Evaluation of the implementation of Metrobus Line 1 on air quality in Mexico City

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Abstract

The objective of this study is to evaluate the impact generated by the implementation of Metrobús Line 1 on the air quality of Mexico City. This issue becomes relevant as little literature measures the causal effect of bus rapid transit (BRTs) systems on changes in air pollution levels, and since government investments in this means of transport, considered sustainable with the environment, have increased in the last decade.

To this end, pollutant monitoring stations are categorized into control and treatment groups according to their proximity to Metrobús Line 1, the first BRT line in Mexico City. Subsequently, the empirical method of difference-in-differences is used to study the differences in contamination between the groups: i) during the six months of the construction period and ii) during the first two years of operation. The effect during construction is studied since it could cause changes in pollution due to the use of machinery, dust raising, or lane closures and its possible impact on traffic congestion or alternative road usage. Regarding the period of operation, this is being studied due to its possible impact on pollution due to i) the replacement of obsolete public transport vehicles with new ones with polluting emission control technologies, ii) the reduction of lanes for the use of private vehicles, iii) migration of trips in private vehicles for trips in public transport, iv) new traffic measures that accompanied the implementation and their possible impact on vehicular traffic, among others.

Different difference-in-difference estimates are contrasted, concluding that the implementation of Metrobús Line 1 was not an effective environmental policy in the area near the line to

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reduce the levels of nitrogen monoxide (NO) since it increases on average 17%. This is not a favorable result since this contaminant is categorized by the World Health Organization (WHO) as a carcinogenic agent. Despite the increase in NO, it is observed that the emissions of other pollutants related to the transport sector do not increase, including PM_{10} and $PM_{2.5}$, which are the most harmful to health. This suggests that the channel through which the BRT affects air quality is due to its incidence in vehicular congestion, so in order not to increase pollution, road policies are necessary to accompany the reduction of lanes or the establishment of traffic lights that the implementation of the BRT entails.

Finally, for the construction period, significant and consistent reductions were observed between the contrasting models in the levels of nitrogen monoxide (NO), nitrogen dioxide (NO_2), and nitrogen oxides (NO_X), which were in a range of 27%-39%, 9%-12%, and 15%-19%, respectively. Therefore, to obtain unbiased results, it is crucial to consider the construction period and its impact on pollution levels to analyze the effect of this type of project.

1 Background

1.1 Motivation

Air pollution is a negative externality that generates high social and economic costs due to the harmful effects it causes on the health of the inhabitants of urban settlements. It causes respiratory and cardiovascular diseases, among other effects, which translate into high costs for governments. The World Health Organization (WHO) estimates that 3 million people die each year worldwide from this cause, which is equivalent to 1 in 9 deaths. Of the deaths associated with air pollution, 72% are attributed to cardiovascular diseases, such as clogged arteries and heart attacks, and 28% to respiratory system disorders, such as lung cancer and respiratory tract infections (World Health Organization (WHO), 2016). For Mexico, the WHO estimates that every year an average of 25,000 people die from diseases related to air pollution (Sotomayor, 2018). Even the INEGI indicates that air pollution represented in 2017 environmental costs of 619,114 million pesos, equivalent to 2.8% of the Gross Domestic Product (Instituto Nacional de Estadística y Geografía (INEGI), 2018).

This issue is highly relevant for Mexico City (CDMX), the seventh most populous city in the world (United Nations, Department of Economic and Social Affairs, and Population Division, 2016). CDMX is located in a region that enhances the concentration of high contamination levels. It is affected by intense solar radiation and is located 2,240 meters above sea level in a valley surrounded by mountain ranges to the east, west, and south. This minimizes wind flow and the dispersion of pollutants. In addition, CDMX has a high motorization growth rate, this being 3.9% from 2015 to 2016 for private cars (Instituto Nacional de Estadística y Geografía (INEGI), 2016)[1], which is much higher than -0.1% equivalent to the growth rate of the city's population in that period (Consejo Nacional de Población (CONAPO), 2018) and similar to the 4.5% equivalent to the rate of per capita GDP growth of the city's inhabitants in that period (Instituto Nacional de Estadística y Geografía (INEGI), 2017).[2]

In this framework, analyzing the impact on pollution of a public transport system in CDMX is of interest since many polluting emissions come from the transport sector. Bel and Holst (2018) point out that in 1989 vehicles were the leading emitter of carbon monoxide (CO) in CDMX, with 97%. Currently, 86% of CO emissions in CDMX come from this sector (Secretaría del Medio Ambiente del Gobierno de la Ciudad de México, 2018). This sector is the one with the highest consumption of fossil fuels in CDMX (60%) and is related to higher polluting emissions of microparticles ($PM_{2.5}$ and PM_{10}), nitrogen oxides (NO, NO_2 and NO_X), and carbon dioxide (CO_2) (Secretaría del Medio Ambiente del Gobierno de la Ciudad de México, 2018). In this sense, the proportion of polluting emissions in CDMX that come from the transportation sector is equivalent to i) 86% for nitrogen oxides (NO, NO_2 and NO_X), ii) 53% for PM_{10}, iii) 56% for $PM_{2.5}$ and iv) 74% for CO_2. Consequently, the Government of Mexico City has taken various actions whose objectives include the reduction of pollution generated by this sector. Some examples are i) the implementation of the Hoy No Circula program;[3] ii) the implementation of metro lines; iii) the implementation of bus rapid transit (BRT) lines; and iv) restrictions on the use of leaded gasoline, among others.

BRT is a high-quality bus-based transit system that circulates on main arteries and significantly reduces travel times. Some of its characteristics to reduce delays are: i) buses with high passenger capacity and several access doors, generally with more than one car and linked by articulations; ii) confined lanes that exclude other vehicles; iii) payment through a prepaid card that expedites the flow of passengers; and iv) an access platform higher than street level, which prevents passengers from getting on or off at any place other than the stations. Studying the impact of the opening

[1]The motorization growth rate is calculated as the growth rate of personal vehicles registered in the city.
[2]Calculated with population data from CONAPO.
[3]program that seeks to reduce vehicle circulation in the Valley of Mexico to limit air pollution.

of BRT lines on pollution levels is relevant since the demand of governments for this means of transport has increased substantially in the last decade. From 1992 to 2002, BRT lines were built in 23 cities worldwide, while from 2002 to date, BRT lines have been implemented in 115 cities around the world (Carrigan et al., 2018).

BRT systems have also emerged as a more demanded alternative to meet mobility needs because they involve less initial investment and maintenance costs than metro lines and work similarly. Building a BRT line has an average cost of USD 10.24 million per mile while creating a subway line costs USD 128.2 million per mile. Therefore, building a BRT line is, on average, 10 times cheaper than building a metro line. This makes investments in BRT attractive despite having almost five times less service capacity than metro lines to transport passengers and entailing a social cost for private vehicles by occupying a confined lane previously used for the circulation of cars (Zhang, 2009).[4]

In addition, BRTs have emerged as an alternative considered sustainable for the environment since they promote the reduction of air pollution. Carrigan et al. (2018) attribute this effect to i) the reduction of private vehicles in circulation, ii) the replacement of old transport by new vehicles with greater capacity and new cleaner technologies, and iii) the optimization of trips and fast buses in circulation, which leads to lower fuel consumption and lower emissions. Another reason BRTs can help reduce pollution is by increasing circulation speed in low-speed avenues. The Secretary of the Environment of Mexico City points out, based on European Environment Agency (2011) and Barth and Boriboonsomsin (2008), that pollutant emissions by vehicles decrease if the speed of vehicle circulation is between 20 and 85 km per hour, avoiding variations in speed (Moreno Chávez, 2016).

On the other hand, Gallego et al. (2013) study different public transport policies and point out that they have been effective in the short term by reducing pollutant emissions after a few months of their implementation.[5] However, they indicate that the adjustment of the dynamic behavior of various factors in the long term (such as the composition of vehicles in circulation, the demand for public transport induced, or the economic activity generated) shows that the effects observed in the short term do not necessarily persist. They conclude that the reduction of pollution observed

[4] Calculated in 1990 dollars.

[5] In particular, they study the program Hoy No Circula in CDMX and a public transport reorganization program in Santiago, Chile.

in the short term can be prolonged if there are complementing policies, such as the disincentive of using private vehicles through taxes or setting speed limits.

The scope of this study considers previous studies, indicating that due to the dynamic behavior of various factors and the scarce information available, it is difficult to determine the long-term effects to conclude if policies of this nature are environmentally friendly in the long run.

The objective of this study is to evaluate the impact generated by the implementation of Metrobús Line 1 on the air quality of CDMX, taking as the study period the two years after the implementation of this policy and taking into account the changes in contamination that could cause the construction period. Line 1, as will be described in the following sections, was the first BRT line built in Mexico City, which considered a distance of 20 km on the longest main avenue in the city and the replacement of microbuses by rapid buses.

1.2 Literature review

As mentioned in the previous section of this study, little empirical literature measures the effects of BRT implementation on air quality. Most existing literature analyzes the impact of opening metro lines or road congestion. The analyses carried out in general use the experimental method of regression discontinuity or the difference-in-differences approach. Some studies that analyze the impact of different transport policies on air quality in various cities worldwide are described below. In addition, a summary of the results of these studies is included in Table 1.

Beaudoin et al. (2015) qualitatively analyze different empirical literature to contrast the short- and long-term effects of investments in public transport and point out a framework to evaluate the benefits. They conclude that these investments can reduce traffic congestion and its costs, consistent with what was indicated by Anderson (2014). They also suggest that investments in public transport are efficient for improving air quality in the short term and point out that the magnitudes of the benefits are specific to the place where the policy is carried out; thus, external validity should not be assumed. They point out that the externalities caused by policies to reduce traffic congestion or to improve air quality should be included in cost-benefit analyses to define transportation policies and select investment projects. Likewise, they consider it necessary for users of private vehicles to internalize the social costs of their trips to discourage their use and increase the effects caused by public transport in reducing traffic congestion and pollution levels.

Regarding biases due to experimental methods, Beaudoin et al. (2015) indicate that the results of the studies should not be extrapolated to the future since the substitution of modes of transport may be a function of transport policies and the characteristics of the modes of transport offered in each period. Finally, they conclude that reducing congestion and pollution in the short term can be prolonged to the long term if accompanying policies are carried out that promote changes in travel patterns, such as the use of new technologies or the implementation of regulations.

Gallego et al. (2013) study the program Hoy No Circula in CDMX to test the reduction of polluting emissions of carbon monoxide (CO) in the first month and the first year of its implementation. They use the experimental method of difference-in-differences for their study. They conclude that there is no decrease in pollution levels in the long term, despite observing a 5%-13% reduction in the first month of implementation. They point out that the policy adversely affected pollution levels since it led to purchasing of more private vehicles. The latter caused higher pollution levels one year after implementation (11%); Consistently, Lin et al. (2011) find that these movement restriction policies are effective in changing travel patterns but do not necessarily reduce pollution levels in the long term. In addition, Gallego et al. (2013) conclude that the measure is regressive to income since the social cost of the policy is not absorbed homogeneously among the population because households with higher incomes acquired more vehicles avoiding regulation. Similarly, Pfutze et al. (2018) pointed out that the benefits or costs of transport policies, in this case, the implementation of a BRT in Colombia, are distributed heterogeneously among the population according to their income level. Pfutze et al. (2018) record that when housing prices increased in places close to the implementation of the BRT, households with lower incomes were replaced by higher-income households. Finally, Gallego et al. (2013) infer that for the effects of these policies to persist in the long term, they must have a longer planning horizon. They must also be accompanied by other complementing policies, such as a total ban on driving old vehicles or sporadic bans on driving new cars based on air quality.

Gendron-Carrier et al. (2018) study the effects of implementing metro lines on air quality through an analysis of 171 cities for 18 months before and after the opening of the lines. They use a type of airborne particle called Aerosol Optical Depth (AOD), which behaves similarly to microparticles smaller than 10 microns ($PM10$) and 2.5 microns ($PM2.5$). They use the regression discontinuity method to contrast AOD levels around the implementation period. They include controls for climatic variables and economic activity. They conclude that pollution decreases in the short term, and the effect remains in the long term. They calculate a reduction from 2000 to 2014, equivalent to 4% on average, in a radius of 10 km around the center of the city in question; they point out that the effect of the decrease is more significant the closer the metro line is to the center. They estimate that each metro line opening implies an external health benefit of up to 594 thousand dollars per year. Therefore, the magnitude of the benefit is greater than the investment required for construction, so they consider moderate subsidies for the construction of metro lines appropriate. However, their analysis does not account for the cost of operation and maintenance. They base their calculation on existing estimates of AOD damage to health, taking into account infant and adult mortality rates. They indicate that the channel through which the metro affects pollution remains to be determined. A possible explanation is that users who migrate from car to metro were particularly polluting before migrating, either due to the use of old vehicles or the high frequency of trips they made at peak hours.

The study by Chen and Whalley (2012) is mentioned in several studies as being one of the first to quantify the causal effect of a public transport policy on air quality. They measure the impact of opening the first subway line in Taipei, Taiwan, on air quality. They use the regression discontinuity method to measure the difference in pollution behavior when comparing the year before and after the start of the project. They include controls for cases when gasoline regulations apply on a particular day, climatic variables such as temperature, wind speed, and humidity, and hourly fixed effects. With these controls, they seek to support the key assumption that the only reason for pollution levels to change from the day of commissioning is the implementation of the metro itself. They observe a reduction in carbon monoxide pollution (CO) in a range of 5% to 15% with nitrogen oxides (NO_X) behaving similarly to CO; no significant effect was observed concerning ozone (O_3). In addition, they indicate no evidence of an adjustment in the pattern of car trips in terms of changes in routes and travel times in response to the opening of the metro. They attribute this to the fact that the measurement of pollutants is not a good indicator of travel patterns due to the possible permanence of contaminants in the atmosphere. Finally, they point out that the effects may vary depending on the characteristics of each city and the behavior of its population in response to the policy.

