# Is the bicycle a substitute for the automobile? Evidence from Mexico City

Amado Crôtte*, Ricardo Gómez†, Jorge Narezo‡,
and Marc Jacob§

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**Abstract**

With this research, we seek to find out if the bicycle is a substitute for the car in Mexico City (CDMX) and calculate the effect of the said substitution if it exists. For this purpose, we use a difference-in-differences methodology, where we utilize as exogenous variation the discontinuity in gasoline supply in some CDMX gas stations during the second and third weeks of 2019. This effect increased the opportunity cost of traveling by car and allows us to identify if users were migrating from the car to the bicycle. We used data from Ecobici, the first CDMX bicycle-sharing system, to construct the control and treatment groups. We observe that the number of trips per hour in Ecobici increased by 4-7 during the shortage period. In addition, we observe that the effect is not transitory since there is an increase in the number of Ecobici trips per hour after the shortage. During the first month, the use of Ecobici increased by 7 trips per hour, and during the first three and five months, the use of Ecobici increased by 3 trips per hour. For this reason, the bicycle is a substitute for internal combustion vehicles for the areas where the Ecobici program is present in CDMX. Furthermore, the evidence suggests that some users who migrate to bicycles permanently substitute their mode of transportation.

*Inter-American Development Bank. Email: amadoc@iadb.org.

†Banco de México, Dirección General de Investigación Económica. Email: ricardo.gomez@banxico.org.mx. Corresponding author. Any views expressed herein are those of the authors and do not necessarily reflect those of Banco de México or its Board of Governors. All errors are our own.

‡Inter-American Development Bank. Email: jnarezo7@gmail.com.

§Inter-American Development Bank. Email: marcjacobgarcia@gmail.com.

# 1 Introduction

This research explores if the bicycle is a substitute for the automobile in Mexico City (CDMX). We employ a quasi-experimental model of difference-in-differences in which we utilize the gasoline shortage that occurred in the Valley of Mexico from January 9 to 20, 2019, as a source of exogenous variation (Espinosa et al., 2019). We use data from Ecobici, the first bike-sharing system in CDMX, and exploit the spatial variation of the location of Ecobici stations about their distance from gas stations. The variable of interest is the number of bicycle trips per hour that starts at each Ecobici station.

This research is relevant given the importance of the transport sector to boosting the economy and because a paradigm shift is currently taking place at a global level in terms of the prevalence of sustainable, resilient, inclusive, and safe modes of transport. Within the transport sector, the use of bicycles has emerged as a less expensive, more accessible, and sustainable alternative to the use of the car (de Chardon, Caruso, and Thomas (2017), Kroesen (2017), and Wang and Zhou (2017)).

Policymakers often assume the bicycle is a substitute for the car, but this depends on the characteristics of each city. In particular, it may not be accurate for CDMX, a megalopolis in a country with an emerging economy, where public transportation costs are low and commutes are long. The existence of several urban centers makes CDMX a highly complex environment. For this reason, the demand for bicycles could reflect different needs than the demand for cars (Singleton and Clifton, 2014). These reasons motivate our interest in analyzing this area of study.

In this sense, Small et al. (2005) point out that individuals have different preferences for modes of transport that respond to price, journey time, comfort, and safety, among others. Therefore, it is relevant to take the case of CDMX to study if the bicycle is a substitute for the car, a considerably more expensive mode of transport. It is worth mentioning that the possible substitution between these modes of transport is restricted to trips of short duration and distance since users generally opt for automobiles or public transport for long trips Small et al. (2005). In addition, other conditions can encourage the use of bicycles and make substitution more favorable under those conditions. These conditions are flat topography, mild weather, and cycling infrastructure (Schoner et al., 2015).

It is worth mentioning that in CDMX, various public policies have been implemented in favor of sustainable modes of transportation. Some of them are: i) the Metro Collective Transport System (electric trains and light trains), ii) the Metrobús (a Bus Rapid Transit system with confined lane - BRT), iii) the policy to promote cyclist mobility, iv ) the Ecobici public bicycle system, v) the Passenger Transportation Network (buses)-RTP, vi) the Electric Transportation System (trolleybuses), among others (SEMOVI, 2019).

# 2 Background

## 2.1 Literature

There is ample evidence in the literature regarding the effect that the use of the bicycle as a mode of transport has on urban design, transport dynamics, and human health (Mayne et al., 2015). In this sense, the data generated by shared bicycle systems are highly relevant since they provide detailed information on the use of bicycles as a mode of transport. That is, they generate information on the characteristics of the routes and users (Pelechrinis et al. (2017), Campbell and Brakewood (2017), and Wang and Zhou (2017)). Taking into account the nature of the bicycle, the implementation of shared bicycle systems seeks to promote short-distance urban trips or trips that complement different modes of transport (Rojas-Rueda et al., 2011).

Bike-sharing systems (BSSs), or public bicycle systems, have grown in popularity for their social, environmental, and health benefits. Some of these benefits are: i) reduction of urban congestion; ii) less air and noise pollution; iii) greater flexibility in mobility over relatively short distances; iv) promotion of public health as physical activity; v) reduction of spending on transfers; vi) reduction of the severity of traffic incidents; vii) diversification of travel destinations, viii) more efficient use of road space, and ix) promoting multimodality, among others. In some cases, exposure to BSSs encourages the migration from car to bicycle (Fuller et al., 2013). However, the existing literature has not agreed on whether this phenomenon is generally true (Midgley, 2011).

BSSs began as a scheme of bike parking stations.[1] At these stations, a series of bicycles are temporarily made available for users to make trips from one station to another for a fee. Flexible payment models often determine the fee (charge per trip, day, week, month, or year).

These BSSs, generally managed by the local government, provide a cost-effective mobility alternative since they imply low capital investment compared to other means of public transport. For example, the implementation of the first phase of Ecobici in 2010 encompassed a public investment of 6.1 million dollars for 90 cycle stations and 1,200 bicycles (Montes, 2012). On the other hand, building a BRT line has an average cost of 10.2 million dollars per mile, whereas building a subway line has an average cost of 128.2 million dollars per mile (Zhang, 2009).

Frequently, BSSs generate socioeconomic and geographic data that allows us to understand specific mobility patterns. These data include the location and time of origin/destination of the trip, the trip duration, and the age and gender of the user. For this particular case, the data generated by Ecobici allow us to determine if there is an effect on the migration from car use to cycling in CDMX.

Additionally, in this study, we present a brief theoretical outline of the leading positions regarding the effect of BSSs on the substitution of private car usage. On the one hand, Hamilton and Wichman (2018) find, through a matching methodology, a 4% reduction in congestion in the neighborhoods where a BSS was implemented in Washington D.C.

