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“Evaluation of the Impact of Bus Rapid Transit on Air Pollution”

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Abstract

Mexico City's bus rapid transit (BRT) network, Metrobus, was introduced in an attempt to reduce congestion, increase city transport efficiency and cut air polluting emissions. In June 2005, the first BRT line in the metropolitan area began service. We use differences-in-differences and quantile regression techniques in undertaking the first quantitative policy impact assessment of the BRT system on air polluting emissions. The air pollutants considered are carbon monoxide (CO), nitrogen oxides (NO_X), particulate matter of less than 2.5 µm ($PM_{2.5}$), particulate matter of less than 10 µm (PM_{10}), and sulfur dioxide (SO_2). The ex-post analysis uses real field data from air quality monitoring stations for periods before and after BRT implementation. Results show that BRT constitutes an effective environmental policy, reducing emissions of CO, NO_X, $PM_{2.5}$ and PM_{10}.

JEL classification: Q51, Q58, R41, R48
Keywords: Bus Rapid Transit, Differences-in-Differences, Environmental Policy Evaluation, Public Transport, Urban Air Pollution

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Evaluation of the Impact of Bus Rapid Transit on Air Pollution

I. Introduction

In the literature of environmental and transport economics, road transport is widely considered one of the main sources of air pollution. More specifically, a large fraction of GHG emissions and air pollutants are recognized as being derived from road traffic: "In 2004, transport accounted for almost a quarter of carbon dioxide (CO2) emissions from global energy use. Three-quarters of transport-related emissions are from road traffic" (Woodcock et al., 2009, p. 2). Moreover, these pollution levels are particularly high in areas that suffer severe levels of traffic congestion. Conventional road transport produces a series of pollutant emissions, which in high concentrations represent a hazard for the inhabitants of urban areas. The most usual pollutants are particulate matter of different size fractions (PM_{10} and $PM_{2.5}$), carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen oxides (NO_X), and carbon dioxide (CO_2). Combustion engines do not necessarily produce all these pollutants, but some of the emissions from these engines in combination with other particles in the air can react with more complex molecules (such as, ozone) and have a negative impact on human health.

Road transit, as a major determinant of air pollution in urban areas, can be broken down into different sectors, with one of the most relevant being that of public transport. Urban buses emit relatively high levels of $CO_,$ NO_X, PM_{10}, and CO_2. However, due to the use of cleaner, better quality fuels and to stricter regulations on road traffic emissions, the net air quality impact of buses can be positive if vehicles are replaced periodically. This is particularly true if cities adopt electric vehicles and this energy is generated from renewable sources.

Public transport systems, such as subways and or light rail networks, are emission friendly transport options that are able to transport huge numbers of people on a daily basis. The downside of these modes of transportation, however, is the enormous initial investment they require and the rigidity of their services. Most governments operate under considerable budget constraints so that building or expanding local public transport infrastructure requires massive investment, while construction is not always feasible owing to the nature of the local geography.

In the last few decades, governments have sought alternatives that are similarly effective but at the same time more affordable. One such option is the Bus Rapid Transit (BRT) system, a high-quality bus service with a similar performance to that of a subway, but provided at a fraction of the construction cost (Cervero, 1998). Many countries around the world have adopted BRT systems. The main factors in their favor are the low initial investment costs (especially compared to a subway line), low maintenance costs, operating flexibility, and the fact that they provide a rapid, reliable service (Deng & Nelson, 2011). If a BRT line is unable to capture the projected transport demand, or if the usual route is under maintenance, the line can easily be rerouted.

The literature addressing the impact of BRT on air quality does not quantify the reduction in concentrations of the different pollutants. Most assessments are qualitative studies of impact effects or take the form of fuzzy cost-benefit analyses that fail to provide details about individual pollutant levels. Our research seeks to address this gap in the literature. The contributions of this paper are, as such, easily identifiable: a) to provide a rigorous quantification of the impact on air quality of the introduction of a BRT network in a metropolitan area; b) to add to the few analyses to date that employ actual field data in their evaluations of public transport policy; and c) to employ econometric-based methods of differences-in-differences and quantile regression to analyze the environmental impact of a public transportation system like BRT.

II. Related Literature

Several studies have examined the impact of pollutants and report the potential effects for health. PM_{10} and $PM_{2.5}$ have been linked with a decrease in respiratory capacity, aggravating asthmatic conditions, and with severe heart and lung damage (WHO, 2001). Nitrogen oxides (NO_X), and particularly nitrogen dioxide (NO_2), affect the respiratory system and intensify existing cases of pneumonia or bronchitis, while NO_X in high concentrations can seriously damage lung tissue. Sulfur dioxide (SO_2) can worsen existing symptoms of respiratory or cardiovascular diseases.

Carbon monoxide (CO) is one of the most common types of poisoning. It can disable the transport of oxygen to the cells and cause dizziness, headaches and nausea; in high concentrations can lead to unconsciousness and death (Neidell, 2004; Schlenker & Walker, 2011).

Moreover, PM_{10} is considered a risk factor for respiratory related post-neonatal mortality and sudden infant death syndrome (Woodruff et al., 2008). The effects of alleviating traffic congestion on infant health are analyzed extensively in Currie & Walker (2011), who show that a reduction in congestion increases the health and development of infants significantly (see also Kampa & Castanas, 2008; Wilhelm & Ritz, 2003; Wilhelm et al., 2008; and Lleras-Muney, 2010).

Many institutions are aware that substantial government efforts are needed to initiate change and have accepted the challenge of fighting the problems of air pollution. And, indeed, many governments have introduced policies to reduce the emissions generated by their services. For example, in 2009, the São Paulo city council approved the Municipal Policy for Climate Change, aimed at reducing GHG emissions by 20% in 2020, taking 2005 as its baseline (Lucon & Goldemberg, 2010, p. 348). In this instance, the council's measures focused on transportation, renewable energy, energy efficiency, waste management, construction and land use.

Some governments have specifically targeted road traffic pollutants (World Resources Institute, 2011). For example, in 2009, the Japanese central government announced a USD $154 billion package to foster environmentally friendly technologies. Among others, the package gives incentives (tax breaks worth as much as $2,500) to automobile consumers for the purchase of hybrid/electric cars, as well as subsidies of 5% on other energy efficient consumer goods. In Germany, the government introduced low emission zones (LEZ) in many cities. Using differences-in-differences, Wolff (2013) finds that the LEZs managed to reduce emission of PM_{10} by 9%.

An alternative policy for abating emissions from road traffic is the introduction of maximum speed limits on highways or in certain metropolitan areas. Many studies have examined the impact of such policies by employing a vast range of analytical techniques. The majority calculate the impact on pollution rates resulting from changes at a local level. However, it is implicitly assumed that no other factors play a role and, thus, the changes are summed at an aggregate level. Moreover, the computations are often made ex-ante. In the literature, we find Gonçalves et al. (2008), who report modest reductions of polluting emissions in Barcelona; Keuken at al. (2010), who find a substantial reduction in polluting levels in the Netherlands; and, Keller at al. (2008), who estimate a 4% reduction in NO_X due to this policy in Switzerland.

An alternative way of evaluating the impact of a policy on pollution levels is to measure the effect ex-post using field data. However, few studies of this type have been reported to date. Exceptions include Bel & Rosell (2013) on the impact of an 80km/h speed limit and a variable speed limit policy in the metro-area of Barcelona. They report that the variable speed policy was much more effective, reducing NO_X and PM_{10} emissions by 7.7–17.1% and 14.5–17.3% respectively. Similarly, Van Benthem (2015) analyzed speed limits on the U.S. West Coast, and concludes that the optimal speed, considering costs and benefits, is about 88km/h (55 mph) and that increasing the speed would increase CO, NO_X, and O_2 levels. Note that Bel & Rosell (2013) and Van Benthem (2015) use real field data; thus, they are able to measure the actual policy impact rather than making computations based on a series of assumptions.

This paper contributes to the existing literature by providing a robust quantification of the impact on air quality of the BRT network in a metropolitan area. We employ actual field data in our evaluation, and use econometric-based methods of differences-in-differences and quantile regression to analyze the environmental impact of the Bus Rapid Transit System in Mexico.

III. Bus Rapid Transit in Mexico City

Bus Rapid Transit and pollution

Bus Rapid Transit –BRT- is a relatively new mode of public transportation that has found broad acceptance in developing countries since the early 1990s. By the end of 2014, 186 cities around the world had adopted some form of BRT. We find prominent examples in Bogotá, Curitiba, Guangzhou, Jakarta, and Istanbul. Latin America is seen as the epicenter of the global BRT movement (Cervero, 2013) with over 60 cities using BRT, moving about 20 million people each day; that is, 62% of the global demand for BRT services. Above all, cities in Brazil (34), Mexico (9) and Colombia (6) have led the rapid growth of BRT networks in the region. BRT has also developed in Europe and the U.S. Over 50 cities in Europe provide this service to an average of 2 million people daily. BRT systems exist in 18 cities in the US, transporting an average of almost half a million people daily (see http://brtdata.org/) for figures and statistics on BRT cities).

