AIR QUALITY, MOBILITY AND METROPOLITAN POLICY:

EMPIRICAL EVIDENCE FROM MEXICO CITY,

LOS ANGELES AND SAN FRANCISCO

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For my parents Carmelita and Poncho,

who supported me patiently and without restrictions throughout these years.

For Jimena and Juan,

who gave me strength when I needed it most.

For Valen and Sofi,

for whom I try to be a role model in these turbulent times.

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who lovingly endured all those long, sometimes happy and sometime bitter conversations that ended up producing these pages.

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AIR QUALITY, MOBILITY AND METROPOLITAN POLICY: EMPIRICAL EVIDENCE FROM MEXICO CITY, LOS ANGELES AND SAN FRANCISCO

This research addresses some of the most pressing problems related to metropolitan areas: The relationship between road congestion and air pollution. Chapter one develops an impact evaluation of the flagship air pollution control program of Mexico City named *Hoy No Circula* -*HNC*- (No Driving Day). This program regulates the days in which private vehicles can be used. It was first implemented in November 1989, then changed in July 2014 from an emissions-based to vehicles' age regulation, and changed again to its original form in July 2015. This research builds upon past studies by using two difference-in-differences specifications, and addressing potential spatial correlation among ambient data, and looks at the program's first implementation, and the two policy changes that have not been subject to evaluation. The findings are consistent with the results of past studies for 1989, where *HNC* had a positive impact on air quality right after its implementation, but there was a reversion of this effect after about six months due to increments in the size of the vehicle fleet and the amount of driving. For the policy change of 2014, the results show extremely modest improvements in air quality, close to nonexistent. Finally, the evidence of the 2015 return to the original rules suggest loses in air quality.

Chapters two and three address the Induced Travel phenomenon in the metropolitan areas of Mexico City (chapter two) and Los Angeles and San Francisco (chapter three). This phenomenon portrays the relationship between road capacity, and the use of private vehicles, reflecting that additional road capacity tends to induce decisions about increasing the amount of driving by shifting hours, routes, transportation modes, distance traveled, or making additional trips in the short run; and overall increases in vehicle ownership, reallocation of activities, and shifts in urban development patterns in the long run. The main concern behind Induced Travel is that increments of road capacity may end up reducing the overall efficiency of the transit system. This relationship is affected by the availability of public transportation, since it is an alternative for vehicle use, and increasing road capacity represents an opportunity cost to increasing public transportation capacity. This research uses recursive and simultaneous equations systems for a 17-year period (2000-2016), at the municipality and metro area levels. The findings show the existence of Induced Travel in the three metropolitan areas, and measure the effect size in terms of additional (induced) registered vehicles as a consequence of road-related infrastructure investments.

Chapter four summarizes the policy implications of the three chapters and puts forward a set of policy alternatives to address road congestion and driving-related air quality loss in Mexico City. The proposal is based on the limitations of current policies, and the implementation of more advanced market-based policies in different cities of the world.

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CURRICULUM VITAE

CHAPTER 1:

HOY NO CIRCULA: AN IMPACT EVALUATION OF MEXICO CITY'S FLAGSHIP AIR POLLUTION CONTROL PROGRAM

Abstract

The flagship air pollution control program in Mexico City Metro Area (MCMA) named *Hoy No Circula -HNC-* (loosely translated as No Driving Day) regulates the frequency in which motor vehicles can be used in the city from Monday to Saturday based on a biannual vehicle-emissions checkup. Such mandate was first implemented in November 1989, then changed in July 2014 from the emissions-based standard to vehicles' age regulation, and changed again to its original form in July 2015. It can be argued that neither of the two policy changes responded to shifts in the trends of air pollution concentrations in the city, but rather to increased levels of corruption in the emissions checkup centers in 2014, and to judicial contentions about the new rules in 2015, making them exogenous policy changes. The goal of this paper is to conduct an impact evaluation of *HNC* on MCMA's air quality at its three most relevant moments in time: its first implementation (1989), and the two policy changes (2014 and 2015). Past studies used interrupted time-series to show that the program, when first implemented, was relatively ineffective for reducing pollution; however, it substantially increased the number of vehicles in the city, offsetting environmental quality improvements. While the effects are consistent in the short run, in the longer run they remain elusive. This research builds upon those studies by using two difference-in-differences specifications with alternative controls, and addressing potential spatial confounders between monitoring stations that are inherent to ambient data, thus providing a more robust quasi-experimental design. In addition, this research looks at the program's first implementation, but also at the

latest two policy changes that have not been subject to evaluation. For *HNC*'s first implementation, the results show statistically significant decreases in CO and O_3 concentrations in the short run, and increments in the middle/long run. A similar pattern is observed for NO_X and NO_2 in the long run. This evidence supports the findings of past studies, where *HNC* had a positive impact on air quality right after its implementation, but a reversion of this effect after about six months due to increments in the size of the vehicle fleet and the amount of driving. For the policy change of 2014, the results show extremely modest improvements in air quality, close to nonexistent. CO experienced mild increases in concentrations, however the opposite is true for NO_X, NO_2 and O_3. Finally, the evidence of the 2015 return to the original rules suggests significant loses in air quality. CO, NO_2 and O_3 experienced short and long run increments in concentrations, however this was not the case for NO_X.

1. Introduction

The flagship air pollution control program in Mexico City Metro Area (MCMA) named *Hoy No Circula* (-*HNC*- loosely translated as No Driving Day) regulates the frequency in which most motor vehicles[1] can be used in the city on weekdays based on a biannual vehicle-emissions checkup. *HNC* was first implemented on November 20, 1989, and then faced two likely exogenous substantive policy changes on July 1st, 2014, and then a little over one year afterwards, on July 9, 2015. The goal of this research is to identify the impact that implementing, and then reforming *HNC,* had on air quality and on the size of the vehicle fleet in MCMA.

[1] Exempt vehicles are: Emergency vehicles, motorcycles, school transportation, funeral service vehicles, intercity bus services, vehicles that do not use fossil fuels, vehicles used by the disabled, and approved vintage/classic vehicles.

HNC was implemented in 1989 as an emergency measure for reducing extreme pollution concentrations caused by the phenomenon of thermal inversion, which regularly occurs in Mexico City during the winter season. Data from the short-term period at the time showed reductions in several pollutants presumably related to the program. Reinforced by the public's warm welcome, policy makers decided to make *HNC* a permanent program, thus becoming the most important air pollution control policy in MCMA.

Before *HNC*, several cities around the world had implemented similar policies, such as *Día de Parada* (Stay Put Day) in Caracas, Venezuela in 1979, *Dactylios* (Drive Around) in downtown Athens, Greece in 1982, and *Restricción Vehicular* (Vehicle Restriction) in Santiago, Chile in 1986. Since then, more and more cities around the world have adopted similar driving restriction policies, such as Beijing, Bogota, Lima, London, or Paris. Their aim is to reduce vehicle usage by raising its costs, either at the city level or in specific zones, which in turn should reduce emissions, traffic congestion, or both.

When first implemented, Mexico City's *HNC* worked as follows: Every private motor vehicle registered in the Federal District (currently known as Mexico City) and in the State of Mexico[2] was required to undergo an engine check-up (*verificación vehicular*) twice a year. Each check-up had to be performed at specifically designated facilities within a two-month predefined period that depended on the last number of the vehicle's license plate. The check-up used an index that included measures of hydrocarbons, NO ppm emissions, CO, O_2, and their diluted percent volume in the overall emissions. The resulting index value was then compared to a standard based on the vehicle's model year. Depending on the relative engine performance, the vehicle would receive a zero-, one- or two-day usage restriction.

[2] The State of Mexico surrounds the Federal District on its north, east and west portions. In 1990, the Metropolitan Area of the Valley of Mexico (Greater Mexico City Metropolitan Area) had 15.5 million inhabitants, out of whom 52.9% lived in the Federal District, 47.1% lived in the State of Mexico, and 0.01% in (the state of) Hidalgo. (CONAPO, 2010)

After the check-up, a hologram sticker was put on the vehicle with a printed zero, one, or two, corresponding to the number of days the vehicle would face the restriction. The applicable days depended on the last number of the vehicle's license plate, which was coupled with an identification color sticker. For example, license plates ending in five or six (yellow sticker) were restricted on Mondays, nine or zero (blue sticker) on Fridays, and so on. Weekends were free of restriction.

As mentioned, the program was originally designed to be an emergency measure to address the extreme pollution concentration at the time. However, when the program became permanent, it had several unintended consequences. Most authors agree that the most important one was that a few months after the *HNC*'s implementation, households made calculations on the additional costs induced by the driving restrictions and adjusted accordingly, in many cases by acquiring additional vehicles. These additional vehicles were mostly older vehicles imported from other states, with lower expected fuel efficiency. (Cantillo & Ortúzar, 2014; Davis, 2008; Eskeland & Feyzioglu, 1997; Gallego, Montero, & Salas, 2013)

Therefore, the claim is that the presumed benefits of the program in the period right after its implementation (lower air-pollution concentrations due to fewer and more fuel-efficient vehicles), were offset in the middle and long run. Furthermore, it is possible that the number of trips made by members of households that acquired additional vehicles increased, since the number of unrestricted vehicle-days went up, even if all vehicles had a two-day restriction. Hence, it is possible that these additional trips offset the number of avoided trips due to the restriction, even to the point of having a net increment in trips, traffic congestion, and pollution emissions.

Twenty-five years after *HNC* was implemented, in July 1st, 2014, the program was changed, shifting from emissions-based regulation to a policy based on the vehicles' age. The new rule stated that vehicles of up to eight years of age would face no restriction, and vehicles from nine to 15 years old would have a one-day restriction on weekdays, in addition to two Saturdays a month. Vehicles of 16 years old and older would face this same restriction as long as they met the standard's emissions limit, otherwise facing a one-day restriction on weekdays, in addition to all Saturdays.

It can be argued that this policy change did not respond to shifts in the trends of air pollution concentrations in the city, but rather to increased levels of corruption at engine check-up centers, where vehicle owners would pay bribes to obtain hologram stickers that allowed them to use their vehicles daily, instead of being forced to stay put up to two days per week. The new rule only lasted for a little over a year, since many vehicle owners claimed that their older, however well-maintained automobiles met the emissions standards, contending there was no legitimate justification for restricting their use.

These contentions reached the Supreme Court of Justice, which ruled in favor of vehicle owners in early July 2015. Even though the Supreme Court's ruling applied only to those who filed the contentions, the environmental authorities of the Federal District, the State of Mexico, and the neighboring states of Hidalgo, Morelos, Puebla, and Tlaxcala decided to go back to the previous emissions-based program on July 9, 2015. Thus, it is fair to assume that both policy changes were exogenous, providing the opportunity for undertaking an impact evaluation of the effects of the policy changes on air pollution emissions and trips in MCMA.

2. Literature Review

Road-based transport has several negative effects (negative externalities), mainly in the form of pollution emissions and road congestion, that have been widely researched especially for the United States, but also for many developed countries. (Rothengatter, 1994) In the case of Mexico, there are only a few such studies that suggest that this field of research is still on its early stages, nonetheless they show that the air quality loss problem occurring in all major Mexican cities, coupled with increasing road congestion is becoming a relevant issue in the research agenda. (Guzmán, Yúnez-Naude, & Wionczek, 1985; Parry & Timilsina, 2010) Cravioto, Yamasue, Okumura, and Ishihara (2013) measure overall road transport negative externalities for Mexico (at the country level) using seven categories: a) air pollution, b) greenhouse gases, c) noise, d) accidents, e) congestion, f) infrastructure and g) other externalities. They found that the total costs of road transport negative externalities amount to an average of US$59.4 billion per year, or 6.2% of the nominal GDP (for 2006).

In order to cope with these negative externalities, several approaches have been put in practice in different cities of the world. Some of the most salient are the congestion charges, which have been mostly studied in London, Singapore and Stockholm. (Albalate & Bel, 2009) These measures have proved to be relatively successful, despite the fact that they have faced relevant obstacles, mainly in the form of public acceptance and because of concerns related to social equity and the distribution of the costs of these measures. (Quigley & Hårsman, 2010; Santos, Fraser, & Newbery, 2006; Thomson, 1998) Another set of instruments that have been widely studied from a theoretical perspective, however have not yet been implemented in any city, are the so-called tradable driving permit programs, which are analogous to the cap-and-trade systems for point source pollution emissions control. (Dogterom, Ettema, & Dijst, 2017; Goddard, 1997; Grant-Muller & Xu, 2014) These tradable driving permit programs have the potential, at least in theory, to transform the way in which mobile-source pollution and road congestion in cities are managed, but there is still no city that has moved toward implementing such a system, thus there is no empirical evidence about its actual ability to internalize these negative externalities, and about its effects over controlling air pollution and road congestion problems.

The third policy approach to tackle these problems, is to enforce driving restrictions based not on economic incentives, but rather on direct vehicle use restrictions on specific days, times and areas of the city, such as the *HNC*. These programs have been implemented in many cities of the world, since they are relatively simpler to implement by relying on direct enforcement by the transportation authorities. These programs have been found generally ineffective or with limited positive effects, coupled with side effects, such as the increase in the vehicle fleet as was observed in Mexico City. The observed effects for the case of the *Dactylios* program in Athens, which is one of the early vehicle restriction programs, were of reducing road congestion within the controlled area, but with an opposite effect for the area outside the restriction zone, where road congestion substantially increased. (Matsoukis, 1985) Studies have found that the *Pico y Placa* programs in Bogota and Medellin, Colombia had a mild positive effect in the short run in terms of reducing pollution emissions, however, these emissions returned over time to levels similar to when the programs were implemented. However, in both cities there was an observed increment in the vehicle fleet size. (Camargo Diaz, 2017; Posada Henao, Farbiarz Castro, & Gonzalez Calderon, 2011; Ramos, Cantillo, Arellana, & Sarmiento, 2017) Opposite to what was observed in Colombia, in Quito, Ecuador, the *Pico y Placa* program had a positive effect on air quality, without the commonly associated road congestion side effects. (Carrillo, Malik, & Yoo, 2016).

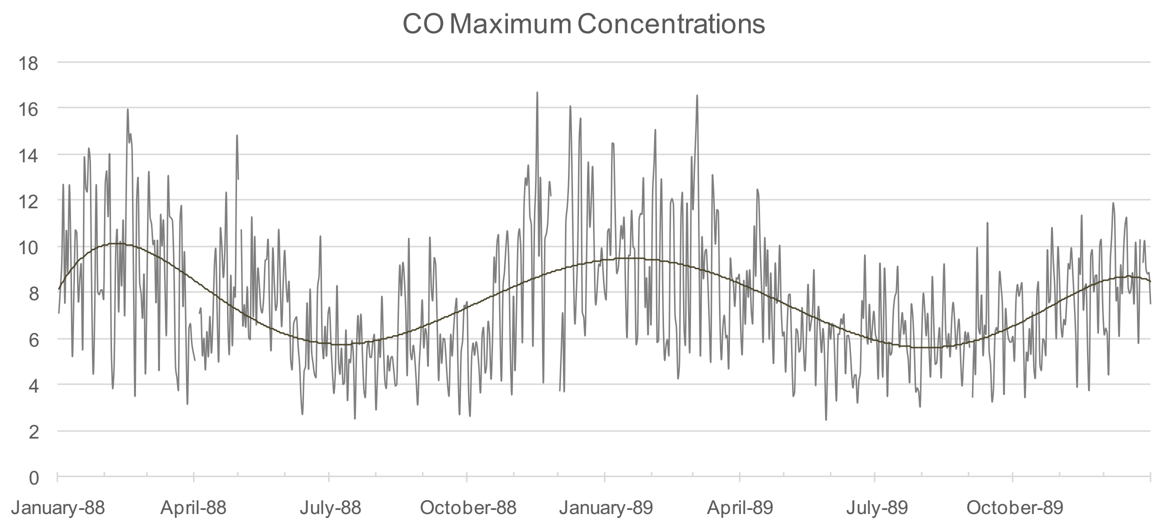
For the case of Mexico City, several assessments about the effects of *HNC* have been developed in the past. Most of them are observational or correlational studies that lack the ability to provide causal evidence of the impacts of the program. However, three of them use quasi-experimental methods, reaching conclusions that reflect stronger evidence than the former type of studies. Nonetheless, there are methodological concerns that might affect their findings. Eskeland and Feyzioglu (1997) look at the effects of *HNC* on fuel consumption and vehicle ownership by developing two formal models. The first model shapes the gasoline demand function. The second focuses on behavioral change based on household characteristics suggesting expected responses to the vehicle usage restrictions, such as shifting to different transportation means or acquiring additional vehicles. Using data prior to the first implementation in 1989, Eskeland and Feyzioglu estimate the values for fuel consumption and vehicle usage for the post implementation period. These predicted values are then used as counterfactual to the observed values, where the differences reflect the causal effects of the program. Regardless of the relative strength of their models, the fact that they do not have actual empirical data to use as a counterfactual, but rather the estimated values of their models, makes their findings contestable.