Goel and Gupta (2017) use the regression discontinuity method to analyze the effect of six Delhi metro extensions on air pollution during three years. They argue that a three-year period is better as sporadic changes in Delhi's pollution levels may bias their results when studying a shorter period. They include controls for specific climatic issues by regions of the city. They conclude that the measure led to a reduction in pollution in the short term (9 weeks) when CO (34%) is analyzed, but they do not find significant decreases for NO_2, and they cannot conclude for $PM_{2.5}$ due to lack of data. Similarly, they need more data to conclude for the long term. Although they do not include it as part of their analysis, they point out that the source of electricity generation must be accounted for to analyze the net effect of implementing this type of transport, mainly if the energy is generated through fossil fuels. They infer that an analysis of this nature requires a database with more observations since this was not the case for their study period (2004-2006). Finally, they point out that the decision of governments to invest in metro lines or bus lines should be based on the population density of the city in question.

The research carried out by Wöhrnschimmel et al. (2008) is particularly relevant to this study. The authors analyze which type of public transport emits less benzene (C_4H_6), CO, $PM_{2.5}$, and PM_{10} in Mexico City: microbuses, regular buses (RTP), or BRTs. They conclude that the Metrobús (BRT) is the least polluting type of public transport in Mexico City. An explanation is that the newer Metrobús units use certified technologies to reduce polluting emissions. In addition, they argue that the minibusses and RTPs are given little maintenance, and they make continuous stops by allowing boarding and disembarking almost anywhere, negatively affecting traffic congestion. They compare the pollution levels before and after the implementation of the BRT line (June 2005), which was accompanied by the substitution of microbuses (262) and RTPs (90) along the 20 km where the BRT circulated.[6] Their data were obtained by technicians with measuring devices that transited in minibusses and RTPs from May to August 2004 (before the line's opening) and from August to October 2005 in BRTs on the same route. They use the empirical method of ordinary least squares, with the pollutant in question as the dependent variable and humidity, wind speed, and temperature as explanatory variables. They include a dummy variable for the mode of transport and another for differences in traffic due to seasonality. Their experimental method does not ensure that they measure causality by not using a counterfactual methodology.

[6] The characteristics that accompanied the implementation of the Metrobús are further discussed in Section 1.3.

They observe that the exposure to pollutants (C_6H_6, CO, and $PM_{2.5}$) was reduced for public transport users between 20% and 70%; they do not observe significant effects for $PM10$. They also argue that the shorter travel times caused by the Metrobús reduced exposure to pollutants. Their general conclusion is that BRTs can reduce public transport users' exposure to harmful pollutants associated with adverse health impacts.

Other studies that analyze the effect of transportation policies on pollution are mentioned below:

- Nugroho et al. (2011) analyze the implementation of the first BRT in Jakarta, Indonesia, and its impact on pollution. They use structural equation models and artificial neural networks and report a reduction of PM_{10} and O_3 that they attribute to the migration from private vehicles to BRT. This method does not consider a counterfactual, so causality is not necessarily measured.

- Turner et al. (2012) indicate, based on figures from the government of Bogotá, that the implementation of a BRT (TransMilenio) in Bogotá, Colombia resulted in a reduction of sulfur dioxide (SO_2) by 43%, NO_X by 18%, and PM_{10} by 12%. However, the methodology for obtaining these figures is not indicated.

- Hodgson et al. (2013) compare pollutant emissions from the light rail system and BRTs in the United Kingdom. With a non-econometric methodology, they find that the BRT produces fewer emissions of PM_{10} but more of NO_X than the light rail (electric).

- Salehi et al. (2016) analyze the effect on pollution of the opening of a BRT in Tehran, Iran. They find a reduction of 5.8% for PM_{10}, 6.7% for CO, 6.7% for NO_X, and 12.5% for SO_2. However, they do not use a counterfactual methodology.

- Beaudoin and Lin Lawell (2017) analyze the effects of increasing the supply of public transportation on air quality in 96 cities in the United States. They point out that this causal effect was not observed in large urban areas for the study period 1991-2011. They conclude that the improvements in air quality cannot be attributed to the increased supply of public transport. They use a methodology of instrumental variables of the public transport offered to reach this conclusion. The instrumental variables are i) the registration of Democratic voters by city, since these tend more to support investments in public transport, and ii) the level of federal resources granted for transportation policies in the region.

The most relevant literature for this study is the study by Bel and Holst (2018), in which they question precisely the impact of the implementation of Metrobús Line 1 on air quality in CDMX, for which they use the experimental method of difference-in-differences. Their study compared the contamination levels before and after the program implementation. They relied on the assumption that the level of contamination observed before the implementation would have remained constant if the program was not implemented. Their study is interesting since they use pollutant monitoring stations less than 5 km from the Metrobús line as a treatment group and stations between 5 and 30 km from the Metrobús line as a control group. For their analysis, they use the measurements of emissions of CO, NO_X, PM_{10}, and SO_2. They argue that implementing the line reduces pollutants, making it an effective environmental policy. They observe a decrease of 5% for CO, 6% for NO_X, and 9% for PM_{10}; They do not observe significant effects for SO_2. Their methodology includes control variables for humidity, temperature, wind direction, wind speed, and precipitation. In addition, they include fixed effects for each monitoring station and per day. Their study period is two years before the line's opening and two years after the opening. Lastly, they include a lag of one day in their estimate to avoid autocorrelation.

Despite being very comprehensive, the Bel and Holst (2018) study can yield biased impact estimates. They do not analyze the bias that the construction period of the line can cause on pollution levels. Construction can alter pollution levels as a result of changes in the circulation of vehicles due to the closure of lanes, the increase of airborne dust due to construction work, or the use of heavy machinery. Additionally, Bel and Holst (2018) assume that the effect of the opening of the Metrobús can be solely observed on the opening day. In reality, there may be an adjustment period for the BRT users or the users of private vehicles. A graph of difference-in-difference coefficients can shed light on the existence of the mentioned adjustment period. However, this kind of graph is not included in the Bel and Holst (2018) study. Additionally, with a coefficients plot, it is possible to analyze if there are parallel trends in the levels of contamination between the groups before the implementation of Line 1, so its incorporation is highly relevant.

The purpose of this research is to analyze the impact of the opening of Metrobús Line 1 on air quality and avoid falling into biased results that may be caused by the issues previously described for the Bel and Holst (2018) study.

Table 1: Literary review summary.

Author	**Topic**	**Results**	**Considerations**
Beaudoin et al. (2015)	Contrast of results of studies about the effect of investments in public transport.	Reduction of congestion and pollution in the short term.	Magnitudes of benefits depend on local characteristics. Do not extrapolate results to the future.
Gallego et al. (2013)	Effect of the Hoy No Circula program in CDMX. They use difference-in-differences.	CO decreases (5-13%) in the short term (1 month) but increases (11%) in the long term (1 year).	Higher social cost absorption at a lower income. Accompanying policies are necessary.
Gendron-Carrier et al. (2018)	Effect of metro opening in 171 cities on pollution. They use regression discontinuity.	AOD decreased by 4%, behaving similarly to PM_{10} and $PM_{2.5}$.	Effect is larger at closer proximity. Benefit of USD 594 thousand per year.
Chen and Whalley (2012)	Effect of the opening of a subway in Taiwan on pollution. They use regression discontinuity.	CO decreases from 5 to 15%, it behaves similar to NO_X. They do not observe significant effects on O_3.	Little evidence of adjustment in the pattern of private trips.
Goel and Gupta (2017)	Effect of metro expansions in India on pollution. They use regression discontinuity.	CO decreased 34%. They cannot conclude for $PM_{2.5}$ due to lack of data.	Building a metro or bus line should be based on population density.
Wöhrnschimmel et al. (2008)	Effect of the opening of Metrobús Line 1 in CDMX on pollution. They use ordinary least squares.	C_6H_6, CO, and $PM_{2.5}$ decrease between 20% and 70%. They do not observe significant effects on $PM10$.	Experimental method without counterfactual, so it is not necessarily causality.
Bel and Holst (2018)	Effect of the opening of Metrobús Line 1 in CDMX on pollution. They use difference-in-differences	CO (5%), NO_X (6%), and PM_{10} (9%) decrease. They do not observe significant effects on SO_2.	**They do not control for the construction period. They do not include coefficients plots.**

1.3 Characteristics of Metrobús Line 1

It is essential to identify which are the milestones and important characteristics of the mentioned line (Table 2[7]).

[7]Information obtained from Fichas Técnicas Metrobús (2018), Padilla Zenteno (2015), Mapa Línea 1 Metrobús (2018), Mendoza Arrubarena (2018) y Secretaría del Medio Ambiente del Gobierno del Distrito Federal (2006), Gómez Flores (2005), Secretaría de Transportes y Vialidad del Distrito Federal (2005a), Secretaría de Transportes y

Metrobús Line 1 is located on Avenida Insurgentes, one of the longest roads in CDMX, with approximately 29 km in length. It is, together with the Reforma Corridor, one of the leading commercial corridors in the city. The line construction began on December 4, 2004, and operation started on June 19, 2005. The project included a length of 20 km, 36 stations, and a fleet of 80 buses to serve four delegations/municipalities and a demand of 220,000 passengers per day. (Padilla Zenteno, 2015). On March 13, 2008, the BRT line was extended to the south by 10 km. Nine stations were opened to serve two additional delegations. Another station opened on the extended section on December 19, 2011.

Like the entire Metrobús system, paying the fare (3.50 pesos in 2005[8]) can only be made through a prepaid card, which can be purchased at any station. In its beginnings, Line 1 operated from 5:00 a.m. to 11:00 p.m. Currently, it operates in a range of 4:30-01:00 hrs., depending on the day of the week.

Since 2005, the line has provided connectivity with the city's main roads, such as the Reforma Corridor, Circuito Interior, and Viaducto Río la Piedad. Connectivity with these and other main roads could cause the measurement of higher levels of contamination at nearby monitoring stations. The relocation of minibusses that traveled through these roads after the implementation of the BRT line can also alter the pollution levels. Therefore, it is essential to include fixed effects by each monitoring station and by period to isolate those effects.

Metrobús Line 1 provides connectivity with another five BRT lines, eight metro lines, and the Ferrocarril Suburbano (an urban train). Connectivity in 2005 is shown in Table 2.

The construction of Metrobús Line 1 included reducing the number of lanes in the Insurgentes corridor since the Metrobús system operates with a confined lane, which means that only Metrobús buses can use the lane. In addition, since the stations are located in the center of the avenue, it was necessary to establish new pedestrian crossings and traffic lights. Both examples illustrate possible causes for the increase in traffic congestion and pollution. To counteract these effects, the implementation of Line 1 was accompanied by road policies such as: i) not being able to make a U-turn or park in the low-speed lane on Avenida Insurgentes to expedite traffic; ii) the replacement of 352 minibusses and RTPs for 80 confined lane buses; and iii) the prohibition that another means

Vialidad del Distrito Federal (2005b), Secretaría de Transportes y Vialidad del Distrito Federal (2005c) y proyectada a 2005.

[8]It was increased to 4.50 pesos in March 2008. It currently costs 6 pesos.

Table 2: **Main characteristics of Metrobús Line 1 in 2005.**

Characteristic	2005	Considerations.
Length	20 km.	Until 2008, when it was extended by 10 km.
Start of construction	04-Dec-2004.	Included the closure of the high-speed lane in both directions.
Start of operation	19-June-2005.	Started operation with works pending, such as paving of complete sections.
Start of operation of the expansion	13-Mar-2008.	It included 10 km to the south of the original section with 9 additional stations.
Terminal stations	2.	Indios Verdes and Dr. Gálvez.
Intermediate stations	34.	-
Streets covered	3.	Insurgentes Sur, Insurgentes Centro, and Insurgentes Norte.
Delegations/ Municipalities attended	4.	Gustavo A. Madero, Cuauhtémoc, Benito Juárez, and Álvaro Obregón. Coyoacán and Tlapan were added with the extension of 2008.
User demand	220 thousand pax/day.	600 thousand pax/day in 2016.
Connectivity in 2005	STC-Metro. Reforma.	Lines: 1, 2, 3, 5, 6, 9, and B. -
Fleet	60 articulated buses (160 pax) and 20 RTPs (88 pax).	Confined lane operation. In 2006 the fleet was expanded by 18 articulated buses.
Rate	3.50 pesos (increased to 4.50 pesos in March 2008).	The prepaid card cost 8 pesos in 2005, available at any station. For the first 15 days, the service was free. The first 100,000 cards were free.
Fuel	Diesel (Euro IV).	Diesel usage increase PM_{10} and $PM_{2.5}$ emissions. Euro IV emission control technology helps to decrease emissions.
Universal accessibility	In all stations and units.	-
Working hours	5:00-23:00.	-
Travel time	52 minutes.	Before implementation, travel time was 105 minutes on minibusses.
Substitution of transport	262 minibusses (35 pax) and 90 RTP (88 pax).	No other public transport can circulate through Insurgentes avenue since the signing of the Concession Title on June 24, 2005.
Environmental mitigation	None in the affected area.	More than 5,000 trees were planted in the Ajusco forest, more than 15 km away.

of mass transportation could circulate through the corridor. Likewise, due to the felling of trees for the construction of the line, it was necessary to carry out an environmental mitigation policy that included the planting of more than 5,000 trees; however, it was carried out far from the affected area, in the Ajusco forest, which is more than 15 km from the line. Some secondary characteristics of the line can be seen in Table 3.[9]

Table 3: Secondary characteristics of Metrobús Line 1 in 2005.

% of Line 1 that replaced other means of transportation	100.0%
# of traffic lights per km	2.25
% of stations in the median	100.0%
% of buses with universal accessibility	100.0%
% of stations where you can buy cards	100.0%
% of prohibited U-turns	100.0%
% of routes parallel to bike paths	0.0%
% of the route with 4 lanes	0.0%
% of the route with 3 lanes	91.7%
% of the route with 2 lanes	8.3%
% of the route with Metrobús lanes totally confined	89.1%
# of intersections with main avenues	21
# of connections with the metro	8

1.4 Events with possible impact on air quality

It is essential to mention that around the dates of construction and commissioning of Metrobús Line 1 in CDMX, some other events, environmental policies, or transportation policies were carried out that could have impacted the pollution levels observed in that period. These events are summarized chronologically in Table 4.

