The Effects of Rapid Bus Lanes at Decreasing Local Pollution Emissions: Analysis of the Impact of Mexico City Metrobus System

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Abstract

The transportation sector is responsible for a large proportion of the estimated 4.2 million premature deaths that are attributable to urban air pollution worldwide[1]. After being declared the most polluted city in the world in 1992[2], Mexico City has worked over the past decades to decrease the amount of urban air pollution in the city. This paper analyzes the potential impact of protected bus lanes, found in Mexico City's Metrobús system, on improving urban air quality in areas surrounding stations. Using satellite imagery and remote sensing techniques on data from 2005 (the year the first Metrobús line opened) to 2019, this analysis employs a difference in differences approach, comparing urban air pollution (via aerosol concentrations) on areas surrounding the Metrobús system, to control streets which have similar magnitudes of traffic. The result of this analysis finds that the implementation of the Metrobús system led to an additional decrease in urban air pollution levels than seen in control streets, although this decrease was of a relatively small magnitude.

Keywords: Transportation, Rapid Bus Lanes, Metrobús, Urban Air Pollution, PM10, PM2.5, MODIS, Protected Bus Lanes

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1 WHO. "Air Pollution." *World Health Organization*, World Health Organization, 30 Jan. 2020, www.who.int/sustainable-development/transport/health-risks/air-pollution/en/.

2 Sheridan, Mary Beth. "The Scary Images of Mexico City's Pollution Emergency." *The Washington Post*, WP Company, 16 May 2019, www.washingtonpost.com/world/2019/05/16/scary-images-mexico-citys-pollution-emergency/.

Introduction

Urban air pollution is attributable to an estimated 4.2 million premature deaths worldwide. In both increasing the risk of cardiovascular and respiratory diseases, and cancer and adverse birth outcomes, it is crucial that the appropriate steps regarding urban air pollution mitigation are taken in cities across the world. Among urban air pollutants, the effects of particulate matter (PM) are linked most closely with causing premature death or illness[3]. Whether that be PM2.5 or PM10, these small particulates bypass the body's defenses against dust, penetrating deep into the respiratory system.

With a population of approximately twenty million, and a history of terrible urban air pollution, Mexico City, in the both the 1990's and the 2000's, took significant steps towards combating this reality. Among these steps was an increased focus towards public transportation infrastructure, a scheme of replacing old cars, removing lead from gasoline, and closing refineries and factories [4]. This analysis focuses on the advancements made in the public transportation sector, specifically the potential impacts of the Metrobús rapid bus system, which currently has an average of 159,234 riders per day[5]. The Metrobús system, which opened with a single line in 2005, has seen the addition of six more lines, as in the subsequent fourteen years, ridership has skyrocketed[6]. It is important to note that in comparison to a traditional rapid bus system, the Metrobús system has designated protected bus lanes, in which cars cannot drive. Because of this creation of a lane solely dedicated to buses, these buses do not have to sit in traffic and release emissions through the process of idling. Additionally, as these bus lanes have shrunk the number of lanes dedicated to cars, on these routes it is actually faster to travel by bus than it is by car, and as a result these buses are readily used. Because of this change in behavior, and the fact that these bus lanes were constructed on roads that had a significant amount of traffic in the city, this analysis aims to determine if the Metrobús system has had an impact on increasing urban air quality in the immediate surroundings of where its stations were built.

Literature Review

Although there does not readily exist specific literature in which remote sensing is used to analyze changes in air quality in regards to public transportation, there does exist literature relating to the use of remote sensing to study changes in air quality. Examples of these papers

[3] WHO. "Air Pollution." *World Health Organization*, World Health Organization, 30 Jan. 2020, www.who.int/sustainable-development/transport/health-risks/air-pollution/en/.

[4] Sheridan, Mary Beth. "The Scary Images of Mexico City's Pollution Emergency." *The Washington Post*, WP Company, 16 May 2019, www.washingtonpost.com/world/2019/05/16/scary-images-mexico-citys-pollution-emergency/.