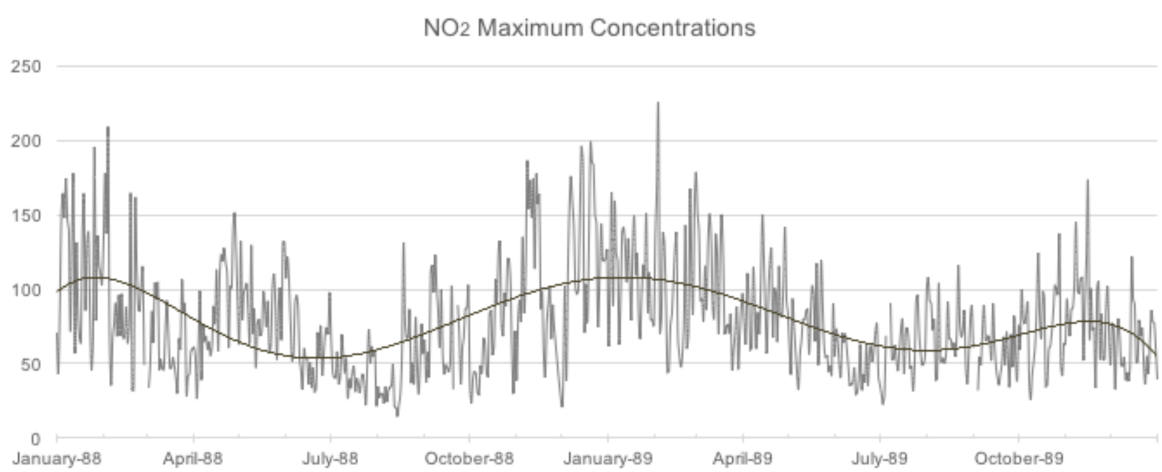
Davis (2008) and Gallego et al. (2013) use interrupted time-series, which is the simplest type of regression discontinuity design (RDD), (Shadish, Cook, & Campbell, 2002) to look at the effects of *HNC* on pollution emissions, and on the size of the vehicle fleet. In both studies, no running (or forcing) variable that randomly assigns treatment and control groups on either side of the cut point is present, other than time. The basic idea in this design is that, for a short period of time, right before and after the implementation of *HNC*, nothing changed in the conditions affecting pollution concentrations, except the implementation of the policy. Thus, comparing the outcome variable on both periods should provide a measure of the causal effects of the program.

For an RDD, a key internal validity assumption is that the control and treatment groups are equal in expectations, and this is only plausible over a narrow window around the cut point. (Murnane & Willett, 2010) Since an interrupted time-series uses time as the cut point, the equality of expectations assumption will be plausibly met at relatively short periods of time before and after implementation of the policy only. In practical terms, the equality of expectations assumption for an interrupted time-series means that the more time passes by, the greater the chances that conditions, other than the implementation of the policy, will change, therefore challenging any claim of causal effects. In other words, in both studies only those effects observed in the short-term (local average treatment effects) would plausibly be meeting the equality in expectations assumption.

However, even the findings for a short-time window around the policy implementation may be challenged by the fact that pollution concentrations follow a seasonal trend, although the intensity of the cycle varies for each pollutant. Most of them reach the peak during the winter, and the lowest point is reached during the summer months as shown in Figure 1 for CO and NO_2 (O_3 follows the opposite pattern).

Figure 1. CO and NO_2 maximum concentrations 1988-1989





Source: Iracheta, J.A. using MCMA's Automatic Network of Atmospheric Monitoring data.

It is plausible to consider that some of the variation in pollution concentrations responds to a seasonal change, rather than to the actual policy. Furthermore, the most important unintended consequence of *HNC* (many households acquiring additional vehicles, which in turn increased the size of the vehicle fleet that potentially offset the emissions reductions), may not be captured under those designs. It is likely that such adjustment by households took place over a longer period of time, since acquiring a vehicle implies an unusually large expense. Therefore, it is reasonable to consider that a simple interrupted time-series design will not be able to capture these unintended, yet causally related effects, since they happened outside the window where the equality in expectations assumption was likely met.

Because of the previous arguments, the research design in these three studies limits the validity of their findings even though they are relatively consistent. A more robust design would include a counterfactual that accounts for variations on the secular trend (i.e. the seasonal nature of pollution concentrations over time) as well as for other potential changes in the conditions that affect pollution concentrations but are not related to the implementation of the policy. A difference-in-differences would be such a design, and in addition would allow to better control variations in the outcome variable within a broader time window. This would allow capturing the immediate effects of the policy, as well as those that presumably took place when households acquired additional vehicles to adjust to the policy.

Another methodological concern with the existing research is that spatial data, such as pollution concentration, is likely to be correlated with observations from neighboring geographical units. Since emissions flow from one location to the next, such correlations may be biasing the results. Such a feature of ambient data is usually addressed by including variables controlling for geographic proximity between stations; however, none of the existing studies considers this potential confounder. A widely accepted method for testing the existence of spatial correlation is using Moran's I statistical test. (Ward & Gleditsch,

2008) For the case of air quality monitoring stations, a good way for running this test is building a standardized inverse Euclidean distance matrix, that is then used for weighting the correlation between stations. (Pisati, 2016) There is strong evidence of the existence of spatial correlation between monitoring stations in Mexico City, both in 1989 and 2014:

Table 1. Moran's I test of no spatial correlation

November 1989					
Pollutant	Time period	Type of weight matrix	Matrix size	Mondays (p-value)	Fridays (p-value)
CO max 8 hrs.	November 1989	Distance-based (inverse distance)	8x8	0.365	0.047
NO_X max day			5x5	0.181	0.051

June-July 2014					
Pollutant	Time period	Type of weight matrix	Matrix size	Mondays (p-value)	Fridays (p-value)
CO max 8 hrs.	June-July 2014	Distance-based (inverse distance)	20x20	0.014	0.007
NO_X max day			26x26	0.000	0.000

Source: Iracheta, J.A. using MCMA's Automatic Network of Atmospheric Monitoring data.

The results of the Moran's I test present evidence to assert that measurements of ambient pollution concentrations in MCMA are correlated between neighboring monitoring stations, and such a feature should be included in all models that use their data. Such evidence is very strong for 2014, however it is not as much for 1989, but when running the test for every day of the week, its value increases (therefore reducing the p-value) as it approaches Friday. This research intends to build upon past studies to improve the understanding of the *HNC* impacts on Mexico City's air quality.

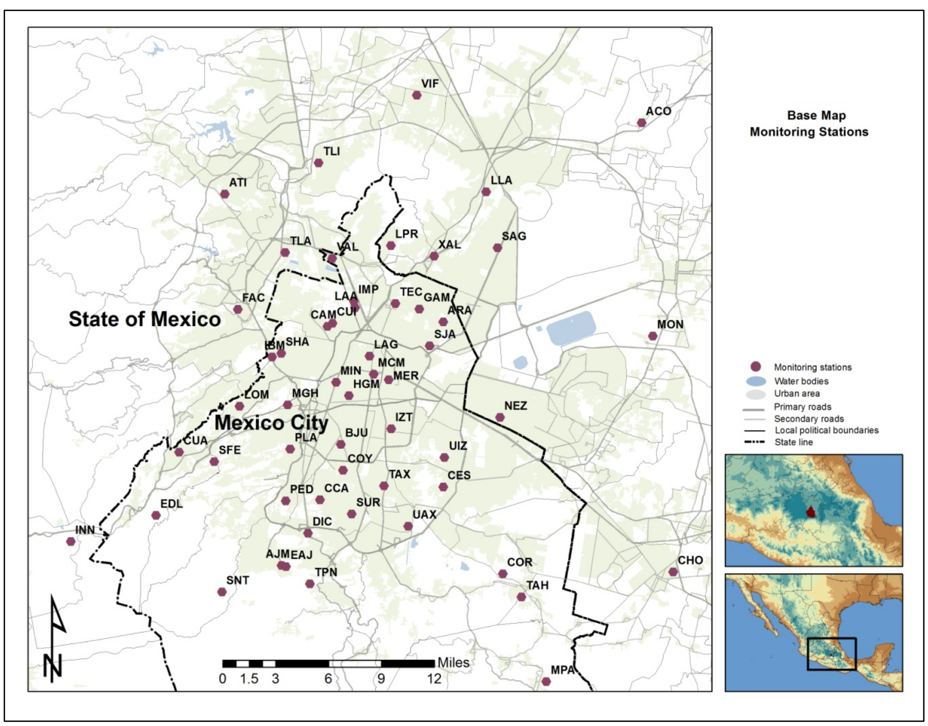
3. Data and Methods

a) Data

This paper uses historical data for CO, NO_X, NO_2 and O_3 emissions as outcome variables. The data were obtained from Mexico City's Automatic Network of Atmospheric Monitoring

(*RAMA* for its Spanish acronym), where each station reports hourly measurements of those pollutants (however not all stations measure all pollutants). PM_{10} and $PM_{2.5}$ were not considered in the analysis since these pollutants are strongly dependent on other environmental factors, rather than on vehicle's emissions. The *RAMA* network started working in 1986 with 11 stations and, together with three other networks, the monitoring capacity has substantially increased to 56 stations as of 2017. In 1989, only 15 stations were in place and reporting pollution measurements, and for 2015, between 21 and 36 stations reported data depending on the compound. The hourly measurements were transformed to daily measurements based on the Mexican standards for ambient pollution concentrations. The transformations used the maximum eight-hour mean concentration per day for CO, (Salud, 1993a) the maximum daily value for NO_X, for NO_2, (Salud, 1993b) and for O_3. (Salud, 2014)

Map 1. Mexico City Metro Area air quality monitoring stations



Source: Iracheta, J.A. using MCMA's Automatic Network of Atmospheric Monitoring website, monitoring stations location.

There are additional variables, such as those related to weather conditions, as well as economic activity, that are expected to affect pollution concentrations in Mexico City, and therefore they should be controlled for in order to limit the effect that confounding factors might have on the models. As for weather conditions, wind and rain serve for dispersing the pollutants, therefore having a positive effect on air quality. Higher temperature tends to have a negative effect on air quality since it may favor the generation of photochemical smog and ozone. All models use three-hour measurements for maximum and minimum temperatures, wind speed during pollution peak hours, and maximum daily levels of rain in Mexico City. These variables were provided by the Mexican National Meteorological Service.

Economic activity may also have an effect over pollution concentrations. When economic activity is more dynamic, everything else constant, one would expect to observe higher levels of pollution concentrations due to presumably higher number of trips of all kinds taking place in the city, higher levels of production output and of production and delivery of all kind of services. Therefore, since it is expected that economic activity would have an effect on pollution emissions, however unrelated to *HNC*, it might be a confounder, thus it should be controlled for within the models. Several sources were used to include variations on economic activity, depending on their availability. Given the lack of daily or weekly information for 1989 about economic activity or economic output, the best available proxy was the daily close values of the Dow Jones Index, and starting in 1988, the Mexican Stock Exchange (MexBol) index. For 2014 and 2015, the biweekly Mexican National Index of Consumer Prices (*INPC* for its Spanish acronym), and the daily MexBol index were used, in addition to the monthly index of industrial activity by sector for Mexico City (*IMAI* for its Spanish acronym). In the case of the *INPC*, the expected effect depends on its changes relative to past periods, where higher inflation would reduce consumption and economic activity, and relatively lower inflation would increase both. Finally, for controlling for spatial correlation, a matrix of standardized inverse Euclidean distances between monitoring stations was used, where smaller distances reflect higher values.

b) Methods

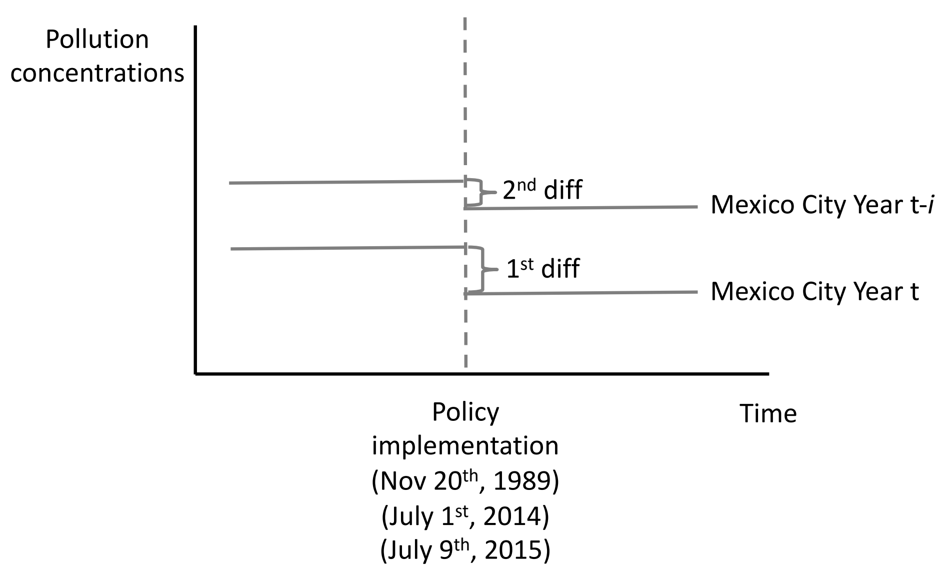
All models use a Difference-in-Differences research design (DID), considering alternative specifications with two different control groups that are intended to estimate the impact of *HNC* on pollution emissions. To estimate the dimension of the impacts of *HNC*, the DID research design estimates the expected value of the outcome variable before and after the implementation of the program, taking the difference between both periods, and then subtracting the difference observed in the control variable for the same pre and post periods. The remaining difference (the difference in the outcome variable minus the difference in the control variable) provides the net causal effect of the program. The general functional form is the following:

$$Y_i = \beta_0 + \beta_1(Treat_i) + \beta_2(Post_i) + \beta_3(Treat_i * Post_i) + X_i\beta + \epsilon_i$$

Where Y_i is the outcome variable, $Treat_i$ is a dummy for the treatment group, $Post_i$ is a dummy for the post implementation period, and $(Treat_i * Post_i)$ is an interaction term of the two dummies, where β_3 represents the policy effect (net impact). $X_i\beta$ is a vector of covariates that includes variables for weather conditions, economic activity and an index of the inverse Euclidean distance between monitoring stations; and ϵ_i is the error term. The purpose of using two different specifications for measuring the impact of *HNC* on pollution concentrations is to reduce the potential bias inherent to the limitations of each DID design given the availability of data, in particular for 1989. Under such conditions, none of the possible counterfactuals is ideal, and each of them faces particular restrictions, however considering the overall relative consistency and convergence of the findings, the likeliness of obtaining biased results is minimized. As such, this paper is able to provide stronger evidence about the effects of the *HNC* on MCMA's air quality. Since the two specifications are intended to measure the environmental impact of *HNC*, pollution emissions are the outcome variable.

To understand the structure of the first DID specification it is best to allow some level of abstraction. One can assume that there is an identical city to Mexico City that shares the same geographic and weather conditions with the same seasonality, as well as other relevant characteristics, such as population, economic activity and productive plant. If such city existed, it would be an ideal candidate to use as counterfactual for comparing the changes in pollution concentrations resulting from the implementation of *HNC*. Such city is Mexico City itself, but looking at it in previous time periods. In particular, one can look at the same corresponding days of the year in which the *HNC* program was implemented, but one and two years before. It should be evident that the vast majority of conditions would be the same, except for those changes that occurred during the last year. Of special interest would be those changes that might affect pollution emissions, such as changes in economic and/or industrial activity.

Figure 2: DID using data from prior years as control (specification one)



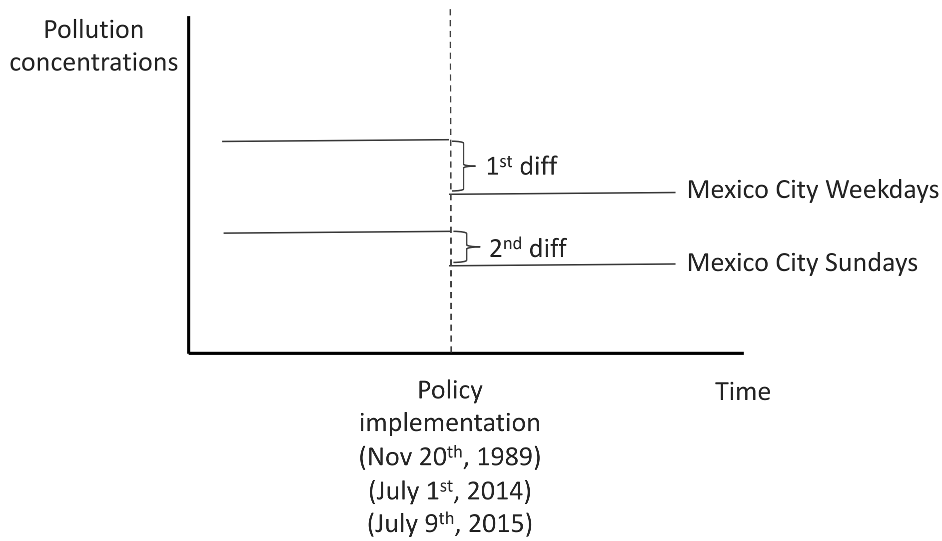
Source: Iracheta, J.A.