[9] Information collected in field research and projected to 2005.

Table 4: **Events with possible incidence on pollution.**

Event	**Start**	**End**
Construction of Section 1 (n-s) 2^{do} Piso Periférico.	oct-2002.	aug-2004.
Construction of Section 2 (n-s) 2^{do} Piso Periférico.	sept-2003.	jan-2005.
Ciclovía inauguration.	dec-2003.	present.
RTP vehicle fleet renewal (103 and 240 units)..	feb-2004.	mar-2006.
Updating of the Hoy No Circula program.	jun-2004.	jun-2014.
Construction of MB Line 1.	**dec-2004.**	**jun-2005.**
Construction of Section 1 (s-n) 2^{do} Piso Periférico.	feb-2005.	nov-2005.
Operation of MB Line 1.	**jun-2005.**	**present.**
Construction of Section 2 (s-n) 2^{do} Piso Periférico.	sept-2005.	may-2006.
Strict limits on CO, NOs, and PMs for new vehicles.	sept-2005.	present.
Construction of Ferrocarril Suburbano.	apr-2006.	jun-2008.
Demonstration in Reforma.	jul-2006.	sept-2006.
Regulation for low sulfur premium gasoline.	oct-2006.	present.
Hard diesel limits for new vehicles.	oct-2006.	present.
Extension of the MB Line 1.	**sept-2007.**	**mar-2008.**

One transportation policy is the construction of the Second Floor of the Anillo Periférico. This high-speed peripheral circuit surrounds Mexico City and is parallel, at a distance of less than 2 km, to the BRT line's route in its first 5 km (south), without considering the expansion. The sections parallel to the Line 1 are San Antonio - Las Flores and Las Flores - San Jerónimo. The former (parallel from stations 4 to 10 in a south-to-north direction) was built from north to south from October 2002 to August 2004. The south-to-north construction of the former encompassed from February 2005 to November 2005. The latter (parallel to Line 1 from stations 1 to 4 in a south-to-north direction) was built from north to south from September 2003 to January 2005 and from south to north from September 2005 to May 2006 (Bolaños Sánchez (2004), Bolaños Sánchez (2005) and WRadio (2006)).

Two other transportation policies were the inauguration of 35 km of a bike path (Ciclovía) in December 2003 (Secretaría del Medio Ambiente del Gobierno del Distrito Federal, 2006); and the renewal of vehicle units of the public transport RTP vehicle fleet: 103 in February 2004 and 240 in March 2006 (Órgano de Difusión del Gobierno del Distrito Federal, 2013).

An additionally identified transportation policy is the construction of the Ferrocarril Suburbano that began on April 26, 2006, and began operating on June 1, 2008 (Iniesta (2006) and Notimex (2018)). This urban train connects with Metrobús Line 1 at Buenavista Station (station number

28 of Line 1 from south to north without extension), rebuilt in 2008. It belonged to an old disused railway system.

One exogenous event that could have caused changes in pollution levels is the 45-day "sit-in" (a demonstration) on Avenida Reforma from July 30, 2006, to September 15, 2006.

Regarding environmental policies, in June 2004, the Hoy No Circula program was updated to make the exemption criteria stricter, thereby restricting circulation to private gasoline vehicles that were more than 10 years old (Secretaría del Medio Ambiente del Gobierno del Distrito Federal, 2006).

On the other hand, the publication on September 7, 2005, of NOM-042-SEMARNAT-2003 was made, in which stricter limits were established for emissions of carbon monoxide (CO), nitrogen oxides (NO, NO_2, NO_X), and microparticles (PM_{10} and $PM_{2.5}$) for new private vehicles at the (Secretaría del Medio Ambiente del Gobierno del Distrito Federal, 2006) plant.

Similarly, on January 30, 2006, the NOM-086-SEMARNAT-SENER-SCFI-2005 was published. It established that for the metropolitan area of Mexico City, as of October 2006, only low-sulfur (SO_2) Premium gasoline would be supplied (with greater anti-knock capacity for the engine). Magna gasoline (the regular and cheapest type of gasoline) would be provided until July 2009 (Secretaría del Medio Ambiente del Gobierno del Distrito Federal, 2006).

Lastly, on October 12, 2006, the NOM-044-SEMARNAT-2006 was published. It established stricter limits for diesel emissions, thus promoting the use of EPA 2004 and Euro IV technologies for new vehicles (Secretaría del Medio Ambiente del Gobierno del Distrito Federal, 2006).[10]

These events can cause heterogeneous effects on pollution behavior over time or location. For example, new regulations that apply to the entire city, such as the Hoy No Circula Program update or the restriction on gasoline that pollutes the most, would affect pollution levels observed before and after regulation. Another example along Line 1 is the construction of the second floor of Periférico, which would affect the south of the line and not the north. Similarly, the demonstration on Reforma would not significantly impact the levels of contamination observed in stations far to

[10] Due to pollution from diesel engines, new pollutant control technologies for heavy-duty buses have emerged since the 1990s. They help to produce less nitrogen oxide emissions (NO, NO_2, and NO_X), sulfur dioxide (SO_2), and mainly microparticles ($PM10$ and $PM2.5$). There are American (EPA) and European (Euro) technologies. Currently, the newest technologies NOM-044-SEMARNAT-2006 instructs to respect are EPA 10 and Euro VI as of January 2019. As of December 2020, the standard will be the adoption of EPA 07 and EURO V (Ramírez, 2018) technologies.

the south and north of the line but in the center. Therefore, the estimated model needs to consider these events and policies.

2 Methodology

2.1 Empirical strategy

Given that the objective of this study is to evaluate the impact caused by the implementation of Metrobús Line 1 on the air quality of CDMX, it is necessary to avoid possible biases to measure causal effects and not correlations. Therefore a simple regression with OLS is ruled out. Likewise, it is essential to isolate the effects that are the consequence of reverse causation or that may be due to possible omitted variables. To illustrate an example of reverse causation, the decision of the CDMX Government to build the Metrobús Line 1 on Avenida Insurgentes could have been due precisely to the high levels of contamination observed in the corridor before its construction. Similarly, for omitted variables, the decision to build a BRT line on a particular street may be due to various preceding factors that could be correlated with pollution levels, such as high economic activity, high population density, or high levels of traffic congestion.

This study considers difference-in-differences to address the problem of reverse causality and omitted variables. A set of pollution monitoring stations is selected as a treatment group and another as a control group. These are categorized according to their proximity to Metrobús Line 1, as explained in the next section. In the absence of the implementation of the line, the evolution of the contamination levels around the stations in the treatment group would follow the same trend observed for the control group stations.

This study considers the initial specification to analyze the evolution of pollution levels around the opening of Metrobús Line 1 (1).

$$
\begin{aligned}
log(C_{it}) = \alpha_i + \gamma_t + & \sum_{s=-T}^{T} \beta_s^1 MB_i \times \mathbb{1}(\tau_c \leq s < \tau_o) \\
& + \sum_{s=-T}^{T} \beta_s^2 MB_i \times \mathbb{1}(\tau_o \leq s) + \epsilon_{it}
\end{aligned}
\tag{1}
$$

Where C_{it} is the contamination level for the monitoring station i at hour t; α_i indicates that fixed effects per monitoring station i are included, these control for the different levels of contamination between stations; and γ_t means that hourly fixed effects t are included, these control for the different levels of pollution in each hour. It is worth mentioning that the fixed effects by period, in this case, hour, and by monitoring station help to control for the heterogeneous effects on pollution that events such as the construction of the Second Floor of the Periférico or the renewal of the RTPs fleet, among others mentioned in Table 4, could entail. It is also important to note that by including these fixed effects, it is no longer necessary to include dummy variables due to the type of events mentioned since these are omitted due to multicollinearity. MB_i is a dummy variable that takes the value of 1 if station i belongs to the treatment group and 0 if station i belongs to the control group; T is the number of periods considered; τ_c is the date on which the construction of the line begins; and τ_o is the date the line started to operate. In this way, $\mathbb{1}(\tau_c \leq s < \tau_o)$ is a set of dummy variables that take the value of 1 if the date s is in the construction period and zero in any other case. Similarly, $\mathbb{1}(\tau_o \leq s)$ is a set of dummy variables that take the value of 1 if the date s is greater than or equal to the date of entry into operation and zero in any other case. Finally, the error term is ϵ_{it}. The main contribution of this model is to include the construction period as a control, unlike what was done in the Bel and Holst (2018) study.

In this specification, the estimators $\hat{\beta}_s$ are the coefficients of interest since they are the difference-in-differences estimators. These are useful in the study to measure the average difference in contamination levels between the treatment and control groups before and after implementation. In this way, if the assumption of parallel trends holds, it is possible to reject the null hypothesis that $\beta_{-T} = \beta_{-T+1} = ... = \beta_{\tau_c}$ and $\beta_{-T} = \beta_{-T+1} = ... = \beta_{\tau_o}$. Similarly, if the construction of Line 1 had an impact on air quality on date τ_c, the hypothesis that $\beta_{\tau_c} = \beta_{\tau_c - 1}$ would have to be rejected. Likewise, if the entry into operation of Line 1 had an impact on air quality on date τ_o, the hypothesis that $\beta_{\tau_o} = \beta_{\tau_c wouldhavetoberejected - 1}$. The latter is possible since the opening date between Metrobús stations does not vary.

It is worth mentioning that this study recognizes that contamination levels can change over time for different monitoring stations that have specific effects due to their location. Some examples are the level of economic activity in the area, the number of vehicles in circulation on nearby roads, or the number of people in the area. This study proposes using the base model in equation (2) to avoid biases caused by these reasons.

$$
\begin{aligned}
log(C_{it}) = \alpha_i + \gamma_t + \sum_{s=-T}^{T} \beta_s^1 MB_i \times \mathbb{1}(\tau_c \leq s < \tau_o) \\
+ \sum_{s=-T}^{T} \beta_s^2 MB_i \times \mathbb{1}(\tau_o \leq s) + \sum_{s=-T}^{T}\sum_{j=1}^{J} \psi_{sj} EE_i^j \times \mathbb{1}(\tau_c \leq s < \tau_o) \\
+ \sum_{s=-T}^{T}\sum_{j=1}^{J} \lambda_{sj} EE_i^j \times \mathbb{1}(\tau_o \leq s) + \epsilon_{it}
\end{aligned}
\tag{2}
$$

Where the element EE_i^j is the specific variable with which an interaction is created between it and a dummy variable in case it is in the construction or operation period to control for the differences between the periods. The specific characteristics considered in the first instance are economic activity, the population in the area, and vehicles in circulation. These are measured at the municipal/delegation level, so each monitoring station is attributed the specific characteristic of its municipality/delegation to control for variations in these characteristics between the monitoring stations. For this second estimate, the coefficients of interest continue to be the $\hat{\beta}_s$, the estimators of differences in differences, so the same assumptions as for the specification (1) must continue to be met.

Additionally, in this study, in Section 3, the results obtained from the base model (2) are contrasted with the model estimated in the Bel and Holst (2018) study, whose estimate is presented in the model (3).

$$
\begin{aligned}
log(C_{it}) = \alpha_i + \gamma_t + \phi_{it} log(C_{it-24}) + \sum_{s=-T}^{T} \beta_s MB_i \times \mathbb{1}(\tau_o \leq s) \\
+ \sum_{s=-T}^{T}\sum_{j=1}^{J} \lambda_{sj} EE_i^j \times \mathbb{1}(\tau_o \leq s) + \epsilon_{it}
\end{aligned}
\tag{3}
$$

This model differs from the base model (2) in that it does not control for the construction period and that it includes a one-day lag in pollution levels. Likewise, in the model (3), instead of considering the economic activity, the population in the area, and the vehicles in circulation as specific characteristics that affect each monitoring station, humidity levels, temperature, wind direction, wind speed, and rainfall are considered. In this case, the coefficient of interest is $\hat{\beta}_s$.

Finally, the results of the model (2) and (3) are contrasted with the results of a combined model, which is presented in the estimation (4).

$$\begin{aligned}
log(C_{it}) = \alpha_i + \gamma_t + \phi_{it} log(C_{it-24}) + \sum_{s=-T}^{T} \beta_s^1 MB_i \times \mathbb{1}(\tau_c \leq s < \tau_o) \\
+ \sum_{s=-T}^{T} \beta_s^2 MB_i \times \mathbb{1}(\tau_o \leq s) + \sum_{s=-T}^{T} \sum_{j=1}^{J} \psi_{sj} EE_i^j \times \mathbb{1}(\tau_c \leq s < \tau_o) \\
+ \sum_{s=-T}^{T} \sum_{j=1}^{J} \lambda_{sj} EE_i^j \times \mathbb{1}(\tau_o \leq s) + \epsilon_{it}
\end{aligned} \tag{4}$$

This model includes the construction period as a control, a lag of the level of contamination from the previous day, and fixed effects per monitoring station and hour. The latter considers economic activity, the population in the area, vehicles in circulation, humidity levels, temperature, wind direction, wind speed, and rain as specific characteristics. Dummy variables are not included for the events that could impact pollution levels, presented in Table 4, since multicollinearity is observed with fixed effects per hour variables. In this model (4), the coefficients of interest are again the $\hat{\beta}_s$.

2.2 Data

It is necessary to have information about pollution levels in CDMX to measure the impact of the implementation of Line 1 on air quality. In this sense, the CDMX Ministry of Environment currently has 42 monitoring stations that, among other functions, measure the concentration levels of different air pollutants in CDMX.