A key feature of BRT is that it acts not only as a transport policy, but also forms part of a country's environmental policy. In this latter regard, it needs to be borne in mind that old buses are being replaced by modern vehicles run on cleaner fuels, while the introduction of BRT lines should also reduce congestion. According to Cervero (2013, p. 19), BRT is 'likely' to have net benefits regarding emissions: "BRT generally emits less carbon dioxide than LRT [light rail train] vehicles due to the use of cleaner fuels". Cervero & Murakami (2010) consider that attracting former motorists to BRT can reduce vehicle kilometers traveled and thus polluting emissions.

The reduction in emission levels thanks to the introduction of BRT systems is noticeable. In Bogotá's TransMilenio, Hidalgo et al. (2013) estimate health-cost savings from reduced emissions following the completion of TransMilenio's first two phases at US$114 million over a 20-year period, based on a rough computation of data. They calculate that about 8% of total benefits can be attributed to air pollution and traffic accident savings (that is, reductions in associated illnesses and deaths). However, the authors do not use real field data to quantify the pollution-reduction benefits. Indeed, in Bogotá, the buses displaced by the BRT were reallocated to the urban edge and smaller surrounding townships, leading Echeverry et al. (2005) to argue that BRT may not have reduced the problem of polluting emissions but simply displaced it to other areas.

Geography and Institutions

Mexico City is one of the most heavily populated metropolitan areas in the world. The estimated population in 2005 was 19.2 million inhabitants, growing to over 20 million by 2010 (population density was estimated at 2560 inhabitants/km^2). The city has a subtropical highland climate and occupies a valley at 2,220 meters above sea level. Diurnal temperatures oscillate between 10 and 22°C, and can easily climb above 30°C on hot days and fall to freezing on cold winter days. Rainfall is intense from June to October, but it is scarce from November to May. Pollution levels are much higher during the dry season. Wind speed plays a critical role in the city's weather and pollution levels: weak winds and the shape of the valley do not allow air pollutants to disperse.

The city hosts many different modes of public transport, including an extensive metro network, light rail, buses, trolleybuses, micro-buses, taxis, etc. All modes are regulated by Mexico City's Mobility Secretary (SEMOVI, Mexico City Government). For several years, most modes of public transport have operated at full capacity, resulting in lengthy commuting times, e.g., subway commuters will typically have a long wait and have to let several trains pass before they can board. Metro, buses and micro-buses are typically perceived as serving the lower socioeconomic classes, as they are constantly overloaded, offer poor quality service, and due to an increasing income gap. Those who can afford a car prefer to use it for their daily commute. Crôtte et al. (2009) show that Mexico's metro users that earn low wages and do not own a car perceive the metro as a normal good, while middle/high income earners perceive the metro as inferior good.

Many bus lines serve Mexico City's main streets and avenues. In certain cases, several bus and micro-bus lines overlap, resulting in chaos and congestion because of the extremely slow speeds attained and the constant stopping and starting of the bus units. *Av. de los Insurgentes*, one of the longest avenues in the world at 28.8 km, and the city's main north-to-south arterial route used to be especially affected by congestion. The city's public micro-bus lines suffer from an absence of effective regulations, which means there are no official bus stops and drivers can stop anywhere to let people on and off. The congestion attributable to the micro-buses exacerbated commuting times. At peak hours, a commuter could take two hours to travel a distance of just 20 kilometers. This was the situation by the early 2000s, before the BRT operations were introduced.

The Metrobus Policy

The pollution problem is not new for Mexico City. Over the years the government tried to implement programs aimed at reducing pollution levels. The most known one was the 'Hoy no circula' (today you do not circulate) program introduced in 1989, according to which cars that do not fulfill emission criteria could not circulate on one particular day during the week depending on the last number of their license plate. Analyzing the impact of this program with a regression discontinuity design, Davis (2008, p. 40) showed that this policy is not effective, but it also "led to an increase in the total number of vehicles in circulation as well as a change in the composition of vehicles toward high-emissions vehicles".

On 5 November 2002, the governor of Mexico City announced an ambitious program to deal with the worst cases of congestion. The aim was to reduce commuting times and to tackle the city's air quality problems, and several policies were implemented. In 2004 a few buses from the public network were renewed. In 2006-07 some parts of the 'second floor' of the inner-city highway *Anillo Periférico* were inaugurated. This helped reducing congestion in some areas, but the overall amount of cars using both levels increased; so reduction of emissions was not significant. Other minor policies were introduced in 2007, such as a pilot project of a bicycle program. All in all, results obtained with these different programs and measures were modest.

At the heart of the 2002 program lay the introduction of a BRT ('Metrobus') system, designed to reduce traffic and air pollutant emissions. The intention was not to compete with existing public modes of transport; rather, BRT was seen as an alternative to existing options in order to reduce congestion. Note that, as found by Anderson (2014) for Los Angeles, congestion relief benefits alone may justify transit infrastructure investments. On March 2005, SEMOVI oversaw the creation of the public entity Metrobus, with an initial operating budget of MXN 42.4 million pesos (USD 3.8 M in 2005). Metrobus was to be fully responsible for the BRT's operation planning and its control and administration.

The main idea underpinning the BRT system was to create an exclusive bus lane in which only authorized buses could operate subject to certain rules and criteria (schedule time, designated stops, physical dimensions of buses, and amount of emissions), to guarantee efficient operation. To promote the system, several stations had to be built to enable passengers to access the service. The project was implemented in 2005 with an initial investment of around USD $80 million to build up the infrastructure (Schipper et al., 2009). The investment included the construction of 37 BRT stations and exclusive bus lanes and the introduction of new articulated buses run on conventional diesel fuel. BRT was first opened on *Av. de los Insurgentes;* the first line in this corridor was 19.6 km long (it was extended to 28.1 km in 2008). BRT lanes reduced traffic congestion, as the measure eliminated overlapping of services with other bus lines. At the same time, flow in the car lanes was improved as traffic no longer had to stop whenever a bus stopped.

Following the introduction of the Metrobus, the city's old buses and micro-buses operating on the same BRT route were reallocated or simply scrapped. The substitution of these old units represented an important change in terms of the air quality conditions in the areas adjacent to the new Metrobus route. Micro-buses, often allowed to operate because of the authority's negligence, represented one of the main sources of health-threatening gases for the population. The aim of the policy was to lower the air polluting emissions of public transportation, and the units operating the BRT network satisfy specific standards (Euro V emission standard).

The analysis of historical trends of energy demand, air pollutants and GHG emissions attributable to passenger vehicles commuting in Mexico City's metro-area done by Chavez-Baeza & Sheinbaum-Pardo (2014), reported that the primary sources of small particle matter are road passenger transport vehicles. According to in-vehicle measurements by Shiohara et al. (2005), carcinogenic risks caused by micro-buses were much higher than those caused by buses and the metro. In a related study, Gómez-Perales et al. (2004) measured (in-vehicle) commuters' exposure to $PM_{2.5}$, CO and benzene in micro-buses, buses and the metro in Mexico City during morning and evening rush hours. They reported that pollution levels inside the micro-bus units presented the highest concentrations for all the pollutants during rush hours. Wöhrnschimmel et al. (2008) compared micro-bus, regular bus and BRT unit emissions in Mexico City. Based on in-vehicle emission measurements, they concluded that Metrobus units were the least polluting of the three options given that the buses are newer, more efficient and run on diesel instead of regular fuel.

While it seems intuitive that there is less pollution because of vehicle substitution, it is not clear whether pollution levels in the metropolitan area have also been reduced. Less congestion on a particular route may induce more people to use it. Hence, an increase in demand may even increase pollution levels in a given area if a sufficient number of commuters are attracted to use it. According to the Metrobus office, standard commuting times have fallen from 1 hour 30 minutes to 1 hour on the route, while passenger exposure to benzene, CO, and $PM_{2.5}$ has fallen by up to 50 percent, compared to the figures for the previous bus service operating in this corridor. The office also claims that CO_2 emissions have been cut by 35,000 tons per annum. However, the accuracy of this information is questionable as these outcomes are likely to be based on computations from in-vehicle emission changes, rather than real field data.

The Mexico City government monitors the air quality within its metropolitan area, by measuring levels of various pollutants within its network of automatic air quality monitoring stations distributed across the city. These stations have been operational during a number of years and the information is made publicly available. We use this information to measure the impact of the introduction of the Metrobus system on the concentrations of five pollutants.