Unavailability of economic or industrial activity data for 1989 (other than yearly measurements for Mexico City, or three-month GDP at the national level) raised the question of whether having relevant information that may affect pollution was being excluded from the models, thus biasing the results. In 1988, the General Law of Ecological Equilibrium and Environmental Protection (*LGEEPA* by its Spanish acronym) was promulgated, considering several actions to improve air quality in Mexico City. Some of those actions involved reducing lead content in gasoline fuels, gradually substituting fuel oil with natural gas in the main Mexico City's power plant, as well as relocating highly polluting industries out of the city. (Molina & Molina, 2002) Most of these actions started taking place on the early years of the 1990s under the Comprehensive Program for Air Pollution in MCMA (*PICCA* by its Spanish acronym). (Molina & Molina, 2002) One of the most significant actions was the shutdown of the Ascapotzalco-18 de Marzo oil refinery, located in northern Mexico City, in March 18, 1991, which was the facility with the worst air pollution record. Other industrial facilities were also moved out of the city during this period; however most of these actions took place at least one year after the period of implementation of *HNC*. Therefore, it is fair to assume that no major changes over factors affecting air pollution occurred in the two-year period prior to the program's implementation, making this specification viable.

Nonetheless, it is likely that some unobserved factors that are consequence of *PICCA* and that have a positive effect on Mexico City's pollution concentrations, such as early relocation of minor polluting facilities or marginal increments in the substitution of gasoline fuels by natural gas, will remain uncontrolled for. Thus, it is reasonable to expect some degree of positive bias in the results, i.e. an overestimation of the effects of *HNC*. That being said, it is also reasonable to expect that the degree of such bias will be relatively low, and will not substantially affect the outcome.

The second DID specification uses Sundays' concentrations as counterfactual. Since *HNC* in its original design did not impose driving restrictions on weekends (later on, some level of restriction was imposed on Saturdays), one would be able to use changes in pollution concentrations during these days as control for the changes occurring on weekdays. The data for 1989 show a consistently different pattern in pollution concentrations on Sundays when compared to weekdays. This difference is particularly clear for CO and NO_2, however it is not so much for O_3.

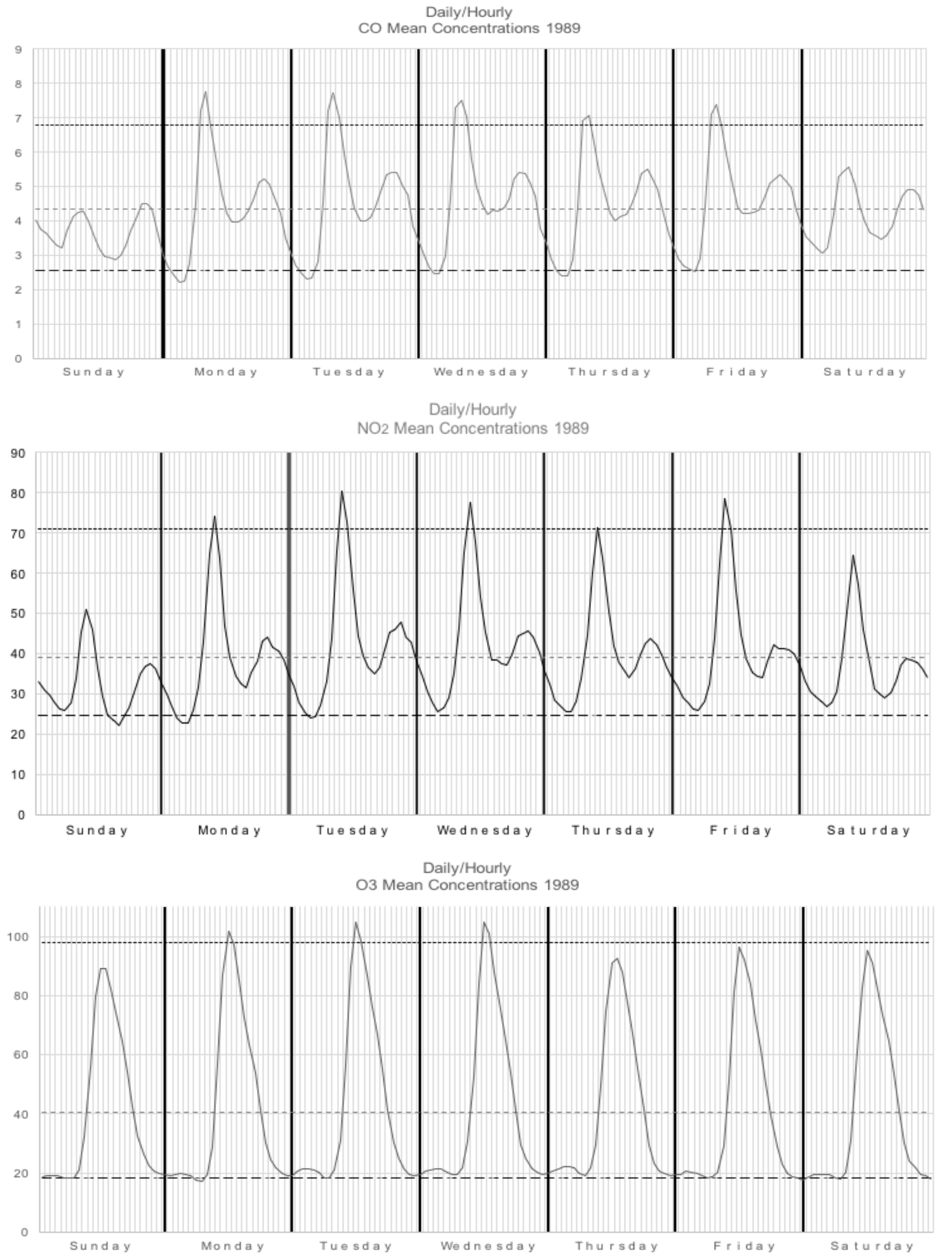
Figure 3. DID using Sundays' concentrations as control (specification two)



Source: Iracheta, J.A.

Median life of pollution concentrations is usually longer than 24 hours; therefore, it is likely that some proportion of the concentration observed over the weekend remains as residual from Fridays, or even Thursdays, conceivably generating some bias. By using Sundays only, such potential for bias is reduced; however, it is likely that some of it would remain.

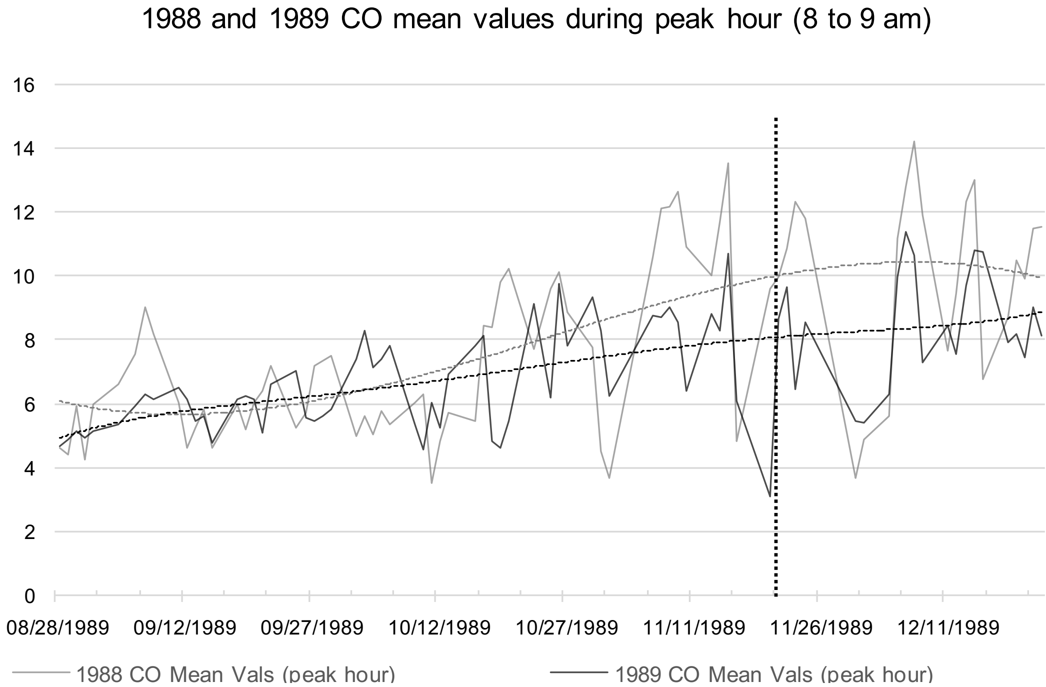
Figure 4. MCMA CO, NO_2 and O_3 mean daily and hourly concentrations

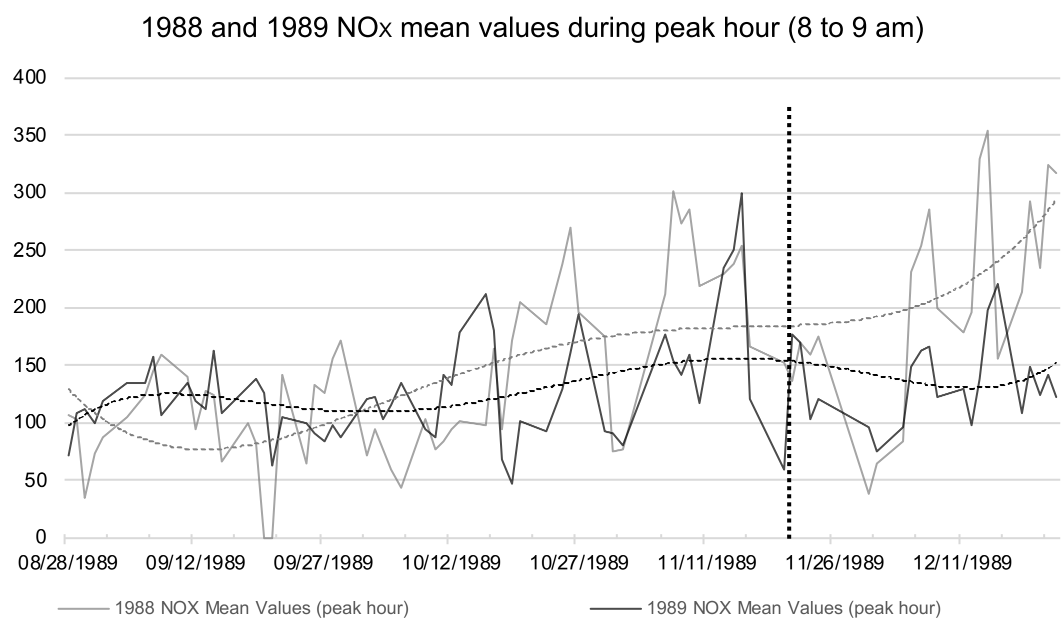


Source: Iracheta, J.A. using MCMA's Automatic Network of Atmospheric Monitoring data.

Finally, in order to assess the compliance of the parallel trend assumption that is required for a consistent DID research design, visual tests of the performance of all pollutants at the three time periods (1989, 2014, and 2015) were performed and the assumption was met.

Figure 5. CO and NO$_X$ parallel trend assumption visual test 1988-1989





Note: Lighter dotted lines show the control groups, whereas darker dotted lines show the treatment groups.

Source: Iracheta, J.A. using MCMA's Automatic Network of Atmospheric Monitoring data.

4. Results and Discussion

This section begins by discussing the impacts of *HNC* on CO, NO_X, NO_2 and O_3 emissions at the program's first implementation in 1989, then moves on to the 2014 policy change, and finally discusses the 2015 return to the prior rules of *HNC*. The analysis for each pollutant and DID specification uses, in the first place, the pooled overall daily mean and maximum values for all stations with available data controlling for spatial correlation and, in the second place, the maximum concentrations for each individual station. Also, the results are differentiated for the short- and middle-run (three to six months, and six to 24 months), since it is likely to find different, and even opposite directions for the effects depending on the time span. Recall that most literature indicates that a relevant indirect effect of *HNC* was to increase the size of the vehicle fleet in the city a few months after the enforcement began, which conceivably offset the reduction in pollution concentrations occurring right after the program's implementation. Such an effect should be observable in a period between three months and one year, which is enough time for households to adjust to the policy and acquire additional vehicles. While this adjustment has been widely discussed in the literature for the first implementation, there is no evidence available for the 2014 and 2015 policy changes. To make comparisons and interpretations straightforward, all regression coefficients for all models are presented in standard deviation units.

a) *HNC* 1989 First Implementation

We first take a look at the results for **specification one**, in which the previous years' pollution concentrations are used as control, considering pooled data with all observations from all available monitoring stations. This specification allows to run tests for as much as the equivalent of six months' time (125 days, excluding weekends) because after that, there is an overlap of the daily observations, therefore affecting the results. The summary of results for all specifications, pollutants and time periods are presented on tables 2 and 3. The complete tables with all relevant results can be found in **Appendix 1**.

When looking at the maximum, as well as the mean daily concentrations for CO, the *HNC*'s impact follows the expected direction of the effect in the short and middle run. This means that there is a short-term reduction in both mean daily and maximum concentrations across Mexico City (60 days excluding weekends or three months approximately), and then there is a reversion of this effect, observed in the middle run (125 days, excluding weekends or six months approximately). The case of NO_X in the short and middle run is different since there is a significant decrease in concentrations for both mean daily values and maximum concentrations during the first 60 days after implementing *HNC*, but there are no significant effects for the 125-day period. With the exception of the 125-day test for NO_X, these results are consistent with what other studies have found, and with what is expected, especially since CO and NO_X are the two pollutants closest related to mobile sources, therefore, most affected by *HNC*.

Table 2. MCMA 1989. Impacts summary (mean daily concentrations)

1989 Pooled data for all monitoring stations using pollution mean daily concentrations								
Pollutant	**CO**		**NO_X**		**NO_2**		**O_3**	
Design	**D1**	**D2**	**D1**	**D2**	**D1**	**D2**	**D1**	**D2**
Control	**Previous Years**	**Sunday**	**Previous Years**	**Sunday**	**Previous Years**	**Sunday**	**Previous Years**	**Sunday**
60 Days	-0.070***	-0.018	-0.137***	-0.025	-0.214***	-0.092	0.109***	0.019
125 Days	0.036**	0.000	-0.035	0.037	-0.265***	-0.069	0.193***	0.031
250-260 Days		-0.010		-0.007		-0.098**		0.024
500-520 Days		-0.028		-0.020		-0.093***		0.017

* p-val<0.1; ** p-val<0.05; *** p-val<0.01

Source: Iracheta, J.A. using MCMA's Automatic Network of Atmospheric Monitoring data.

Note: For comparison purposes, standardized coefficients are used.

Table 3. MCMA 1989. Impacts summary (maximum daily concentrations)

1989 Pooled data for all monitoring stations using pollution maximum daily concentrations								
Pollutant	**CO**		**NO_X**		**NO_2**		**O_3**	
Design	**D1**	**D2**	**D1**	**D2**	**D1**	**D2**	**D1**	**D2**
Control	**Previous Years**	**Sunday**	**Previous Years**	**Sunday**	**Previous Years**	**Sunday**	**Previous Years**	**Sunday**
60 Days	-0.050**	-0.048	-0.079*	0.060	-0.168***	0.065	0.128***	-0.017
125 Days	0.031**	-0.003	0.018	0.144**	-0.156***	0.064	0.238***	-0.027
250-260 Days		-0.029		-0.030		-0.062		-0.027
500-520 Days		-0.059***		-0.052		-0.080**		-0.037

* p-val<0.1; ** p-val<0.05; *** p-val<0.01

Source: Iracheta, J.A. using MCMA's Automatic Network of Atmospheric Monitoring data.

Note: For comparison purposes, standardized coefficients are used.

For the case of NO_2, there is a strong and significant reduction in maximum and mean daily concentrations both on the short and middle run; however, the opposite effects are true for O_3, since there is an even stronger increment for the maximum and daily mean concentrations in the short and middle run. Note that on all cases the direction of the impacts is consistent between mean daily values and maximum concentrations, where maximum concentrations have an overall smaller impact size. All models include the standardized inverse Euclidean distance matrix in order to control for spatial correlation, as well as several control variables for weather conditions and economic activity.

The findings from **specification two** are inconclusive. This design utilizes Sundays' concentrations as counterfactual for testing the values observed during the weekdays. The data available for this specification allows for testing CO, NO_X, NO_2 and O_3 for 60-, 125-, 250- and 500-day periods. Unfortunately, almost no effect is statistically significant, with the exception of a positive, however small reduction in NO_2 concentrations in the long run.

Therefore, it is not possible to make any claim besides the seemingly positive long run NO_2 positive effect on air quality.

After looking at both specifications' results for estimating the impact of *HNC* on air quality, as measured by CO, NO_X, NO_2 and O_3 maximum and mean daily concentrations for different time periods, it is possible to draw some conclusions. In the first place, CO, which is the pollutant that is emitted the most by mobile sources, shows the expected behavior under specification one, i.e. there is a reduction in its concentration over a short period after the *Hoy No Circula* was implemented, and a reversion of this effect in the middle run, in the form of statistically significant increments in CO concentrations, both for mean daily values as well as for maximum values. Such effect can be explained by the broadly discussed increase in the size of the vehicle fleet in the city, in which families acquired additional (mostly older) vehicles as a way to overcome the imposed driving restrictions.