Similarly, García-Palomares et al. (2012) find that after the implementation of a BSS, the proportion of trips made by bicycle grew by i) 1% in Barcelona (between 2005 and 2007), 1.5% in Paris (between 2001 and 2007), and iii) 1.5% in Lyon (between 1995 and 2006). Fuller et al. (2012) use the discontinuity in public transport in London caused by strikes to identify increases in cycling trips. DeMaio (2009) shows that the BSS implemented in Montreal contributed to reducing greenhouse gas emissions by more than 1,300 tons since its inauguration in 2009, an issue associated with the decrease in the use of automobiles. Noland and Ishaque (2006) conclude that 40% of car users in London migrated to the BSS when the latter was implemented in the area where they traveled.

[1] Currently, there are BSSs without parking stations, but in this study, we focus on the case where parking stations are available.

In addition to the effects mentioned above, some studies indicate that increased cycling due to BSSs implementation is associated with significant improvements in health and fitness, such as reduced risks of heart disease and cancer (Cavill et al. (2006), Rojas-Rueda et al. (2011), and Shaheen et al. (2013)). In sum, all of the above evidence indicates that BSSs increase urban cycling in localized areas of cities.

Campbell and Brakewood (2017) observe, through difference-in-differences, that for every 1,000 bicycles in the New York BSS, the number of daily bus trips from Manhattan to Brooklyn decreases by 2.42%. However, they conclude that the increase in demand for the BSS arose from the decrease in demand for public transport (buses).

Wang and Zhou (2017) use difference-in-differences to argue that the effects of implementing BSSs depend on the specific characteristics of each city. In their study regarding cities in the United States, they find that, with a larger population, implementing a BSS causes less traffic congestion. What they argue may be associated with the migration from cars to bicycles. Contrarily, they also find that if a city has a high per capita income, implementing a BSS could cause more traffic congestion. This is associated with the population usually having more cars in the wealthiest cities. They conclude that BSSs directly affect traffic congestion, which may imply modal substitution from bus/automobile to bicycle.

Another literature strand rejects the hypothesis that implementing BSSs has prompted users to substitute the car for the bicycle, for which several reasons are argued. One of them is that many BSSs users utilize bicycles for pleasure and leisure trips instead of commuting to work or school. In this sense, Noland et al. (2011) conducted a statewide study where they found that most people in New Jersey use bicycles for recreational purposes. This could imply that BSSs have promoted trips that would only have happened if the BSS had been implemented (Ahillen et al., 2016). Similarly, Buck et al. (2013) found that in some cases, BSSs users are not regular bicycle users. López-Valpuesta et al. (2016) found that in Seville, the BSS and private bicycles are complementary modes of transport and that the average distance of trips made using the BSS is 700-800 meters less than the distance of trips made on private bicycles.

Additionally, some authors point out that BSSs only reinforce the behavior of users who already prefer bicycles without achieving additional migration to this means of transport. Mitra et al. (2017)

report that even after implementing a cycling infrastructure improvement program in Toronto, young people were less likely to migrate from cars to bicycles.

There is also literature that argues that other policies, instead of BSSs, can be behind the substitution effect. Schoner et al. (2015) show that the implementation of exclusive bicycle lanes is more likely to attract existing bicycle users to certain neighborhoods rather than encourage users to migrate to use bicycles instead of another mode of transport.

Some researchers in the literature have expressed concern about the negative externalities associated with implementing BSSs or infrastructure that promotes cycling mobility. The implementation of these systems commonly entails several changes in the road infrastructure. For example, the installation of cycle stations occupies public space and establishing or expanding bicycle lanes implies a reduction in the lanes for the use of automobiles, which in turn decreases the operational capacity of the road for motorized vehicles, leading to more traffic and lower circulation speed (Burke and Scott, 2016).

In summary, several BSSs users may use bicycles to complement their current means of transport. In addition, implementing cycling infrastructure that accompanies the BSS can lead to adverse consequences for the flow in roads initially focused on the use of automobiles. Since there are conflicting positions about the effect of implementing BSSs on the migration from car to bicycle, it is of great relevance to carry out a study like this one, where said effect is analyzed. Our vision is that an approach of shared roads between car users, public transport, bicycles, and pedestrians can bring environmental, social, security, and mobility benefits, among others. Therefore, a BSS that supports the migration from cars to bikes would benefit the urban environment.

## 2.2 Cycling in CDMX and the Ecobici Program

To provide more context about the use of bicycles in CDMX and the Ecobici program, we additionally studied three surveys: i) Survey of Origin Destination in Households of the Metropolitan Area of the Valley of Mexico 2017 (EOD 17); ii) 2018 Cyclist Mobility Survey of Mexico City (EMC 18); and iii) Ecobici Survey, 2014 and 2017.

The first BSS in CDMX was the Ecobici program, which was implemented in 2010 and is, to date, the most widely used BSS in the city (Instituto de Geografía, UNAM, 2018). In this system, bicycles are anchored in cycle stations, and users can unanchor them only if they have a membership card with an annual cost of approximately 23 dollars. Ecobici has 443 cycle stations and more than 6,800 bicycles throughout three municipalities within Mexico City: Miguel Hidalgo, Benito Juárez, and Cuauhtémoc, which are part of the planning region known as Central City. In this area, the topography is predominantly flat, the weather is mild, and most of the city's low-capacity bicycle parking lots, bicycle paths, and bicycle lanes are concentrated. In addition, it is an area with mixed land uses, which allows the identification of a substitution effect from automobiles to bicycles.

The EOD 17 is constructed by the National Autonomous University of Mexico (UNAM) in conjunction with the National Institute of Statistics and Geography (INEGI, 2017). It seeks to understand better the composition of public transport users in CDMX and the area where Ecobici has a presence. This survey shows that the inhabitants of the Ecobici area belong, in general, to a higher socioeconomic stratum than the average of the inhabitants of the rest of the city (see Table 1). The survey shows that the Ecobici area has a high floating population since it attracts the employed population due to its many businesses and shops. Finally, the survey provides essential data on travel patterns in CDMX; it indicates that most of the population in CDMX who use a bicycle do so regularly during weekdays to commute.