This study employs the Ministry of the Environment's Automatic Atmospheric Monitoring Network (RAMA) database. This database contains hourly data since August 2003 of pollution levels per monitoring station for the following pollutants: carbon monoxide (CO), nitrogen monoxide (NO), nitrogen dioxide (NO_2), nitrogen oxides (NO_X), sulfur dioxide (SO_2), particles smaller than 10 micrometers (PM_{10}), particles smaller than 2.5 micrometers ($PM_{2.5}$), and ozone (O_3).

To measure these pollutants equivalently, the Ministry of the Environment uses different comparable methods according to international standards, which are mainly based on the measurement of the light absorbed or emitted by them or on the permanence of particles in filters (Secretaría del Medio Ambiente del Gobierno de la Ciudad de México, 2018).

These pollutants differ because they are not evenly distributed in space. According to the most recent literature on the matter found in Tietenberg and Lewis (2016), of the pollutants studied, only CO is not distributed uniformly. Hence, its emissions are relatively insensitive to where it is emitted, which could cause volatility.

It is important to note that studying particle emissions (PM_{10} and $PM_{2.5}$) is crucial because they are the pollutants that most negatively affect health. Additionally, these microparticles, together with nitrogen oxides (NO, NO_2, and NO_X), are pollutants whose emissions come largely from the transportation sector. In addition, it is worth mentioning that heavy vehicles, such as Metrobús buses, have a significant contribution to the emissions of PM_{10} and $PM_{2.5}$ (Secretaría del Medio Ambiente del Gobierno de la Ciudad de México, 2018).

2.3 Treatment and control groups

As previously mentioned, Metrobús Line 1 was inaugurated on June 19, 2005, after six and a half months of construction. Although the line currently has 46 stations and is 30 km long, in 2005, it was inaugurated with two terminal stations: Dr. Gálvez and Indios Verdes, with 34 intermediate stations along 20 km.

At the time of commissioning in 2005, 16 monitoring stations measured the abovementioned pollutants. These were in the following municipalities/delegations of the CDMX metropolitan area: Álvaro Obregón, Atizapán, Azcapotzalco, Coacalco, Cuajimalpa, Ecatepec (3), Iztapalapa, Naucalpan, Texcoco, Tlalnepantla (2), Tultitlán, Venustiano Carranza, and Xochimilco. The pollutants each station monitored in 2005 can be seen in Table 5.

This study considers the results of Gendron-Carrier et al. (2018) in that the effect on pollution of implementing a public transport line is greater in the area close to the implementation. Therefore, in this study, treatment stations to measure the polluting effects caused by Metrobús Line 1 are considered to be those located at a distance of less than 5 km from the line. The use of monitoring stations in a range of less than 10 km is ruled out since the effects of the change in contamination

Table 5: Monitoring stations in 2005.

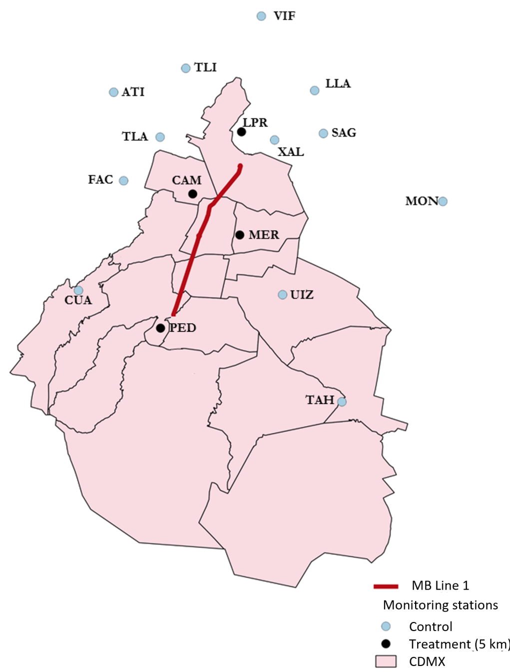
Code	Delegation/municipality	Pollutants	5 km
ATI	Atizapán de Zaragoza	CO, NO, NO_2, NO_X, and SO_2	Control
CAM	Azcapotzalco	$PM_{2.5}$	Treatment
CUA	Cuajimalpa de Morelos	O_3	Control
FAC	Naucalpan de Juárez	CO, NO, NO_2, NO_X, SO_2, PM_{10}, and O_3	Control
LPR	Tlalnepantla de Baz	SO_2	Treatment
LLA	Ecatepec de Morelos	SO_2	Control
MER	Venustiano Carranza	CO, NO, NO_2, NO_X, SO_2, PM_{10}, $PM_{2.5}$, and O_3	Treatment
MON	Texcoco	O_3	Control
PED	Álvaro Obregón	CO, NO, NO_2, NO_X, SO_2, PM_{10}, and O_3	Treatment
SAG	Ecatepec de Morelos	CO, NO, NO_2, NO_X, SO_2, PM_{10}, $PM_{2.5}$, and O_3	Control
TAH	Xochimilco	SO_2, PM_{10}, and O_3	Control
TLA	Tlalnepantla de Baz	CO, NO, NO_2, NO_X, SO_2, PM_{10}, $PM_{2.5}$, and O_3	Control
TLI	Tultitlán	CO, NO, NO_2, NO_X, SO_2, and PM_{10}	Control
UIZ	Iztapalapa	CO, NO, NO_2, NO_X, SO_2, $PM_{2.5}$, and O_3	Control
VIF	Coacalco de Berriozábal	CO, NO, NO_2, NO_X, SO_2, and PM_{10}	Control
XAL	Ecatepec de Morelos	CO, NO, NO_2, NO_X, SO_2, PM_{10}, and O_3	Control

are assumed to be greater the closer the line implementation area is. Additionally, variability in the results could be observed as a consequence of having a greater treatment area with a potentially larger number of exogenous factors affecting contamination levels. In this sense, of the 16 monitoring stations, the four less than 5 km away are located in: Álvaro Obregón, Azcapotzalco, Tlalnepantla, and Venustiano Carranza. The rest are categorized as control stations due to their distance from the line. The location and categorization of the monitoring stations can be seen in Figure 1.[11] [12]

[11] Own preparation with data from the Mexico City Ministry of the Environment.

[12] Since the closest station to the Ajusco forest, Álvaro Obregón, is more than 10 km away from the forest, the effects of the trees planted in the Ajusco due to the environmental mitigation policy are not quantified.

Figure 1: Metrobús Line 1 and monitoring stations (control and treatment 5 km) at the time of the inauguration.



Due to the reduced number of pollutant monitoring stations, a high variance in the results is to be expected. It is also observed that in some cases, there is a considerable distance between the treatment station and the nearest control station, which is undesirable as it does not contribute to reducing biases. This type of analysis can be strengthened with more polluting monitoring stations. However, it is an opportunity area for 2005, a year with few monitoring stations.

2.4 Heterogeneity between groups

Once the control group and the treatment group have been selected, it is necessary to identify whether there are characteristics where the monitoring stations are located that may lead to different levels of contamination between the control group and the treatment group. Based on the model (2), this section analyzes whether the number of vehicles in circulation, economic activity, or population activity in the municipalities/delegations where the monitoring stations are located are significantly different between the groups. The latter tests whether the control and treatment groups have heterogeneous characteristics.

The data sources are i) the State and Municipal Database System (SIMBAD) of the National Institute of Statistics and Geography (INEGI) to obtain the number of motor vehicles registered by municipality in circulation in 2005; ii) the II Population and Housing Count 2005 of INEGI, to obtain the total population by each municipality in 2005; and iii) the National Institute for Federalism and Municipal Development (INAFED), to obtain the municipal Gross Domestic Product (GDP) for 2005 (in pesos at current prices).

This methodology identifies to which municipality/delegation each monitoring station (control and treatment) and the corresponding data belong. Subsequently, the group average of the three heterogeneity-studying variables is calculated. Finally, a balance table is made to identify differences between the groups.

Table 6: Balance table for model (2).

Variable	(1) Control group	(2) Treatment group (5 km)	(3) Difference
Vehicles in 2005 (miles)	107.932	132.915	24.982
	(66.553)	(7.897)	(0.476)
Population in 2005 (thousands)	867.470	565.783	-301.687
	(656.768)	(149.985)	(0.388)
GDP in 2005 (millions)	72,478.484	56,317.328	-16,161.158
	(46,734.813)	(15,627.602)	(0.516)
Obs.	12	4	16

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

Table 6 shows that when the that there are no significant differences between both groups, that could explain the differences in contamination levels between the groups. However, it is necessary to include these variables to control for heterogeneity and avoid a biased estimation.

3 Results

3.1 Main model (2)

The model (2) helps analyze the causal effects of implementing Metrobús Line 1 on pollution levels. Table 7 shows the results. The construction period is from December 4, 2004, to June 18, 2005. Finally, the operation phase encompasses the two years from June 19, 2005, until June 18, 2007.[13]

[13] Because the analyzed periods before construction and after the operation are different, in the model (2) the periods T and -T are different.

The two years after the implementation is considered to avoid biases due to the construction of the extension (in 2007). This period is also considered to avoid having a short study period that may include biases due to adjustment behaviors in the few months following the implementation of the policy, which can be observed in the coefficient plots.[14]

Table 7: Results for model (2).

	(1) log(CO)	(2) log(NO)	(3) log(NO_2)	(4) log(NO_X)	(5) log(SO_2)	(6) log(PM_{10})	(7) log($PM_{2.5}$)	(8) log(O_3)
Construction	0.143	-0.387**	-0.121*	-0.194**	-0.118	-0.0127	0.0918***	0.0373
	(0.146)	(0.162)	(0.0541)	(0.0618)	(0.108)	(0.0533)	(0.00547)	(0.100)
Operation	0.0314	-0.238**	-0.0811	-0.154**	-0.0392	0.0619*	-0.271***	0.0603
	(0.0985)	(0.0932)	(0.0548)	(0.0611)	(0.101)	(0.0303)	(0.00878)	(0.0701)
Obs.	306,535	299,875	319,348	319,381	340,469	231,163	152,359	316,935
R^2	0.630	0.706	0.678	0.738	0.610	0.716	0.715	0.793

Standard errors clustered at MB station level in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 7[15] shows that the contamination is significantly different during construction than before the construction period, for NO, NO_2, NO_X, and $PM_{2.5}$, pollutants coming mainly from the transportation sector. As for NO, NO_2, and NO_X, these are lower due to construction by 39%, 12%, and 19%, respectively. The lower circulation of vehicles may explain this reduction in the area due to the closure of lanes and the use of alternate roads. On the other hand, the construction of the line caused an increase of $PM_{2.5}$, equivalent to 9% on average. The latter may be due to construction work and the dust that it entails or the use of heavy machinery for the construction, explanations that are consistent with what is stated in the studies by Fuller and Green (2004) and Tucker (2000). This indicates that it is important to consider the construction period to analyze the impact on pollution of the implementation of this type of transport policy. Therefore, not using the construction period as a control, as was done in the Bel and Holst (2018) study, may yield biased results.

[14] Two additional models to the one presented in Table 7 were estimated with the estimation (2) and with homogeneous and shorter study periods. The same study period was used before construction and after the operation phase (491 days and 90 days). However, they were discarded because adjustment behaviors and atypical behaviors were observed in the graphs of coefficients in some pollutants, which can lead to biased results if the analysis period is shortened. It is considered that an extended study period contains more information that can help identify atypical behaviors.

[15] The model showing the controls is found in the Appendix Table 10.

The opening of Line 1 caused the levels of NO, NO_X, and $PM_{2.5}$ in the treatment zone to be, on average, 24%, 15%, and 27% lower, respectively. Since these are pollutants related to emissions by the transport sector in general, the result suggests there could have been less traffic congestion due to the implementation of Line 1. However, it is necessary to conduct a more specific analysis to conclude this with certainty. Another possible explanation is that as of June 24, 2005, five days after the start of Line 1, as a complementary measure, minibusses were prohibited from driving along the avenue, which could have reduced the levels of $PM_{2.5}$ due to the circulation of only units with newer and cleaner technologies.

The results observed for $PM_{2.5}$ are favorable because it is the pollutant most harmful to health. It is a pollutant highly related to diesel fuel emissions and heavy vehicles, such as Metrobús buses. Therefore, this is a result that leads one to think that Euro IV technology, for the control of emissions of this pollutant, is effective in reducing pollution, coupled with the policy of relocating the minibusses that used to circulate on Avenida Insurgentes.

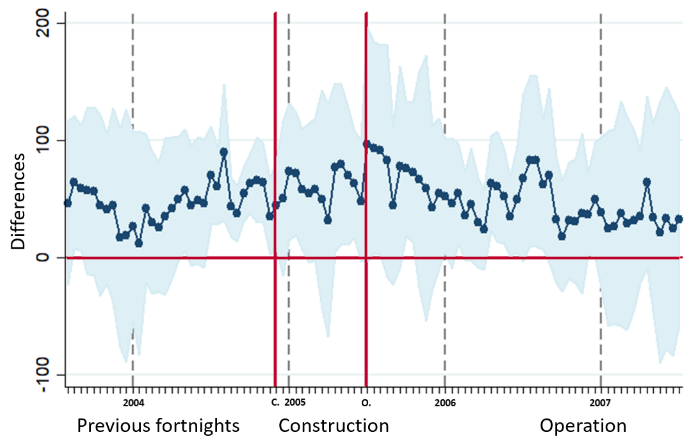
However, Table 7 also shows that the start of operation of the line caused the levels of PM_{10} to be higher by 6% on average for the treatment area. Since these are also particles emitted to a large extent by heavy vehicles and are larger than $PM_{2.5}$, Euro IV technology should have at least the same efficiency in reducing their levels as for $PM_{2.5}$, this is a contradictory and interesting result. These particles also have a great incidence of damage to the respiratory system, although to a lesser extent than $PM_{2.5}$, so the magnitude of the decrease of $PM_{2.5}$ (27%) compared to the magnitude of the increase in PM_{10} (6%) yields positive results to conclude that the implementation of Metrobús Line 1 contributed to reducing the harmful effects of pollution on health.

