction measure on the day they are affected, Fig. 1 presents a summary of the decisions made by respondents to either i) pay the LPRC established by the Municipality of COP 214,890 (USD 71.63) for driving during the restriction; ii) use a second vehicle; iii) use the restricted vehicle during the authorised hours; iv) travel in a shared vehicle; v) use a Taxi/Uber; vi) use public transport, or vii) use other transport modes such as motorcycle, bicycle or walking.

The graph shows that paying the LPRC is the least popular option, followed by using other modes of transport such as motorbike, bicycle or walking. On the other hand, using the restricted vehicle within the permitted time window is shown as the most desired alternative, followed by using a second vehicle. Both decisions are supported by factors associated with flexible working hours and the possibility of not paying for parking at the destination, as is the case for a significant proportion of the sample. The responses to the other options presented are also shown in Fig. 1.

The present study was made using stated preferences only. The authors acknowledge that the use of the stated preference method, although valid, could be improved using a combination of stated and revealed preference data. We did not collect revealed preferences (RP) data because the percentage of users that paid for the measure was tiny. This made it challenging to obtain a significant number of surveys of users that pay in an RP context. Also, using RP data poses a challenge since the attributes of the policy (e.g. price, restriction time) are fixed, so it is difficult to capture the sensitivity of individuals to them. We believe that, although hypothetical in nature, the stated preference experiment was more believable to respondents, as it was referencing a policy already implemented.

Table 4
Profile of the respondents.

Characteristic	Level	Our sample (%)	Cali's mobility survey (%)
Gender	Male	63%	62%
	Female	37%	38%
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%
Household income (Millions COP)	Less than 2.0 (670 USD)	11%	
	2.0–4.0 (670 USD – 1340 USD)	39%	
	4.0–6.0 (1340 USD – 2000 USD)	28%	
	More than 6.0 (2000 USD)	22%	
Level of education	Primary or secondary	6%	28%
	Technical	8%	13%
	College	57%	49%
	Graduate	29%	10%
Occupation	Employee	57%	37%
	Independent	30%	31%
	Other	13%	32%
Cars per household	1	39%	
	2	43%	
	3 or more	18%	
Household Size	2 or less people	31%	28%
	3–4	59%	53%
	5 or more people	10%	19%