Table 1: Socioeconomic strata (% of population)

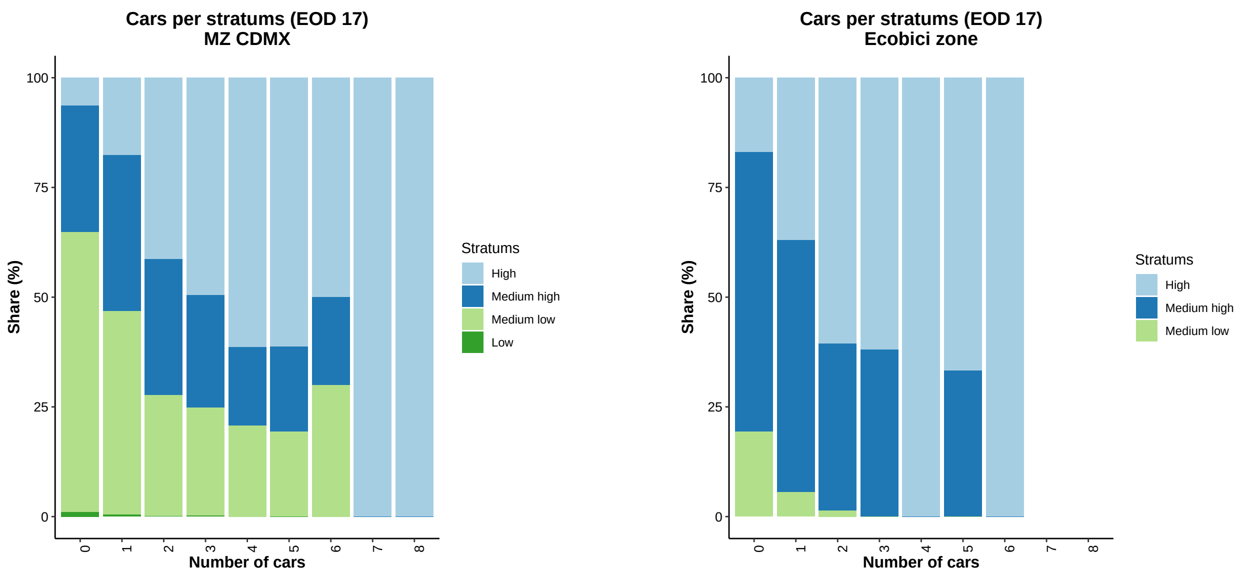
| | | Municipality | | |
|---|---|---|---|---|
| Stratum | Benito Juárez | Cuauhtémoc | Miguel Hidalgo | CDMX |
| High | 49 | 6 | 40 | 13 |
| Medium High | 51 | 70 | 50 | 31 |
| Medium Low | 0 | 24 | 11 | 55 |
| Low | 0 | 0 | 0 | 1 |

Source: EOD 17 (INEGI, 2017).

This survey also shows that individuals who travel by car experience longer commuting times than those who travel by bicycle. This difference in trips, concerning time and distance, can prevent the substitution of trips by car for trips by bicycle since the longer the trip, the less attractive the use of the bicycle becomes. For this reason, if there is substitutability between these modes, it would not be perfect.

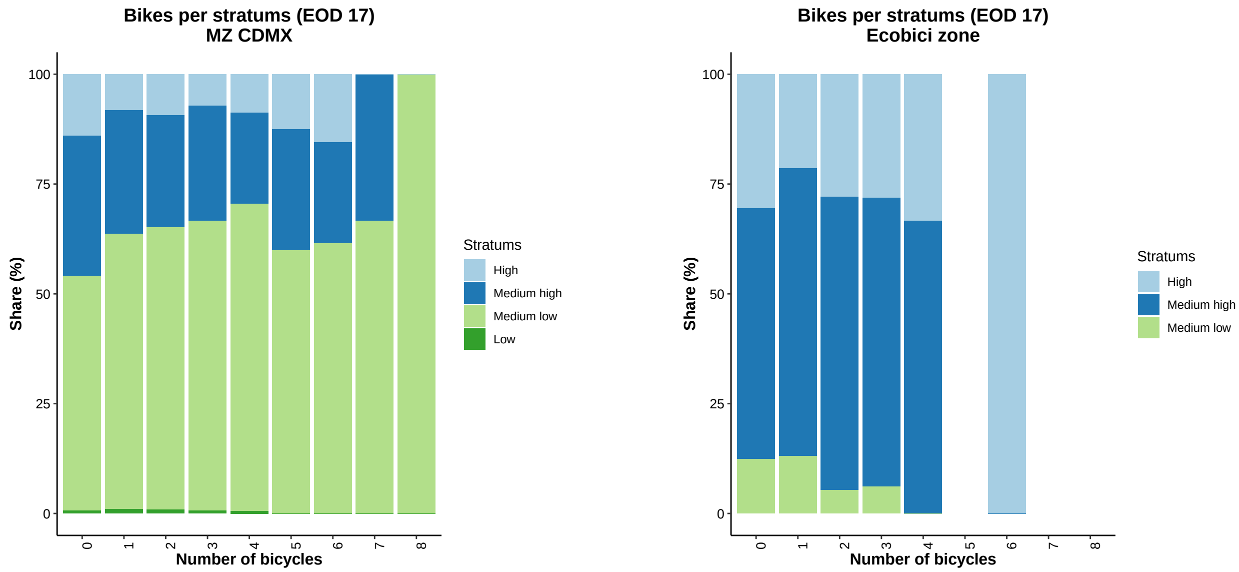
The EOD 17 (INEGI, 2017) survey shows that households in CDMX with more cars usually belong to a higher socioeconomic stratum and income. In general, households with lower income have more bicycles, although this is not the case for the Ecobici area, where the households with the highest income usually own more bicycles (see Figures 1 and 2). Thus, it can be concluded that automobiles are a normal good regarding income for the CDMX population in general. Contrarily, bicycles are a normal good in the Ecobici area but an inferior good for the CDMX general population. As previously stated, the city is made up of several nuclei, which makes it highly heterogeneous. No area is entirely representative since the city is made up of many realities. Therefore, the results of this study should not be extrapolated.

Figure 1: Cars ownership per stratum (%)




Note: Authors' calculations were computed with data from EOD 17 (INEGI, 2017).

Figure 2: Bicycles ownership per stratum (%)




Note: Authors' calculations were computed with data from EOD 17 (INEGI, 2017).

In 2018, the CDMX Environment Secretariat, the UNAM Institute of Geography, and the IDB published the CDMX Bike Plan to continue the cycling policy in CDMX. As a complement, they published the Cyclist Mobility Survey 2018 (EMC-2018). The survey aims to identify the demographic profile of cyclists in CDMX and its metropolitan area, and it does this by surveying 297,890 cyclists. Its design allows representativeness at the municipal level (Romerías, 2018).

In the EMC 18 (Instituto de Geografía, UNAM, 2018), the respondents indicate that the bicycle infrastructure, specifically the bicycle lanes, positively affects their decision to use a bicycle. This response is associated with the fact that 40% of bicycle users have experienced an accident. It also relates to the fact that most accidents are due to the coexistence of bicycles and cars in the same lanes.

In addition, in this survey, most bicycle users indicate that they would only stop using the bicycle as a means of regular transportation if they had an injury or due to a mechanical failure, that is, temporary impediments. Therefore, it can be concluded from this survey that most bicycle users in CDMX have an inelastic demand for this means of transport.

The latest Ecobici Survey (López (2015) and Rivera Flores (2019)) shows that the proportion of Ecobici users who use this mode of transport to commute is higher than the proportion of users who use a bicycle they own to commute. So Ecobici trips are a better measure of regular trips. In addition, Ecobici users are primarily commuters. Therefore, an increase in Ecobicis trips (regular trips) would mean that more people are migrating to the program, allowing us to find a substitution effect if it exists.