The case for NO_X and NO_2 is different. While there is a convergence on the effect sign under both specifications, only under specification one there are statistically significant reductions for both compounds in the short run. In the long run, there are statistically significant reductions of NO_2 concentrations under specification two as a result of the implementation of *HNC*. These reductions tend to be smaller in size for NO_X than for NO_2, but there is, nonetheless, a positive impact of *HNC* on these pollutants' concentrations.

Finally, the impacts of HNC on O_3 concentrations are consistent across time periods. There is an observed increment in concentrations for the short and middle run, for mean daily values as well as for maximum concentrations. These effects are only observed under specification one, since the results are not statistically significant under specification two (most likely due to the relatively small variation in concentrations across week-days and Sundays), nonetheless there is still evidence that the program was ineffective, and even counterproductive to reducing ozone pollution.

So far, the impacts of *HNC* on air quality have been analyzed assuming that Mexico City is a homogeneous entity, with no differences between areas of the city. However, this could not be farther from the truth and, in fact, the available data points at relevant differences in air quality depending on the location of the monitoring stations. Therefore, the next section analyses the differentiated impacts of *HNC* on pollution concentrations by area of the city using data at the monitoring station level. Even though these measurements are taken at specific points, each monitoring station is considered to reflect the conditions of its area of influence. The extent of such area will depend on various factors that are usually not homogeneous across geographical regions. For the purposes of presenting the estimated impacts on air quality, this study uses an area of 5 km. radius around the monitoring stations. It is important to keep in mind that these models do not include any spatial correlation control variable since each one considers data at its specific monitoring station only. Only selected maps are used to support the analysis, but the complete set is available in **Appendix 2**.

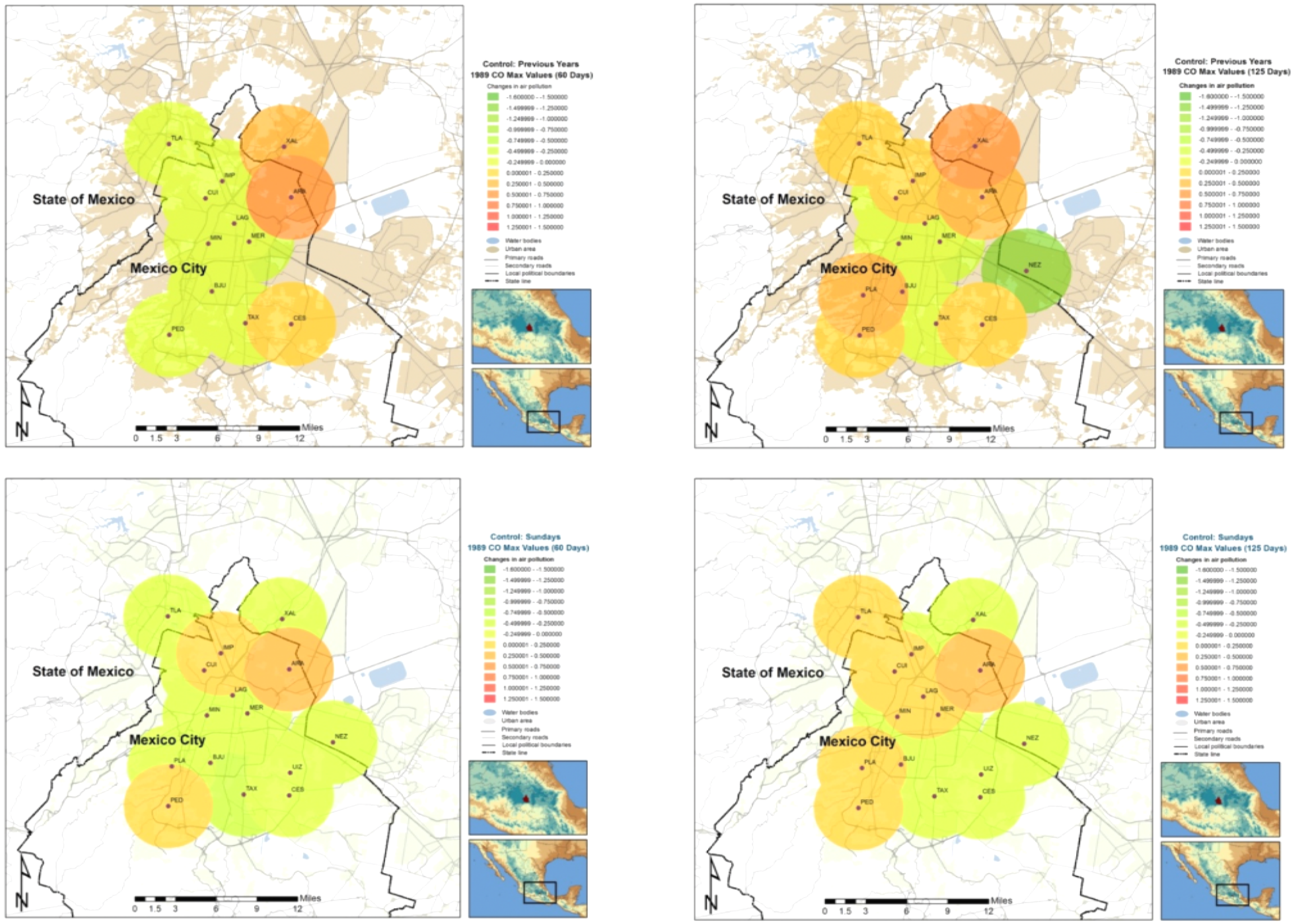
The results for CO show a consistent pattern. There is an overall reduction in maximum concentrations in the central parts of the city for the 60- and 125-day periods; however, there are strong increments in the periphery, particularly in the northern areas. These results are consistent with the direction of the prevailing winds in Mexico City, which flow mainly to the north, north-west and west. The differences between the short and middle run are particularly clear for specification one, where one can observe dramatic increments in pollution in the north part of the city. This is also reflected in specification two, but with a lesser magnitude. When looking at longer periods of time, there is a clear pattern of air quality loss as time goes by. For the 125-day period, both designs show increments in CO maximum concentrations covering larger areas of the city, but particularly in the north.

Map 2 shows, on the left side, the impacts of *HNC* in the short run (60-day period), and the middle run impacts on the right side (125-day period). The top maps correspond to specification one (previous years' data as control) and the bottom maps correspond to specification two (Sundays concentrations as control). Each circle is a buffer representing the area that is captured by each monitoring station and the buffer's color represent changes in concentration. The greener the buffer, the larger is the reduction in concentrations (i.e. better air quality), whereas more orange/red buffers represent larger increments in concentrations (i.e. worse air quality). Note that only statistically significant impacts are shown in the maps, therefore there are some stations for which the impacts were measured, but they are not depicted in the maps if the results were not statistically significant.

There is a consistent general increment in maximum NO_X concentrations for the two specifications, and for the 60- and 125-day periods, which contrasts with the findings using the pooled data. This is not to say that the entire city suffered from higher concentrations of NO_X as a result of the implementation of *HNC*, but rather that the general trend is one of lower air quality, even though some areas of the city experienced improvements.

Similar results are observed for NO_2 and O_3. The former shows improvements in air quality in the center and north of the city that remain when going from the 60- to the 125-day period; however, strong increments in maximum concentrations of NO_2 taking place in the south side of the city, and they get worse as time goes by. For O_3 there is a strong reduction in air quality almost in the entire city, which is broadly consistent with what was found when looking at the impacts using pooled data. Furthermore, when we move from 60 to 125 days, the negative impacts of *HNC* are even stronger. These findings are presented on **maps 3 and 4.**

Map 2. MCMA 1989. CO maximum concentrations, 60 and 125 days

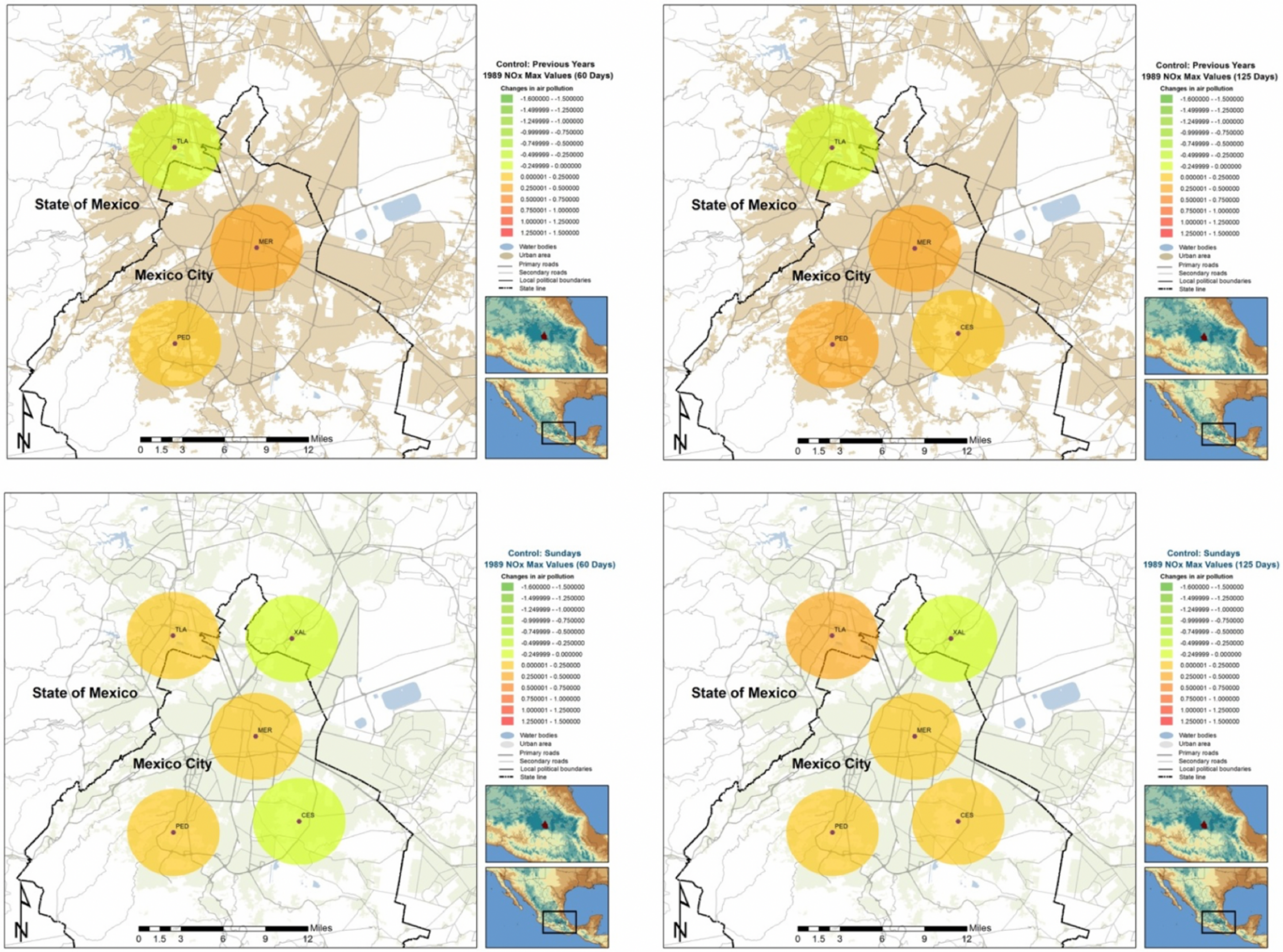


Source: Iracheta, J.A. using MCMA's Automatic Network of Atmospheric Monitoring data.

In conclusion, the evidence shows that the *Hoy No Circula* program was highly ineffective in 1989 for dealing with Mexico City's air quality problem. Furthermore, the evidence points out that, even though at first it had some mixed results, favoring improvements in air quality, they were reversed in the middle run. This coincides with the reaction of families living in Mexico City that acquired additional vehicles when the program became permanent, eventually offsetting the gains in air quality and even reversing those effects. It is of special interest the findings regarding concentrations of CO and O_3. In both cases, *HNC* had a perverse effect by increasing the levels of mean daily and maximum values in the medium and long run (from six to 24 months after the program's implementation). Furthermore, these effects took place in most of the city (even though some areas experienced improvements in air quality). For NO_X and NO_2 there are some mixed impacts, and it is not possible to make uncontroverted assertions. Nonetheless, the evidence points at reductions in air quality in the long run, with more variation than the one observed for CO and O_3.

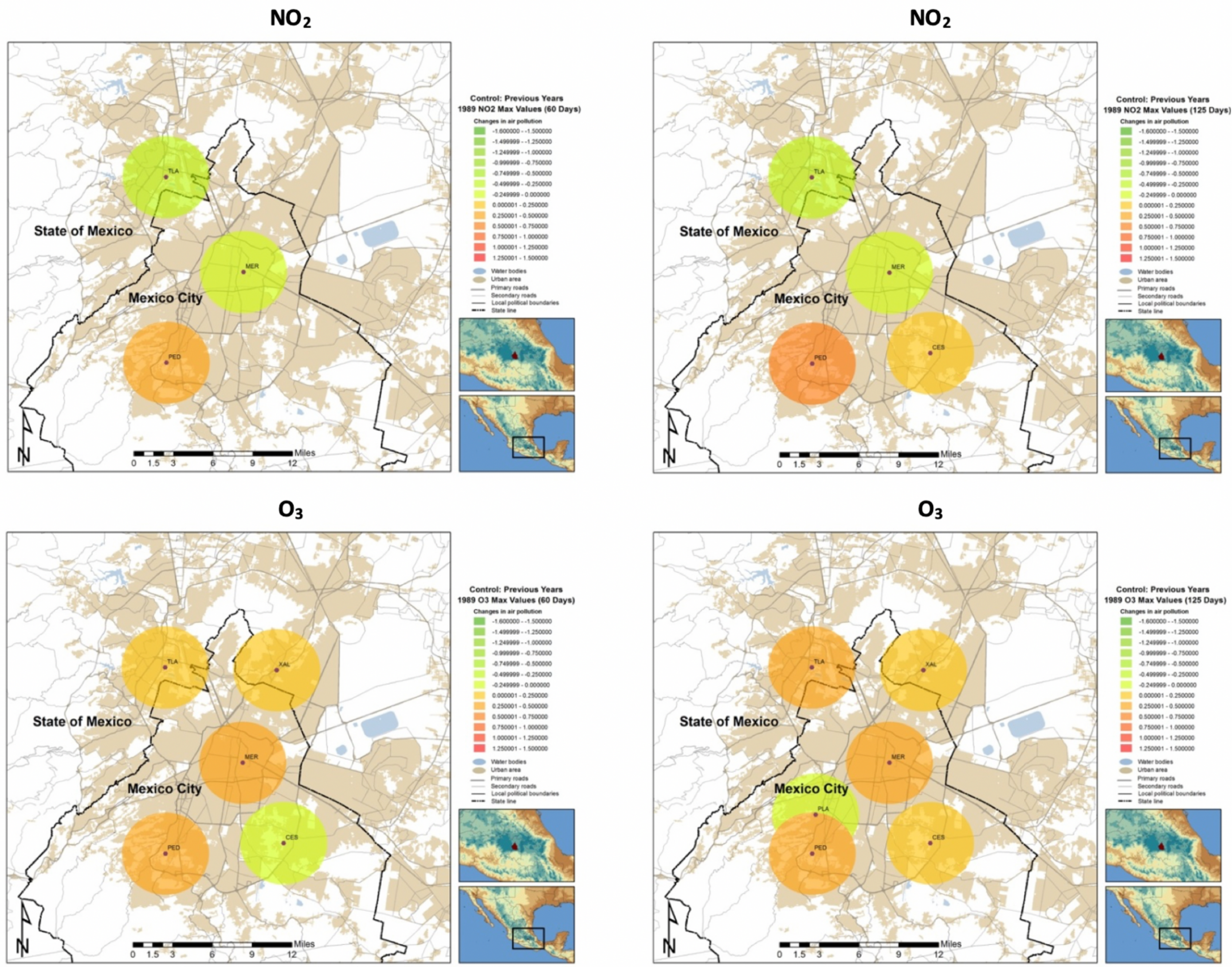
The evidence presented here supports the findings of past studies and provides a more in-depth analysis of the effects of *HNC* on air pollution levels in Mexico City, addressing both the overall results and location-based impacts. Recall that past studies did not consider the effects of spatial correlation, in addition to seasonal effects and lack of strong counterfactuals. This analysis builds upon those studies, and finds stronger evidence about the unintended consequences of *HNC.*

Map 3. MCMA 1989. NO_X maximum concentrations, 60 and 125 days



Source: Iracheta, J.A. using MCMA's Automatic Network of Atmospheric Monitoring data.

Map 4. MCMA 1989. NO_2 and O_3 maximum concentrations, 60 and 125 days



Source: Iracheta, J.A. using MCMA's Automatic Network of Atmospheric Monitoring data.

b) *HNC* 2014 Policy Change

The policy change that took place in 2014 is analyzed in this section. The summary of all impacts is shown on **tables 4 and 5**, but the full results for all models are available in **Appendix 1**. Recall that the new set of rules for *HNC* redefined the driving restrictions according to the age of the car, as opposed to its meeting the emissions standards. The goal of such an approach was to enable a stronger ability to curb corruption occurring at engine check-up centers.