[5] "Gobierno de la Ciudad de Mexico. "Afluencia Diaria De Metrobús CDMX." *Datos Abiertos Ciudad De México*, 19 Dec. 2019, datos.cdmx.gob.mx/explore/dataset/afluencia-diaria-de-metrobus-cdmx/table/.

[6] Figure 1, Amount of Ridership on Mexico City Metrobus Network, Appendix

consist of studies relating to specific regions[7] and deltas[8] of countries, and cities[9] to just name a few. However, the most notable aspect from these studies, is the consistent finding of strong correlations between remotely sensed aerosol measures and ground level data relating to PM 2.5[10] as well as PM10[11]. Using aerosol measures from the Moderate Resolution Imaging Spectroradiometer (MODIS) NASA satellite, these studies demonstrate that these aerosol measures function as a good proxy for levels of PM2.5 and PM10, allowing for the further analysis of urban air quality from remotely sensed images. Additionally, it is of note that the analysis found in this paper is largely based off literature which uses MODIS aerosol concentrations to analyze PM concentrations over the Yangtze Delta in China from 2000 to 2013[12].

Ultimately it is important to note, that because of my inability to find literature pertaining to the use of remotely sensed images in analyzing the potential impacts of new innovations in public transportation infrastructure on urban air quality, this study can be considered the first of its kind.

Background and Data

To analyze the potential impact of the Metrobús raid bus system on urban air pollution in areas surrounding its stations, this paper uses a shapefile delineating where Metrobús stations are located, the MODIS MCD19A2 satellite imagery dataset, Google Earth Engine Coder (GEEC), and OpenStreetMap data on the busiest streets in Mexico City.

To perform the difference and difference approach that this analysis relies on, I had to first identify the streets that would act as my controls to the areas which had Metrobús stations. After obtaining a shapefile from the Mexico City government which demarcated all of the stations of the current Metrobús system[13], I then consulted OpenStreetMap to finds streets that did not heavily contain Metrobús stations. After this consultation the following streets were used as a

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[7] Kopačková, Veronika, and Jan Harbula. "Air Pollution Detection Using MODIS Data." ResearchGate, 2011.

[8] Xu , Jianhui, and Hong Jiang. "Estimating Air Particulate Matter Using MODIS Data and Analyzing Its Spatial and Temporal Pattern over the Yangtze Delta Region." MDPI Sustainability, 2016.

[9] Gupta, Pawan, et al. "Satellite Remote Sensing of Particulate Matter and Air Quality Assessment over Global Cities." Science Direct- Atmospheric Enviornment, 2006.

[10] Gupta, Pawan, et al. "Satellite Remote Sensing of Particulate Matter and Air Quality Assessment over Global Cities." Science Direct- Atmospheric Enviornment, 2006.

[11] Kopačková, Veronika, and Jan Harbula. "Air Pollution Detection Using MODIS Data." ResearchGate, 2011.

[12] Xu , Jianhui, and Hong Jiang. "Estimating Air Particulate Matter Using MODIS Data and Analyzing Its Spatial and Temporal Pattern over the Yangtze Delta Region." MDPI Sustainability, 2016.

[13] Gobierno de la Ciudad de Mexico "Estaciones De Metrobús." *Datos Abiertos Ciudad De México*, 12 Nov. 2018, datos.cdmx.gob.mx/explore/dataset/estaciones-metrobus/export/.

control: Eje 6, Eje 5, Eje 7, Eje Central Lázaro Cardenas and Avenida Reforma (but the Northern portion after El Zócalo).

In addition to this information, this analysis employed the use of GEEC, to obtain satellite imagery surrounding the differing levels of aerosol level concentrations between the control and treatment streets. This analysis uses data from the NASA MODIS MCD19A2.006 Terra & Aqua MAIAC and Aerosol Optical Depth Daily 1km satellite, specifically employing the use of the aerosol optical depth and type blue band of 0.47μm.