Regarding the sociodemographic characteristics of Ecobici users, as in the other two surveys, most are men between 20 and 35 years old. This represents a challenge for replacing the car with a bicycle since most car users are people over 40 (INEGI (2017), Instituto de Geografía, UNAM (2018), and Rivera Flores (2019)). It is also observed in the Ecobici Survey that the average Ecobici users are different from the rest of the regular bicycle users since they have higher education and a higher socioeconomic level (López (2015) and Rivera Flores (2019)).

The modal distribution for the municipalities where the Ecobici program is present is as follows: i) 25% use exclusively a car, ii) 17% combine the subway, the bus, and walking, iii) 15% walk exclusively, iv) 9% combine walking and the subway, v) 9% combine walking and the bus, vi) 4% exclusively use a taxi or similar, vii) 3% exclusively use the bus, viii) 1% exclusively use the bicycle, and ix) the rest is distributed in other combinations (INEGI, 2017). It is worth mentioning that 1.3% of those surveyed use a bicycle, either exclusively or combined with another means. From these data, it is possible to conclude that the bicycle still has low penetration as a mode of transport in the study area. It is also possible to conclude that most people use a car. Therefore, if its use is restricted, it is from the car segment that there could be a greater proportion of the population susceptible to a modal change.

Of the users who use their own bicycles, 84% do so exclusively. The rest of the sample population in the Ecobici area combines the bicycle with other means of transport as follows: walking 7%, walking and subway 3%, and only subway 2%; the remaining percentage is distributed in various categories (INEGI, 2017). Therefore, most private bicycle trips in the area use only one mode of transport. However, the behavior of Ecobici users is different, given that 99% of Ecobici trips are combined with another mode of transport (Rivera Flores, 2019), which is consistent with the fact that only 2% of the cycling population from CDMX uses Ecobici as a regular means of transportation (Instituto de Geografía, UNAM, 2018).

Ecobici's complementary means of travel are i) walking 47%, ii) subway 16%, iii) Bus Rapid Transit -BRT- 9%, iv) bus 7%, v) car 7%, vi) taxi 5%, vii) own bicycle 3%, and viii) others 6% (Rivera Flores, 2019). Therefore, in this case, the argument of complementarity between the car and the bicycle indicated by Singleton and Clifton (2014) cannot be completely ruled out, although there are other means of transport whose complementarity with the bicycle would be considerably greater.

In the Ecobici Survey, users are also asked what alternative mode of transport they would use if they could not use Ecobici. The responses of the respondents were: i) walking 36%, ii) subway 13%, iii) personal bicycle 11%, iv) bus 10%, v) car (10%, vi) taxi or similar 10%, vii) BRT 8%, and viii) others 2% (Rivera Flores, 2019).

In short, the Ecobici and automobile users we analyze in this study are different from those of CDMX in general, so we cannot generalize our findings. On the other hand, we expect a car substitution effect for Ecobici, although we cannot yet rule out the theory that these modes of transport are complements or that there is no effect. To analyze the substitution effect, we will need to analyze the behavior of users under a scenario where the use of the car is limited.

### 2.3 Gasoline shortage in CDMX

During the last decade, the problem of drilling oil pipelines to steal fuel, called *huachicoleo*, has increased in Mexico. Rural residents and organized crime groups are responsible, making it a big problem for the government (Vieira, 2018). From 2006 to 2017, the number of clandestine taps in the country increased from 213 to 10,363 (Aroche, 2018). Because of this problem, on December 27, 2018, the Federal Government of Mexico announced a change in fuel distribution logistics as a strategy to combat hydrocarbon theft. In this change, truck distribution was prioritized instead of pipelines, causing a shortage in several areas of the country during the transition period.

Espinosa et al. (2019) indicate that there was an anticipation of the scarcity due to the announcement. Therefore, the gasoline demand in CDMX increased as of January 8, 2019. This translated into longer queues, waiting times, and even a lack of supply at some gas stations. All these translated into increased traffic congestion. An increase in the gasoline price could be expected, given a sudden increase in demand. However, the gasoline market in Mexico is different from most gasoline markets.

Gasoline is demanded in Mexico as an essential good; therefore, price inelasticity exists. However, since 94% of gasoline is offered through the public company Petróleos Mexicanos (PEMEX), there is a monopsony. Thus, the state regulates and monitors the retail price to protect the consumer, so the supply is perfectly elastic. This means that the price does not vary despite the amount exchanged Espinosa et al. (2019). Had there been a price adjustment due to the government's new fuel distribution strategy, the price increase would have reflected the scarcity and discouraged demand, but in the absence of this mechanism, the demand exceeded the supply, and a significant shortage was generated during the second and third week of January 2019.

Espinosa et al. (2019) indicate that gasoline inventories in CDMX and the State of Mexico decreased by 44% during the first weeks of January 2019, compared to the first weeks of January 2018. In addition, they indicate that the inhabitants of CDMX bought 16% more gasoline per transaction during the stockout.

As already mentioned, the shortage and the long lines to gasoline stations led to significant traffic jams. This phenomenon offers an excellent opportunity to identify if there was a substitution of means of transportation, given the increase in the opportunity cost of using the car during this period. Thus, users with less inelastic demand for car usage could have migrated to cycling (Adler and van Ommeren, 2016).

## 3 Identification strategy

As previously mentioned, we use the gasoline shortage at some CDMX gas stations as a source of exogenous variation to measure the substitution effect. This shock was not expected before December 27, 2019, and it affected gas stations regardless of location, so it was a random shock.