(Insert Figure 1 around here)

The number of passengers using BRT has increased over the years, reaching satiation point in some parts (see Table 1). Some years after the first line was opened, the network was expanded, with lines two (20 km) and three (17 km) opening on December 2008 and February 2011, respectively. Line four (14 km) started operations on April 2012 and line five (10 km) on November 2013. Metrobus network transported a total of 254 million passengers in 2014. The

Institute for Transportation and Development Policies (ITDP) evaluates BRT networks around the world. In 2013 Mexico Metrobus was given a 'Silver' ranking according to the BRT Standard Score indicating that it "includes most of the elements of international best practice and is likely to be cost-effective on any corridor with sufficient demand to justify BRT investment. These systems achieve high operational performance and quality of service" (BRT Standard 2014, p.10).

(Insert Table 1 around here)

IV. Data and variables

Pollution levels vary depending on a range of meteorological factors that have to be taken into consideration to capture this variation. Air contaminants are not static and so the average daily wind speed and average daily wind direction are included in the model. Wind direction is an important factor as a significant amount of pollution might be created in heavily industrial areas and then transported to other parts of the metropolitan area. Not only are pollutants transported, they also undergo a number of reaction processes. The rates of these reactions are influenced by temperature, so the average daily temperature needs to be considered. Water can result in a reactive change in the equilibrium or it may increase sedimentation; thus, relative humidity and daily rainfall are both included. Rainfall also reduces significantly the amount of pollutants in the air and so this meteorological variable has to be included. Note, however, that owing to data limitations, rainfall is calculated as the sum of daily rainfall amounts.

Data on air-related control variables (relative humidity, temperature, wind direction and wind speed) were obtained from Mexico City's Environment Secretary, which serves as the official monitoring entity. Data on air quality and amount of polluting emissions come from the Atmosphere Monitoring System (SIMAT), which comprises a network of around 40 monitoring points distributed across the Mexico City metro-area. The SIMAT network is divided into four monitoring subsystems, each measuring different atmospheric components and factors.

For the analysis of air pollutants, the RAMA (Automatic Network for Atmospheric Monitoring) subsystem serves as the source for all pollutant measurements. The RAMA network comprises 29 monitoring stations. The pollutants monitored are carbon monoxide (CO), nitrogen oxides (NO_X), sulfur dioxide (SO_2), particles of the order of 10 micrometers or less in aerodynamic diameter (PM_{10}), and particles of the order of 2.5 micrometers or less ($PM_{2.5}$).

Data on the meteorological parameters are obtained from the Meteorology and Solar Radiation Network subsystem (REDMET), which comprises 19 continuous monitoring stations that measure wind direction, wind speed, temperature, humidity, atmospheric pressure and solar radiation. Unfortunately, data on atmospheric pressure and solar radiation are not available after 2003, which is a limitation of the model presented below.

Further data on rainfall were provided by Mexico City's Water Systems office (SACM). This network of rainfall measuring stations comprises 78 monitoring stations distributed across the metropolitan area. Information on the exact location of the measuring stations was denied for reasons of "national security", given that details regarding the city's waterworks infrastructure are restricted access only. However, the names of the stations were provided and as these typically include a reference to their location, it was possible with Google Maps to approximate the location of most of them. Of the stations, 70.5% were easy to locate, 16.7% were roughly approximated and 12.8% of the stations were impossible to locate based on their name.

(Insert Table 2 around here)

As the air quality monitoring stations and rainfall measuring stations did not coincide, a matching was undertaken. Using the location of the air quality monitoring stations the closest rainfall station within a range of less than 10 km was selected. We assume that the weather conditions present at the air quality stations and at their closest respective rainfall stations do not differ. The rainfall stations that could not be located are not considered here given the impossibility of matching them to the air quality monitoring stations (the result of the station matching is available upon request).

Our analysis of Metrobus focuses solely on line 1 (opened on 19 June 2005). We measure its impact for the two-year period prior to its opening and the two-year post-operational period.

(Insert Table 3 around here)

V. Differences-in-Differences

The first part of the analysis employs the differences-in-differences method to facilitate the measurement of the impact of the new BRT system on polluting emissions. By so doing, the intention is to estimate the atmospheric concentration of pollutants in Mexico City between 2003 and 2007 and to assess the impact of the introduction of the Metrobus.

Methodology

The panel data used for this analysis are unbalanced. This characteristic of our panel comes from the fact that some stations were in operation from the beginning of the period of analysis, while other new ones were introduced at a later point in time, sometimes substituting older ones. On the other hand, most stations required maintenance at some point. The introduction or switching-off of the stations is exogenous and not correlated with the variables in the model.

In the absence of a randomized trial, the method adopted here is an extension of the differences-in-differences estimation procedure specified as a two-way fixed effects model. As stated in Wooldridg (2010: p. 828), “the usual fixed effects estimator on the unbalanced panel is consistent”

$$Y_{it} = \beta X_{it} + \gamma Z_{it} + \theta_i + \delta_t + \varepsilon_{it} \qquad (1)$$

where Y_{it} is air pollutant concentration, X_{it} is a vector of time-varying control covariates that include atmospheric characteristics, and Z_{it} is the BRT impact dummy variable to be evaluated. As usual in this kind of models, θ_i are station-specific fixed effects, δ_t are time-specific fixed effects and ε_{it} is the random error. Station fixed effects control for time-invariant station-specific omitted variables; time fixed effects control for trends around each monitoring station.

The key variable in this differences-in-differences approach is γ, which measures the difference between the average change in air pollutant concentrations for the treatment group (stations close to the Metrobus line) and average change in concentrations for the control group (stations located some distance from the area through which the Metrobus passes). Specifically,

$$\gamma = [E(Y_B \mid BRT=1) - E(Y_A \mid BRT=1)] - [E(Y_B \mid BRT=0) - E(Y_A \mid BRT=0)] \tag{2}$$

where Y_B and Y_A denote the air pollutant concentrations before and after Metrobus came into operation. BRT=1 and BRT=0 denote treatment and control group observations respectively.

The equation for the dependent variables (CO, NO_X, $PM_{2.5}$, $PM_{2.5}$ and SO_2) is:

$$Y_{it} = \beta_0 + \beta_1\,\mathit{Metrobus}_{it} + \beta_2\,\mathit{Pollutant\ Lag}_{it} + \beta_3\,\mathit{Humidity}_{it} + \beta_4\,\mathit{Temperature}_{it} + \beta_5\,\mathit{Wind\ Direction}_{it} + \beta_6\,\mathit{Wind\ Speed}_{it} + \beta_7\,\mathit{Rainfall}_{it} + \beta_8\,\mathit{Workday}_t + \beta_9\,\mathit{Month}_t + \theta_i + \delta_t + \varepsilon_{it} \tag{3}$$

A basic assumption when using differences-in-differences is that the temporal trend in the two areas is the same in the absence of the intervention. If this were not the case, the impact being measured would be biased. The problem of endogeneity can also bias an impact evaluation. According to Bertrand et al. (2004), most problems related to endogeneity can be avoided by using the differences-in-differences technique. When using differences-in-differences in a panel data setting, regressions must be undertaken with fixed effects: the correlation between the error components of station i and the explanatory variables should be different from zero. Closely related to this, an important assumption here is that unobservable variables and unobservable characteristics remain constant over time.

In conducting the analysis the parallel trend assumption is tested to see if the parallel trend is satisfied in the time period before treatment (i.e. before policy implementation). For the test, the data were grouped by trimester. The mean value of each pollutant in the treated group (within a 2.5-km radius of the Metrobus line) was then compared with the corresponding value in the control groups. The null hypothesis is that in the absence of intervention, the trend presented by the treated group is equal to that presented by the control group. The null hypothesis is accepted at the 95% confidence level, indicating that the parallel trend is satisfied for all pollutants except for PM_{10}. Moreover, the evolution in the pollutant levels over time is provided in graph form in Figure A1 in the Appendix. These graphs show how the treated and the non-treated pollutant levels behaved similarly during the pre-treatment period.

The failure to satisfy the parallel trend assumption in the case of PM_{10} leads to a biased impact evaluation for this particular pollutant. However, despite this slightly upward bias, the PM_{10} analysis is included because of the importance of this pollutant. The impact evaluation of the remaining pollutants is not biased since the parallel trends assumption is satisfied.

As mentioned, an unbalanced panel data setting requires the use of a panel fixed effects estimation. To confirm the correct use of fixed effects in this panel, the Hausman test was run with every pollutant. In all cases the null hypothesis of the Hausman test was rejected at the 99% confidence level, which confirms the correct use of the method. We test the model's basic assumptions (homoscedasticity, time dependence, spatial dependence and exogeneity of explanatory variables). Autocorrelation is a persistent problem for all pollutants. To account for this problem, we included a one-period lag of the respective pollutant in each regression.