Methodology

To properly analyze the potential impacts of the Metobús rapid bust system on urban air pollution in areas surrounding its stations, buffers were created using GEEC. To properly encapsulate an area surrounding a station this analysis employed a 400 meter buffer, although it is of note that the MODIS satellite used, measures the aerosol optical daily depth at a range of 1 km. As these areas surrounding a station were compared to control streets, these controls were also applied a buffer of 400m. Once these buffers were created for the control and treatment areas respectively, GEEC was used to extract the annual means of air pollution in each respective area. This was achieved through first selecting the Optical_Depth_047 band from MODIS MCD19A2.006, filtering by the desired date of analysis, and then subsequently using the ReduceRegion command with the desired treatment or control buffer in GEEC. After running the print command, the results of this analysis were then demonstrated in the console apparatus of GEEC. As the analysis of this paper is concerned in the potential change from 2005 to 2019, this process was conducted for both the treatment and control buffered regions in the years 2005 and 2019.

It is of important to note however, that in order to appropriately employ the use of a difference in differences strategy, the parallel trends assumption has to be satisfied. As seen in Figure 2[14], after running the same aforementioned process of analyzation in GEEC for aerosol levels in 2002, there are serious challenges regarding the satisfaction of the parallel trends assumption. Although the treatment areas had relatively more horizontal slope before the first implementation of the Metrobús network occurred, a difference in differences approach can still be employed given that one would expect to observe the control areas having lower pollution levels. However it is important to note that because of the lack of parallel trends the conclusions of this paper should be taken with a grain of salt. Lastly it is also important to mention that because the MODIS MCD19A2.006 was only fully online in 2002, the analysis of parallel trends is limited to the expressed timeframe.

The following four figures demonstrate the results of this analysis:

[14] Figure 2, Establishment of Parallel Trends, Appendix

Figure 3

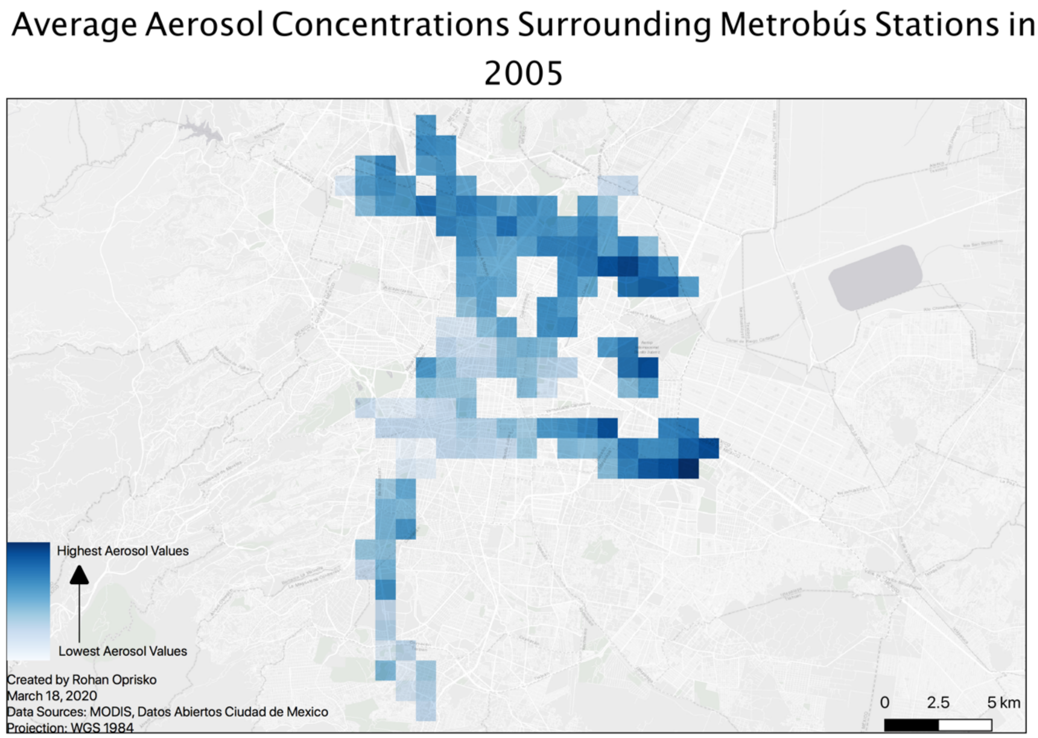


Figure 4

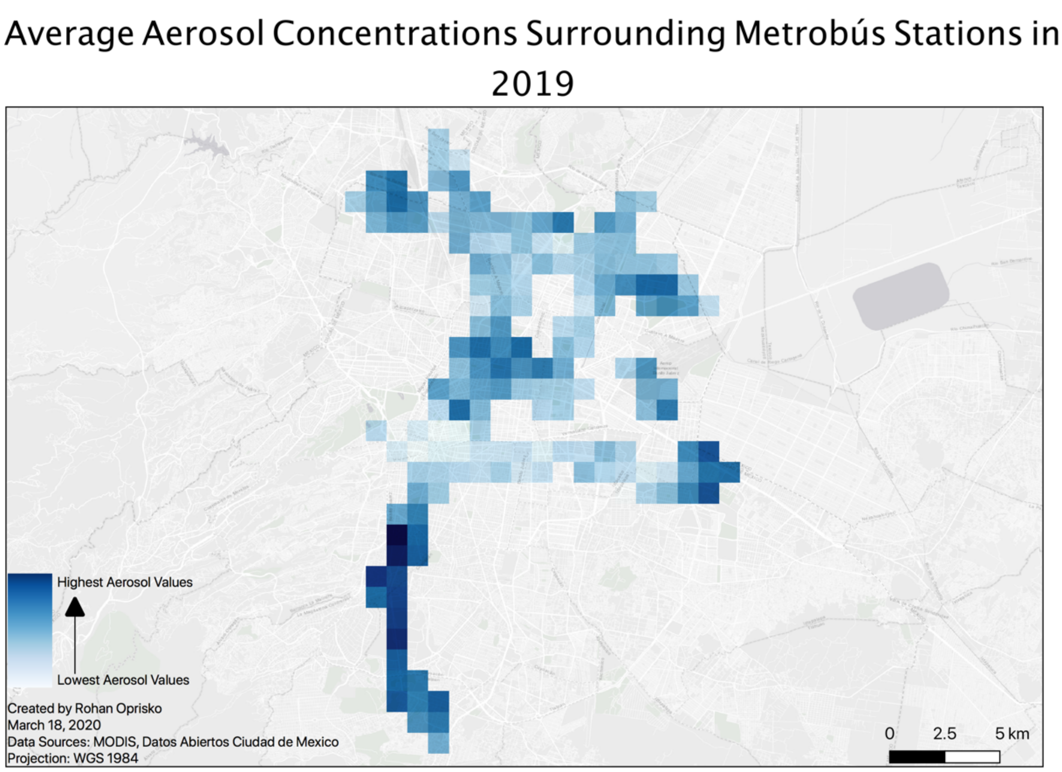


Figure 5

Average Aerosol Concentrations on Control Streets in 2005

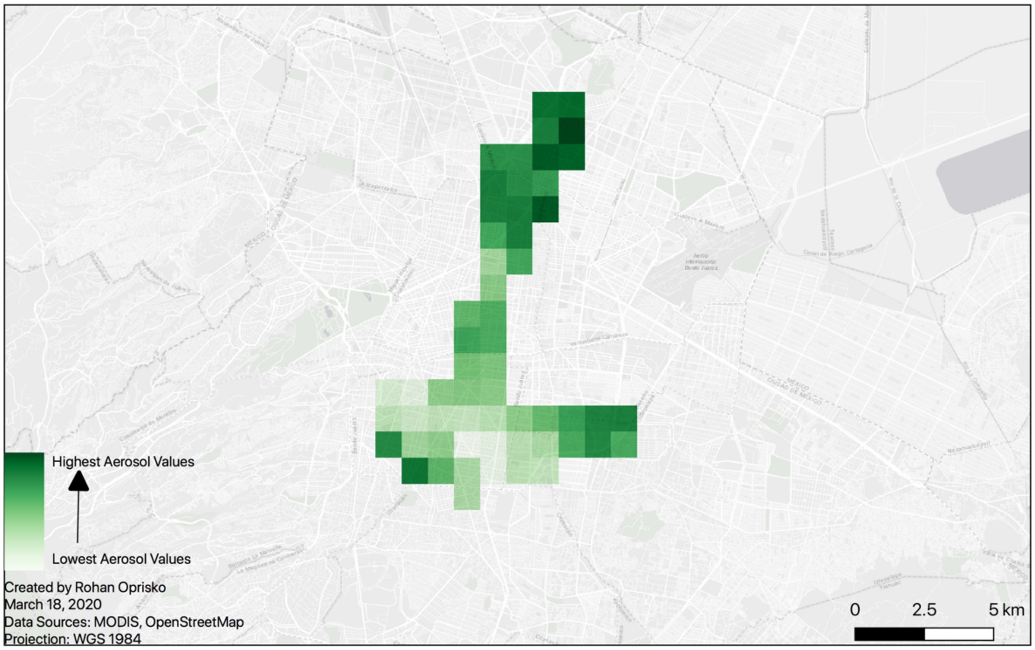
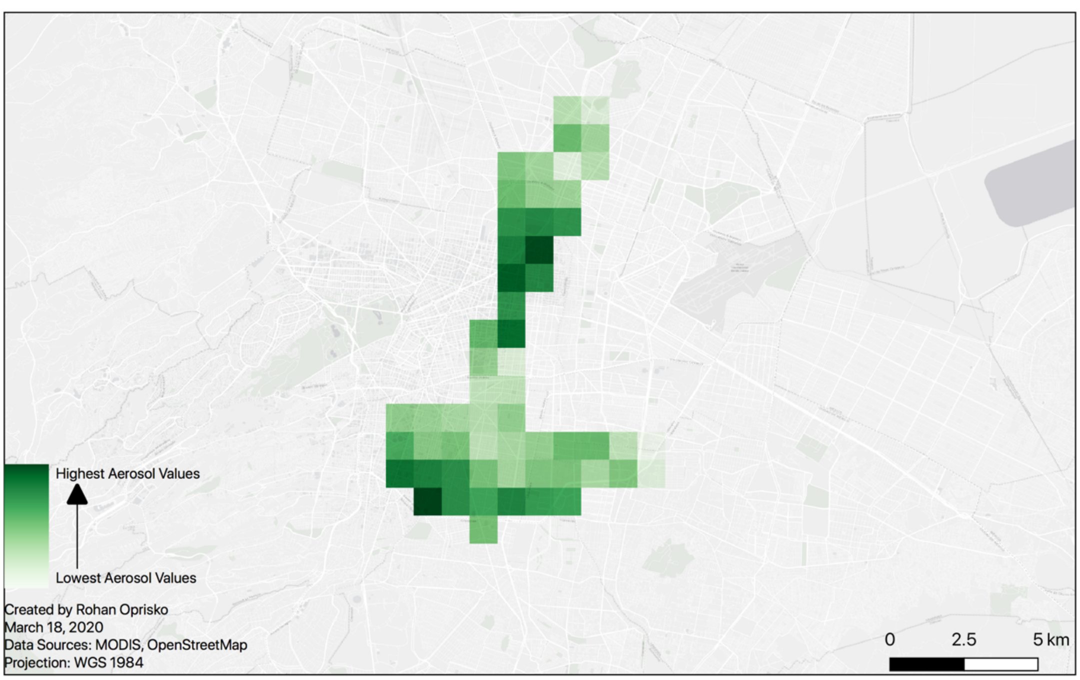


Figure 6

Average Aerosol Concentrations on Control Streets in 2019



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This analysis results in one main conclusion, that the implementation of the Metrobús rapid bus system led to a decrease in urban air pollution from 2005-2019, greater than that seen in the control streets. As demonstrated in Table 1, although both the areas saw relative decreases in urban air pollution, the areas surrounding Metrobús stations saw a decrease in aerosol optical thickness that was superior by a thickness of 4.29 to that of control streets. This supports the notion that the construction of this public transportation infrastructure decreased urban air pollution.