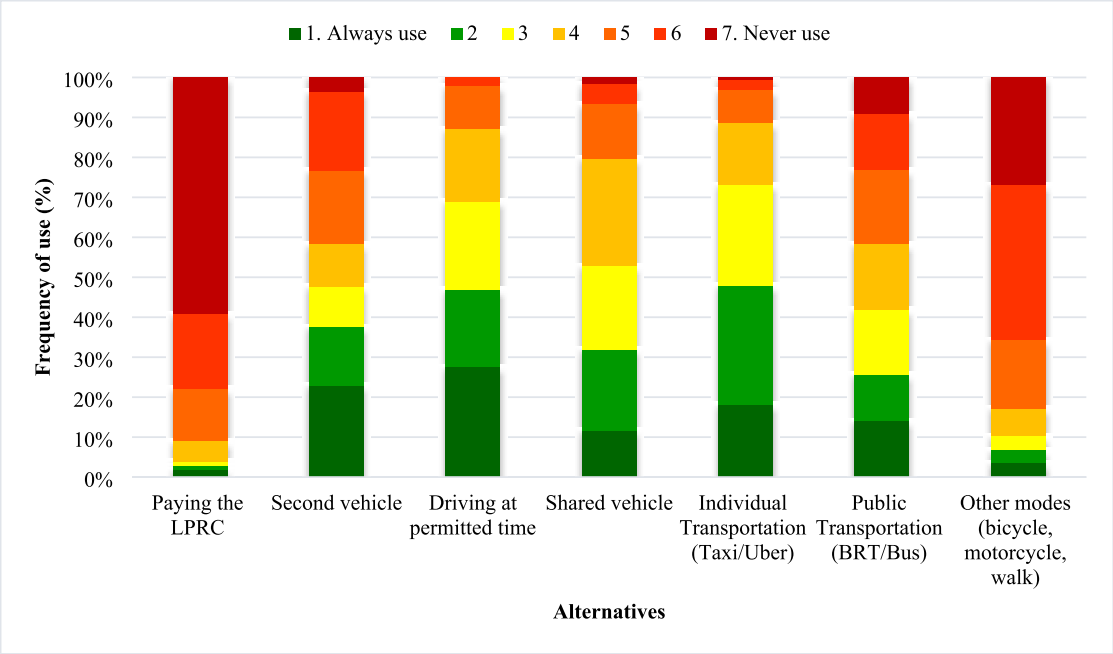

Fig. 1. Respondents' preferences in response to LPRC driving restrictions.

4.3. Results and discussion

We estimated a Mixed Logit model with a panel effect to consider the correlation between responses from the same individual. The model considers systematic variations of tastes to income and flexibility of arrival time. Travel time (minutes) was included in all alternatives in defining the specification of utility functions. The monthly LPRC cost (COP) was specified for alternative 1, Car paying the LPRC, while fares (COP) are in alternatives 3, Taxi/Uber, and 4, BRT/BUS. The number of restricted days per week and a dummy variable for an extended restriction during the day were specified for alternative 1.

Table 5 shows the parameters for the estimated model. The estimation was done with Ox Console software (Doornik, 2015), using maximum simulated likelihood (Train, 2009). For the random parameters, we used five hundred Modified Latin Hypercube Sampling (MLHS) draws (Hess et al., 2006). Most parameters are statistically significant at the 95% level. Signs are conceptually consistent according to microeconomic theory.

Flexibility on arrival time positively impacts travelling by car during the non-restricted hour. The interactions between the cost parameters (i.e. Fare and LPRC) and high income are positive and significant, suggesting that high-income individuals are less sensitive to the cost. The positive and significant value of the specific constant for Taxi/Uber suggests that ceteris paribus, this alternative is preferable to the others.

As car users try to bypass the restriction by leaving home and coming back during the allowed hours (before 6 am), which is uncomfortable or inconvenient in many cases, they penalise more the travel time outside the restriction period than during the restricted hours. This finding is also presented by Ramos et al. (2017). The subjective value of travel time during restricted hours is 110 COP/min. In turn, the subjective value of the travel time during the allowed hours is 180 COP/min. This indicates a greater willingness to pay for reducing travel time during off-restriction hours than during restricted hours.

According to the model, when the number of restricted days per week increases, the probability of paying the LPRC increases. As the LPRC is a fixed value that does not depend on car use, this behaviour reflects the incentive of paying the monthly cost when there are more restricted days, given that the price per day decreases.

The parameter of the dummy variable for an all-business hours extended period (06:00 am to 8:00 pm), related to the length of the restricted time window per day, is positive and significant. This result suggests that, as expected, when there are more restricted hours per day, there is a higher chance of paying the LPRC charge.

4.4. Elasticity analysis

We conducted an elasticity analysis using sample enumeration. We evaluated demand elasticities to price, the number of rationed weekdays and restricted hours per day. To estimate the empirical demand elasticity to price, we used the price change from 2018 to 2019.

Elasticities are shown in Table 6. According to the estimates from the model, demand for the LPRC is elastic to the price. It is interesting to note that the model's value is very similar to the empirical value. The elasticity values indicate a high sensitivity of the

Table 5
Modelling results.