By using Driscoll-Kraay standard errors, the estimator is modified in such a way that it is robust to cross-section and time dependence. In this way, standard errors are also heteroscedasticity-consistent (Driscoll & Kraay, 1998). In addition, panel-corrected standard errors (PCSE) are used to provide a robustness analysis of the results, as PCSE yield more accurate standard errors than estimations using feasible generalized least squares (Beck, 2001).

Results

Tables 4-8 present the results for the fixed effects regression. The models for CO, NO_X, $PM_{2.5}$, $PM_{2.5}$ and SO_2 are all jointly statistically significant at the 1% level. All estimations include year dummies, which capture time fixed effects (coefficients for year dummies and the constant term are not included in the outputs, and are available upon request). R^2 values range between 0.59-0.61 for CO, 0.54-0.61 for CO_X, 0.57-0.63 for $PM_{2.5}$, 0.52-0.58 for PM_{10}, and 0.29-0.38 for SO_2.

Table 4 presents the output for the fixed effects estimation of carbon monoxide. The estimation shows a downward trend in the relationship between the impact of the introduction of the Metrobus on pollution and distance from the Metrobus route. In areas near the BRT line, the reduction in concentration was 19.4%, while in the areas lying between 2.5 and 10 km and between 10 and 30 km from the route the reduction was 17.2% and 16.6%, respectively. The results also identify the influence of the time lag on current levels of carbon monoxide, i.e., yesterday's pollution levels determine to a large extent today's pollution levels. A further factor playing a key role in the levels of CO in the air is the day of the week. Thus, pollutant levels are much higher during the week, when workers have to commute, than on the weekends. Environmental factors such as wind and humidity also play a marked role in air pollutant concentrations over the city as both variables are significant.

(Insert Table 4 around here)

The estimations of NO_X present the opposite pattern to that presented by CO. Although the outcome is not significant in areas close to the Metrobus route, the reduction in NO_X concentrations is greater in more distant areas. The coefficient sign is negative, which is consistent with that of the other pollutants, and presents values between 12.2 and 18.1%. The temporal lag plays an important role in the case of NO_X, as well as in all three areas defined around the Metrobus route. Higher wind speeds have a significant effect on the concentration levels, blowing the pollutant into other areas when the wind speed is high. Week days have a similar effect on pollutant concentrations as that described above for CO. For this pollutant the year dummies are significant, capturing unobserved characteristics related to the time trend.

(Insert Table 5 around here)

Table 6 presents the output of $PM_{2.5}$. In this case, only seven air quality stations monitor this pollutant within the three areas around the Metrobus route and they are not evenly distributed. Thus, there is only one station within a 2.5-km radius of the Metrobus route, five in the area lying between 2.5 and 10 km from the BRT line and another one in the last zone. Due to the small number of stations, the $PM_{2.5}$ regressions in the areas with just one station are estimated with OLS using robust standard errors. Fixed effect estimations are not feasible for these areas since the panel structure no longer holds.

Bearing this in mind, distance from the route has a similar impact on concentrations to that reported above for NO_X. The introduction of the Metrobus was highly significant (at the 1% level) in bringing the concentration levels of $PM_{2.5}$ down by 20.8% in the area closest to the Metrobus line and by 39.0% in the area lying at a distance of between 10 -30 km. The temporal lag once again is highly significant (1%), which means that the levels of concentration of this pollutant are also largely determined by the levels the day before. The environmental factors affecting the concentration of $PM_{2.5}$ are similar to those for NO_X, with the difference that temperature plays a more important role in the area lying up to 10 km from the route. The 5% significance of the dummy controlling for the month of the year indicates that this variable captures significant seasonal variations within the year.

(Insert Table 6 around here)

As noted, the results for PM_{10} present a slight upward bias and should be treated with caution. However, the reduction in concentrations was substantial. In the area in the 2.5-km radius of the Metrobus route, the PM_{10} level fell by 12.9 $\mu g/m^3$ or 24.4% following the opening of the line. The areas lying between 2.5 and 10 and between 10 and 30 km from the route had a reduction of 17.7 and 15.5% in the levels of PM_{10}, respectively (all reductions are statistically significant). Table 7 shows how the impact on this pollutant fell with increasing distance from the Metrobus; the reverse of the pattern presented by $PM_{2.5}$ and NO_X but the same as that of CO.

(Insert Table 7 around here)

Humidity levels, wind speed and week days have an influence on PM_{10} concentration levels, all three being statistically significant. Higher humidity levels reduce PM_{10} concentrations in the air. Week days present higher levels of pollutant concentrations than those recorded on weekends. In the areas lying furthest from the Metrobus route (2.5-10 km and 10-30 km), the year dummies are significant. The temporal lag of the endogenous variable indicates that past emission levels significantly affect today's concentration levels. The impact of the weekday dummy is in line with the effect on the other pollutants. Commuting to work or school at peak times during the week creates congestion within the city, which increases pollution levels in areas closest to these congested roads.

Finally, our estimations of the SO_2 concentrations do not show any significant effect of the introduction of the Metrobus in any of the three areas defined around *Av. de los Insurgentes*. As expected the signs of the coefficients are negative, but the variation of the error term is too high to capture any significant impact from the Metrobus operation. Interestingly, the model for this pollutant performs worse in terms of explanatory power, as the coefficient of determination R^2 is below that of the other pollutants. It seems probable that the model is omitting other important determinants. As above, however, the lagged value of the endogenous variable, wind and week day variables have a significant influence on the concentration level of SO. Higher wind speeds reduce levels of concentration while the levels rise on days when commuters take to the roads.

The estimation outputs of the different pollutant molecules show that the introduction of the Metrobus had a marked impact on the concentration levels of the different pollutants in the three areas defined. To appreciate better the impact of the Metrobus operation on air quality in the Mexico City metropolitan area, Table 9 summarizes this impact for all pollutants. In the case of NO_X and PM_{10} the pollutant concentration increases with distance, while in the case of CO, $PM_{2.5}$ and SO_2 the concentration reduces with distance. This difference might be related to the molecular composition of each pollutant, its molecular weight, the interaction of each pollutant with the other molecules floating in the air, and the extent to which each pollutant is affected by environmental factors such as wind and humidity levels.

(Insert Table 8 around here)

Since estimations were carried out using Driscoll-Kraay standard errors, we also include the results using PCSE to ensure a more robust methodological analysis. Table 9 presents the results for the policy variable with both corrections. The policy is effective across pollutants, but for SO_2 effectiveness depends on the computation of the standard errors.

(Insert Table 9 around here)

VI. Quantile Regression

The differences-in-differences method using fixed effects, in common with most econometric methods, deals with the averages of distributions. This means that what is happening in different segments of a distribution is often ignored. In order to further our analysis of the changes in air quality following the opening of the BRT line, we divide the sample into quantiles (more precisely, into deciles). By so doing, the analysis becomes much more detailed and we are able to determine which deciles of the pollutants are affected most by the introduction of the Metrobus. Quantile regression allows us to identify whether the impact concentrates around the median or, alternatively, at the extremes of the distribution.

Methodology

The equation specified for the quantile regression resembles that specified above for the fixed effects regression using differences-in-differences:

$$Q_{Yit}(\tau) = \beta(\tau)X_{it} + \varphi(\tau)Z_{it} + \theta_i + \delta_t \qquad (4)$$

where $Q_{Yit}(\tau)$ is the quantile function at confidence level τ. This model allows the influence of the control variables X_{it} and the policy variable Z_{it} to depend on the quantile confidence level τ. Again, θ_i and δ_t are station-specific and time-specific fixed effects. To estimate this model, Koenker (2004) proposes the simultaneous estimation of the following equation:

$$min_{(\beta,\,\gamma,\,\theta)} \sum_{(q=1\ldots Q)} \sum_{(i=1\ldots n)} \sum_{(t=1\ldots T)} w_q \varrho_{\tau q} (Y_{it} - \beta(\tau)X_{it} - \varphi(\tau)Z_{it} - \theta_i - \delta_t) \qquad (5)$$

where $\varrho_{\tau q}(\cdot)$ is the function below (as in Koenker & Bassett, 1978; see also Koenker, 1984):

$$\varrho_{\tau}(u) = \begin{cases} \tau|u|, & u \geq 0 \\ (1-\tau)|u|, & u < 0 \end{cases} \qquad (6)$$

The term w_q are chosen weights and they control the influence of the quantiles on the estimation of the fixed effects. Note that neither the Gaussian condition nor the classical hypothesis related to the random error term is necessary here. Bel et al. (2015), who suggest this way of proceeding, stress this aspect about the error term. In common with these authors, we also assume that the weights are the same for all the quantiles analyzed. As discussed above, the quantile regression expression can be seen as the differences-in-differences model decomposed into quantiles (deciles). Therefore for any given confidence level τ,

$$\varphi = [Q_{(YB \mid BRT=1)} - Q_{(YA \mid BRT=1)}] - [Q_{(YB \mid BRT=0)} - Q_{(YA \mid BRT=0)}] \tag{7}$$

where Y_B and Y_A denote the air pollutant concentrations before and after the introduction of Metrobus. As in the first analysis, here we seek to estimate the differences between the treated air quality monitoring stations and the stations that lie furthest away from the BRT system (control group), while considering the changes in emissions before and after introducing Metrobus.