Table 4. MCMA 2014. Impacts summary (mean daily concentrations)

2014 Pooled data for all monitoring stations using pollution mean daily concentrations								
Pollutant	CO		NO_X		NO_2		O_3	
Design	D1	D2	D1	D2	D1	D2	D1	D2
Control	Previous Years	Sunday	Previous Years	Sunday	Previous Years	Sunday	Previous Years	Sunday
60 Days	0.029**	0.055*	-0.008	0.133***	0.019	0.090***	0.033***	-0.074**
125 Days	0.007	-0.010	-0.057***	-0.032*	-0.052***	-0.032*	-0.046***	-0.182***

* p-val<0.1; ** p-val<0.05; *** p-val<0.01

Source: Iracheta, J.A. using MCMA's Automatic Network of Atmospheric Monitoring data.

Note: For comparison purposes, standardized coefficients are used.

We start by looking at the impacts of these rule changes on CO concentrations. Under specification one, there is a very small increment in the 60-, as well as in the 125-day periods for both mean daily values and maximum concentrations. However, these increments are almost negligible. Something similar is observed under specification two, where there are low increments in the short and long run for CO. For the case of maximum concentrations, there is a stronger increase in CO concentrations under specification two for 60 and 125 days. These results are generally consistent with what was observed under specification one.

Table 5. MCMA 2014. Impacts summary (maximum daily concentrations)

2014 Pooled data for all monitoring stations using pollution maximum daily concentrations								
Pollutant	**CO**		**NO_X**		**NO_2**		**O_3**	
Design	**D1**	**D2**	**D1**	**D2**	**D1**	**D2**	**D1**	**D2**
Control	**Previous Years**	**Sunday**	**Previous Years**	**Sunday**	**Previous Years**	**Sunday**	**Previous Years**	**Sunday**
60 Days	0.040***	0.142***	-0.011	0.016	0.011	0.060**	0.054***	-0.023
125 Days	0.043***	0.056**	-0.035***	-0.087***	-0.043***	-0.049***	-0.023**	-0.127***

* p-val<0.1; ** p-val<0.05; *** p-val<0.01

Source: Iracheta, J.A. using MCMA's Automatic Network of Atmospheric Monitoring data.

Note: For comparison purposes, standardized coefficients are used.

For NO_X and NO_2, there are consistent increments in concentrations under specification two in the short run, for both mean and maximum daily values. Nonetheless, in the middle run, these effects are reversed, and one can observe reductions in mean daily values as well as on maximum concentrations under both specifications but, again, very small in magnitude. The point to be taken is that the evidence points at positive impacts of the changes in rules of *HNC* on air quality regarding NO_X and NO_2 concentrations in the middle run.

Finally, for the case of O_3, under specification one there is an observed increment in concentrations in the short run, and then a reduction after six months, for both the mean daily values as well as for maximum concentrations. Similar to the effects on the other components, they are also very small. Under specification two, there is a consistent reduction of concentrations in O_3 on all cases, that is, in the 60- and 125-day periods, and for mean daily values and maximum concentrations. Even though there is weak evidence of an increase in O_3 concentrations in the short run, it is fair to say that the 2014 rules change had an overall positive effect on air quality (in terms of O_3), since there are consistent concentration reductions in the middle run.

The impact that the 2014 *HNC* rules change had on air quality is less clear than what was observed in 1989. The magnitude in most cases is considerably small, and in some even negligible. For the case of CO, the evidence points at small increments in concentrations (lower air quality), both for mean daily values and for maximum values; therefore, the results in terms of CO are overall negative.

The case for reduction of NO_X and NO_2 is somewhat stronger. On both specifications, there is a clear reduction in mean daily values and maximum concentrations in the 125-day period (six months), and such results are also statistically significant; however, they are very small in magnitude. The impact in the short term (3 months) remains unclear since many of the coefficients are not statistically significant; however, one can still observe small increments in concentrations in the short run. It is fair to say that the 2014 HNC rules change had a positive impact on air quality in terms of these two pollutants.

Similar to NO_X and NO_2, the evidence about changes in concentrations for O_3 is clear and negative (i.e. improved air quality) in the 125-day period since all coefficients on both specifications are consistent and significant. That is not the case for the short-term impacts. It appears that the 2014 HNC rules change had a positive effect on air quality in terms of O_3, even though it is not clear what happened right after the rules change was enforced. What is clear is that after six months, the overall O_3 concentrations went down.

Overall, the impacts of the 2014 *HNC* rules change on air quality were very small. For some pollutants, there were small reductions in concentrations, but for others there were small increments. All in all, the evidence suggests that the impact of this policy change was close to nonexistent. However, it is important to acknowledge that the positive effects on air quality are better supported by the evidence than the negative ones, and it is possible that, given a longer period of time (recall that these rules lasted only one year), the positive impacts would have prevailed.

Now, let us take a look at the differentiated effects that the 2014 *HNC* policy change had over different areas of MCMA. The full set of maps is presented in **Appendix 2**. The analysis starts by looking at the impacts on CO concentrations. Recall that the data for the overall impact on the city was somewhat inconclusive; nonetheless, the results seemed to suggest very low losses of air quality (i.e. small increments in CO concentrations). The changes in maximum CO concentrations for 60 and 125 days, by area of the city, show a pattern of reduction of air quality due to CO. As opposed to what was observed for the pooled data, the results show a clear air quality loss pattern for the entire city. The evidence suggests that the north side of the city seems to be the one that experienced the best outcome, having reduction in CO concentrations in some parts; however, the central and south portions of the city seem to be the most negatively affected. It is worth noting that, even though the overall results seem to be negative, there is a decreasing trend for the increments in CO concentrations, i.e., had the policy lasted longer time, it is possible that the impacts would have turned positive. The results for CO are presented in **Map 5.**

Different than what the evidence shows for CO, the cases of NO_X and NO_2 are considerably stronger and consistent. On both specifications there is a clear pattern of reduction of maximum concentrations, both for 60 and 125 days. This, of course, is not the case for all areas of the city, but it is fair to say that the reductions were experienced on the vast majority of them. Particularly, under specification two for NO_2 there is a reduction in maximum concentrations on all but two monitoring stations in the four-month period. What is important to take from this analysis is that most of the stations do have consistent results, and that reductions in NO_X and NO_2 were observed almost in the entire city. The results for NO_X are presented in **Map 6**.

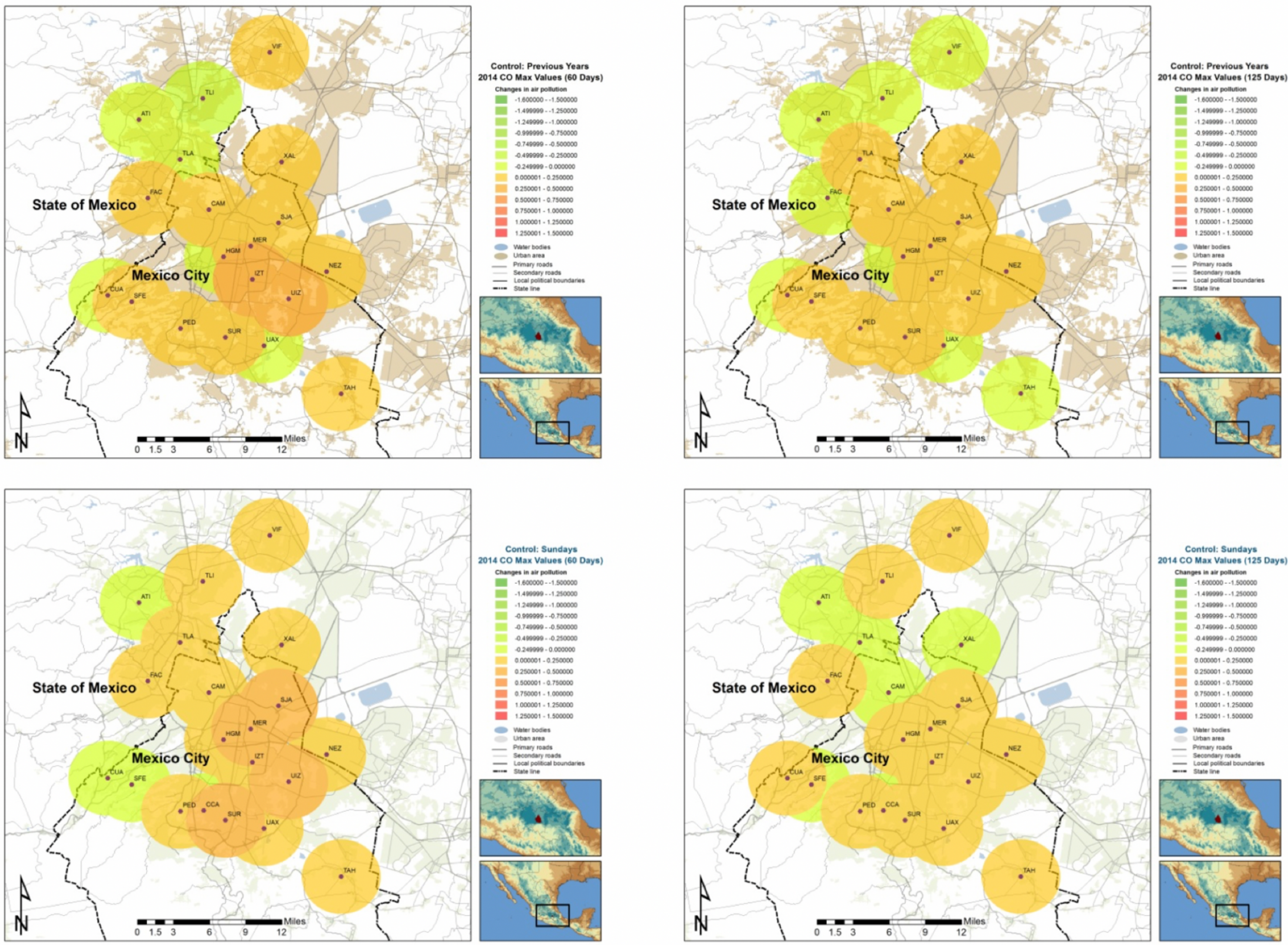
The results observed for O_3 concentrations are similar to those of NO_2 and NO_X. On both specifications there is a clear pattern of improvements on air quality due to reductions in O_3

concentrations. With the exception of the station located at the Metropolitan Autonomous University campus Xochimilco (UAX) which experienced a strong increment in O_3 maximum concentration, the impact of the 2014 *HNC* rules change was positive for most of the city. These results are presented on **Map 7**.

Briefly summarizing the results of the 2014 *HNC* rules change, the program had a positive, however low impact on air quality. On one hand, the evidence suggests that mean daily values and maximum concentrations of NO_X, NO_2 and O_3 experienced an overall reduction, after three and six months of the new rules being enforced. On the other hand, the results for CO are not as straightforward. Depending on whether the data were pooled or by station, on the specification used and the period, the results varied considerably. For CO, there is weak evidence of very mild increments in concentrations that seem to be decreasing in time.

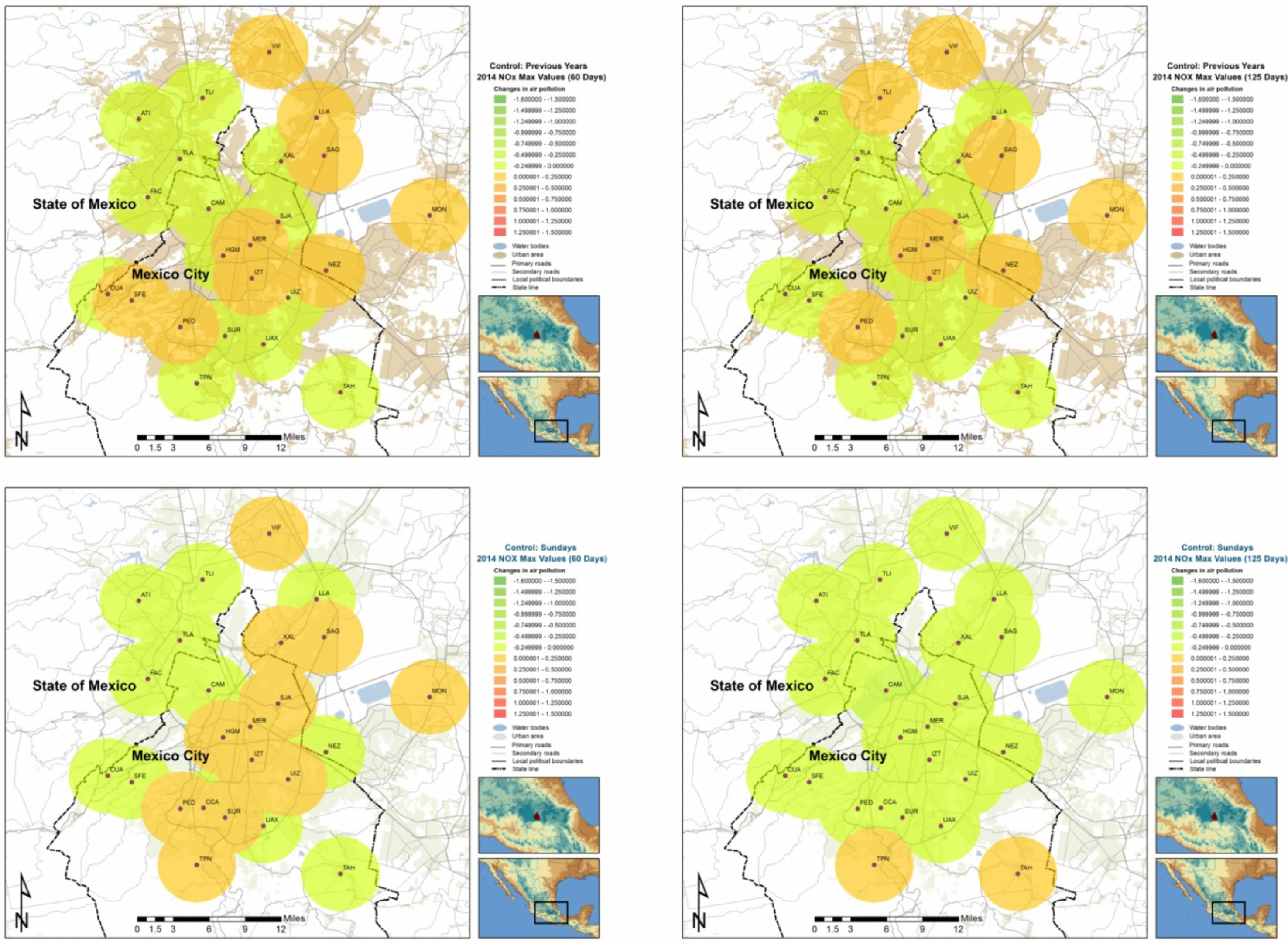
Despite the limitations of the results that have been discussed throughout this section, it is fair to say that the 2014 *HNC* rules change had a positive effect on MCMA's air quality. The evidence of positive impacts is strong, and even though these effects are small, they are positive nonetheless. The evidence of negative impacts is not as clear, and remains elusive. In any case, regardless of being positive or negative, all impacts were very small, and close to nonexistent.

Map 5. MCMA 2014. CO maximum concentrations, 60 and 125 days



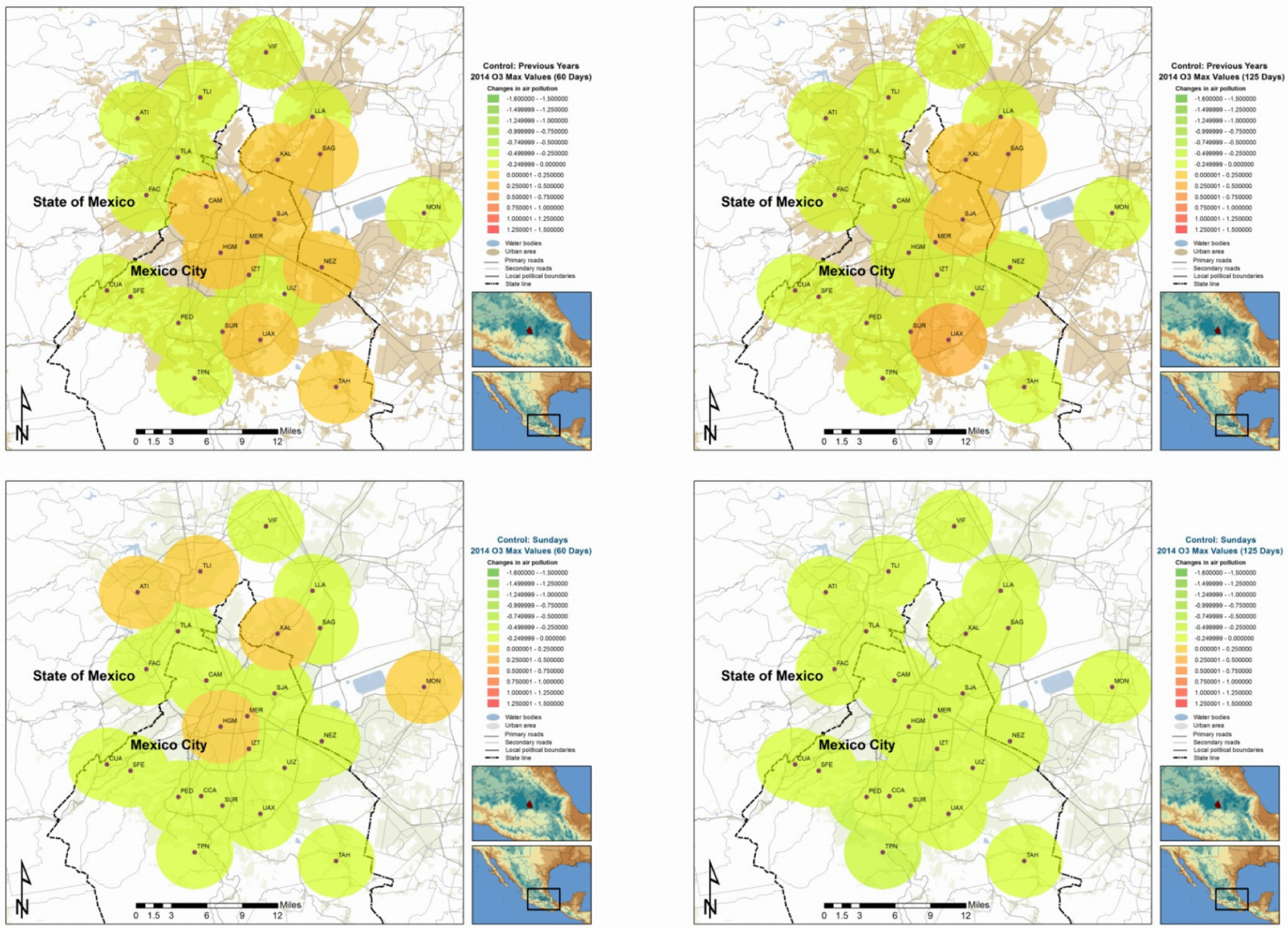
Source: Iracheta, J.A. using MCMA's Automatic Network of Atmospheric Monitoring data.