Variables		Coefficients	T-test
Alternative Specific Constants	Car paying the LPRC {1}	0	–
	Private car during permitted hours {2}	0.545	1.11
	Taxi/Uber {3}	1.837	3.31
	BRT/Bus {4}	−0.268	−0.64
Attributes	Travel time (min) {1,3,4}	−0.022	−2.80
	Travel time by car during permitted hours (min) {2}	−0.036	−3.80
	LPRC cost (10^3 COP){1}	−0.035	−9.79
	Fare (10^3 COP) {3,4}	−0.203	−6.25
	Number of restricted days per week {1}	1.195	9.72
	Dummy for Extended restricted time window per day {1}	0.944	6.83
	Dummy for travel Flexibility {2}	0.632	1.90
Interactions	LPRC cost – High Income	0.019	6.03
	Fare –High Income	0.049	1.91
Standard Deviation (Panel Effect)		2.643	22.27
Parameters		13	
Observations		4,050	
Draws		500	
Loglikelihood		−3,545.4	
Rho-squared		0.369	
Adjusted rho-squared		0.359	

Note: The curly brackets refer to which alternative(s) to which the coefficients apply.! UDD = 3,000 COP.

Table 6
Demand elasticities.

Elasticity		Model		Empirical
		Point Elasticity	Arc Elasticity	Arc Elasticity
LPRC cost		−2.51		−2.85
Restriction Days/Week	1 to 2		1.18	
	1 to 2.5		1.41	
Restriction Hours	Peak Hours to All Business Day		1.14	

demand for LPRC to the value to be paid.

When the restriction increases from 1 to 2 days a week, the demand for the LPRC grows 1.18%, and when it increases from 1 to 2.5 days a week (every other day), the demand grows 1.41%, ceteris paribus. In turn, going from a restriction only in peak hours to one in all working hours increases the demand for LPRC by 1.14%.

4.5. Scenario analysis

The model allows for evaluating the sensitivity of demand and revenue to the measure's policy variables and progressively migrating to a daily congestion charge scheme. Fig. 2 shows the demand curve (probabilities) for six modelled scenarios of paying the LPRC charge considering variations in restriction days per week (1 day, 2 days, and every other day) and charged periods (morning and afternoon rush hours and extended hours from 06:00 am to 8:00 pm). These curves were built using the proposed model. Previously, the alternative specific constants were adjusted to reproduce the LPRC market share in 2019.

The behaviour of the demand curves is as theoretically expected since when the LPRC price goes up, the quantity demanded goes down and vice-versa. However, each curve has different elasticity levels according to the price change and the analysed scenario's restriction. Applying the measure one day per week in the morning and afternoon rush hours is the most flexible scenario since the car owner has many more alternatives to use their car, which is why it is less responsive to the price, as presented in Fig. 2. Meanwhile, applying the measure every other day for extended hours is the most restricted scenario. In this case, car owners are more willing to pay the LPRC.

The demand curve of the most flexible scenario, which corresponds to the current situation in Cali, presents an elastic behaviour. Any other more restricted scenarios are even more sensitive to changes in price. This pattern can be different in the long run since car owners can adjust their behaviour by finding substitutes.

Demand elasticities to policy variables affect revenue since price and revenue move opposite or in the same direction depending on whether the demand curve is more or less elastic to price. Fig. 3 presents estimations of the monthly revenue (in millions COP) for different LPRC prices, the number of restricted weekdays and the restricted daily hours. The results indicate that the maximum revenue is gathered when the LPRC price is around COP 100,000 ($34 USD) per month and when the measure is applied every other day for extended hours. However, this price is lower in more flexible scenarios.

Although extending the restriction's time window may significantly impact revenues, evaluating the effect on off-peak mobility would be necessary. The maximum revenue is close to COP 40,000 million (USD 13.33 million) for the most restrictive scenario. This