Recall that for the quantile regressions robust standard errors have also been used. The robust standard errors are computed under the assumption that the residual density is continuous and bounded away from 0 and infinity at the specified quantile (Koenker, 2005).

Results

Tables 10-12 show the results of the quantile regressions. The results of the diff-in-diff analyses suggested that some pollutant impacts were not always significant in the three areas defined around the Metrobus corridor. Now we determine if the areas that did not register any significant impact on a pollutant did in fact experience some effect in some parts of the distribution.

Table 10 presents the results for the area lying closest to the Metrobus route. We obtain a negative sign across all pollutants and deciles of the distribution. Interestingly, CO, NO_X and PM_{10} levels are significantly affected across the distribution, while $PM_{2.5}$ shows a significant impact in the lower deciles, becoming weaker at the upper end. SO_2, which did not present significant outcomes when using the Driscoll-Kraay standard errors, presents a significant impact in this area at the upper end of the distribution, with the concentration level down by 63.9%.

(Insert Table 10 around here)

The results for the area lying between 2.5 and 10.0 km from the line (Table 11) are consistent with those from the differences-in-differences analysis for CO, NO_X and $PM_{2.5}$. In this area, PM_{10} presents significant values around the median of the distribution but not at the bottom end. This pollutant presented significant outcomes in the differences-in-differences analysis, but here we see that the impact is located around the middle and upper parts of the distribution. In common with the area adjacent to the BRT line, this area presents negative and highly significant results for SO_2. Again, when using Driscoll-Kraay standard errors this pollutant did not present any significant results and so these results would be more in line with the PCSE estimation.

(Insert Table 11 around here)

Table 12 shows the results for the area lying at a distance of between 10-30 km from the Metrobus. This area presents very similar results to those in the second zone (2.5 to 10 km). CO, NO_X and $PM_{2.5}$ are significant in all parts of the distribution while PM_{10} shows significant results around the median. SO_2, on the other hand, is significant around the median and at the lower part of the distribution.

(Insert Table 12 around here)

VII. Conclusions

This paper has evaluated the impact of the introduction of Bus Rapid Transit on pollution levels in Mexico City. The analysis has been based on real field data obtained from automatic air quality monitoring stations and has focused on five pollutants: CO, NO_X, $PM_{2.5}$, PM_{10} and SO_2.

Using unbalanced panel data, we conduct an impact evaluation using the econometric-based techniques of differences-in-differences and quantile regression, an approach not previously used to quantify the environmental impact of this mode of transport. Results from the differences-in-differences analysis show a significant reduction in the concentrations of all pollutants, but SO_2. Specifically, CO concentrations were reduced by 16.6-20.4%, NO_X by 12.9-18.1%, $PM_{2.5}$ by 20.8-39.0% and PM_{10} by 9.6-24.4%, according to the city area.

In the case of SO_2, the results are inconclusive. The estimation based on Driscoll-Kraay standard errors failed to reveal any significant impact of the introduction of BRT; however, the estimation using panel-corrected standard errors showed a significant reduction of 27.7% within a 2.5-km radius of the Metrobus and a reduction of 23.1% in the area lying between 2.5 and 10 km from the BRT corridor.

The quantile regressions conducted identify the levels of the distribution at which the policy had most impact. In the area within a 2.5-km radius of the Metrobus, the results for CO, NO_X and PM_{10} are significant for almost all selected quantiles of the distribution, while $PM_{2.5}$ is significant only in the lower half of the distribution (recall $PM_{2.5}$ was highly significant according to the differences-in-differences test). It is interesting to note that SO_2, for which the differences-in-differences estimation using Driscoll-Kraay standard errors showed no significance and the estimation using PCSE revealed an impact, is significant only in the upper levels of the distribution. However, the significance at the upper extreme is not sufficient to make the differences-in-differences analysis with Driscoll-Kraay standard errors significant. These results are, nevertheless, in line though with those provided by PCSE analysis.

It would be inappropriate to generalize the impact of BRT on air quality reported here to all cities. Geographical and atmospheric traits obviously differ from one location to another. Future research would benefit from comparing the reduction in emissions reported here with those detected in other metropolitan areas based on real field data, and from determining whether the latter are consistent with the findings herein. Similarly, future studies might build on the present model and include additional environmental factors such as atmospheric pressure and congestion monitoring variables.

For cities with similar characteristics to those of Mexico City, our results should encourage the expansion of their BRT networks, the continuous introduction of cleaner BRT-units, and an increase in the size of their BRT fleets to provide a better standard of service, measures that should motivate more people to switch from private cars to public transport. It is important to recall, however, that the emission impact of each BRT line will be different for every corridor, and that other factors are likely to play a role. In short, decision makers that are truly committed to the climate change fight should consider BRT as a public transport option, and analyze whether it meets their city's needs.

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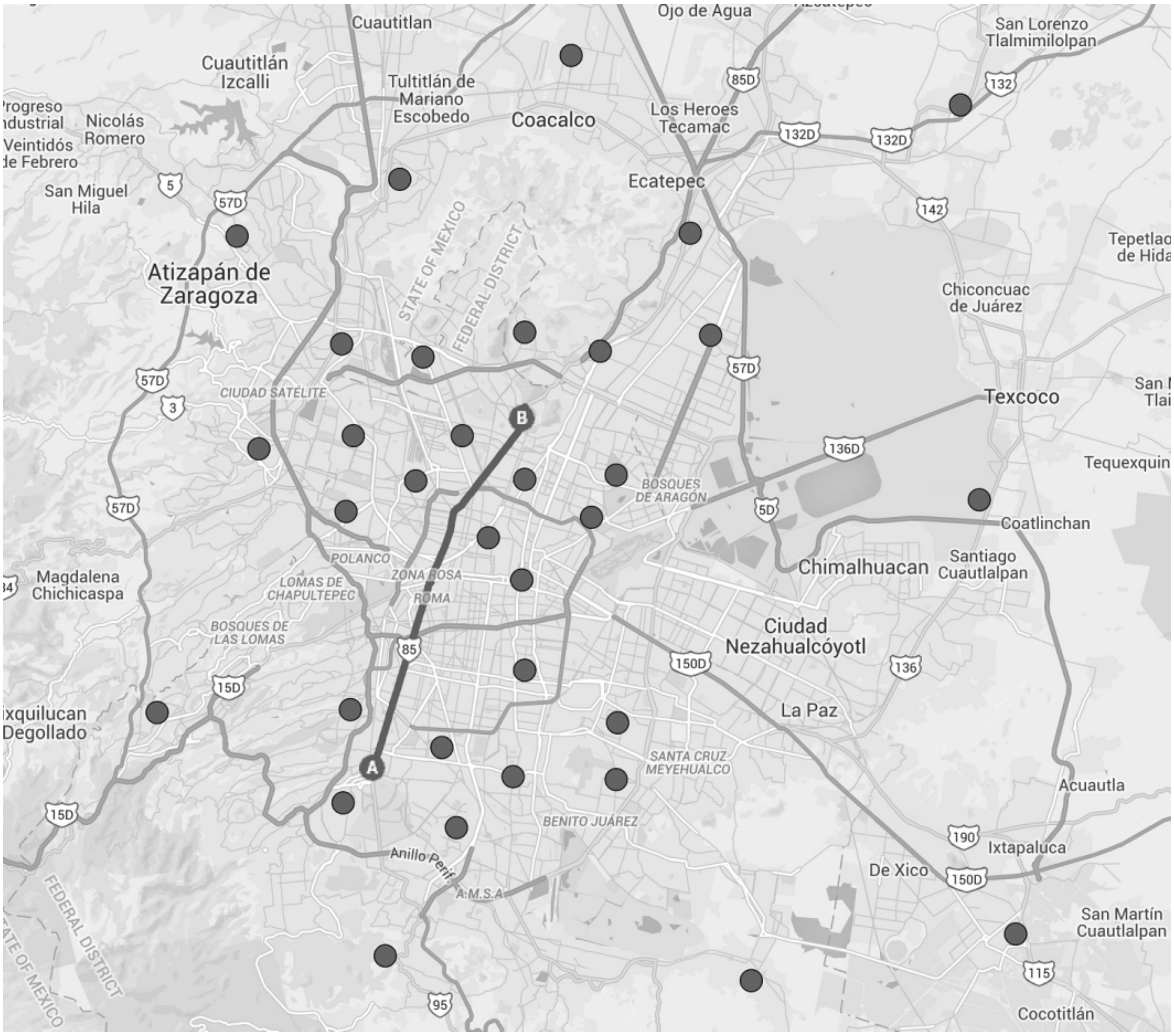
FIGURES