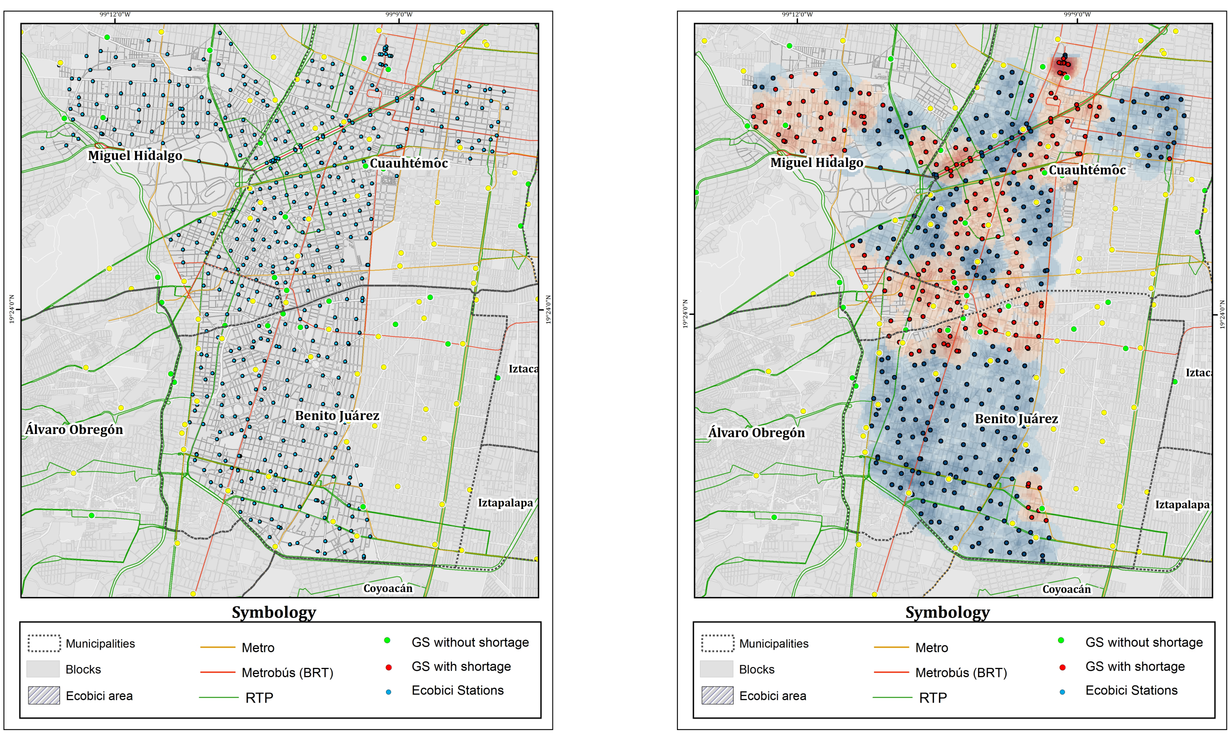
In addition, this study exploits the spatial variation of the location of the bicycle stations about the location of gas stations that experienced shortages. In this way, we use the georeferenced location of the gas stations that experienced shortages, published by the Radio Fórmula news channel (Radio Fórmula, 2019).

Figure 3 shows on the left panel the location of the Ecobici stations, the gas stations with shortages, and the gas stations without shortages. We categorize the treatment groups (Ecobici stations near gas stations with shortages) and control groups (Ecobici stations near gas stations without shortages); we assume that cars go to the nearest gas station. For this reason, the Ecobici stations less than 500 meters from the gas stations with shortages are the ones that received the treatment, and the Ecobici stations less than 500 meters from the gas stations without shortages are the ones that did not receive the treatment. If a cycle station is within both radii, it is assumed to be within the control group.

Since bicycles have relatively lower fixed costs and marginal costs than cars, and users want to optimize their transport costs in terms of time and money (Small et al., 2006), the basic assumption is that individuals living near gas stations without shortage will not change their travel patterns. The individuals who live near gas stations that experience shortage will change their travel patterns because using their cars is difficult for them.

In Figure 3, the panel on the right shows the Ecobici stations that belong to the control group in red and the Ecobici stations that belong to the treatment group in blue. Since the groups are in the same area, they share demographic, economic, geographic, and weather characteristics. Therefore, its location is independent of whether or not there is a shortage, so there should be no significant differences between the two groups. This will be tested with a balance table.

Figure 3: Ecobici and gasoline stations




Note: Authors' calculations were computed with data from Ecobici, Radio Fórmula, STC Metro, Metrobús, and RTP.

The empirical strategy takes up what was done by Bel and Holst (2018) and Gómez Carrera (2019) for evaluating air quality in CDMX after implementing a public transport policy. The utilized estimation is described in Equation 1 where $B_{it}$ is the number of trips per hour $t$ that start at each Ecobici station $i$; $\alpha_i$ is a fixed effects variable for each Ecobici station $i$; $\gamma_t$ is a fixed effects variable for each hour $t$; $E_i$ is a dummy variable that takes the value of one each time an Ecobici station $i$ belongs to the treatment group (it is close to a gas station with shortage) and zero when it belongs to the control group (it is close to a gas station with no shortage); $T$ is the number of periods considered (up to five months before and after the shortage); $\tau$ corresponds to each day when there is a gasoline shortage in the Valley of Mexico (January 9-20, 2019); and $\epsilon_{it}$ is the error term.

Therefore, $\mathbb{1}(s = \tau)$ is a set of dummy variables that take the value of one each day that there is a gasoline shortage and zero in any other case. Similarly, $\mathbb{1}(s > \tau)$ is a set of dummy variables that take the value of one each day after the gasoline shortage and zero in any other case. $C_{it}$ refers to a number $J$ of control variables that it is necessary to include because there are significant differences between the groups in terms of these variables, and the aim is to gain efficiency to isolate the effect of the shortage.

$$log(B_{it}) = \alpha_i + \gamma_t + \sum_{s=-T}^{T} \beta_{s1} E_i \times \mathbb{1}(s = \tau) + \sum_{s=-T}^{T} \beta_{s2} E_i \times \mathbb{1}(s > \tau) + \sum_{j=1}^{J} \lambda_j C_{it}^j + \epsilon_{it} \quad (1)$$

Thus, if the assumption of parallel trends holds, which is necessary for the use of difference-in-differences, it must be the case that the null hypothesis $\beta_{-T} = \beta_{-T+1} = ... = \beta_\tau$ can be rejected. Similarly, if the gasoline shortage significantly affected the number of Ecobici trips, it is possible to reject the hypothesis $\beta_\tau = \beta_{\tau-1}$. With this methodology, we seek to estimate the effect of substituting the means of transportation and discern whether it is a transitory effect, which can be done through an analysis of coefficient plots.

The advantage of the difference-in-differences methodology is that it identifies causal effects. In this sense, it eliminates biases due to reverse causation, or that may exist due to permanent differences between the control and treatment groups, as well as biases that may be caused by temporary trends that impact the sample. Additionally, the fixed effects by time and observation unit (Ecobici stations) allow to reduce the variance and gain efficiency. Also, controls for which there are significant differences between the groups are included to reduce the bias due to omitted variables and, even more, to gain efficiency by reducing the variance of errors.

The difference-in-differences method is one of the most widely used quasi-experimental methods to carry out impact evaluations. This is because it is an intuitive, simple method that substantially reduces bias and implies causality. Other quasi-experimental methods used in the literature are regression discontinuity, instrumental variables, and randomized experiments. In this case, difference-in-differences are chosen to exploit the spatial variation of the cycle stations and the discontinuity caused by the shortage. This allows us to find a counterfactual of the shortage's effect.

# 4 Data

We use data from Ecobici that encompass five months before to five months after the gasoline shortage in January 2019. The data include the number of slots available to anchor bicycles for each Ecobici station, the Ecobici station location, the time each trip starts/ends, the duration of each trip, and the age and gender of each user. The trip variable we use is the sum of trips per hour starting at each Ecobici station. To identify regular Ecobici users, we only use trips made during peak traffic hours, between 8 am-10 am and 6 pm-8 pm on weekdays.