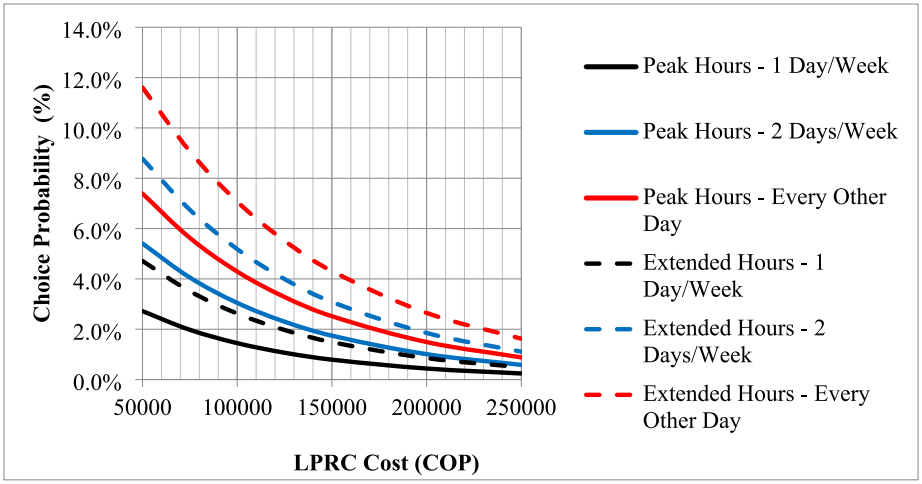

Fig. 2. Probabilities of paying the LPRC price.

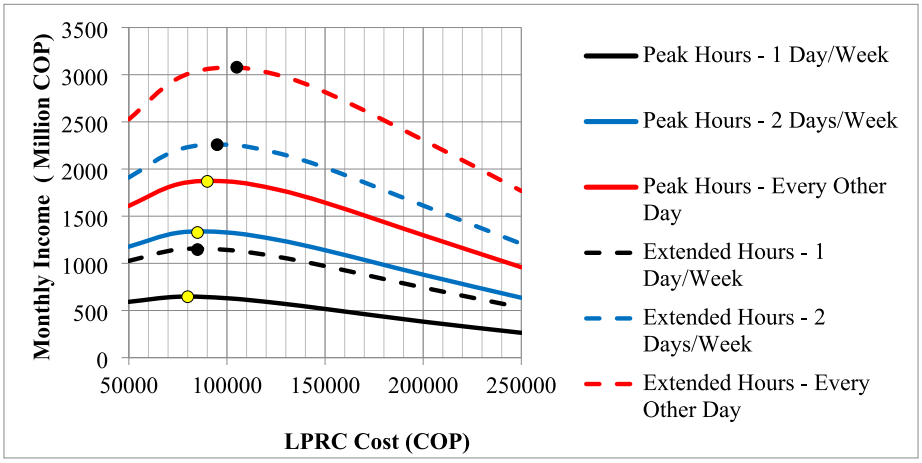

Fig. 3. Monthly income of the measure considering different scenarios.

value corresponds to about 15% of the total current income from the system's tariff. A model limitation is that it does not consider long-term effects. Too high values could stimulate users to acquire a second vehicle (mainly a motorcycle or a used car).

Considering the number of office workdays of the month, the price of the LPRC per day for maximising revenue in the most restricted scenario is around COP 10,000 (3.3 USD). It allows users to pay only on the days when their cars are needed, motivating people to use their cars in a more rationalised way. Although this value is not related to the marginal cost of using the car, it can be a starting point for a conventional congestion charging scheme.

4.6. Implications for policy

There are several lessons learned from the Cali case study in its experience of applying a restriction to cars according to the license plate number and the possibility of paying to avoid it. The measure can be an intermediate step before applying a full congestion charging measure. For this purpose, our research suggests a scheme restricting 40 or 50% of vehicles every weekday, during all working hours and not only in the peak period, as suggested by Basso et al. (2021). On the other hand, the charge must be paid per week or per day, in accordance with car usage.

In the case of Cali, the policy was implemented without a technological platform for control. Investing in a control system is necessary to improve the measure's efficiency. This platform must be flexible enough to be used if it evolves towards a complete congestion charging system.

Not a minor issue is the value to be charged for a daily payment. If the objective is to maximise revenue to subsidise public transport, a value that can be considered a reference floor is 10,000 COP per day. However, more detailed specific studies are required for this purpose. When defining the price, it should be considered that a too-expensive payment may stimulate purchasing a second

vehicle or motorcycle.