In addition to the results observed in Table 7 with the model (2), it is necessary to analyze the graphs of coefficients of difference-in-differences of these pollutants to study the dynamics of their average differences and in this way elaborate a deeper analysis. From Figure 2 to Figure 9, you can see the coefficient graphs mentioned, for which biweekly interactions are included in the model (2) to study the dynamics of the differences in contamination between the groups in the different periods.[16]

[16] Due to the atypical behavior observed in the previous fortnightly differences close to the start of construction, the 25th fortnight before construction is used as the reference period. It is considered that this period is not subject to changes in contamination due to the possible adjustment of behaviors in preparation at the start of construction that could have been carried out in the treatment area.

Figure 2 shows the behavior of CO, with which it can be seen that there are no significant divergences in the differences between the groups throughout the periods, despite the fact that a substantial increase is observed for CO in the treatment zone immediately after the operation begins which follows a declining trajectory.

Figure 2: Coefficients plot for CO. Model (2).

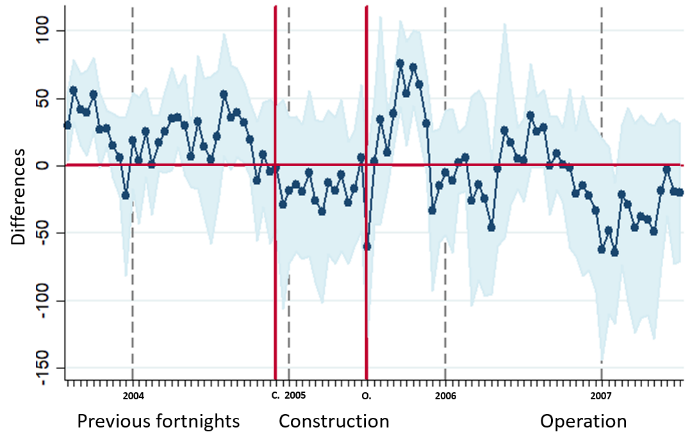


One year of implementation, the average differences stabilized at a lower level than previously observed. However, it cannot be concluded that this is due to the implementation of the line. The observed volatility for CO is consistent with it being a pollutant whose emissions are dispersed so that it is insensitive to emission location (Tietenberg and Lewis, 2016).

Figure 3 shows that the average contamination levels of NO for the treatment group decreased during construction and operation, except for an atypical peak in the first months and one year after the operation began. The atypical increase in the first months of operation may be due to a period of adjustment of the behavior of vehicle users as they learn to coexist with a confined lane and a more significant number of traffic lights or seek alternate routes. In turn, the atypical behavior observed in mid-2006 may be due to the completion of the construction of the Segundo Piso de Periférico.

The results observed in the graph reinforce that the construction period should be taken into account when carrying out an impact analysis of this nature and that there may be an adjustment period after the start of operation. Therefore, evaluating the difference only considering the first day is inappropriate because it can yield biased results. Lastly, the behavior observed in the graph reinforces what was observed in Table 7 to conclude that the line caused the levels of NO to

Figure 3: Coefficients plot for NO. Model (2).



decrease in the treatment area from the start of operation. It is worth mentioning that the variance increases after construction and during operation. This may be due to the heterogeneous behavior of contamination levels due to the specific characteristics of each area.

In the case of NO_2, observed in Figure 4, it can be concluded that the implementation of Line 1 caused a slight decrease in the average levels of contamination in the treatment area during construction. However, the average levels during operation are not very different from the pre-construction period, except for an atypical increase during the first months of operation, which may be due to the adjustment mentioned above period. Figure 4 also shows that the variance increases halfway through construction and approximately one year after operation; this may be due to heterogeneous changes in contamination levels such as those mentioned above.

Figure 4: Coefficients plot for NO_2. Model (2).

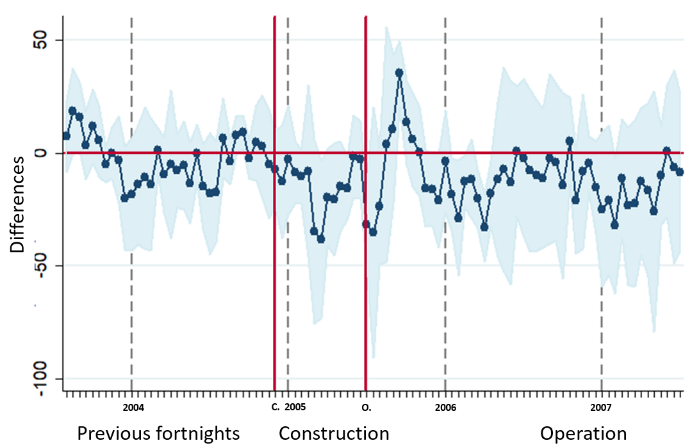
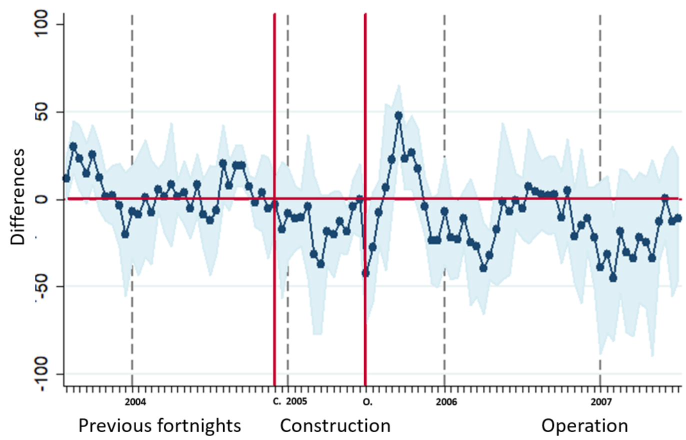


Figure 5 shows that the behavior of NO_X is very similar to that of the differences of NO and NO_2 when measured as the sum of the previous two. The average of the differences decreases during the construction, which indicates that the contamination levels were lower for the treatment group. This behavior is maintained during most of the entire study period of the operation, except for the atypical behavior a few fortnights after commissioning. In this case, the variance begins to increase in great magnitude almost a year and a half after the start-up, so it is not a behavior caused by the implementation of Line 1. As in the case of NO, the increase in mid-2006 may be due to a greater number of vehicles in the region due to the completion of the Second Floor of Periférico.

Figure 5: Coefficients plot for NO$_X$. Model (2).



The behavior of the differences of SO_2, observed in Figure 6, does not allow us to conclude due to its significant volatility and variance. However, it is interesting to note that the behavior of SO_2 stabilized at low levels from the end of 2006, which is consistent with the implementation of the regulation that favors the use of low-sulfur gasoline in October 2006. This is consistent with the fact that SO_2 is a pollutant whose emissions come more substantially from aircraft activity (Secretaría del Medio Ambiente del Gobierno de la Ciudad de México, 2018).

Figure 6: Coefficients plot for SO_2. Model (2).

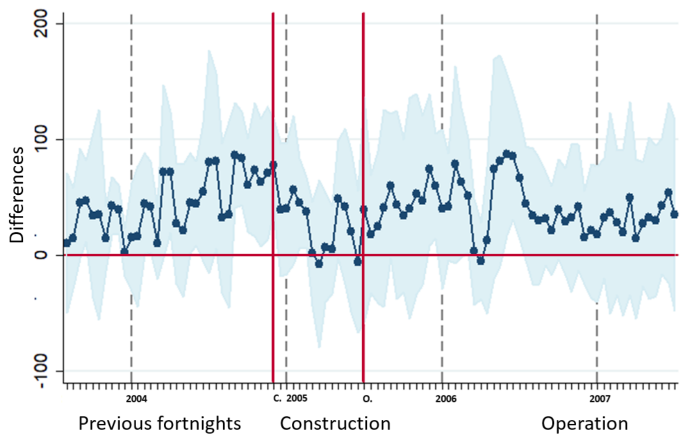
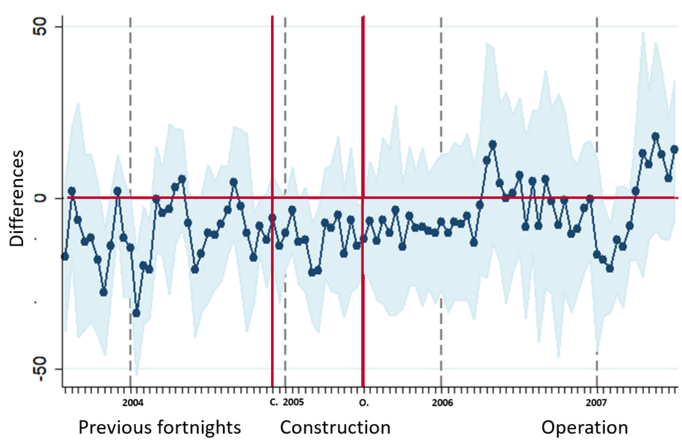


Figure 7 shows the behavior of PM_{10}. In this, atypical peaks of decreases can be seen at the beginning of 2004 and in mid-2004 that are consistent with the substitution of regular bus units (RTP) in February 2004 and with the inauguration of the first section of the Second Floor of the Periférico.

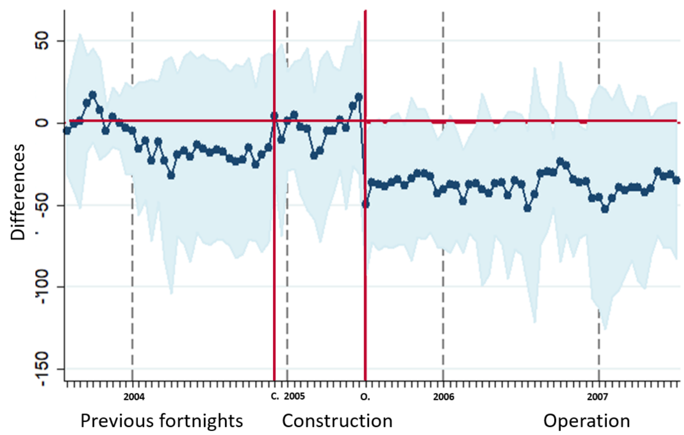
Figure 7: Coefficients plot for PM_{10}. Model (2).



Discarding those atypical behaviors during the previous period, it is observed that for the treatment group, the average levels of PM_{10} remain at pre-construction levels during construction and operation, except for atypical behaviors approximately one year and two years after the start of the operation. It can be seen that these atypical behaviors during operation are not caused by the implementation of Metrobús Line 1 due to its remoteness in time and its significant variance. The atypical behavior after a few months in 2006 may be due to the beginning of the construction of the Suburban Railroad or the completion of the Second Floor of the Periférico. This graph helps to conclude that the increase in PM_{10} observed in Table 7 is not necessarily caused by the implementation of Metrobús Line 1.

The behavior of $PM_{2.5}$, observed in Figure 8, shows that the levels of contamination by $PM_{2.5}$ decreased with certainty since the operation. On the other hand, an increase in the average levels of $PM_{2.5}$ for the treatment group is observed for the construction period. This may be due to the use of machines that emit this pollutant during construction, the lifting of dust due to the construction of the line, or the construction in the zone of the Second Floor of the Peripheral.

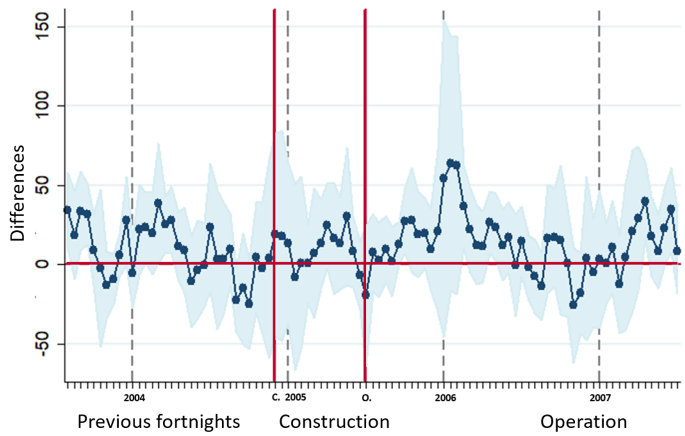
Figure 8: Coefficients plot for PM$_{2.5}$. Model (2).



The decrease in $PM_{2.5}$ during operation, compared to the period before the construction period, reinforces what was observed in Table 7 and confirms that the implementation of Line 1 caused lower levels of contamination by $PM_{2.5}$, the pollutant most harmful to health.

Finally, Figure 9 shows the behavior of O_3. From this, it is clear that the average levels do not change between groups. This volatile behavior is consistent with the fact that O_3 is generated from the chemical reaction between NO_X and volatile organic compounds (VOCs) (Tietenberg and Lewis, 2016), which is mainly associated with population activities, mainly by use of LP gas in homes (Secretaría del Medio Ambiente del Gobierno de la Ciudad de México, 2018). However, it is also observed that the variance increases in some construction and operation periods. This may be due to heterogeneity in the behavior of O_3 within the treatment zone for both the construction and operation stages.

Figure 9: Coefficients plot for O_3. Model (2).



3.2 Contrast with models (3) and (4)

Once the results have been obtained with the model (2), it is necessary to contrast them with the results obtained with the Bel and Holst (2018) model, estimation (3), and with the combined model (4) to analyze if the results are maintained or if there are reported differences depending on the model used. Table 9 shows the results for this contrast.

As a first step, it is necessary to show the balance table that includes the new controls for humidity, temperature, wind direction, wind speed, and precipitation. This is useful to know if there are significant differences between the groups that could explain the differences in contamination levels.

For this, the Meteorology Network (REDMET) database of the Ministry of the Environment of Mexico City is used, which has measurements since 1986 per hour and day of relative humidity, temperature, wind direction, and the speed of the wind. Some REDMET monitoring stations coincide with the RAMA monitoring stations. The RAMA station at a shorter distance was used for those not overlapping. Regarding precipitation, data from the Center for Scientific Research and Higher Education of Ensenada (CICESE) and the National Council of Science and Technology (CONACYT) are used. The data that comprised the study period, which has a daily frequency, are included. The precipitation measurement stations closest to the pollutant monitoring stations are used. The results are presented in Table 8.