Figure 1: Metrobus Line 1 and the air quality monitoring stations in Mexico City's metro-area



TABLES

Table 1: Number of passengers using Mexico-City's Metrobus Network

Year	Line 1	Line 2	Line 3	Line 4	Line 5	Total
2005	31,515,511	0	0	0	0	34,720,301
2006	74,321,914	0	0	0	0	74,218,369
2007	77,505,395	0	0	0	0	77,652,053
2008	89,201,679	1,891,080	0	0	0	89,804,339
2009	93,455,128	33,869,530	0	0	0	127,134,909
2010	99,342,235	38,187,092	0	0	0	136,915,678
2011	113,046,246	43,469,130	32,954,167	0	0	187,183,000
2012	122,082,471	47,364,386	39,890,301	10,982,706	0	220,319,864
2013	124,891,960	48,078,130	40,546,259	13,599,680	3,157,914	230,273,943
2014	124,560,033	47,995,096	42,072,979	18,171,539	21,209,779	254,009,426

Source: Data from the Metrobus Public Information Office

Table 2: Description and Source of the model variables

Variable	Description	Source
CO	Carbon Monoxide daily average concentration (ppm)	RAMA
NO_X	Nitrogen oxides daily average concentration (ppm)	RAMA
$PM_{2.5}$	Particulate Matter with less than 2.5 μm (μg/m³) daily average concentration	RAMA
PM_{10}	Particulate Matter with less than 10 μm (μg/m³) daily average concentration	RAMA
SO_2	Sulfur Dioxide daily average concentration (ppm)	RAMA
CO(-1), NO_X(-1), $PM_{2.5}$(-1), PM_{10}(-1), SO_2(-1)	One period lag (1 day) of the polluting variables	RAMA
Metrobus	Binary variable: 1 if the Metrobus is implemented, 0 otherwise.	Metrobus Public Information Office
Relative humidity	Daily average relative humidity (%)	REDMET
Temperature	Daily average temperature (°C)	REDMET
Wind Direction	Daily average wind direction (Azimuth Degrees)	REDMET
Wind speed	Daily average wind speed (m/s)	REDMET
Rainfall	Sum of the daily rainfall (mm)	SACM
Weekdays	Binary variable: 1 if the day is a labor day (Monday-Friday), 0 if day is a Saturday or a Sunday.	

Note: ppm = parts per million; μg/m³ = micrograms per cubic meter; m/s = meters per second; mm = millimeters

Table 3: Descriptive statistics of the model variables

Variable	Mean	Std. Deviation	Min.	Max.	Obs.	Stations
CO	1.294	0.601	0.39	6.84	23.589	17
NO_X	59.444	30.011	3.75	241.65	24.139	17
$PM_{2.5}$	27.515	12.629	5.22	160.75	9.528	7
PM_{10}	51.397	25.074	1.67	318.29	17.925	14
SO_2	9.928	9.928	0.86	115	29.935	23
Metrobus	0.5	0.5	0	1	1.461	-
Relative humidity	56.461	12.44	24.74	87.23	16.491	18
Temperature	16.194	2.406	7.45	23.57	15.469	18
Wind Direction	186.96	23.53	116.4	295.93	16.612	17
Wind speed	1.74	0.449	0.92	3.84	16.612	17
Rainfall	1.633	2.877	0	18.88	113.958	78
Weekdays	0.714	0.452	0	1	1461	-

Table 4: Estimation of the logarithm of Carbon Monoxide (CO) daily average concentration

Dependent Variable: Log(CO)	**(1)** 0 - 2.5 km		**(2)** 2.5 - 10.0 km		**(3)** 10.0 - 30.0 km	
Metrobus	-0.1940	**	-0.1720	***	-0.1660	**
	(0.0506)		(0.0394)		(0.0456)	
Temporal lag: Log(CO)	0.5780	**	0.5340	***	0.5570	***
	(0.0353)		(0.0217)		(0.0223)	
Humidity	0.0049	*	0.00381	**	0.0060	**
	(0.00206)		(0.00157)		(0.00193)	
Temperature	0.0045		-0.0108		0.0011	
	(0.0123)		(0.00792)		(0.00966)	
Wind Direction	-0.0004		0.0000954		-0.0007	*
	(0.000234)		(0.000168)		(0.000278)	
Log(Wind Speed)	-0.4060	***	-0.444	***	-0.4290	***
	(0.0351)		(0.0344)		(0.0342)	
Log(Rainfall)	0.0085		-0.00125		-0.0041	
	(0.00502)		(0.00533)		(0.0063)	
Workday	0.254	***	0.211	***	0.169	***
	(0.0186)		(0.018)		(0.0201)	
Month	-0.000382		-0.00979		-0.0135	
	(0.00674)		(0.00537)		(0.00682)	
Number of Obs.	1402		2292		1555	
R^2	0.6546		0.5907		0.5966	
Joint significance	180.00	***	166.52	***	151.85	***

The regression includes a dummy for each year from 2003 to 2007 and a constant. Driscoll-Kraay standard errors in parentheses. * $p<0.10$, ** $p<0.05$, *** $p<0.01$

Table 5: Estimation of the logarithm of Nitrogen Oxides (NO_X) daily average concentration

Dependent Variable:	**(1)**	**(2)**	**(3)**
Log(NO_X)	0 - 2.5 km	2.5 - 10.0 km	10.0 - 30.0 km
Metrobus	-0.1220	-0.1290 **	-0.1810 ***
	(0.0545)	(0.0522)	(0.0449)
Temporal lag: Log(NO_X)	0.4480 ***	0.3770 ***	0.4650 ***
	(0.0257)	(0.0199)	(0.0237)
Humidity	0.0023	-0.000742	0.0036
	(0.00162)	(0.00103)	(0.00197)
Temperature	-0.0154	-0.0234 ***	-0.0050
	(0.00871)	(0.00499)	(0.0105)
Wind Direction	-0.0003	-0.000083	-0.0008 **
	(0.000181)	(0.000124)	(0.000255)
Log(Wind Speed)	-0.4060 ***	-0.4620 ***	-0.4340 ***
	(0.0339)	(0.0245)	(0.0322)
Log(Rainfall)	-0.0014	-0.00113	-0.0071
	(0.00471)	(0.0045)	(0.00581)
Workday	0.315 ***	0.265 ***	0.273 ***
	(0.0142)	(0.0146)	(0.0182)
Month	-0.00179	-0.00418	-0.0188 **
	(0.00521)	(0.00454)	(0.00705)
Number of Obs.	1103	2313	1883
R^2	0.6063	0.5642	0.5393
Joint significance	161.43 ***	141.73 ***	125.99 ***

The regression includes a dummy for each year from 2003 to 2007 and a constant. Driscoll-Kraay standard errors in parentheses. * $p<0.10$, ** $p<0.05$, *** $p<0.01$

Table 6: Estimation of the logarithm of Particulate Matter with less than 2.5 μm ($PM_{2.5}$) daily average concentration

Dependent Variable: Log($PM_{2.5}$)	**(1)** 0 - 2.5 km		**(2)** 2.5 - 10.0 km		**(3)** 10.0 - 30.0 km	
Metrobus	-0.2080	***	-0.2530	**	-0.3900	***
	(0.0787)		(0.0855)		(0.096)	
Temporal lag: Log($PM_{2.5}$)	0.4320	***	0.4400	***	0.5130	***
	(0.0447)		(0.0291)		(0.0507)	
Humidity	-0.0176	***	-0.00854	**	-0.0023	
	(0.00237)		(0.00195)		(0.00429)	
Temperature	-0.0261	**	0.0087		0.0494	**
	(0.0112)		(0.0092)		(0.0211)	
Wind Direction	0.0003		0.0003540		-0.0009	
	(0.000495)		(0.000241)		(0.000791)	
Log(Wind Speed)	-0.5850	***	-0.5990	***	-0.5700	***
	(0.069)		(0.0548)		(0.0858)	
Log(Rainfall)	0.0125		0.00996		0.0415	**
	(0.0108)		(0.00683)		(0.0161)	
Workday	0.120	***	0.1240	***	0.223	***
	(0.0305)		(0.0250)		-0.043	
Month	0.0167	**	0.00136		-0.0429	***
	(0.00847)		(0.00695)		(0.0155)	
Number of Obs.	328		1416		235	
R^2	0.6295		0.5678		0.6205	
Joint significance	49.65	***	70.85	***	35.68	***

The regression includes a dummy for each year from 2003 to 2007 and a constant. (1) & (3) use robust standard errors and (2) uses Driscoll-Kraay standard errors. S.E. in parentheses. * $p<0.10$, ** $p<0.05$, *** $p<0.01$

Table 7: Estimation of the logarithm of Particulate Matter with less than 10 µm (PM_{10}) daily average concentration