Motorcycles are currently excluded from the policy, which has stimulated the growth of this means of transport. The measure will be more efficient if extended to motorcycles. For this purpose, it is necessary to conduct specific analyses on the willingness to pay, which is undoubtedly less than that of cars. However, charging motorcycles requires changes in Colombian law, which currently does not allow it.

Following Cali, Bogotá introduced a similar policy at the beginning of 2020, and called it "Pico y Placa Solidario" (roughly translated as "Solidary Peak and Plate")[2] as a program exception to the license plate restriction program. It was implemented to allow car users to purchase six-monthly circulation permits to circumvent the restriction. At this time, the "Pico y Placa" policy was applied Monday to Friday, in the morning (06:00–08:30) and afternoon (15:00–19:30) peak hours, restricting the circulation of half the vehicle fleet according to the last number of the license plate, on an even–odd basis. If the last plate number was even, the restriction applied to dates with an even day, and, similarly, with odd days. The permit cost around 590 USD, and on average 732 permits were issued monthly.

In September 2021, Bogotá's authorities implemented a second program phase, including daily and monthly passes. In addition, this stage contemplates differential costs to reduce the externalities, as vehicles with higher environmental impact, higher purchase cost or those registered out of town had a cost that could be as much as 80% higher than the base cost. The base cost of the monthly permit was one-fifth the cost of the six-monthly pass, while the daily pass was one-eighth of the monthly pass. During phase 2, between September and December, the policy collected close to 3.8 million USD and around 34,600 permits were issued, of which 80% were daily, 6% were monthly passes and the rest were six-monthly.

In January 2022, the "Pico y Placa" scheme changed, and the restriction was extended to hours between 06:00 and 21:00 in Bogotá. Two months after this decision took place, 103,363 permits were issued, with 81% daily, 9% monthly and 10% six-monthly, meaning a collection close to 9.8 million USD. It is relevant to mention that, similar to Cali, in Bogotá, the resources collected through the permits are invested in a fund aimed to stabilise and subsidise the fare of the city's public transport system and cover the system's financial deficit.

The case of Bogotá has shown that the measure, when applied more closely related to a congestion charge, that is, allowing daily payments, has a good overall acceptance among car users. Also, this shows that daily payment, if available, is vastly preferred for users rather than monthly payments. Finally, allowing daily payments and more restricted hours per day also raised revenue. The preliminary results of the Bogotá experience support the recommendations suggested by the Cali analysis.

4.7. Global perspectives

Although this experience is based on a Latin American medium-sized city, its findings have broader importance. As previously noted, a similar policy has not been studied after its implementation, but the policy itself has been proposed in various contexts. Similarly, many cities have license plate restriction policies that could be easily updated to consider charging to avoid restriction.

Hence, recommendations must consider the city context and the presence or absence of congestion-tackling measures. In this sense, the transition to a complete charging scheme could be implemented for cities with license plate restrictions using optional exemption charges as an intermedia step. In this case, willingness to pay analysis must be taken into account to determine the cost to be paid by users. The payment structure needs to be in balance between not being too expensive that users prefer to purchase another vehicle and not being too cheap to be considered as a fixed cost by users, which will fail to fulfil the congestion reduction goal, as average speed is going to be lower when adding paying vehicles (Montero et al., 2022).

On the other hand, for cities planning to implement license plate restriction policies as a congestion relief policy, we recommend evaluating the use of the charging scheme right from the start. As stated by Cantillo & Ortuzar (2014), license plate restriction alone is a policy with a social loss net effect. The effect of the payment reduces social loss and helps to internalise some of the congestion externality, making its implementation a benefit from just license plate restriction.

However, in the case of cities which are willing to implement a license plate restriction policy purely for environmental reasons, i. e only for old vehicles or during environmental emergency days, we do not recommend the charging scheme, as the priority in these cases is to avoid highly-pollutant vehicles altogether. A total exemption could accelerate the transition towards newer and cleaner vehicles; in this case, an approach such as Low Emission Zones (LEZ) could be evaluated, considering its popularity in Europe. However, generally, LEZ are implemented in high-income cities, where the majority of the population have low emission vehicles that are not affected by the restriction (Fageda et al., 2022; Bernardo et al., 2021). In the case of cities with older vehicle fleets and lower income (like Global South cities), more in-depth analyses are needed.