Map 6. MCMA 2014. NO_X maximum concentrations, 60 and 125 days



Source: Iracheta, J.A. using MCMA's Automatic Network of Atmospheric Monitoring data.

Map 7. MCMA 2014. O_3 maximum concentrations, 60 and 125 days



Source: Iracheta, J.A. using MCMA's Automatic Network of Atmospheric Monitoring data.

c) *HNC* 2015 Return to the Previous Rules

Since the beginning of the changes in rules of *HNC* in July 2014, a strong resistance took place, particularly from vehicle owners who kept their cars under good conditions, meeting the emissions standards, and complying with all the related regulations. One group of such owners pushed their case through the legal figure of *Juicio de Amparo,* which is designed to protect the private citizens from illegitimate actions performed by public authorities that affect their Constitutional rights (the figure of *habeas corpus* is somehow similar under the Anglo-Saxon legal systems). The legal proceeding made it all the way up to the Mexican National Supreme Court of Justice, which ruled in favor of the plaintiffs and declared that the 2014 *HNC* rules change were restraining some of their basic rights, therefore, they should be allowed to use their vehicle as long as they met the emissions standards. This ruling represented a *de facto* return to the previous *HNC*'s operation rules, which were then made official by the governments of Mexico City, the State of Mexico, and all the other political jurisdictions affected by it. This section analyzes the impact of returning to the original *HNC* rules, after one year with the vehicle age-related driving restriction. The complete results are presented in **Appendix 1**.

We start by looking at the impacts of this change on CO, NO_X, NO_2 and O_3 concentrations under **specification one**. The results for the policy change of 2015 are overwhelmingly negative. All pollutants experienced statistically significant increments on mean daily concentrations, and most of them faced a similar impact for maximum concentrations (there are a couple of not significant coefficients). However, these results are most likely showing an overestimation of the actual impacts. The reason is that specification one relies on the data observed for the same day of the previous year as a way for controlling for changes in air quality. Since this control group uses 2014 data that experienced another policy change around the same time of the year (there is about one-week difference), it would be more precise to understand the impacts under specification one in terms of the difference between the policy changes of 2014 and 2015. In other words, the impacts of the 2015 *HNC* policy change are estimating the difference in relation to the impacts of 2014, but not in terms of the air quality observed before the 2014 policy change.

Table 6. MCMA 2015. Impacts summary (mean daily concentrations)

2015 Pooled data for all monitoring stations using pollution mean daily concentrations								
Pollutant	CO		NO_X		NO_2		O_3	
Design	D1	D2	D1	D2	D1	D2	D1	D2
$	Previous Years	Sunday	Previous Years	Sunday	Previous Years	Sunday	Previous Years	Sunday
60 Days	0.117***	0.066***	0.073***	0.046**	0.139***	0.071***	0.238***	0.109***
125 Days	0.116***	0.164***	0.065***	0.124***	0.131***	0.089***	0.081***	0.027

* p-val<0.1; ** p-val<0.05; *** p-val<0.01

Source: Iracheta, J.A. using MCMA's Automatic Network of Atmospheric Monitoring data.

Note: For comparison purposes, standardized coefficients are used.

Table 7. MCMA 2015. Impacts summary (maximum daily concentrations)

2015 Pooled data for all monitoring stations using pollution maximum daily concentrations								
Pollutant	CO		NO_X		NO_2		O_3	
Design	D1	D2	D1	D2	D1	D2	D1	D2
Control	Previous Years	Sunday	Previous Years	Sunday	Previous Years	Sunday	Previous Years	Sunday
60 Days	0.076***	0.029	0.002	-0.019	0.091***	0.031	0.172***	-0.014
125 Days	0.086***	0.109***	0.046***	-0.061***	0.100***	0.086***	0.015	-0.012

* p-val<0.1; ** p-val<0.05; *** p-val<0.01

Source: Iracheta, J.A. using MCMA's Automatic Network of Atmospheric Monitoring data.

Note: For comparison purposes, standardized coefficients are used.

Moving forward, the results under **specification two** seem to point in the same direction as what was observed under specification one. For CO there are relatively strong increments in maximum and mean daily concentrations for the 125-day period. For 60 days, the impact size is smaller in both cases, but the coefficient for maximum concentrations is not statistically significant. Nonetheless, all signs are consistent and show a similar behavior than specification one.

NO_X concentrations are more problematic. Under specification two the direction of the effect for the six-month period on maximum daily concentrations is inconsistent with the rest of the NO_X coefficients, since all of them show a statistically significant increment, except that one. The results about NO_2 concentrations, on the other hand, are consistent across time periods and specifications. On all cases, there is an increment of concentrations (for 60 and 125 days, as well as for mean daily, and maximum values). Also, on all cases the impact size is relatively small, but particularly so for the 60-day period. The results of specification two have consistently lower effect size than those observed under specification one, which makes sense considering that the impacts under specification one are defined in terms of the 2014 policy change that is likely overestimating them.

Finally, the evidence of the impact of the 2015 *HNC* policy change on O_3 show an overall increase in concentrations for mean daily values across specifications; however, for maximum daily concentrations, only for the three-month period the coefficient is statistically significant and consistent with the other results. Since only under specification one there are clear results, it is possible to say that the 2015 policy change had a negative effect in terms of O_3 concentrations; however, these results are not as strong as what was observed for the rest of the pollutants.

To conclude this section, the evidence seems to suggest a negative impact caused by the 2015 return to the previous rules of *HNC*. These results are reasonable, since the policy change meant that a large proportion of vehicles (those of 15 years of age and older), would be able to go back into the streets on an almost daily basis. For some pollutants, such as

CO and NO_2, the data point out a clear increment in concentrations for 60 and 125 days, both on mean daily as well as maximum concentrations. For NO_X the evidence is not as strong, however there is still overall consistency across specifications for mean daily values in terms of the direction of the signs and the effects size. More problematic are the results for maximum daily values, since there are some inconsistencies in the signs. Nonetheless, similar to the results for NO_2, there seems to be a pattern of reduction in air quality in terms of this pollutant, as a consequence of the 2015 *HNC* policy change.

Finally, for O_3, the impact of the 2015 rules change also seems to be a negative one. There are a few coefficients with an opposite sign (i.e., showing a reduction in concentrations); however, none is statistically significant. For the rest, there is a consistency in the direction and magnitude of the effects.

The next stage is to look at the impacts of the *HNC* rules change of 2015 differentiated by area of the city. The analysis starts by looking at CO maximum concentrations. There is a clear increment in CO maximum concentrations in most parts of the city, particularly in the central area. On both specifications, there is a slight reduction in concentrations in the 125-day period for the north side of the city, but overall there is a clear pattern of a lower air quality in MCMA. These results are consistent with what was observed using pooled data for the entire city under both specifications and it is fair to suggest that the *HNC* rules change of 2015 increased CO concentrations in MCMA. These results are presented on **Map 8**.

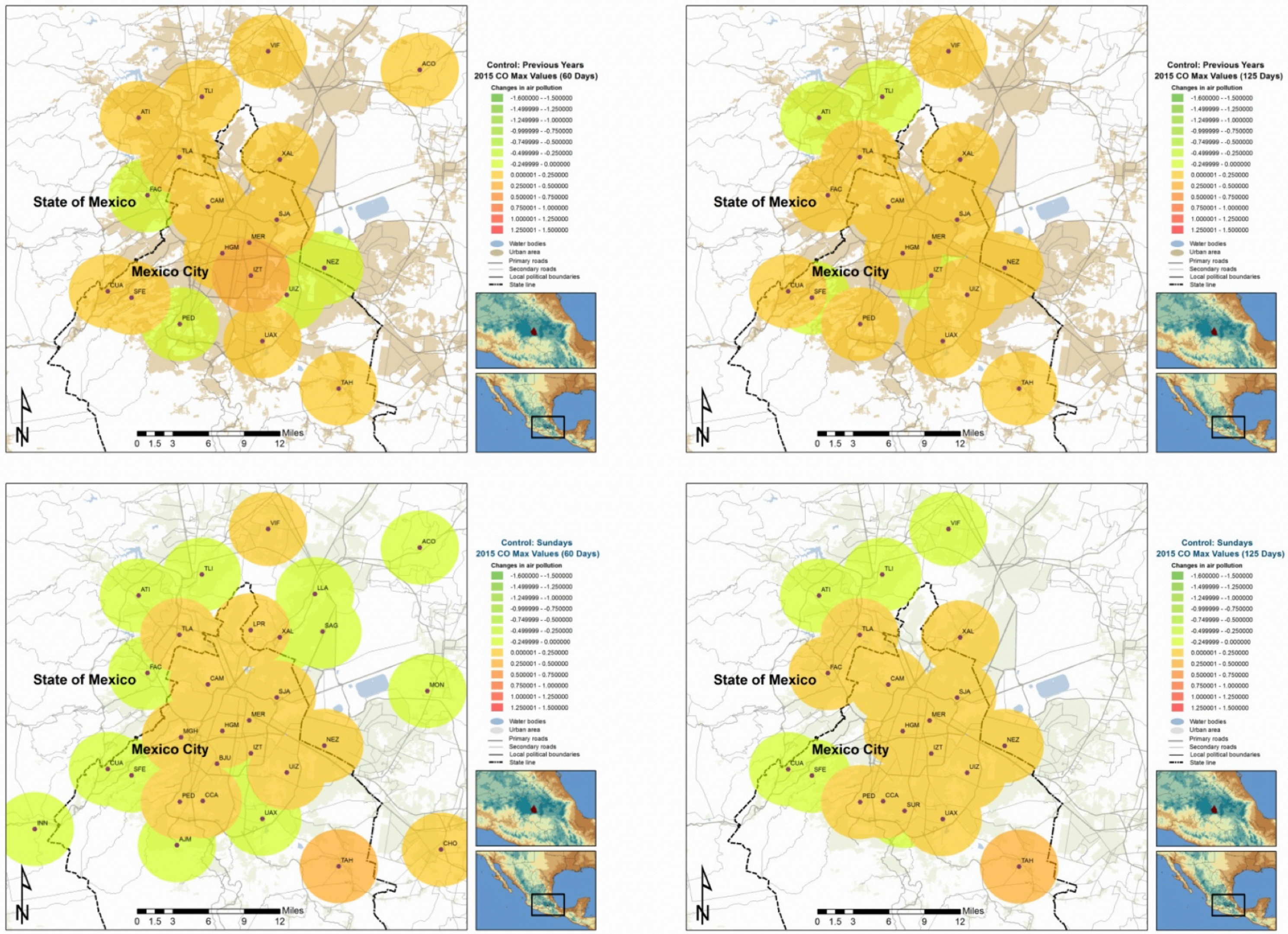
When looking at pooled data for NO_X concentrations, there were some questions on the confidence of the results in light of their apparent inconsistency for maximum daily values. Unfortunately, this pattern is also observed when analyzing behavior at the monitoring station level. Under both specifications, there is a short-term increment in maximum NO_X concentrations for the central part of the city. While such increases remain for 125 days under specification one, under specification two they are reversed, and most parts of the city seem to experience reductions in maximum concentrations.

These inconsistencies are difficult to reconcile, but one possible explanation is that specification one is showing the difference between the 2014 and 2015 policy changes, since they took place with around one-week difference in each respective year. From this perspective, the *HNC* 2014 policy change had a relatively higher positive impact on air quality (reduced NO_X concentrations) than the one observed in 2015. Therefore, if we look at the results of 2015, they may be just pointing out that, compared to 2014, the 2015 policy change had smaller, however positive impacts. Such explanation would be supported by the results observed under specification two. These results are presented on **Map 9**.

For NO_2, the analysis at the monitoring station provides stronger evidence of the impacts of the 2015 *HNC* policy change. Under both specifications, there is a clear and general increment in NO_2 maximum concentrations, both at the 60- as well as at the 125-day periods. In particular, the increments in maximum concentrations seem to be located mostly on the central area of the city, while the north and west sides seem to have experienced improvements in air quality in terms of NO_2 concentrations.

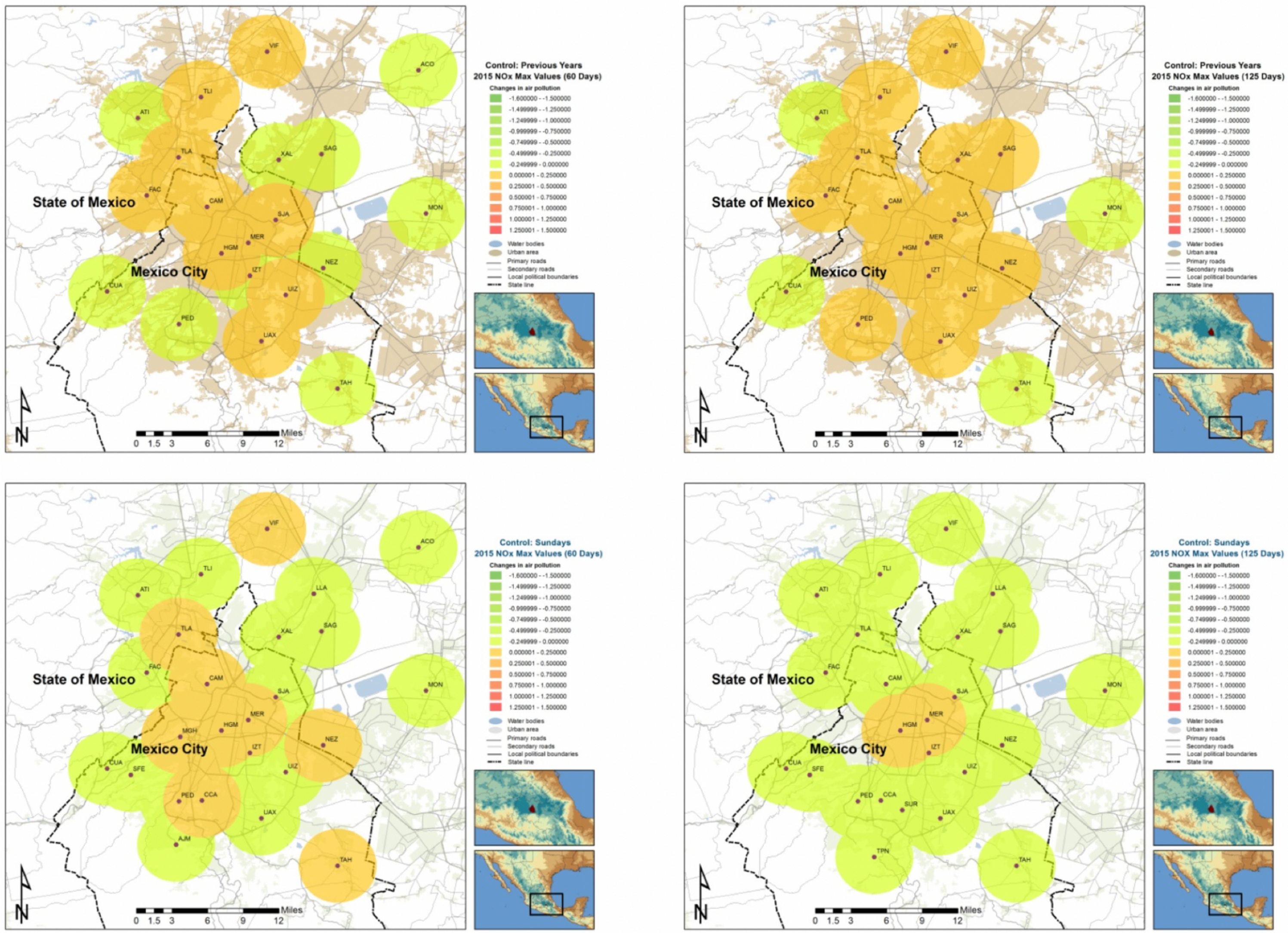
For the case of O_3, there is evidence of increments in maximum concentrations particularly in the center and north sides of the city. This pattern can be observed for the 60- and 125-day periods. However, there is a clearer pattern under specification one, while there somehow mixed effects under specification two for both mean and maximum daily values. Under specification one, there is a dramatic increase in O_3 concentrations across the city, with three stations in the center and north of the city with very strong negative results. Under specification two, there is only a reduction in air quality in the center and north of the city, but the rest shows reductions in maximum concentrations. These results are presented in **Map 10.**