Regarding the control variables, it is observed in the literature that the decision to use a bicycle may be related to the sociodemographic and socioeconomic characteristics of the user (Bere et al., 2008). To obtain information on the socioeconomic conditions of the population where the Ecobici program was implemented, we used data from the Population and Housing Census 2010 (INEGI, 2012). The advantage of this database is that it is disaggregated at the electoral district level, allowing to exploit the spatial variation. We assign the data for each electoral district to the Ecobici station where each trip begins. It is crucial to account for the total population, average schooling, employed population, and the number of households with private vehicles. These are characteristics that could influence the decision of individuals to use Ecobici.

We also account for other transport systems near the BSS stations, as this can influence the decision on how to get around (Klemmer, Brandt, and Jarvis (2018) and Krizek and Johnson (2006)). To control for this factor, we use available data on the infrastructure of the subway (STC

Metro), the BRT system (Metrobús), and the regular bus system (RTP). In particular, we use the georeferenced location of each station of these systems to exploit spatial variation. Thus, we assign to each Ecobici station the number of other public transport modes stations within a 500-meter radius. It is important to mention that there are other public transport modes such as minibusses and combis, but the data on them is difficult to obtain.

The decision to use a bicycle is also affected by climatic variables, particularly precipitation (Hamilton and Wichman, 2018). Due to the lack of availability of current disaggregated public precipitation data, we use the relative humidity variable as an approximation. The data for this variable is obtained from the Meteorology and Solar Radiation Network (REDMET) of the Ministry of the Environment of Mexico City. These are measured through climate monitoring stations that are scattered throughout the city. We assign to each Ecobici station the data from the nearest climate monitoring station.

Finally, since gasoline prices can also influence the decision of individuals to use or not use the car (Espinosa et al., 2019), we use data from the Energy Regulatory Commission on gasoline prices, disaggregated for each gas station. We assign the gasoline prices of the nearest gas station to each Ecobici station.

Table 2 shows the main descriptive statistics of the variables used in this study. Of these, it stands out that the variable of interest, Ecobici trips, has an average of 13.4 trips per hour, a minimum of 1 trip per hour, and a maximum of 177 trips per hour. All of the above consider peak hours of traffic congestion.

**Table 2: Descriptive statistics**

| Variable | Obs | Mean | Std.Dev. | Min | Max |
|---|---|---|---|---|---|
| Ecobici stations | 2,180,857 | 201.7 | 129.3 | 1 | 443 |
| Ecobici trips | 2,180,857 | 13.37 | 15.41 | 1 | 177 |
| Slots | 2,180,857 | 16.80 | 8.327 | 0 | 36 |
| Group dummy | 2,180,857 | 0.531 | 0.499 | 0 | 1 |
| Shortage dummy | 2,180,857 | 0.0428 | 0.203 | 0 | 1 |
| Post-shortage dummy | 2,180,857 | 0.505 | 0.500 | 0 | 1 |
| Age | 2,180,857 | 19.10 | 9.384 | 1 | 74 |
| Gender | 2,180,857 | 1.741 | 0.438 | 1 | 2 |
| Total population | 2,180,857 | 1,229 | 435.9 | 10 | 3,174 |
| Schooling | 2,180,857 | 13.32 | 1.399 | 5.750 | 14.84 |
| Employed population | 2,180,857 | 645.2 | 229.2 | 2 | 1,626 |
| Households with car | 2,180,857 | 283.3 | 130.3 | 1 | 946 |
| Relative humidity | 2,150,569 | 51.30 | 21.98 | 6 | 95 |
| Regular gasoline price | 2,180,857 | 20.39 | 0.220 | 19.31 | 20.95 |
| High octane gasoline price | 2,180,857 | 21.69 | 0.281 | 21 | 22.89 |
| Regular bus stations | 2,180,857 | 6.050 | 5.942 | 0 | 24 |
| BRT stations | 2,180,857 | 2.428 | 4.014 | 0 | 24 |
| Metro stations | 2,180,857 | 0.498 | 0.694 | 0 | 4 |

Note: Authors' calculations were computed with data from Ecobici, INEGI, Radio Fórmula, STC Metro, Metrobús, and RTP.

In addition, we diagnose missing data to find out if we have a balanced dataset; that is, we have an observation for each Ecobici station, for each hour, within our study period. Table 3 shows only the relative humidity variable has missing data (1.4%), so it does not represent a problem to continue and carry out the estimation of Equation 1 with this database.

Another positive feature of the database can be seen in Table 4, where it can be seen that the number of observations per period and per type of group is almost the same. This increases the comparability of results.

Going deeper into the description of the data and as a complement to Table 2, Figure 4 shows that the distribution of Ecobici trips per hour is skewed to the left. Even the distribution indicates that there are generally less than 40 trips per hour per Ecobici cycle, where the maximum is close to 10 trips per hour per Ecobici cycle. Similarly, Figure 5 shows the distribution of most of the possible explanatory variables.

**Table 3: Missing data**

| Variable | Missing | Total | Percent Missing |
|---|---|---|---|
| Ecobici station | 0 | 2,180,8575 | 0 |
| Date | 0 | 2,180,8575 | 0 |
| Slots | 0 | 2,180,8575 | 0 |
| Group dummy | 0 | 2,180,8575 | 0 |
| Gender | 0 | 2,180,8575 | 0 |
| Age | 0 | 2,180,8575 | 0 |
| Ecobici trips | 0 | 2,180,8575 | 0 |
| Date | 0 | 2,180,8575 | 0 |
| Total population | 0 | 2,180,8575 | 0 |
| Schooling | 0 | 2,180,8575 | 0 |
| Employed population | 0 | 2,180,8575 | 0 |
| Households with car | 0 | 2,180,8575 | 0 |
| Regular bus stations | 0 | 2,180,8575 | 0 |
| BRT stations | 0 | 2,180,8575 | 0 |
| Metro stations | 0 | 2,180,8575 | 0 |
| Relative Humidity | 30,288 | 2,180,8575 | 1.390 |
| Regular gasoline price | 0 | 2,180,8575 | 0 |
| High octane gasoline price | 0 | 2,180,8575 | 0 |
| Shortage dummies | 0 | 2,180,8575 | 0 |
| Post-shortage dummies | 0 | 2,180,8575 | 0 |

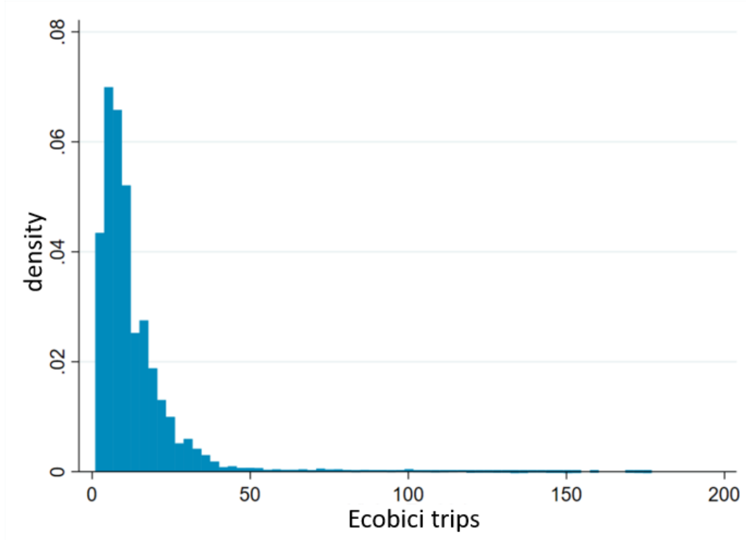
Note: Authors' calculations were computed with data from Ecobici, INEGI, Radio Fórmula, STC Metro, Metrobús, and RTP.