If the city's goals are environmental and congestion related, a charging scheme without the possibility of payment, or a differential -higher- cost, could be implemented. This hybrid scheme has been theoretically proven to be beneficial by Basso et al. (2021) and Fageda et al. (2020), both in terms of pollution and social acceptability, as opposed to the combination of LEZ and congestion charge/urban tolls, which have been implemented in few European cities (Bernardo et al., 2021).

On a more general note, this case study could help policymakers around the world when planning the implementation of the measure or as a stepping-stone to a proper congestion charge scheme. In this direction, the amount to be charged differs by context and needs to be evaluated according to people's willingness to pay, as a very high cost could eliminate the benefits of the measure by low

[2] More information at https://picoyplacasolidario.movilidadbogota.gov.co/.

demand. In this case, a balance is needed to diminish the incentive of a second-hand vehicle.

Regarding the configuration of the restriction, we strongly recommend allowing daily payments to avoid users taking the exemption fee as a fixed cost over more extended periods. Other analyses regarding the number of hours of the measure (peak hours vs business hours or all day) can be studied upon context, although enforcement should be easier if all day is considered.

In sum, the measure implementation is more politically feasible, rather than a congestion charge from zero. It has the potential to be considered by other cities worldwide, mainly those that have already implemented vehicle rationing.

5. Conclusions and further research directions

After three years of its implementation, this article analyses the license plate-based vehicle restriction policy with an exemption charge in Cali, Colombia. We also conducted a stated preference experiment to evaluate car owner behaviour to relevant variables of the policy.

The measure was well-intentioned when implemented; however, it presents some flaws that need to be considered to avoid being a misguided transport policy. The measure is not a proper congestion charge since it does not depend on car use. It is a fixed cost for an extended time (monthly, quarterly or annually); therefore, the unitary cost perceived for each trip is reduced only if the car is used more. Consequently, it encourages using the car when the LPRC is already paid. In addition, the measure should consider the inclusion of motorcycles to disincentivise growth related to this means of transport.

In general, the LPRC requires rethinking in terms of economic efficiency and viability. Despite having lowered the price of the measure by 36% in 2019, with a consequently significant increase in yearly revenues because more people could pay for it, the LPRC in Cali has contributed only very marginally towards financing the city's public transport system (less than 2% of operational costs).

Regarding user behaviour, the LPRC price was the most decisive factor in user decisions to pay the charge, followed by the number of restricted days and the extension of the restriction to all business hours. When estimating the potential revenue, it could be seen that the more restricted the days and hours were, the higher the LPRC cost those users were willing to pay. Therefore, the expected revenue also increases.

If the goal is to maximise revenue to subsidise public transport, restricting 40 or 50% of vehicles every weekday during all working hours could revenue around COP 40,000 million (USD 13.33 million). This is about 15% of the total current income from the system's tariff. Allowing daily payments must be a priority to incentivise a reduction in the use of private vehicles. 10,000 COP (3.4 USD) per day is a good floor price reference.

Future research in this area could be oriented towards analysing the effect of the LPRC on motorcycle use. The measure's impacts on business vehicles and its long-term influence on households purchasing a second vehicle should also be examined. The case of Bogotá also deserves to be studied, particularly by taking direct information from drivers who have or have not availed themselves of the policy. Finally, analysing the impact intangible variables such as travel reliability and convenience have on the willingness of private vehicle users to pay for driving on restricted days under the LPRC measure could be topics for further investigation.

CRediT authorship contribution statement

Jose J. Soto: Conceptualization, Formal analysis, Writing – original draft, Methodology, Software, Writing – review & editing. **Luis F. Macea:** Conceptualization, Formal analysis, Writing – original draft, Methodology, Data curation, Writing – review & editing. **Victor Cantillo:** Formal analysis, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

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

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