Table 8: **Tabla de balance para los modelos (3) y (4).**

	(1)	(2)	(3)
Variable	Control group	Treatment group(5 km)	Difference
Vehicles in 2005 (thousands)	107.932	132.915	24.982
	(66.553)	(7.897)	(0.476)
Population in 2005 (thousands)	867.470	565.783	-301.687
	(656.768)	(149.985)	(0.388)
GDP in 2005 (millions)	72,478.484	56,317.328	-16161.158
	(46,734.813)	(15,627.602)	(0.516)
Relative humidity (%)	56.093	56.499	0.406
	(3.635)	(1.692)	(0.859)
Temperature (^{o}C)	16.068	16.912	0.844
	(0.885)	(0.422)	(0.151)
Wind direction (^{o}Azimut)	179.858	189.910	10.052
	(31.777)	(28.271)	(0.638)
Wind speed (m/s)	1.971	1.456	-0.514
	(0.587)	(0.217)	(0.179)
Precipitation (m/m)	1.975	2.682	0.706
	(0.548)	(0.483)	(0.038)**
Obs.	12	4	16

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

From the balance table, there are significant differences between the groups in terms of precipitation, which is why it is a variable that could significantly impact the differences in pollution levels, so it is essential to include it. As before, all controls are included in the estimates to avoid underestimating results.

It is essential to mention that in the pollutant correlograms, which are not included due to space issues, a high correlation is observed between the contamination of a specific day and the contamination of the previous day, so it is also a control that must be included.

For the Bel and Holst model (3), the controls for temperature, humidity, wind speed, wind direction, precipitation, and a lag of the pollution from the previous day are used. In this case, the construction period is not included as a control. The same study period used by the authors mentioned above is used: two years before the start of the line operation and two years after.

Regarding the combined model (4), in addition to controlling for the construction period, controls are included for economic activity, population, vehicles in circulation, temperature, humidity, wind speed, wind direction, precipitation, and a lag of the contamination the day before. The same study period is used as for the base model (2).

As a summary, the results of the three models are presented in Table 9[17] [18] to contrast the results.

Table 9: Contrast between models (2), (3) y (4).

	(1) log(CO)	(2) log(NO)	(3) log(NO_2)	(4) log(NO_X)	(5) log(SO_2)	(6) log(PM_{10})	(7) log($PM_{2.5}$)	(8) log(O_3)
Base(2.2)								
Construction	0.143	-0.387**	-0.121*	-0.194**	-0.118	-0.0127	0.0918***	0.0373
	(0.146)	(0.162)	(0.0541)	(0.0618)	(0.108)	(0.0533)	(0.00547)	(0.100)
Operation	0.0314	-0.238**	-0.0811	-0.154**	-0.0392	0.0619*	-0.271***	0.0603
	(0.0985)	(0.0932)	(0.0548)	(0.0611)	(0.101)	(0.0303)	(0.00878)	(0.0701)
Obs.	306,535	299,875	319,348	319,381	340,469	231,163	152,359	316,935
Bel&Holst(2.3)								
Operation	-0.120**	-0.0859	-0.113**	-0.107*	-0.00314	-0.0691	0.0240	-0.00223
	(0.0487)	(0.0814)	(0.0409)	(0.0478)	(0.0439)	(0.0426)	(0.0464)	(0.0390)
Obs.	163,810	155,499	167,157	167,198	147,270	145,062	89,026	190,622
Combined(2.4)								
Construction	0.0770	-0.271**	-0.0919**	-0.150***	-0.0582	0.0122	0.149	0.0425
	(0.0620)	(0.0816)	(0.0331)	(0.0376)	(0.0409)	(0.0559)	(0.0849)	(0.0670)
Operation	0.0952	0.166*	-0.0287	0.0169	0.00780	-0.00207	0.0217	0.0824
	(0.0752)	(0.0706)	(0.0474)	(0.0540)	(0.0809)	(0.0303)	(0.0759)	(0.0583)
Obs.	157,830	149,862	161,020	161,065	141,894	140,029	88,057	184,096

Standard errors clustered at the station level in parentheses.

*** p<0.01, ** p<0.05, * p<0.1

In the first instance, it is necessary to mention that the Bel and Holst (2018) study analyzes the behavior of CO, NO_X, SO_2, and PM_{10}. For the comparable case with a treatment group with stations less than 5 km away from the line, they found that: i) CO decreased by 5%, which is less than the 12% observed in Table 9 using the same model; ii) NO_X decreased 6%, which is less than the 11% observed; SO_2 did not present significant differences as in Table 9; and PM_{10} decreased 9%, which contrasts with the fact that no significant differences are observed in Table 9. The differences in the results may lie in the size of the sample since in the Bel and Holst (2018) study their observations are in a range of 1,600 to 6,200, while in this study the range is between 145,000 and 167,000 for those contaminants.

Regarding the comparison of the models carried out in this study, it can be seen that the construction period was consistently significant in explaining the differences in contamination between

[17] The Bel and Holst model showing the controls is found in Appendix Table 11. Similarly, the corresponding coefficient plots are found in the Appendix from Figure 10 to Figure 17.

[18] The combined model showing the controls is found in the Appendix Table 12. Similarly, the corresponding coefficient graphs are found in the Appendix of Figure 18 to Figure 25.

the groups for the models (2) and (4) for the pollutants NO, NO_2, and NO_X. These are pollutants whose emissions are related to the transportation sector in general but not necessarily to heavy vehicles, so it can be inferred that the channel through which pollution decreases during the construction period is related to the possible reduction in traffic circulation in the treatment area. The increase in pollution during the construction period observed in the base model (2) does not hold for $PM_{2.5}$ in the combined model (4), since by including climate controls and of autocorrelation it is observed that the increase observed in the first instance may be due to biases due to the empirical method. These results help to conclude that it is necessary to include the construction period when analyzing the pollution impact of a means of mass transportation that requires the construction of infrastructure in addition to machinery. Otherwise, biased results would be obtained.

Regarding the period of operation, the results are consistent only in terms of the significant decrease of NO_X for the models (2) and (3), equivalent to 19% and 11% respectively; however, the results of the model (3) are discarded as they do not control for the construction period. On the other hand, the decrease in $PM_{2.5}$ and NO_X, as well as the increase in PM_{10} observed for the operation in the base model (2) are no longer significant in the combined model (4) by including climatic controls, as observed in the Appendix Table 14 for the model (4) without lag. The most interesting result of comparing the (2) and (4) models is that the 24% decrease in NO obtained in the base model (2) becomes a significant increase of 17% in the combined model (4) when including climate controls. This leads to the conclusion in the first instance that it is necessary to include control variables for climatic reasons, as is done in the literature, since these variables, which are exogenous at the beginning of construction or operation, can affect the concentration or formation of contaminants and not including them can lead to omitted variable biases. A second conclusion based on the observed increase in NO is that since it is a pollutant related to emissions from the transport sector in general and not only to heavy vehicles, it can be inferred that the channel through which Metrobús Line 1 increases the contamination is related to the increase in traffic congestion in the treatment area. This may be due to the reduction of lanes for the circulation of private vehicles and the implementation of larger pedestrian crossings and traffic lights. Another possible explanation for the increase in NO can be seen in its graph of coefficients in the Appendix Figure 19, where an atypical increase can be seen during the first months of implementation of the

Line, which may be due to the fact that there is an adjustment period while private vehicles learn to live with the Metrobús or begin to use alternative routes.

It is important to note that the sample is reduced by approximately 50% in the (3) and (4) models due to the missing values in the climatic variables databases. However, it is still a large sample size, so the results obtained are not ruled out.

4 Conclusions

4.1 Analysis of results

The purpose of this study is to evaluate the impact of the implementation of Metrobús Line 1 on the air quality of CDMX.

The empirical method of difference-in-differences is used to measure the average changes in contamination between the control group (pollutant monitoring stations more than 5 km from the line) and the treatment group (monitoring stations of contaminants less than 5 km from the line) from the start of construction and operation of the line.

To measure the impact of the line on air quality, the behavior of the following eight pollutants is studied: carbon monoxide (CO), nitrogen monoxide (NO), nitrogen dioxide (NO_2), nitrogen oxides (NO_X), sulfur dioxide (SO_2), particles smaller than 10 micrometers ($PM10$), particles smaller than 2.5 micrometers ($PM2.5$), and ozone (O_3). Of these, the ones most related to emissions by the transport sector are NO, NO_2, NO_X, PM_{10}, and $PM_{2.5}$. The most related to heavy vehicle emissions from diesel fuel are PM_{10} and $PM_{2.5}$, which are the most harmful to health.

The base model (2) controls for economic activity, population, and vehicles in circulation. This model's most important contribution is to control for the construction period since this has not been done before in the literature.

Subsequently, the results obtained with the base model (2) are contrasted against those of the model used in the Bel and Holst (2018) study, which does not control for the construction period, nor economic, population, and vehicular variables, but controls for climatic effects and autocorrelation.

Finally, the results of the models mentioned above are contrasted against those of a combined model (4) between the first two. This includes controls for economic, population, and vehicle activity variables and autocorrelation and climate variables. Likewise, it controls for the construction period.

Based on the estimates made, the first important conclusion is that to carry out an analysis of the change in pollution levels caused by mass transportation policies that include the construction of infrastructure (such as subways, light rails, and BRTs), it is essential to control for the construction period, since otherwise biased results may be obtained. This conclusion is reached because, in the construction period, a significant decrease is observed in the levels of NO, NO_2, and NO_X, which is in a range of 27%-39%, 9%-12%, and 15%-19%, respectively.

Another conclusion from this study is that it is essential to include controls for climate issues when doing an analysis of this nature. This is done in the literature since climatic issues, which do not depend on the start of construction or operation, affect the formation or dispersion of pollutants.

When analyzing the effects on air quality from the implementation of Metrobús Line 1, it is concluded that it was not an effective environmental policy to significantly reduce NO emissions in the area close to its implementation, since this increases 17%. Being a pollutant whose emissions come from the transportation sector in general and not only from heavy vehicles, the result leads to the inference that the channel through which pollution increases is due to the increase in vehicular congestion, which is consistent with the reduction of lanes for circulation of private vehicles and with the implementation of a greater number of pedestrian crossings and traffic lights.

It can be inferred that for NO, the effects of the measures mentioned above that accompanied the implementation of Metrobús Line 1 are more significant than the impact of i) the actions to replace the public transport system with better technologies to control emissions, ii) the prohibition of moving to another means of public transport on the avenue, iii) the prohibition of parking in the low-speed lane or iv) the prohibition of making a left or U-turn (return). However, regarding the rest of the pollutants related to emissions from transportation, the measures mentioned above were effective in not increasing pollution despite reducing lanes and implementing larger pedestrian crossings and traffic lights.

In addition, it is concluded that analyzing the dynamics of the differences between the groups in terms of polluting emissions is essential, given that there may be adjustment periods, atypical peaks, or changes long after implementation.

4.2 Discussion

The results of this study are not consistent with the findings of Beaudoin et al. (2015), Gendron-Carrier et al. (2018), Chen and Whalley (2012), Goel and Gupta (2017), and Bel and Holst (2018) since in this case investments in public transport do not contribute to improve air quality and reduce damage to health. Therefore, if the environmental effect were the decisive factor in determining investments, complementary policies should be considered that control for possible increases in the pollution that the policy may cause.

The increase in NO due to the implementation of Metrobús Line 1 may be due to various factors, such as the increase in traffic congestion in the treatment area or certain types of transport that previously circulated through Insurgentes have been relocated within the same area treatment, among others. The scope of this study does not include identifying the mechanism by which these effects are carried out, so it is recommended to analyze in more detail the effects of the implementation of BRTs and the channels through which changes in air quality are promoted.

As stated by Beaudoin et al. (2015), the results of this study should not be extrapolated into the future since the effects caused by Metrobús Line 1 may be mixed with those of the implementation of other transport or environmental policies. In particular, this study is careful not to include the effects of the construction of the expansion of Metrobús Line 1 (in the second half of 2007) to avoid biased results.

On the other hand, it is recommended to replicate the methodology of this study to analyze the effect of this type of transport policy implementation on the levels of greenhouse effect pollutants (CO_2, CH_4, N_2O, HFC, and black carbon). This is to determine if its implementation effectively reduces the causes of global warming. This issue is of great relevance since, in the Paris Agreement of 2015, the signatory countries committed to take actions to keep the increase in temperature in this century at levels below 2^oC. Mexico, in particular, pledged to reduce its CO_2 emissions by 22% and black carbon by 51% from 2013 to 2030 (Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT), 2015).

In terms of public policy implications, the study helps infer that complementary measures to counteract the reduction in lanes for the circulation of private vehicles or the implementation of traffic lights and pedestrian crossings, such as the prohibition of circulating to other means of public transport in the avenue or the ban to park in the low-speed lane or to return or turn left on the road, are effective in not increasing the emissions of different pollutants related to the transportation sector, except NO. Given that it is inferred that the channel through which the increase in NO occurs is due to the increase in vehicle congestion, which is consistent with the fact that 83% of polluting emissions attributed to the transportation sector comes from private vehicles and only 8% comes from public transport (Secretaría del Medio Ambiente del Gobierno de la Ciudad de México (2018)), it is necessary to carry out transport or environmental policies whose scale is greater when considering the effect it may have on users of private vehicles to reduce polluting emissions.

In this sense, and in line with what was indicated by Beaudoin et al. (2015), it is necessary to promote greater use of public transport and less use of private vehicles to reduce pollution levels, since in this way more people are mobilized with less use of fuel, and therefore emissions are reduced. This can be achieved with policies and regulations encouraging private vehicle users to internalize their marginal social costs. Some examples are: i) high taxes on the ownership of private vehicles used for the development and maintenance of transportation infrastructure; ii) high taxes on gasoline that are higher the more polluting the gasoline in question; iii) taxes to enter congested roads in peak hours by private vehicle; iv) Hoy No Circula program applied to the individual (through his driver's license) and not to the vehicle; v) taxes for private vehicles that circulate with a person on board during peak hours, among others.