Map 8. MCMA 2015. CO maximum concentrations, 60 and 125 days



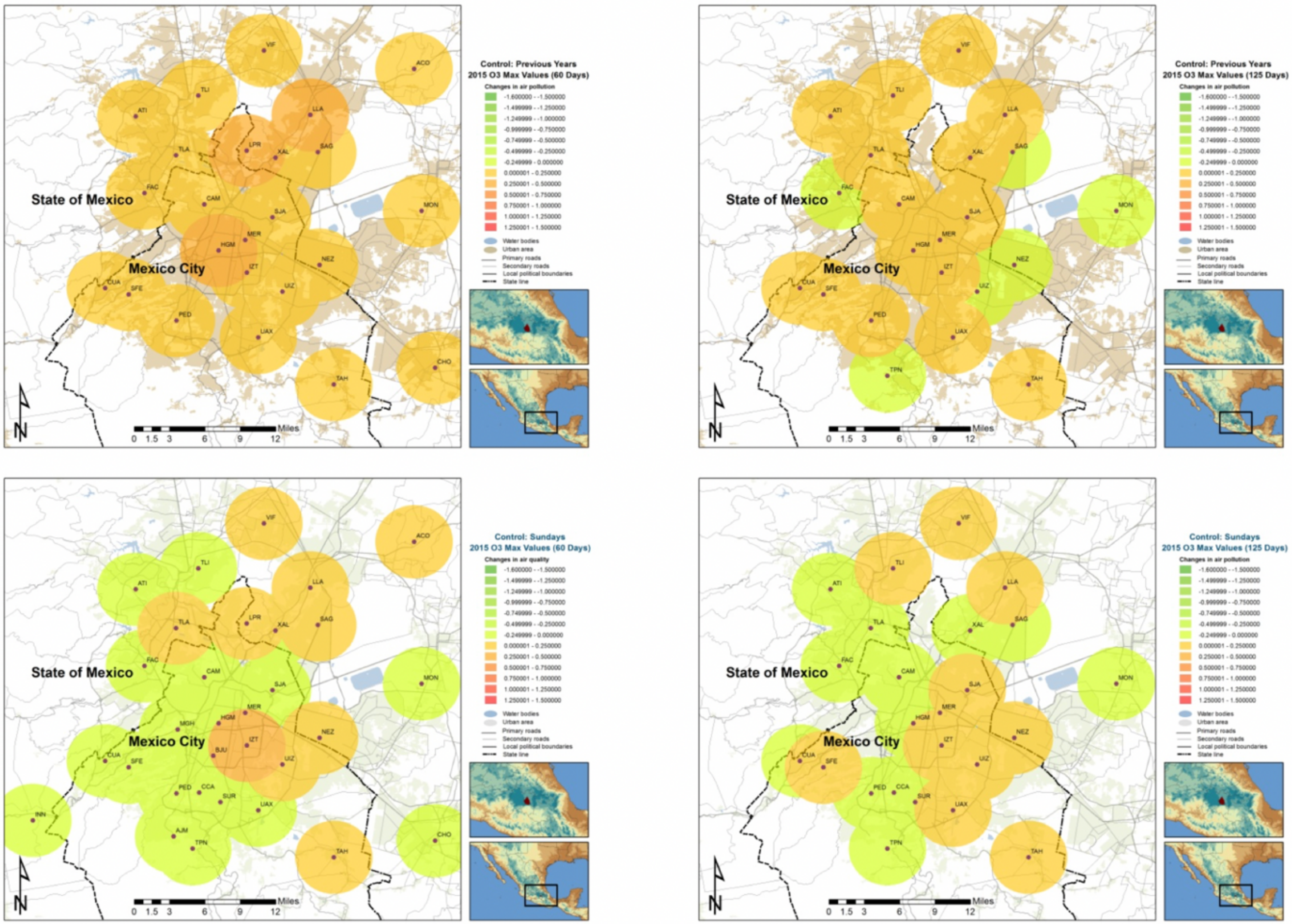
Source: Iracheta, J.A. using MCMA's Automatic Network of Atmospheric Monitoring data.

Map 9. MCMA 2015. NO_X maximum concentrations, 60 and 125 days



Source: Iracheta, J.A. using MCMA's Automatic Network of Atmospheric Monitoring data.

Map 10. MCMA 2015. O_3 maximum concentrations, 60 and 125 days



Source: Iracheta, J.A. using MCMA's Automatic Network of Atmospheric Monitoring data.

To conclude this section, the results of the 2015 *HNC* return to its previous rules suggest an overall reduction in air quality for MCMA. The analysis for 2015 turned out to be very clear for most of the pollutants, however it is important to keep in mind that specification one must be interpreted in terms of the changes observed in 2014 (therefore with some degree of underestimation). CO concentrations, both for pooled and for by-station data, on the short and middle run appear to have gone up, thus reducing air quality in the city. For NO_X and NO_2, the evidence suggests two differentiated effects. For the former, there was an apparent reduction in concentrations, but significantly small in magnitude. The opposite is true for the latter, where relatively small NO_2 concentrations increases took place in most parts of the city.

O_3 concentrations seem to follow a clear pattern of overall increments in concentrations for most parts of the city, with some areas that experienced strong increments in concentrations. This pattern was observed in the short and middle run; however, after six months the effects of the policy change were not as large, and they seem to decrease in time.

5. Conclusions

This study used two difference-in-differences research designs to estimate the impacts that the *Hoy No Circula* program had on air quality in MCMA, in particular for CO, NO_X, NO_2 and O_3 concentrations, in three periods in time: the first implementation in 1989, and two policy changes in 2014 and 2015. Under all DID specifications, the analysis used pooled data from all monitoring stations controlling for spatial correlation for mean as well as for maximum daily values. This study also looked at data at the station level in order to identify geographically differentiated impacts of the program. On all cases, the analysis used different time periods, typically 60 and 125 days which correspond to three and six months, but it also included 260 and 520 days (12 and 24 months respectively) in specific cases.

The findings of this study are consistent with what other studies have found for *HNC*'s first implementation in 1989, (Cantillo & Ortúzar, 2014; Davis, 2008; Eskeland & Feyzioglu, 1997; Gallego et al., 2013) in that *HNC* was an effective program to deal with air pollution generated by mobile sources in Mexico City during the first few months right after its implementation, however its positive effects were offset after six to twelve months. Such impacts took place due to the unintended effects of *HNC* on vehicle ownership. When the program became permanent, it created strong incentives for families to acquire additional vehicles to overcome the driving restrictions. Thus, *HNC*'s expected results of improved air quality were partially observed in the period right after the program's implementation only, but they faded away as time went by.

The most important case is that of CO, which is the compound most emitted by mobile sources subject to *HNC*. While there were reductions in concentrations in the short run as a consequence of *HNC*'s implementation, these effects were reversed after six months' time, and such behavior was reinforced over longer periods of time. Therefore, there is strong evidence to suggest that *HNC*'s unintended effects were large enough as to offset the improvements on air quality that took place right after the program was implemented. Ozone followed a similar pattern, but its concentrations increased both in the short and middle run. The increments over the latter, however, were substantially larger, suggesting that *HNC* was detrimental for air quality in terms of O_3, and the negative impacts increased over time. The effects for both compounds were not homogeneous across the city, and some areas experienced improved air quality. Nonetheless, the overall pattern is one of loses in air quality as a consequence of the implementation of *HNC*.

The evidence is substantially weaker for NO_X and NO_2 than what was observed for CO and O_3. The results seem to suggest that *HNC* had a positive impact on NO_X and NO_2 in the short run, and mildly positive in the middle run. Nonetheless, there remains a lack of clarity that is confirmed when looking at the specific results in different areas of the city. As expected, the results are not homogeneous across the city, and the impacts strongly differ depending on the location. For both compounds, there are reductions in concentrations in the north side of the city; however, the results for the south are the complete opposite. Also, the central part of the city seems to have experienced reductions in air quality due to NO_X and NO_2. These results confirm that it is not possible to make an unequivocal claim about the impact of *HNC* on air quality, but rather that the impacts were highly differentiated. In any case, the implementation of the program brought some level of improved air quality at first, but such improvements disappeared after a few months, therefore making the program ineffective when it was first implemented.

For the 2014 policy change, the results are less straightforward. On most cases the magnitude of the impacts was considerably small, and in some, could be deemed as non-existent. In the case of CO, the evidence seems to suggest a very small, negative impact on air quality that seems to be decreasing in time. These results are confirmed when looking at the impacts at the station level, where several areas of the city experienced some level of decline in air quality. Nonetheless, some other areas, particularly in the north side, seem to have experienced reductions in CO concentrations.

The evidence regarding NO_X, NO_2 and O_3 suggest that the 2014 policy change had a positive impact on air quality, both after three and six months, by reducing their concentrations. However, as with CO, these reductions were substantially low and, in some cases, close to negligible.

The findings for the 2014 policy change are weaker than those of 1989. Recall that this policy change took place to deal with corruption at the check-up centers, and not because of shifts in the trend of pollution concentrations. This would explain why the impacts are so small and difficult to identify and this would also be a confirmation of the reason behind the decision for redesigning the rules of *HNC*. In any case, it is possible to conclude that this policy change did have a slight positive effect on air quality.

Finally, when *HNC* returned to its previous rules in 2015, a relevant number of vehicles were allowed back in the streets on a daily basis. There are no clear figures about how many, but what is clear is that the number of vehicle-days increased. Such behavior is consistent with the findings of this analysis for 2015, that show an overall reduction in air quality not only right after overruling the 2014 rules (i.e., returning to the previous rules), but also after six months passed. It is worth noting that specification one for 2015 is estimating the impacts in terms of what was happening in 2014. Therefore, specification one serves as a way to compare both policy changes.

There is strong evidence showing that CO, NO_2 and O_3 concentrations consistently increased after the policy change; and such decline in air quality was experienced in most parts of the city (however, that was not the case for the north part for CO and NO_2, and the center-south sides for O_3). These impacts are particularly clear under specification one, which means that the policy change of 2015 was considerably detrimental for air quality in terms of the slight gains observed in 2014.

For NO_X, the findings are less clear, since there are relevant inconsistencies across specifications and time periods. That being said, the evidence seems to suggest a very small overall reduction in concentrations, which would mean a small improvement in air quality. However, these results remain contested and it is not possible to make a claim.

The policy change of returning to the previous rules in 2015 proved to be detrimental for MCMA's air quality. Furthermore, when compared to the impacts observed in 2014, the losses in air quality are even more dramatic. Overall, the *Hoy No Circula* program has a negative record. After being analyzed in three different moments in time, only one (2014) seems to have been beneficial for air quality. This policy has been in place for almost three decades and it has yielded limited improvements, yet it has imposed very high costs. Furthermore, there is evidence that the unintended negative consequences of *HNC* in terms of mobility, have been much larger than the benefits, therefore it is possible to say that this policy has worked against the well-being of MCMA's inhabitants. This being said, there are no easy answers or policy alternatives that could be implemented to replace *HNC*.

Eliminating *HNC* without having a strong program to replace it would be catastrophic for MCMA. At this point, it is important to note that, even though *HNC* was created to address a problem of air quality, it has become a core component for the mobility strategy not only for Mexico City, but also for the central region of the country. Therefore, one cannot discuss the future of such program without considering its potential impacts on air quality, as well as on mobility. According to TomTom (2017), Mexico City had the worst traffic congestion levels of the world for 2016 and was in the top ten for 2017 and 2018, becoming one of the most pressing issues for the city.

Therefore, the key question is not whether *HNC* should continue to function as a way for managing the problem of air pollution, but rather what kind of redesign, or which program(s) should be put in place parallel to *HNC* in order to phase it out. The first set of policy options relates to the creation of substitutes to the use of the kind of polluting vehicles that are currently used. The emergence of hybrid, electric, natural gas or biofuel vehicles makes a program of incentives for replacing the current gasoline fuel-based vehicle fleet technically feasible. Nonetheless, there are two strong arguments that would work against this policy. One is that these types of vehicles are still cost restrictive for the majority of MCMA's inhabitants, and particularly for those that live in the lower-income State of Mexico. A second argument is that, even if replacing the vehicle fleet were financially feasible, the traffic congestion problems would remain the same or they would even be enhanced due to the expected incentives that would be created by such program to continue using private vehicles.

A second alternative is the expansion of the mass public transportation system on all of its modes to incentivize a shift in transportation mode in favor of public transportation. Such program would require a considerably large source of funding since a key component would be the expansion of the subway system, extending the current lines mainly to areas in the State of Mexico that are not connected today, but also enlarging its capacity since it is already near its maximum. (CDMX, 2017) The expansion of the bus rapid transit system (Metrobus), as well as the light rail would be required, in addition to the public bike system (EcoBici). These are all strong alternatives, with the potential of effectively addressing both problems of air pollution and transit congestion in the long run. However, for the subway, the bus rapid transit and the light rail systems, they all face several limitations that weaken their feasibility. Such limitations relate to the costs of building and maintaining the infrastructure, as well as the costs for their operation. According to Mexico City's subway system agency CDMX (2017), in 2015, the subway system required a subsidy to cover 38% of its total operational costs, and the real cost per trip represented 2.65 times the user-payed fee. Also, there are political and jurisdictional limitations that have prevented the public transportation system to effectively connect Mexico City with its metropolitan region located in the State of Mexico.

A second set of alternatives consists on using market-based policy instruments. One such alternative is putting a price on the environmental damage caused by the use of polluting vehicles in the form of an emissions Pigouvean tax, or establishing a congestion charge that effectively imposes a Pigouvean tax on road congestion. These kinds of policies have proven to be effective for industrial environmental regulation, (Goulder & Parry, 2008; Stavins, 2007) however they face several limitations. The first one relates to the technical difficulties for accurately measuring the tax level that internalizes the cost of the environmental damage. It is also politically unattractive since there are negative incentives for decision makers to implement such policy. Finally, since the tax would be addressing environmental damage, and not traffic congestion problems, there would be a degree of disconnection between the policy objective and the level of the tax. Going further into that argument, an alternative would be imposing a Pigouvean tax on consumption of city public roads to directly address the congestion problem, however the overall limitations would remain the same.

Another option would be the implementation of a tradable driving permit system, analogous to a cap-and-trade system for point source industrial pollution. Such a program would establish a target for the maximum number of vehicles that can circulate in the city, based on their pollution potential and the roads infrastructure capacity threshold; and define decreasing yearly goals about the number of vehicles allowed for circulation, until the target is reached. To implement such policy, a permit trading system would be required in order to allow market forces to attain the price for both the environmental damage, as well as the consumption of public roads. Such a program would require a definition about how the permits would be granted, such as grandfathering or auctioning all permits, or a mix of both. This policy faces several limitations. The first one is technical, since no driving permit trading system has been implemented in the world, and no cap-and-trade system currently exists in Mexico. This would potentially compromise its implementation due to the steep learning curve that would be faced. This argument is particularly challenging since regular citizens would be the ones that do the actual trading. Another strong argument against this policy is that it could be challenged in courts as an attempt to restrict the right for free circulation within Mexican territory.

These policies are not a comprehensive account of the pool of alternatives that could be implemented, however they are some of the most salient that are or have been subject to public debate. As it has been stated, none of these policies are perfect and they all face relevant shortcomings, therefore it would be wise to use a mixed approach, combining different policies. One such example would be an aggressive expansion of the mass public transportation system, accompanied by a vehicle usage permit trading system.

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APPENDIX 1. STATISTICAL RESULTS SUMMARY TABLES

Table 1. MCMA 1989. Main results for specification one, mean daily concentrations

1989 Control: Previous years Mean daily concentrations	CO		NO_X		NO_2		O_3	
	60 Days	125 Days	60 Days	125 Days	60 Days	125 Days	60 Days	125 Days
Variable	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)
Impact size	-0.070***	0.036**	-0.137***	-0.035	-0.214***	-0.265***	0.109***	0.193***
Eligibility dummy	0.107***	0.056***	0.051	0.083***	0.249***	0.250***	-0.075**	-0.046**
After implementation period dummy	0.287***	0.217***	0.188***	0.087***	0.248***	0.320***	-0.030	-0.0258
Maximum average temperature	0.189***	0.074***	0.144***	0.064***	-	-	0.273***	0.448***
Minimum average temperature	-0.204***	-0.184***	-0.260***	-0.319***	-	-	-0.202***	-0.283***
Average rain	-	-	-	-	-0.071***	-0.063***	-	-
Wind speed during peak hours	-	-	-	-	-	-	-	-
Dow Jones Index closing value	-	-	-	-	-	-	-	-
Spatial correlation vector	Y	Y	Y	Y	Y	Y	Y	Y
N	3,570	7,906	994	2,181	1,035	2,303	1,537	3,437
Adjusted R^2	0.896	0.892	0.887	0.889	0.885	0.856	0.894	0.909
Number of monitoring stations	12	15	5	5	5	5	6	6

* p-val<0.1; ** p-val<0.05; *** p-val<0.01; Y is for included variables; - is for variables not statistically significant.