Dependent Variable: Log(PM_{10})	**(1)** 0 - 2.5 km	**(2)** 2.5 - 10.0 km	**(3)** 10.0 - 30.0 km
Metrobus	-0.2440 *	-0.1770 **	-0.1550 *
	(0.0813)	(0.0637)	(0.0541)
Temporal lag: Log(PM_{10})	0.4390 ***	0.4410 ***	0.4670 ***
	(0.0376)	(0.0300)	(0.0285)
Humidity	-0.0125 **	-0.0137 ***	-0.0166 ***
	(0.0028)	(0.00166)	(0.00205)
Temperature	0.0142	0.0168	0.0180
	(0.0107)	(0.00871)	(0.00865)
Wind Direction	-0.0005	-0.0000011	-0.0007 *
	(0.0003)	(0.000167)	(0.00028)
Log(Wind Speed)	-0.3300 **	-0.2660 ***	-0.2180 ***
	(0.0526)	(0.0310)	(0.0361)
Log(Rainfall)	0.0188	0.0096	0.0091
	(0.0074)	(0.0059)	(0.00648)
Workday	0.1400 **	0.1920 ***	0.1420 ***
	(0.0211)	(0.0202)	(0.0185)
Month	0.0093	0.00117	-0.000677
	-0.0073	(0.00562)	(0.00595)
Number of Obs.	1047	1643	1007
R^2	0.5485	0.5248	0.5804
Joint significance	94.04 ***	110.22 ***	116.86 ***

The regression includes a dummy for each year from 2003 to 2007 and a constant. Driscoll-Kraay standard errors in parentheses. * $p<0.10$, ** $p<0.05$, *** $p<0.01$

Table 8: Estimation of the logarithm of Sulfur Dioxide (SO_2) daily average concentration

Dependent Variable: Log(SO_2)	**(1)** 0 - 2.5 km		**(2)** 2.5 - 10.0 km		**(3)** 10.0 - 30.0 km	
Metrobus	-0.2140		-0,1760		-0,2580	
	(0.177)		(0.173)		(0.179)	
Temporal lag: Log(SO_2)	0.5610	***	0,4440	***	0,4220	***
	(0.038)		(0.026)		(0.0308)	
Humidity	-0.0027		-0,00637	*	-0,0134	**
	(0.00396)		(0.00348)		(0.00406)	
Temperature	-0.0006		0,0034		0,0108	
	(0.0198)		(0.0201)		(0.0213)	
Wind Direction	0.0006		0,00202	***	0,0025	***
	(0.000639)		(0.000446)		(0.000643)	
Log(Wind Speed)	-0.3760	*	-0.496	***	-0,4090	***
	(0.12)		(0.0795)		(0.101)	
Log(Rainfall)	0.0223		-0,00631		0,0120	
	(0.0165)		(0.013)		(0.0179)	
Workday	0.267	**	0,212	***	0,143	**
	(0.0513)		(0.0445)		(0.0551)	
Month	-0.00295		-0,0153		-0,0161	
	(0.018)		(0.0133)		(0.0141)	
Number of Obs.	1344		2987		1867	
R^2	0.3849		0,3326		0,2912	
Joint significance	42.96	***	62.42	***	33.36	***

The regression includes a dummy for each year from 2003 to 2007 and a constant. Driscoll-Kraay standard errors in parentheses. * $p<0.10$, ** $p<0.05$, *** $p<0.01$

Table 9: Summary of the impact of the Metrobus implementation on the different pollutants

		(1) Less than 2.5 km	**(2)** Between 2.5km - 10km	**(3)** Between 10km - 30km
CO	DK	-0.1940 **	-0.1720 ***	-0.1660 **
		(0.0506)	(0.0394)	(0.0456)
	PCSE	-0.2040 ***	-0.2000 ***	-0.1760 ***
		(0.0426)	(0.0460)	(0.0473)
NO_X	DK	-0.1220	-0.1290 **	-0.1810 ***
		(0.0545)	(0.0522)	(0.0449)
	PCSE	-0.1610 ***	-0.1440 ***	-0.1590 ***
		(0.0438)	(0.0408)	(0.0478)
$PM_{2.5}$	DK	-0.2080 ***	-0.2530 **	-0.3900 ***
		(0.0787)	(0.0855)	(0.096)
	PCSE	-0.2080 ***	-0.2980 ***	-0.3900 ***
		(0.0756)	(0.0602)	-0.1020
PM_{10}	DK	-0.2440 *	-0.1770 **	-0.1550 *
		(0.0813)	(0.0637)	(0.0541)
	PCSE	-0.2160 ***	-0.0960 *	-0.1570 **
		(0.0568)	(0.0574)	(0.0619)
SO_2	DK	-0.2140	-0.1760	-0.2580
		(0.177)	(0.173)	(0.179)
	PCSE	-0.2770 **	-0.2310 **	-
		(0.124)	(0.116)	-

Standard errors in parentheses. * $p<0.10$, ** $p<0.05$, *** $p<0.01$

Table 10: Estimated coefficients of the Metrobus implementation on the deciles of the pollutant distributions in the area within 2.5 km around the Metrobus line 1 in Mexico-City.

Confidence Level τ	**(1) CO**	**(2) NO_X**	**(3) $PM_{2.5}$**	**(4) PM_{10}**	**(5) SO_2**
0.90	-0.1990 ***	-0.1170 *	-0.3420	-0.1650 ***	-0.6390 ***
	(0.0443)	(0.0391)	(0.214)	(0.0500)	(0.215)
0.80	-0.1910 ***	-0.1130 *	-0.2620	-0.2100 ***	-0.3610 ***
	(0.0389)	(0.0675)	(0.185)	(0.0412)	(0.107)
0.70	-0.1830 ***	-0.1040 **	-0.2350	-0.1870 ***	-0.3850 ***
	(0.0294)	(0.0650)	(0.152)	(0.0486)	(0.130)
0.60	-0.2080 ***	-0.1100 ***	-0.1730 *	-0.2440 ***	-0.2040
	(0.0365)	(0.0479)	(0.0974)	(0.0573)	(0.128)
0.50	-0.1840 ***	-0.1060 **	-0.1860 *	-0.2350 ***	-0.3100 **
	(0.0413)	(0.0447)	(0.0955)	(0.0504)	(0.122)
0.40	-0.1830 ***	-0.0941 **	-0.2270 **	-0.2560 ***	-0.1710
	(0.0343)	(0.0385)	(0.0889)	(0.0567)	(0.128)
0.30	-0.2190 ***	-0.1020	-0.1700	-0.2090 ***	-0.1880
	(0.0454)	(0.0418)	(0.104)	(0.0595)	(0.166)
0.20	-0.2130 ***	-0.1150 *	-0.1550 **	-0.2130 ***	-0.2980
	(0.0443)	(0.0635)	(0.0716)	(0.0565)	(0.185)
0.10	-0.1840 ***	-0.2180 ***	-0.2800 ***	-0.1310 *	0.0844
	(0.0687)	(0.0660)	(0.103)	(0.0713)	(0.329)

Robust standard errors in parentheses. *p<0.1, **p<0.05,***p<0.01

Table 11: Estimated coefficients of the Metrobus implementation on the deciles of the pollutant distributions in the area within 2.5 and 10.0 km around the Metrobus line 1 in Mexico-City.

Confidence Level τ	**(1) CO**	**(2) NO$_X$**	**(3) PM$_{2.5}$**	**(4) PM$_{10}$**	**(5) SO$_2$**
0.90	-0.157 ***	-0.272 ***	-0.342 ***	-0.139 ***	-0.239 **
	(0.0268)	(0.0725)	(0.0506)	(0.0251)	(0.1070)
0.80	-0.207 ***	-0.18 ***	-0.354 ***	-0.165 ***	-0.311 **
	(0.0385)	(0.0317)	(0.0638)	(0.0439)	(0.1440)
0.70	-0.194 ***	-0.148 ***	-0.275 ***	-0.102 *	-0.311 ***
	(0.0278)	(0.0491)	(0.0488)	(0.0557)	(0.0863)
0.60	-0.197 ***	-0.125 ***	-0.289 ***	-0.12 ***	-0.343 ***
	(0.0381)	(0.0370)	(0.0674)	(0.0411)	(0.0913)
0.50	-0.209 ***	-0.141 ***	-0.254 ***	-0.169 ***	-0.338 ***
	(0.0353)	(0.0297)	(0.0543)	(0.0356)	(0.0808)
0.40	-0.216 ***	-0.157 ***	-0.276 ***	-0.195 ***	-0.331 ***
	(0.0439)	(0.0335)	(0.0574)	(0.0370)	(0.0720)
0.30	-0.227 ***	-0.14 ***	-0.252 ***	-0.163 ***	-0.355 ***
	(0.0497)	(0.0378)	(0.0759)	(0.0381)	(0.0765)
0.20	-0.184 ***	-0.131 **	-0.263 ***	-0.204 ***	-0.229
	(0.0557)	(0.0606)	(0.0825)	(0.0701)	(0.1700)
0.10	-0.152 ***	-0.0921 *	-0.232 ***	-0.12	-0.257 **
	(0.0540)	(0.0522)	(0.0390)	(0.0745)	(0.1190)

Robust standard errors in parentheses. *p<0.1, **p<0.05,***p<0.01

Table 12: Estimated coefficients of the Metrobus implementation on the deciles of the pollutant distributions in the area within 10.0 and 30.0 km around the Metrobus line 1 in Mexico-City.