**Table 4: Observations per group and per period**

| | Period regarding shortage | | |
|---|---|---|---|
| | Before | After | Total |
| Group | 0 | 1 | |
| Control (0) | 511,037 | 510,950 | 1,021,987 |
| Treatment (1) | 567,602 | 591,268 | 1,158,870 |
| Total | 1,078,639 | 1,102,218 | 2,180,857 |

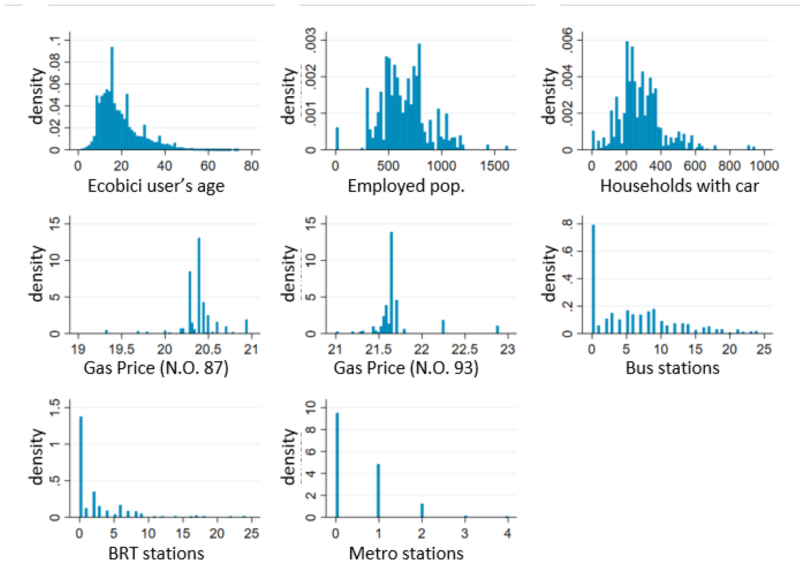
Note: Authors' calculations were computed with data from Ecobici, INEGI, Radio Fórmula, STC Metro, Metrobús, and RTP.

Figure 4: Histogram of the dependent variable




Note: Authors' calculations were computed with data from Ecobici.

Figure 5: Histogram of the explanatory variables




Note: Authors' calculations were computed with data from Ecobici, INEGI, Radio Fórmula, STC Metro, Metrobús, and RTP.

# 5 Results

Before estimating what is indicated in Equation 1, we aim to identify the controls to include in our estimation to gain efficiency and reduce bias. Therefore, we identified these through a balance table that indicates the average significant differences between the control and treatment groups in terms of the variables studied. In this sense, Table 5 shows that there are only significant differences for the variables: i) age of Ecobici users, ii) employed population in the electoral district, iii) households with a private vehicle in the electoral district, iv) price of the regular gasoline, v) price of the high-quality gasoline, vi) nearby regular bus stations, vii) nearby BRT stations, and viii) nearby metro stations. Since these variables can influence the decision on the mode of transport, they are the variables that we include as controls in the estimation to avoid bias in the results.

Table 6 shows the estimation results for Equation 1. Column (1) corresponds to a study period of one month before and after the shortage, column (2) to three months, and column (3) to five months. These estimates show that the shortage caused an increase in Ecobici trips ranging from 4 to 7 trips per hour during the shortage period. The shortage caused significant differences between the control group and the treatment group in terms of the number of trips per hour during the shortage, where there were more trips per hour in the treatment group. Because there are more observations for the five-month estimate, this model is preferred to estimate the effect during the shortage.

On the other hand, the shortage caused an increase of almost 7 Ecobici trips per hour during the first posterior month. Similarly, the shortage caused an increase of 3 trips per hour during the first three and five months.

Figures 6 and 7 suggest parallel trends since there are no significant differences between the groups in the period prior to the shortage. The only exception is the period immediately before the shortage, corresponding to the last two weeks of December and the first week of January. This period corresponds to the holiday period, when Ecobici usage decreases, and coincides with when the government announced the fuel theft prevention strategy. The three graphs show that the increase in differences from the shortage does not seem transitory since the levels of the coefficient differences persist.

**Table 5: Balance table**

| Variable | (1)<br>Control group | (2)<br>Treatment group | (3)<br>Difference |
|---|---|---|---|
| Ecobici commuter age | 18.942 | 19.446 | 0.504 |
| | (0.989) | (1.300) | (0.000)*** |
| Ecobici commuter gender | 1.744 | 1.745 | 0.001 |
| | (0.053) | (0.065) | (0.901) |
| Population in District (Distr.) | 1,280.199 | 1,350.880 | 70.681 |
| | (380.240) | (536.466) | (0.131) |
| Average schooling years(Distr.) | 13.318 | 13.447 | 0.129 |
| | (0.985) | (1.560) | (0.330) |
| Employed population(Distr.) | 648.727 | 701.757 | 53.029 |
| | (211.693) | (269.044) | (0.028)** |
| Households with car or van(Distr.) | 284.347 | 332.240 | 47.893 |
| | (113.730) | (179.470) | (0.002)*** |
| Relative humidity | 51.475 | 50.927 | -0.548 |
| | (5.349) | (3.949) | (0.217) |
| Regular gasoline price | 20.434 | 20.334 | -0.100 |
| | (0.210) | (0.292) | (0.000)*** |
| High octane gasoline price | 21.682 | 21.762 | 0.080 |
| | (0.231) | (0.443) | (0.029)** |
| Regular bus stations | 4.648 | 5.757 | 1.109 |
| | (5.065) | (5.559) | (0.034)** |
| BRT stations | 2.358 | 1.367 | -0.991 |
| | (4.347) | (2.469) | (0.002)*** |
| Metro stations | 0.438 | 0.551 | 0.113 |
| | (0.656) | (0.731) | (0.098)* |
| Slots per Ecobici station | 15.926 | 16.210 | 0.284 |
| | (7.184) | (8.034) | (0.705) |
| Observations | 176 | 267 | 443 |

Standard errors in parentheses for columns (1) y (2)
*** p<0.01, ** p<0.05, * p<0.1 in parentheses for column (3)

Note: Authors' calculations were computed with data from Ecobici, INEGI, Radio Fórmula, STC Metro, Metrobús, and RTP.