Finally, electromobility, understood as the use of electric vehicles, whether private or public transport, is a new alternative assumed to meet mobility needs and contributes to reducing pollution levels. To analyze the impact of electric public transport on pollution levels, it is recommended to use the methodology of this study to study cases such as Gothenburg, Medellín, or Curitiba. The suggested analysis must include the net effect, that is, considering the marginal cost of emissions in the city where the transportation system is implemented and the marginal cost of emissions caused by the source of electricity generation where it is located, as indicated by Goel and Gupta Goel and Gupta (2017). The investments in infrastructure that are made at present will be part of the urban equipment for at least the next 30 years. Therefore, to reduce the damage to health and the environment due to pollution, thinking about electric transport means thinking about the future and maximizing future environmental benefits.

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5 Appendix

Table 10: Model (2) with controls (population, GDP, and cars).

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	log(CO)	log(NO)	log(NO_2)	log(NO_X)	log(SO_2)	log(PM_{10})	log($PM_{2.5}$)	log(O_3)
Construct.	**0.143**	**-0.387****	**-0.121***	**-0.194****	**-0.118**	**-0.0127**	**0.0918*****	**0.0373**
	(0.146)	**(0.162)**	**(0.0541)**	**(0.0618)**	**(0.108)**	**(0.0533)**	**(0.00547)**	**(0.100)**
Operation	**0.0314**	**-0.238****	**-0.0811**	**-0.154****	**-0.0392**	**0.0619***	**-0.271*****	**0.0603**
	(0.0985)	**(0.0932)**	**(0.0548)**	**(0.0611)**	**(0.101)**	**(0.0303)**	**(0.00878)**	**(0.0701)**
pob*constr	0.491	0.128	0.236**	0.208	0.156	-0.331	-0.292***	0.130
	(0.412)	(0.395)	(0.0835)	(0.151)	(0.300)	(0.436)	(0.0375)	(0.0750)
car*constr	-0.0681	-0.0865	-0.0370	-0.0657	0.117	-0.0583	0.400***	0.0581
	(0.183)	(0.211)	(0.0721)	(0.0787)	(0.147)	(0.0674)	(0.00932)	(0.182)
GDP*constr	-0.559	-0.508	-0.357**	-0.388*	-0.407	0.342	0.414***	-0.137
	(0.364)	(0.557)	(0.143)	(0.208)	(0.336)	(0.385)	(0.0531)	(0.109)
pob*opn	0.247	-0.296	-0.303	-0.264	-0.408*	-0.781***	-0.608***	-0.128
	(0.226)	(0.203)	(0.168)	(0.167)	(0.216)	(0.0686)	(0.0113)	(0.0912)
car*opn	-0.144	0.0319	-0.112	-0.0570	-0.119	-0.113**	0.999***	0.000799
	(0.138)	(0.115)	(0.0759)	(0.0791)	(0.157)	(0.0399)	(0.00884)	(0.138)
GDP*opn	-0.00200	0.242	0.372	0.271	0.405	0.859***	0.0804**	0.209**
	(0.253)	(0.236)	(0.219)	(0.218)	(0.322)	(0.106)	(0.0253)	(0.0874)
Constant	-0.00313	2.234	1.735	2.962	0.917	-1.596	-1.100**	1.726**
	(2.037)	(2.357)	(1.650)	(1.863)	(3.012)	(0.955)	(0.243)	(0.761)
Obs.	306,535	299,875	319,348	319,381	340,469	231,163	152,359	316,935
R^2	0.630	0.706	0.678	0.738	0.610	0.716	0.715	0.793

Standard errors clustered at station levels in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 11: Model (3) showing controls (humidity, temperature, wind speed, wind direction, precipitation, and one-day lag in pollution).

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	log(CO)	log(NO)	log(NO_2)	log(NO_X)	log(SO_2)	log(PM_{10})	log($PM_{2.5}$)	log(O_3)
Operation	**-0.120****	**-0.0859**	**-0.113****	**-0.107***	**-0.00314**	**-0.0691**	**0.0240**	**-0.00223**
	(0.0487)	**(0.0814)**	**(0.0409)**	**(0.0478)**	**(0.0439)**	**(0.0426)**	**(0.0464)**	**(0.0390)**
Humidity*opn	0.00391	0.00464	0.00600***	0.00613***	0.00415	0.0105***	0.0145***	-0.00519
	(0.00285)	(0.00268)	(0.000853)	(0.00126)	(0.00282)	(0.00261)	(0.00226)	(0.00318)
Temp*opn	-0.00582	-0.0140	0.0156	0.00667	0.00705	0.00778	0.0360**	0.0628**
	(0.0242)	(0.0100)	(0.0108)	(0.0108)	(0.0207)	(0.00983)	(0.00968)	(0.0244)
Dwind*opn	-2.77e-05	6.65e-05	8.66e-05	0.000111	0.000274**	0.000106	-2.77e-07	0.000154
	(0.000203)	(0.000340)	(0.000173)	(0.000235)	(8.99e-05)	(8.02e-05)	(8.34e-05)	(0.000135)
Vwind*opn	-0.0758***	-0.0928	-0.0750***	-0.0854***	0.0226	0.0165*	-0.0312	0.0816**
	(0.0199)	(0.0530)	(0.0121)	(0.0230)	(0.0153)	(0.00712)	(0.0163)	(0.0255)
Rain*opn	0.00162***	0.00149	0.000410	0.000656	-0.000514	0.000290	0.000645	0.000735
	(0.000375)	(0.00244)	(0.000951)	(0.00121)	(0.00176)	(0.000944)	(0.00139)	(0.000824)
lag lCO	0.516***							
	(0.0226)							
lag lNO		0.387***						
		(0.0338)						
lag lNO_2			0.438***					
			(0.0321)					
laglNO_X				0.412***				
				(0.0364)				
lag lSO_2					0.414***			
					(0.0217)			
laglPM_{10}						0.215***		
						(0.0209)		
lgl$PM_{2.5}$							0.212***	
							(0.0306)	
lag lO_3								0.398***
								(0.0226)
Constant	0.0404	2.103***	1.711***	2.293***	1.119***	2.926***	1.774***	1.128***
	(0.241)	(0.225)	(0.184)	(0.230)	(0.205)	(0.0534)	(0.177)	(0.303)
Obs.	163,810	155,499	167,157	167,198	147,270	145,062	89,026	190,622
R^2	0.770	0.783	0.782	0.817	0.699	0.775	0.795	0.852

Standard errors clustered at station in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 12: Combined model (4) Part A with controls (population, GDP, cars, humidity, temperature, wind speed, wind direction, precipitation, and one-day lag in pollution).

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	log(CO)	log(NO)	log(NO_2)	log(NO_X)	log(SO_2)	log(PM_{10})	log($PM_{2.5}$)	log(O_3)
Construction	**0.0770**	**-0.271****	**-0.0919****	**-0.150*****	**-0.0582**	**0.0122**	**0.149**	**0.0425**
	(0.0620)	**(0.0816)**	**(0.0331)**	**(0.0376)**	**(0.0409)**	**(0.0559)**	**(0.0849)**	**(0.0670)**
Operation	**0.0952**	**0.166***	**-0.0287**	**0.0169**	**0.00780**	**-0.00207**	**0.0217**	**0.0824**
	(0.0752)	**(0.0706)**	**(0.0474)**	**(0.0540)**	**(0.0809)**	**(0.0303)**	**(0.0759)**	**(0.0583)**
pob*constr	0.639*	0.505	0.226	0.316	0.890***	-0.227	-0.260**	-0.0621
	(0.329)	(0.326)	(0.120)	(0.177)	(0.144)	(0.419)	(0.0933)	(0.0922)
car*constr	-0.222**	-0.264**	-0.135*	-0.172**	-0.0357	-0.111	0.443**	0.0530
	(0.0736)	(0.101)	(0.0618)	(0.0661)	(0.0530)	(0.0688)	(0.108)	(0.0992)
GDP*constr	-0.624*	-0.734	-0.246	-0.392*	-1.088***	0.223	0.381***	0.119
	(0.318)	(0.432)	(0.157)	(0.207)	(0.134)	(0.382)	(0.0706)	(0.119)
pob*opn	0.559	-0.216	0.0522	0.0532	0.121	-0.318	-0.731***	-0.376***
	(0.303)	(0.297)	(0.131)	(0.191)	(0.134)	(0.252)	(0.0540)	(0.0638)
car*opn	-0.330***	-0.544***	-0.222***	-0.309***	-0.179*	-0.213***	0.608***	-0.0719
	(0.0655)	(0.0793)	(0.0577)	(0.0654)	(0.0869)	(0.0304)	(0.101)	(0.116)
GDP*opn	-0.219	0.642*	0.0992	0.167	-0.0705	0.421	0.749**	0.519***
	(0.304)	(0.326)	(0.155)	(0.218)	(0.199)	(0.254)	(0.167)	(0.0800)
Humid*constr	0.00953***	0.00513	0.00681***	0.00678*	0.0198***	0.00986*	0.0153**	-0.00739**
	(0.00226)	(0.00542)	(0.00192)	(0.00329)	(0.00272)	(0.00505)	(0.00464)	(0.00249)
Temp*constr	0.0417***	0.0493*	0.0397**	0.0415**	0.0519**	-0.00386	0.00799	0.0602*
	(0.0119)	(0.0237)	(0.0123)	(0.0149)	(0.0215)	(0.0280)	(0.0167)	(0.0297)
Dwind*constr	-0.000119	-0.000268	-0.000165	-0.000195	0.000348*	-0.000150	-2.03e-05	0.000328**
	(0.000132)	(0.000410)	(0.000189)	(0.000262)	(0.000169)	(0.000111)	(5.45e-05)	(0.000134)
Vwind*constr	-0.0870***	-0.119**	-0.0786**	-0.102***	0.0328	-0.0157	-0.0277***	0.0653***
	(0.0212)	(0.0447)	(0.0232)	(0.0281)	(0.0189)	(0.0171)	(0.00446)	(0.0200)
Rain*constr	-0.00308	0.00801**	0.00330**	0.00458**	0.0184**	0.00364	-0.00470**	0.00144
	(0.00343)	(0.00280)	(0.00117)	(0.00180)	(0.00600)	(0.00335)	(0.00151)	(0.00421)
Humid*opn	0.00911***	0.00740*	0.00857***	0.00908***	0.00858**	0.0119***	0.0164***	-0.00666**
	(0.00154)	(0.00330)	(0.00138)	(0.00165)	(0.00265)	(0.00241)	(0.00192)	(0.00253)
Temp*opn	0.00992	-0.000665	0.0231*	0.0158	0.0184	0.0120	0.0329**	0.0826***
	(0.00974)	(0.0109)	(0.0116)	(0.0115)	(0.0208)	(0.0150)	(0.00782)	(0.0252)
Dwind*opn	4.59e-05	7.64e-05	0.000115	0.000145	0.000373***	0.000111	-6.89e-05	0.000168
	(0.000179)	(0.000361)	(0.000185)	(0.000249)	(7.38e-05)	(9.62e-05)	(7.31e-05)	(0.000149)
Obs.	157,830	149,862	161,020	161,065	141,894	140,029	88,057	184,096
R^2	0.775	0.788	0.785	0.820	0.703	0.779	0.799	0.855

Standard errors clustered at station level in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 13: Combined model (4) Part B with controls (population, GDP, cars, humidity, temperature, wind speed, wind direction, precipitation, and one day lag in pollution).

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	log(CO)	log(NO)	log(NO_2)	log(NO_X)	log(SO_2)	log(PM_{10})	log($PM_{2.5}$)	log(O_3)
Construction	**0.0770**	**-0.271****	**-0.0919****	**-0.150*****	**-0.0582**	**0.0122**	**0.149**	**0.0425**
	(0.0620)	**(0.0816)**	**(0.0331)**	**(0.0376)**	**(0.0409)**	**(0.0559)**	**(0.0849)**	**(0.0670)**
Operation	**0.0952**	**0.166***	**-0.0287**	**0.0169**	**0.00780**	**-0.00207**	**0.0217**	**0.0824**
	(0.0752)	**(0.0706)**	**(0.0474)**	**(0.0540)**	**(0.0809)**	**(0.0303)**	**(0.0759)**	**(0.0583)**
Vwind*opn	-0.0714**	-0.0989	-0.0796***	-0.0907***	0.0246*	0.0141	-0.0277**	0.0874***
	(0.0216)	(0.0574)	(0.0135)	(0.0249)	(0.0124)	(0.00805)	(0.00688)	(0.0256)
Rain*opn	0.00126**	0.00105	0.000335	0.000468	-0.000573	7.19e-05	-9.17e-05	0.000179
	(0.000420)	(0.00224)	(0.000865)	(0.00109)	(0.00162)	(0.00103)	(0.00141)	(0.000634)
lag lCO	0.488***							
	(0.0219)							
lag lNO		0.368***						
		(0.0228)						
lag lNO_2			0.428***					
			(0.0275)					
laglNO_X				0.395***				
				(0.0285)				
laglSO_2					0.394***			
					(0.0235)			
laglPM_{10}						0.207***		
						(0.0165)		
lglPM_{25}							0.200***	
							(0.0319)	
laglO_3								0.386***
								(0.0222)
Constant	2.028	1.660	2.068*	2.896*	4.291***	0.851	-7.624***	-2.796**
	(2.208)	(2.616)	(0.929)	(1.480)	(1.242)	(2.346)	(1.548)	(0.878)
Obs.	157,830	149,862	161,020	161,065	141,894	140,029	88,057	184,096
R^2	0.775	0.788	0.785	0.820	0.703	0.779	0.799	0.855

Standard errors clustered at station level in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 14: Combined model (4) without lag showing controls.