Table 1

Year	Treatment (Average Aerosol Optical Thickness)	Control (Average Aerosol Optical Thickness)
2005	311.00	303.82
2019	280.55	277.66
Difference	30.45	26.16

Figures 3-6 also demonstrate important findings relating to the changes in spatial distribution of urban air pollution in Mexico City. As seen in Figures 3 & 4, the implementation of the Metrobús system is associated with a significant decrease in urban air pollution in the northern part of the city, while in the center and southern regions there appears to be an increase in the relative levels of urban air pollution. With the majority of the Metrobús network constructed in the center and the north of the city, it raises the possibility that if a new line was to be constructed in the southern part of the city, that the same levels of urban air pollution reduction could be achieved.

In regards to Figures 5 & 6, it is important to note that urban air pollution levels also appear to mimic those found in the treatment areas---that there is decrease in the northern area of the city, and an increase in the center and the southern parts of the city. It is important to note however, that in comparison to Figures 3 & 4, Figures 5 & 6 demonstrate a larger increase in urban air pollution in the center and southern regions of the city. Furthermore, in regards to the decrease of urban air pollution in Figures 5 & 6 found in the northern part of the city, because of the inability of MODIS to detect at more than a 1km level, it can be said that these regions could have potentially benefited from the implementation of the Metrobús system. As this analysis cannot measure these potential spillover effects, one can conclude that the effects of the Metrobús implementation are under stated in the analysis.

Policy Recommendations

As cities come to grapple with methods on how to decrease urban air pollution, this paper provides stark evidence into the potential of protected bus lanes. As these protected bus lanes resulted in an increase of urban air quality in Mexico City, there is reason to believe that they could be successful in other cities if implemented. Additionally, as the methods of this analysis are relatively straightforward, this analysis can be conducted in a slew of other scenarios relating to novel ideas in public transportation infrastructure, to analyze if a new idea has real effects at increasing urban air quality. Some examples of novel infrastructure could be protected bike lanes, or more sophisticated protected bus lane systems than found in Mexico City. As this analysis was only done on a micro scale it would be very interesting to determine in comparing the relative impact of protected bus lanes on urban air quality across a range of different cities. This cross country and city analysis would be able to concretely determine if protected bus lanes can function in different types of cities, whether that be size or relative density, handing cities a real tool in combating high levels of urban air pollution. Nevertheless, this analysis provides insight into the potential of protected bus lanes at decreasing urban air pollution, and provides a concrete policy for dense cities to begin to tackle issues relating to poor urban air pollution.

Conclusion

This paper analyzes the potential impact of protected bus lanes, found in Mexico City's Metrobús system, on improving urban air quality in areas surrounding stations. Using satellite imagery and remote sensing techniques on data from 2005 to 2019 in Google Earth Engine Coder, this analysis employs a difference in differences approach, comparing urban air pollution in areas surrounding the Metrobús system, to control streets which have similar magnitudes of traffic. This analysis finds, that albeit of a small magnitude, the implementation of the Metrobús rapid bus system, led to a larger relative decrease in urban air pollution than that of the designated control streets. This finding strongly supports the argument that public transportation infrastructure can make a real impact in decreasing urban air pollution levels, and more specifically that the use of protected bus lanes should be explored in a variety of other cities. As urban air pollution causes 42 million premature deaths[15] around the world, it is imperative that the cities across the globe begin to properly address this issue with data proven policies.

[15] WHO. "Air Pollution." *World Health Organization*, World Health Organization, 30 Jan. 2020, www.who.int/sustainable-development/transport/health-risks/air-pollution/en/.