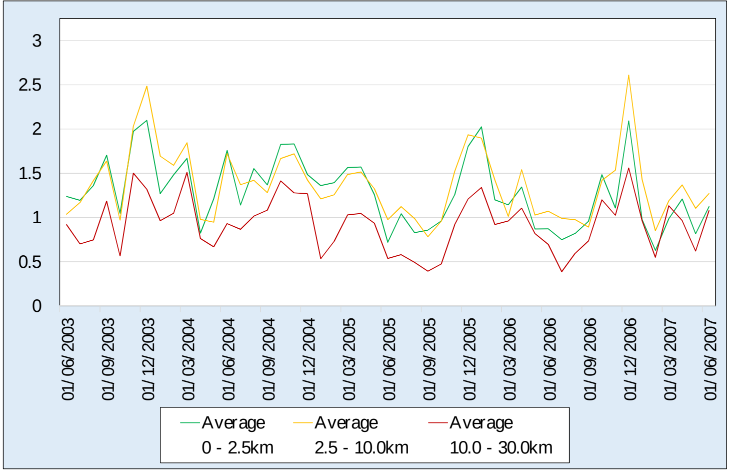
Confidence Level τ	**(1) CO**	**(2) NO_X**	**(3) $PM_{2.5}$**	**(4) PM_{10}**	**(5) SO_2**
0.90	-0.256 ***	-0.187 ***	-0.353 ***	-0.0999	-0.147
	(0.0654)	(0.0546)	(0.0307)	(0.0983)	(0.1440)
0.80	-0.171 ***	-0.164 ***	-0.365 ***	-0.13 ***	-0.313 **
	(0.0564)	(0.0367)	(0.0610)	(0.0391)	(0.1390)
0.70	-0.171 ***	-0.161 ***	-0.281 ***	-0.137 ***	-0.298 ***
	(0.0491)	(0.0405)	(0.0510)	(0.0476)	(0.0922)
0.60	-0.16 ***	-0.166 ***	-0.29 ***	-0.13 **	-0.223 **
	(0.0395)	(0.0395)	(0.0576)	(0.0506)	(0.0881)
0.50	-0.156 ***	-0.146 ***	-0.304 ***	-0.151 ***	-0.338 ***
	(0.0427)	(0.0359)	(0.0488)	(0.0544)	(0.0783)
0.40	-0.167 ***	-0.182 ***	-0.281 ***	-0.184 ***	-0.352 ***
	(0.0516)	(0.0372)	(0.0629)	(0.0588)	(0.0993)
0.30	-0.195 ***	-0.191 ***	-0.266 ***	-0.152 **	-0.279 ***
	(0.0510)	(0.0411)	(0.1020)	(0.0622)	(0.0879)
0.20	-0.145 ***	-0.153 ***	-0.197 **	-0.0896	-0.341 ***
	(0.0532)	(0.0462)	(0.0818)	(0.0626)	(0.1200)
0.10	-0.204 ***	-0.188 **	-0.319 ***	-0.0892	-0.521 ***
	(0.0632)	(0.0773)	(0.0680)	(0.0692)	(0.0878)

Robust standard errors in parentheses. *$p<0.1$, **$p<0.05$,***$p<0.01$

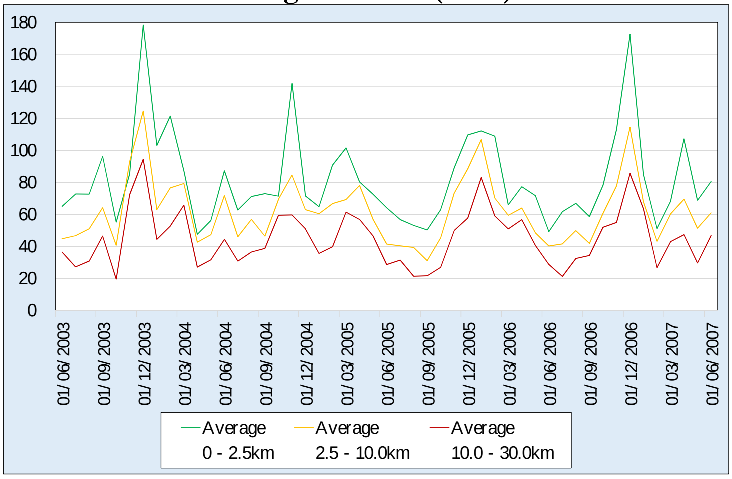
FIGURES

Figure A1: Evolution of the different pollutant concentrations in the period June/2003 - June/2007

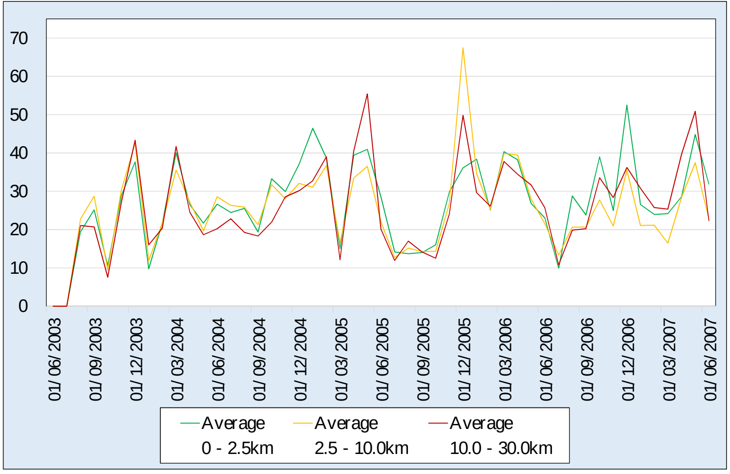
Carbon Monoxide (CO)



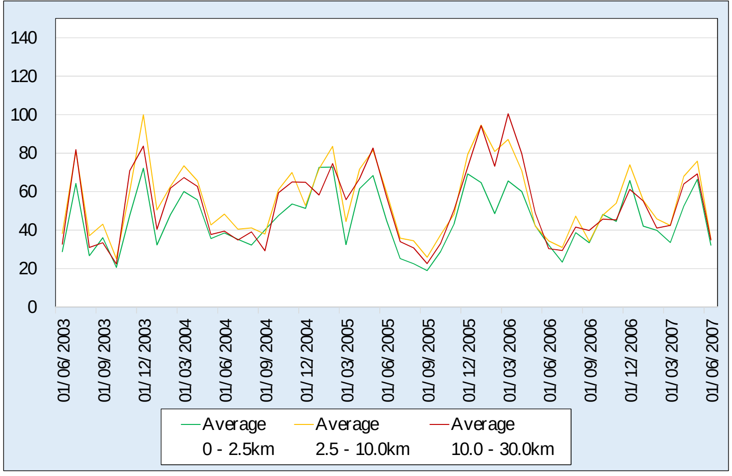
Nitrogen Oxides (NO_X)



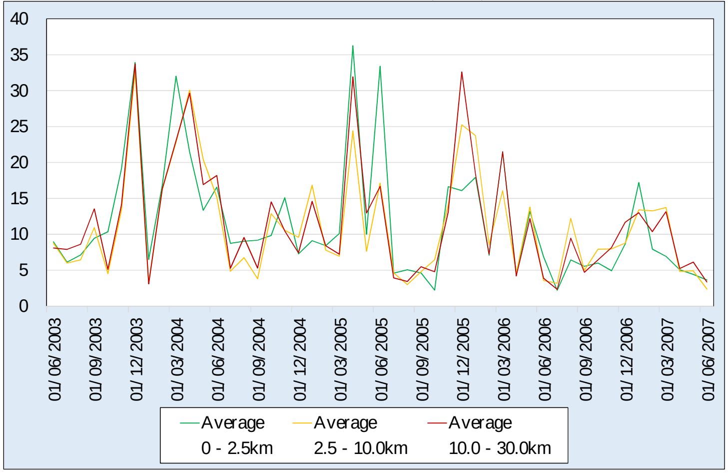
Particle Matter with less than 2.5 μm ($PM_{2.5}$)



Particle Matter with less than 10 μm (PM_{10})



Sulfur Dioxide (SO_2)



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