	$\log(CO)$	$\log(NO)$	$\log(NO_2)$	$\log(NO_X)$	$\log(SO_2)$	$\log(PM_{10})$	$\log(PM_{2.5})$	$\log(O_3)$
Construction	**0.147**	**-0.458*** **	**-0.157** **	**-0.244*** **	**-0.123* **	**-0.00833**	**0.124**	**0.0547**
	(0.122)	**(0.118)**	**(0.0477)**	**(0.0506)**	**(0.0541)**	**(0.0647)**	**(0.101)**	**(0.116)**
Operation	**0.212**	**0.276* **	**-0.0318**	**0.0462**	**0.0270**	**-0.0233**	**-0.0418**	**0.122**
	(0.136)	**(0.117)**	**(0.0878)**	**(0.0968)**	**(0.121)**	**(0.0391)**	**(0.0846)**	**(0.0951)**
pob*constr	1.269	0.810	0.428**	0.544*	1.268***	-0.325	-0.357**	-0.0739
	(0.681)	(0.500)	(0.177)	(0.259)	(0.204)	(0.506)	(0.0889)	(0.146)
car*constr	-0.380**	-0.354*	-0.216*	-0.262**	-0.0500	-0.116	0.556***	0.0535
	(0.143)	(0.163)	(0.0944)	(0.103)	(0.0800)	(0.0841)	(0.110)	(0.167)
GDP*constr	-1.266*	-1.210	-0.471*	-0.677**	-1.610***	0.302	0.458**	0.165
	(0.660)	(0.649)	(0.224)	(0.282)	(0.187)	(0.457)	(0.120)	(0.194)
pob*opn	0.946	-0.469	0.0248	-0.0145	0.00337	-0.452	-0.881***	-0.524***
	(0.557)	(0.427)	(0.187)	(0.271)	(0.209)	(0.283)	(0.0896)	(0.106)
car*opn	-0.592***	-0.808***	-0.359**	-0.471***	-0.262*	-0.218***	0.808***	-0.182
	(0.110)	(0.149)	(0.108)	(0.122)	(0.121)	(0.0394)	(0.0877)	(0.183)
GDP*opn	-0.304	1.133*	0.228	0.362	0.0383	0.544*	0.809**	0.796***
	(0.548)	(0.488)	(0.262)	(0.343)	(0.308)	(0.286)	(0.228)	(0.130)
Humid*constr	0.0145**	0.00858	0.00946**	0.00931	0.0236***	0.00939	0.0162**	-0.00876*
	(0.00483)	(0.00831)	(0.00295)	(0.00516)	(0.00305)	(0.00609)	(0.00547)	(0.00408)
Temp*constr	0.0844***	0.0774*	0.0645**	0.0647**	0.0760**	-0.00557	0.0137	0.0826*
	(0.0206)	(0.0328)	(0.0206)	(0.0237)	(0.0259)	(0.0347)	(0.0228)	(0.0431)
Dwind*constr	-0.000165	-0.000393	-0.000199	-0.000272	0.000416*	-0.000151	-1.84e-05	0.000430**
	(0.000182)	(0.000485)	(0.000265)	(0.000333)	(0.000217)	(0.000122)	(6.51e-05)	(0.000161)
Vwind*constr	-0.0968***	-0.129**	-0.0890**	-0.119***	0.0524*	-0.0203	-0.0315***	0.0732**
	(0.0197)	(0.0498)	(0.0296)	(0.0310)	(0.0240)	(0.0173)	(0.00604)	(0.0267)
Humid*opn	0.0113***	0.00892	0.0106***	0.0104***	0.00883*	0.0124***	0.0188***	-0.00516
	(0.00255)	(0.00512)	(0.00225)	(0.00263)	(0.00417)	(0.00287)	(0.00208)	(0.00413)
Temp*opn	0.0246*	-0.00324	0.0380*	0.0239	0.0115	0.0132	0.0440**	0.119**
	(0.0119)	(0.0152)	(0.0176)	(0.0162)	(0.0309)	(0.0172)	(0.0122)	(0.0381)
Dwind*opn	1.04e-05	3.20e-05	0.000118	0.000133	0.000407***	0.000119	-9.34e-05	0.000259
	(0.000234)	(0.000418)	(0.000246)	(0.000309)	(8.37e-05)	(0.000106)	(8.60e-05)	(0.000184)
Vwind*opn	-0.0831**	-0.118*	-0.107***	-0.115***	0.0310	0.0141	-0.0320**	0.103**
	(0.0257)	(0.0593)	(0.0152)	(0.0212)	(0.0194)	(0.0111)	(0.00994)	(0.0334)
Rain*constr	-0.00177	0.00517	0.00452**	0.00497**	0.0160**	0.00457	-0.00462**	0.00143
	(0.00587)	(0.00331)	(0.00146)	(0.00185)	(0.00688)	(0.00393)	(0.00159)	(0.00617)
Rain*opn	0.00165*	0.00236	0.000541	0.000759	0.000397	0.000246	0.000331	0.000392
	(0.000803)	(0.00297)	(0.00145)	(0.00160)	(0.00207)	(0.00102)	(0.00181)	(0.000878)
Constant	3.393	1.925	3.455*	4.417*	6.540**	1.053	-8.145**	-4.047**
	(4.186)	(3.870)	(1.468)	(2.231)	(2.098)	(2.629)	(2.339)	(1.409)
Obs.	163,954	158,376	165,849	165,878	153,913	150,439	94,013	190,146
R^2	0.697	0.753	0.731	0.784	0.631	0.759	0.782	0.828

Standard errors clustered at station level in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Figure 10: Coefficients plot for CO. Model (3).

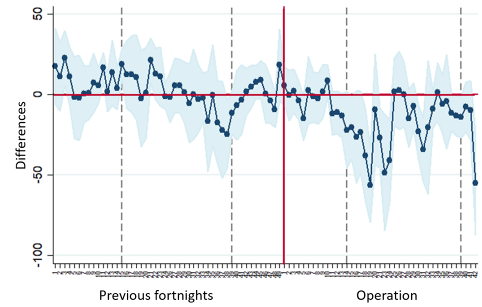

Figure 11: Coefficients plot for NO. Model (3).

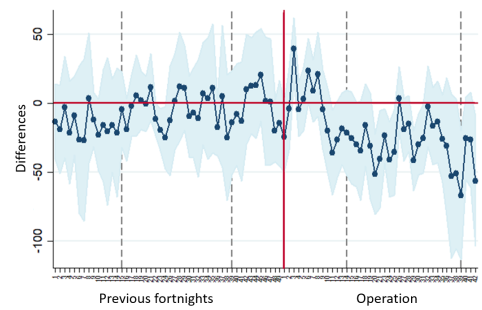

Figure 12: Coefficients plot for NO_2. Model (3).

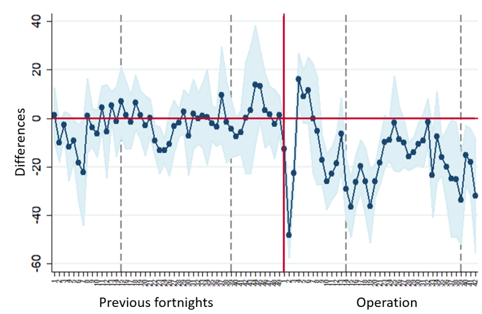

Figure 13: Coefficients plot for NO_X. Model (3).

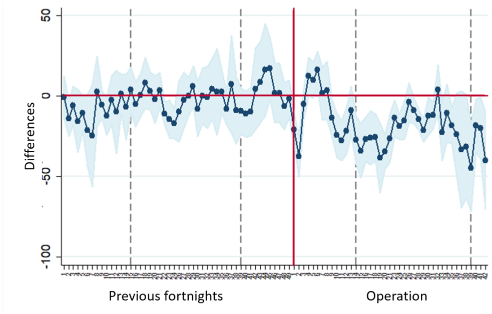

Figure 14: Coefficients plot for SO_2. Model (3).

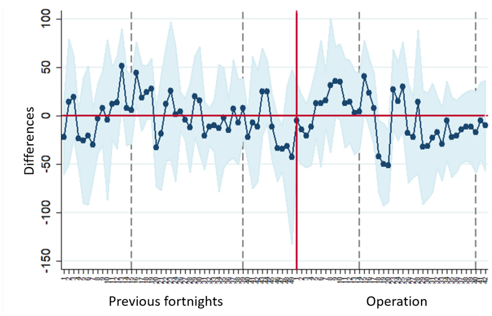

Figure 15: Coefficients plot for PM_{10}. Model (3).

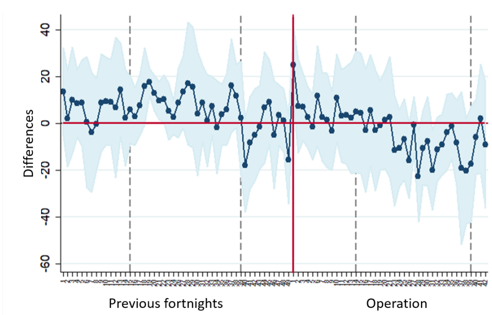

Figure 16: Coefficients plot for $PM_{2.5}$. Model (3).

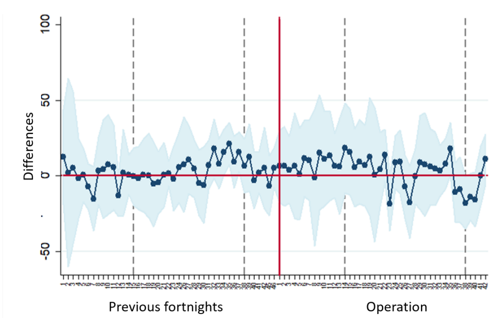

Figure 17: Coefficients plot for O_3. Model (3).

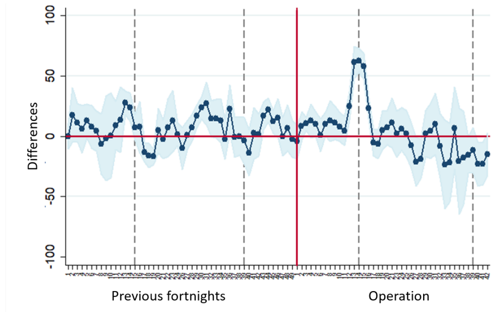

Figure 18: Coefficients plot for CO. Model (4).

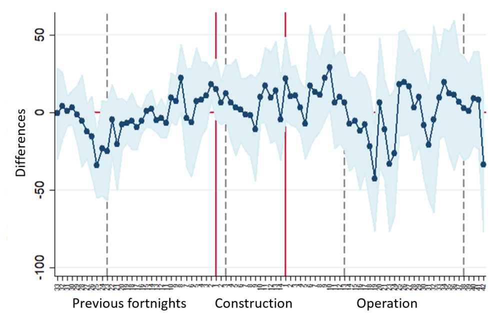

Figure 19: Coefficients plot for NO. Model (4).

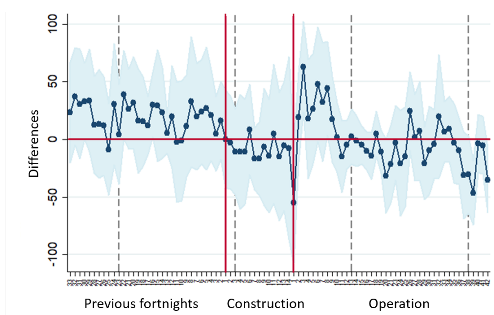

Figure 20: Coefficients plot for NO_2. Model (4).

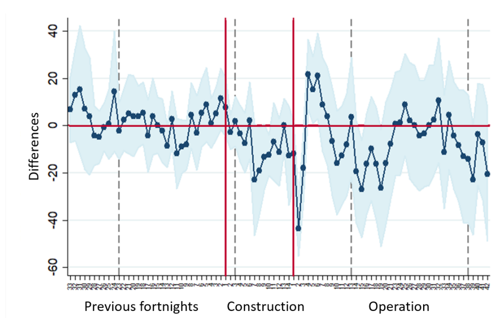

Figure 21: Coefficients plot for NO_X. Model (4).

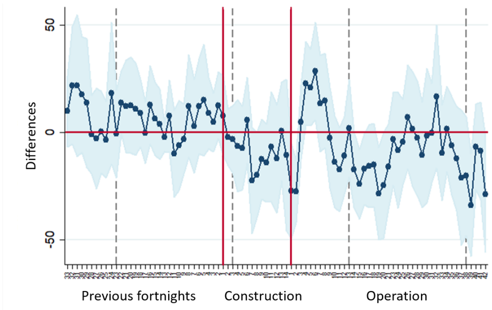

Figure 22: Coefficients plot for SO_2. Model (4).

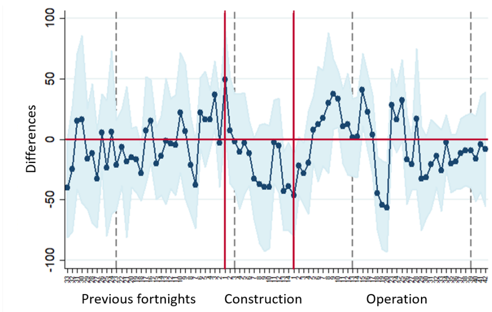

Figure 23: Coefficients plot for PM_{10}. Model (4).

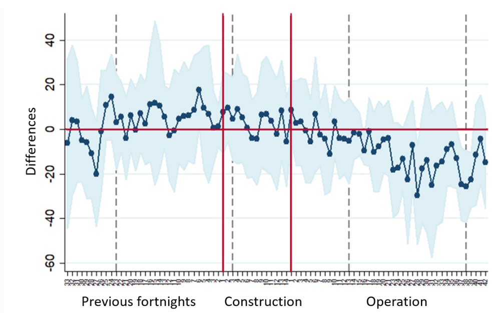

Figure 24: Coefficients plot for $PM_{2.5}$. Model (4).

Figure 25: Coefficients plot for O_3. Model (4).