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Appendix

Figure 1

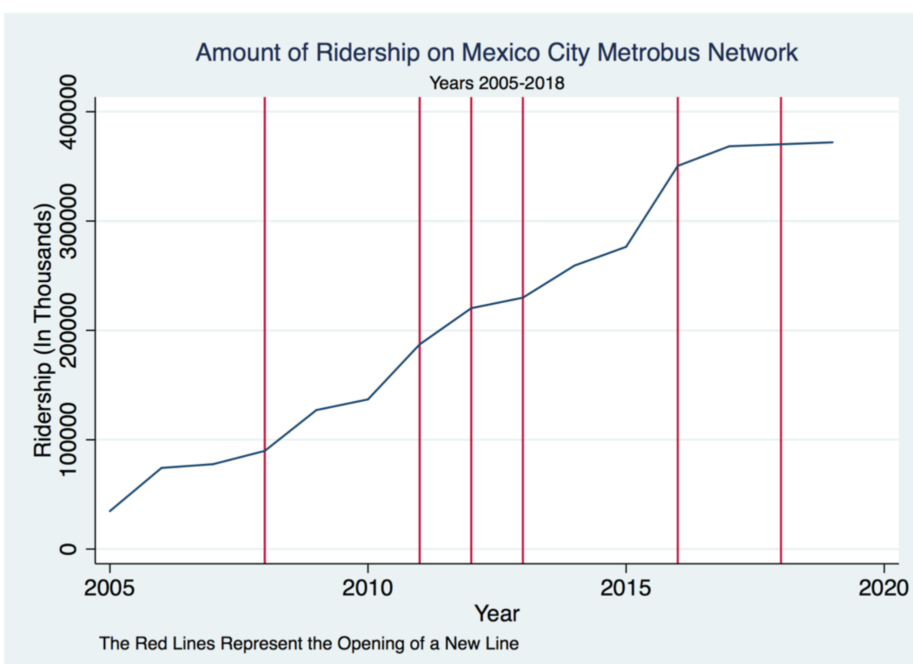
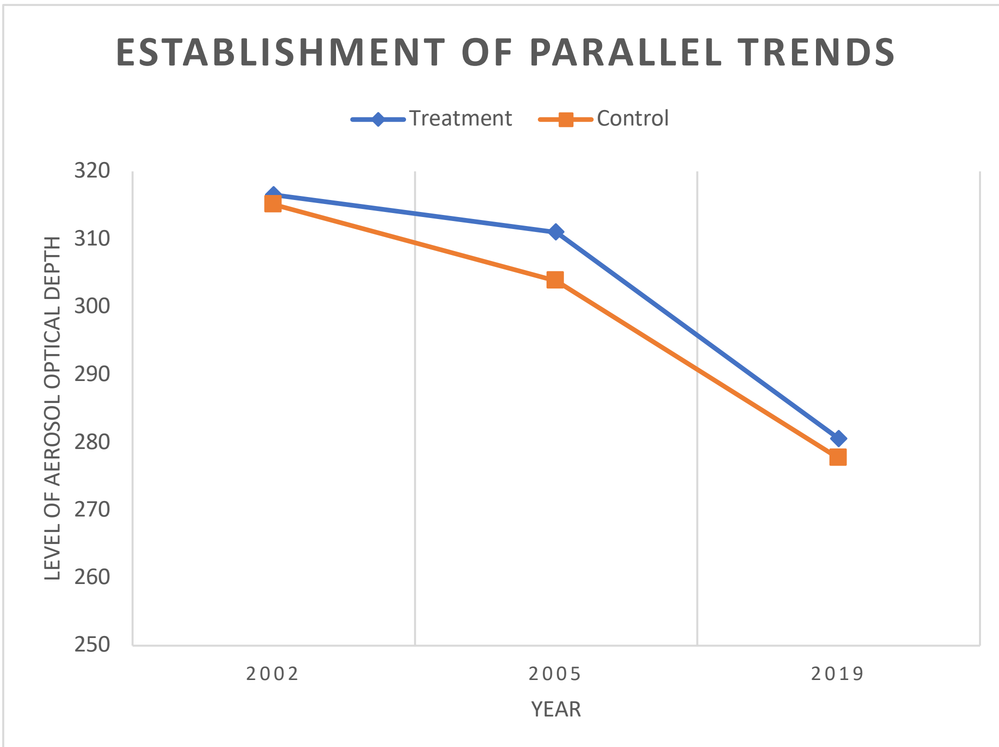


Figure 2


ESTABLISHMENT OF PARALLEL TRENDS
Treatment
Control
320
310
300
290
280
270
260
250
LEVEL OF AEROSOL OPTICAL DEPTH
2002
2005
2019
YEAR