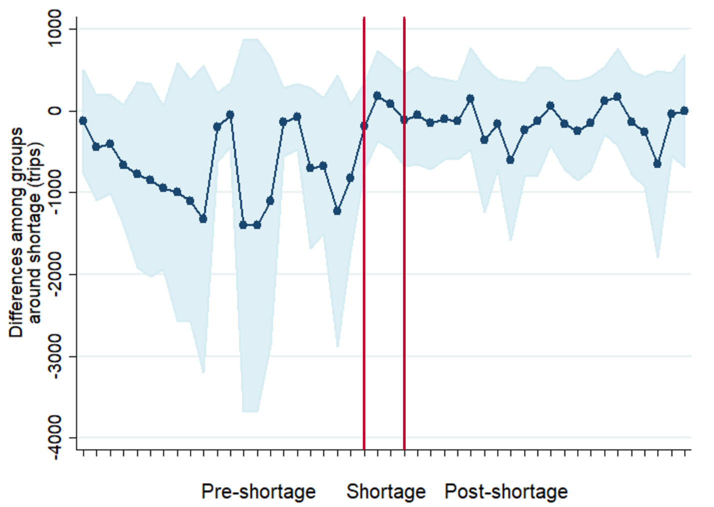
**Table 6: Regressions**

| VARIABLES | (1) | (2) | (3) |
|---|---|---|---|
| | *Dep. variable: Ecobici trips per hour* | | |
| *Shortage days interaction* | 7.486*** | 3.969*** | 3.889*** |
| | (1.557) | (0.877) | (0.805) |
| *Post-shortage days interaction* | 6.610*** | 2.965*** | 2.972*** |
| | (1.489) | (0.589) | (0.437) |
| Study period (months) | 1 | 3 | 5 |
| Observations | 446,296 | 1,328,963 | 2,180,857 |
| R-squared | 0.107 | 0.094 | 0.089 |

All regressions include the following controls: *edad*, *POCUPADA*, *VPH_AUTOM*, *regular*, *premium*, *RTP*, *BRT*, and *metro*.
Cluster errors by Ecobici stations in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

Note: Authors' calculations were computed with data from Ecobici, INEGI, Radio Fórmula, STC Metro, Metrobús, and RTP.

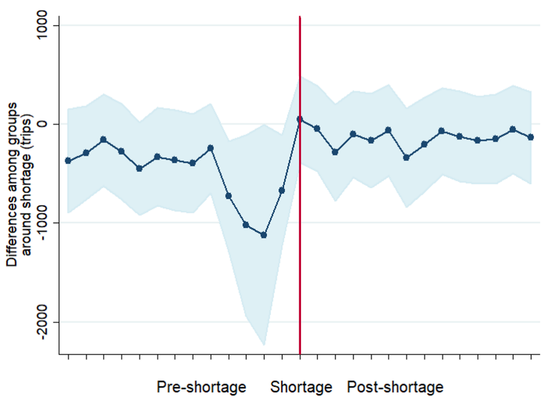
Figure 6: Coefficient plot for 1 month (frequency: days)



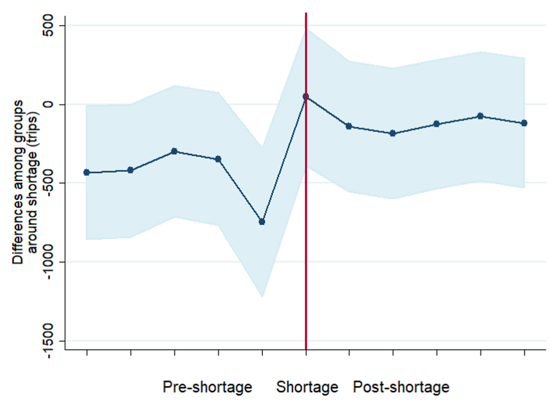

Note: Authors' calculations were computed with data from Ecobici, Radio Fórmula, STC Metro, Metrobús, and RTP.

Figure 7: Coefficient plots

(a) 3 months (frequency: weeks)




(b) 5 months (frequency: months)




Note: Authors' calculations were computed with data from Ecobici, Radio Fórmula, STC Metro, Metrobús, and RTP.

# 6 Conclusions

The shortage caused increased Ecobici trips per hour by a range of 4 to 7, while the shortage was present. Furthermore, the increase in Ecibici trips per hour persisted after the shortage.

These results imply that controlling for the shortage period to measure the subsequent impact is necessary when carrying out impact assessments of this nature. This avoids overestimating the actual effect. If this were not done, the observed effect during the shortage would be attributed to the post-shortage period.

Based on these results and the coefficient plots, we conclude that the shortage did cause a migration from the use of internal combustion vehicles to the use of bicycles. In addition, this change was not transitory since it persisted even five months after the shortage. Therefore, the evidence indicates that once individuals try Ecobici, this means of transport provides them with utility, and they prefer to refrain from returning to internal combustion means of transport. This is consistent with the fact that individuals who prefer cycling have an inelastic demand (Instituto de Geografía, UNAM, 2018).

However, this study fails to identify whether the migration channel to Ecobici comes from private cars or internal combustion public transport since both categories use gasoline for their operation, which is why they were affected by the shortage.

It is worth mentioning that this result cannot be extrapolated to other bicycle users or the rest of CDMX since users in the Ecobici area have different socioeconomic characteristics and mobility patterns than users in the rest of the city.

Another drawback of the observed results is that the average number of Ecobici trips per hour is 13, so the significant increase (if the five-month result is considered) leads to the conclusion that, per hour, there are only 3 more people who do not travel in an internal combustion vehicle and replace it with Ecobici. Therefore, despite being significant, the effect of the increase (23%) is small.

However, it can be concluded that the impossibility of using internal combustion vehicles causes individuals in the Ecobici area to use bicycles. In addition, once individuals try the bicycle, they feel attracted to this means of transport, which is why some do not return to internal combustion means of transport. Three out of the seven individuals who remain in Ecobici one month after the shortage remain in Ecobici five months after the shortage, equivalent to 45%.

These conclusions have important implications for public mobility and transport policy. First, it is essential to replicate the security, inclusion, resilience, and sustainability conditions that exist in the area where the Ecobici program has been implemented for the rest of CDMX, which has also been achieved with the implementation of urban cycling infrastructure, for example, exclusive lanes for bicycles. Second, it is necessary to encourage a first approach to bicycle usage since the evidence from this study indicates that once users start using the bicycle, they prefer not to stop using it. Third, limitations on using internal combustion vehicles encourage bicycle usage, so stricter policies such as a ban on old vehicles or higher taxes for internal combustion vehicles can encourage bicycle usage and entail health benefits.

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