Source: Iracheta, J.A. using MCMA's Automatic Network of Atmospheric Monitoring data.

Note: The models estimations consider all variables, but only statistically significant coefficients are included in the table.

Table 2. MCMA 1989. Main results for specification one, maximum daily concentrations

1989 Control: Previous years Maximum concentrations	CO		NO_X		NO_2		O_3	
	60 Days	125 Days	60 Days	125 Days	60 Days	125 Days	60 Days	125 Days
Variable	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)
Impact size	-0.050**	0.031**	-0.079*	0.018	-0.168***	-0.156***	0.128***	0.238***
Eligibility dummy	0.046***	0.082***	0.205***	0.098***	0.178***	0.090***	-0.083***	-0.125***
After implementation period dummy	0.214***	0.156***	0.248***	0.120***	0.165***	0.130***	-0.056*	-0.136***
Maximum average temperature	0.173***	0.118***	0.229***	0.150***	-	0.148***	0.309***	0.378***
Minimum average temperature	-0.227***	-0.268***	-0.245***	-0.406***	-0.246***	-0.398***	-0.248***	-0.313***
Average rain	-	0.097***	-	-	-	-	-	-
Wind speed during peak hours	-	-	-	-	-	-	-	-
Dow Jones Index closing value	-	-0.075***	-0.264***	-0.129***	-0.108**	-	-	-
Spatial correlation vector	Y	Y	Y	Y	Y	Y	Y	Y
N	3,759	8,085	968	2,121	1,011	2,303	1,537	3,437
Adjusted R^2	0.875	0.877	0.870	0.861	0.826	0.810	0.876	0.880
Number of monitoring stations	12	15	5	5	5	5	6	6

* p-val<0.1; ** p-val<0.05; *** p-val<0.01; Y is for included variables; - is for variables not statistically significant.

Source: Iracheta, J.A. using MCMA's Automatic Network of Atmospheric Monitoring data.

Note: The models estimations consider all variables, but only statistically significant coefficients are included in the table.

Table 3.a. MCMA 1989. Main results for specification two, mean daily concentrations

1989 Control: Sundays Mean daily concentrations	CO				NO_X			
	60 Days	125 Days	250 Days	500 Days	60 Days	125 Days	250 Days	500 Days
Variable	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)
Impact size	-0.018	0.000	-0.010	-0.028	-0.025	0.037	-0.007	-0.020
Eligibility dummy	0.186***	0.157***	0.141***	0.144***	0.194***	0.191***	0.225***	0.223***
After implementation period dummy	0.257***	0.273***	0.405***	0.493***	0.121	0.105*	0.059	0.058
Maximum average temperature	0.081***	-	0.017*	0.0245***	0.078*	-	0.084***	0.120***
Minimum average temperature	-0.076***	-	-	-	-0.092*	-0.105***	-0.274***	-0.376***
Average rain	-	-	0.096***	-	-	-	0.077***	0.080***
Wind speed during peak hours	-	-	-	-	-	-	-	-
Dow Jones Index closing value	-	-	-0.292	-0.122***	-	-	-0.058**	0.088***
Spatial correlation vector	Y	Y	Y	Y	Y	Y	Y	Y
N	1,443	3,216	6,491	12,585	484	991	2,088	3,122
Adjusted R^2	0.922	0.923	0.909	0.893	0.852	0.870	0.882	0.876
Number of monitoring stations	15	15	15	15	5	5	5	5

* p-val<0.1; ** p-val<0.05; *** p-val<0.01; Y is for included variables; - is for variables not statistically significant.

Source: Iracheta, J.A. using MCMA's Automatic Network of Atmospheric Monitoring data.

Note: The models estimations consider all variables, but only statistically significant coefficients are included in the table.

Table 3.b. MCMA 1989. Main results for specification two, mean daily concentrations (cont.)

1989 Control: Sundays Mean daily concentrations	NO_2				O_3			
	60 Days	125 Days	250 Days	500 Days	60 Days	125 Days	250 Days	500 Days
Variable	**Std. coeff. (Beta)**	**Std. coeff. (Beta)**	**Std. coeff. (Beta)**	**Std. coeff. (Beta)**	**Std. coeff. (Beta)**	**Std. coeff. (Beta)**	**Std. coeff. (Beta)**	**Std. coeff. (Beta)**
Impact size	-0.092	-0.069	-0.098**	-0.093***	0.019	0.031	0.024	0.017
Eligibility dummy	0.220***	0.202***	0.212***	0.202***	0.068	0.044	0.038*	0.030**
After implementation period dummy	0.065	0.106**	-0.026	-0.093***	0.202***	0.295***	0.182***	0.191***
Maximum average temperature	-	-	0.043**	0.121***	0.305***	0.468**	0.469***	0.453***
Minimum average temperature	-	-	-0.240***	-0.373***	-0.283***	-0.141***	-0.272***	-0.217***
Average rain	-0.089***	-	-	0.042**	-	-	-	0.056***
Wind speed during peak hours	-	-	-	-	-	-	-	-
Dow Jones Index closing value	-	-	-	0.246***	-0.097**	-	-	-
Spatial correlation vector	Y	Y	Y	Y	Y	Y	Y	Y
N	527	1,135	2,247	3,281	515	1,216	3,011	5,143
Adjusted R^2	0.872	0.876	0.857	0.856	0.919	0.917	0.918	0.906
Number of monitoring stations	5	5	5	5	6	6	7	7

* p-val<0.1; ** p-val<0.05; *** p-val<0.01; Y is for included variables; - is for variables not statistically significant.

Source: Iracheta, J.A. using MCMA's Automatic Network of Atmospheric Monitoring data.

Note: The models estimations consider all variables, but only statistically significant coefficients are included in the table.

Table 4.a. MCMA 1989. Main results for specification two, maximum daily concentrations

1989 Control: Sundays Maximum concentrations	CO				NO_X			
	60 Days	125 Days	250 Days	500 Days	60 Days	125 Days	250 Days	500 Days
Variable	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)
Impact size	-0.048	-0.003	-0.029	-0.059***	0.060	0.144**	-0.030	-0.052
Eligibility dummy	0.224***	0.200***	0.198***	0.212***	0.238***	0.208***	0.287***	0.294***
After implementation period dummy	0.260***	0.201***	0.190***	0.366***	0.122	0.091*	0.131***	0.122***
Maximum average temperature	0.078****	0.070***	-	0.102***	0.138***	0.127***	0.153***	0.212***
Minimum average temperature	-0.094****	-0.103***	-0.122***	-0.278***	-0.114**	-0.211***	-0.358***	-0.477***
Average rain	-	0.058***	-	0.087***	-	-	-	0.059***
Wind speed during peak hours	-	-	-	-	-	-	-	-
Dow Jones Index closing value	-	0.035**	-	-0.086***	-0.143***	-0.072**	-0.127***	-
Spatial correlation vector	Y	Y	Y	Y	Y	Y	Y	Y
N	1,529	3,379	6,844	11,071	484	991	2,088	3,122
Adjusted R^2	0.899	0.902	0.888	0.878	0.836	0.844	0.850	0.845
Number of monitoring stations	15	15	15	15	5	5	5	5

* p-val<0.1; ** p-val<0.05; *** p-val<0.01; Y is for included variables; - is for variables not statistically significant.

Source: Iracheta, J.A. using MCMA's Automatic Network of Atmospheric Monitoring data.

Note: The models estimations consider all variables, but only statistically significant coefficients are included in the table.

Table 4.b. MCMA 1989. Main results for specification two, maximum daily concentrations (cont.)

1989 Control: Sundays Maximum concentrations	NO_2				O_3			
	60 Days	125 Days	250 Days	500 Days	60 Days	125 Days	250 Days	500 Days
Variable	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)
Impact size	0.065	0.064	-0.062	-0.080**	-0.017	-0.027	-0.027	-0.037
Eligibility dummy	0.162***	0.167***	0.211***	0.221***	0.123***	0.093***	0.096***	0.094***
After implementation period dummy	-0.074	-0.037	-0.014	-0.034	0.302***	0.310***	0.292***	0.321***
Maximum average temperature	-	0.097***	0.134***	0.207***	0.365***	0.434***	0.392***	0.399***
Minimum average temperature	-0.101*	-0.235***	-0.327***	-0.458***	-0.376***	-0198***	-0.228***	-0.279***
Average rain	-0.140***	-	-	0.038***	-	-	0.045**	0.071***
Wind speed during peak hours	-	-	-	-	-	-	-	-
Dow Jones Index closing value	0.084*	-	-0.044*	0.130***	-0.119***	-	-0.041*	-0.044**
Spatial correlation vector	Y	Y	Y	Y	Y	Y	Y	Y
N	527	1,135	2,247	3,281	515	1,216	3,011	5,143
Adjusted R^2	0.805	0.809	0.798	0.801	0.895	0.893	0.886	0.883
Number of monitoring stations	5	5	5	5	6	6	7	7

* p-val<0.1; ** p-val<0.05; *** p-val<0.01; Y is for included variables; - is for variables not statistically significant.

Source: Iracheta, J.A. using MCMA's Automatic Network of Atmospheric Monitoring data.

Note: The models estimations consider all variables, but only statistically significant coefficients are included in the table.

Table 5. MCMA 2014. Main results for specification one, mean daily concentrations

2014 Control: Previous years Mean daily concentrations	CO		NO_X		NO_2		O_3	
	60 Days	125 Days	60 Days	125 Days	60 Days	125 Days	60 Days	125 Days
Variable	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)
Impact size	0.029**	0.007	-0.008	-0.057***	0.019	-0.052***	0.033***	-0.046***
Eligibility dummy	-0.062***	-0.062***	-0.020	-0.003	-0.056***	0.009	0.012	0.132***
After implementation period dummy	-0.212***	-0.228***	-0.132***	-0.050***	-0.210***	-0.112***	-0.211***	-0.173***
Maximum average temperature	-	0.028***	0.045***	0.076***	0.070***	0.094***	0.582***	0.559***
Minimum average temperature	-	-0.209***	-0.080***	-0.347***	-0.018**	-0.296***	-0.066***	-0.037***
Average rain	-	-	-	-	-	-	-	-
Wind speed during peak hours	-0.337***	-0.345***	-	-0.268***	-	-0.294***	-	-
Dow Jones Index closing value	-	-	-	-	-	-	-	-
Mexican Stock Exchange closing value	0.086***	0.069***	0.075***	0.089***	0.030***	0.069***	-	-
Mexican National Price Index biweekly value	-	0.013*	-	-	-	-	-0.076***	-0.069***
Spatial correlation vector	Y	Y	Y	Y	Y	Y	Y	Y
N	6,952	14,576	8,452	17,225	8,777	17,911	8,704	17,937
Adjusted R^2	0.921	0.920	0.910	0.917	0.942	0.952	0.942	0.930
Number of monitoring stations	20	20	24	24	24	24	24	24

* p-val<0.1; ** p-val<0.05; *** p-val<0.01; Y is for included variables; - is for variables not statistically significant.

Source: Iracheta, J.A. using MCMA's Automatic Network of Atmospheric Monitoring data.

Note: The models estimations consider all variables, but only statistically significant coefficients are included in the table.

Table 6. MCMA 2014. Main results for specification one, maximum daily concentrations

2014 Control: Previous years Maximum concentrations	CO		NO_X		NO_2		O_3	
	60 Days	125 Days	60 Days	125 Days	60 Days	125 Days	60 Days	125 Days
Variable	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)
Impact size	0.040***	0.043***	-0.011	-0.035***	0.011	-0.043***	0.054***	-0.023**
Eligibility dummy	-0.065***	-0.107***	0.016	0.014*	-0.042***	-0.008	0.034**	0.125***
After implementation period dummy	-0.186***	-0.155***	-0.135***	-0.089***	-0.223***	-0.117****	-0.117***	-0.065***
Maximum average temperature	0.108***	0.045***	0.281***	0.228***	0.194***	0.195***	0.509***	0.554***
Minimum average temperature	-0.102***	-	-0.166***	-0.378***	-0.102***	-0.360***	-0.043***	-0.072***
Average rain	-	-	-	-	-	-	-	-
Wind speed during peak hours	-0.278***	-0.328***	-0.180***	-0.196***	-	-0.250***	-	-0.249***
Dow Jones Index closing value	-	-	-	-	-	-	-	-
Mexican Stock Exchange closing value	0.036***	-	0.038***	0.044***	0.023**	0.034**	-0.069***	-0.075***
Mexican National Price Index biweekly value	-	-	-	-	-	0.022***	-	-
Spatial correlation vector	Y	Y	Y	Y	Y	Y	Y	Y
N	6,960	15,068	8,452	17,225	8,452	17,225	8,537	17,371
Adjusted R^2	0.899	0.887	0.847	0.857	0.926	0.930	0.933	0.935
Number of monitoring stations	20	20	24	24	24	24	24	24

* p-val<0.1; ** p-val<0.05; *** p-val<0.01; Y is for included variables; - is for variables not statistically significant.

Source: Iracheta, J.A. using MCMA's Automatic Network of Atmospheric Monitoring data.

Note: The models estimations consider all variables, but only statistically significant coefficients are included in the table.

Table 7. MCMA 2014. Main results for specification two, mean daily concentrations

2014 Control: Sundays Mean daily concentrations	CO		NO_X		NO_2		O_3	
	60 Days	125 Days	60 Days	125 Days	60 Days	125 Days	60 Days	125 Days
Variable	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)
Impact size	0.055*	-0.010	0.133***	-0.032*	0.090***	-0.032*	-0.074**	-0.182***
Eligibility dummy	0.143***	0.142***	0.211***	0.221***	0.203***	0.195***	-0.103***	-0.038***
After implementation period dummy	-0.211***	-0.077***	-0.258***	-0.062***	-0.293***	-0.110***	-0.114***	-0.065***
Maximum average temperature	0.041***	0.034***	0.041***	0.034***	0.054***	0.051***	0.571***	0.522***
Minimum average temperature	-	-0.135***	-0.096***	-0.313***	-0.062***	-0.325***	-0.106***	-0.163***
Average rain	-	-	-	-	-	-	-	-
Wind speed during peak hours	-0.343***	-0.372***	-	-0.290***	-	-0.321***	-	-
Dow Jones Index closing value	-	-	-	-	-	-	-	-
Mexican Stock Exchange closing value	0.106***	0.071***	0.124***	0.081***	0.106***	0.065***	-	-
Mexican National Price Index biweekly value	-	-0.003*	-	-	-	-	-0.012***	-0.018***
Spatial correlation vector	Y	Y	Y	Y	Y	Y	Y	Y
N	2,602	5,499	3,135	6,673	3,271	6,955	3,337	7,024
Adjusted R^2	0.941	0.937	0.919	0.930	0.947	0.956	0.947	0.938
Number of monitoring stations	20	20	24	24	24	24	24	24

* p-val<0.1; ** p-val<0.05; *** p-val<0.01; Y is for included variables; - is for variables not statistically significant.

Source: Iracheta, J.A. using MCMA's Automatic Network of Atmospheric Monitoring data.

Note: The models estimations consider all variables, but only statistically significant coefficients are included in the table.

Table 8. MCMA 2014. Main results for specification two, maximum daily concentrations

2014 Control: Sundays Maximum concentrations	CO		NO_X		NO_2		O_3	
	60 Days	125 Days	60 Days	125 Days	60 Days	125 Days	60 Days	125 Days
Variable	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)
Impact size	0.142***	0.056**	0.016	-0.087***	0.060**	-0.049***	-0.023	-0.127***
Eligibility dummy	0.111***	0.130***	0.245***	0.266***	0.209***	0.197***	-0.051***	0.018
After implementation period dummy	-0.298***	-0.184***	-0.182***	-0.048***	-0.306***	-0.148***	-0.090***	-0.028
Maximum average temperature	0.055***	0.046***	0.214***	0.166***	0.134***	0.110***	0.486***	0.473***
Minimum average temperature	-0.100***	-	-0.156***	-0.331***	-0.100***	-0.350***	-0.099***	-0.148***
Average rain	-	-	-	-	-	-	-	-
Wind speed during peak hours	-0.308***	-0.365***	-0.180***	-0.204***	-	-0.280***	-	-0.228***
Dow Jones Index closing value	-	-	-	-	-	-	-	-
Mexican Stock Exchange closing value	-	-	-	0.081***	-	0.061***	0.045***	0.031***
Mexican National Price Index biweekly value	0.121***	-	0.115***	-0.016***	0.115***	0.017***	-	-
Spatial correlation vector	Y	Y	Y	Y	Y	Y	Y	Y
N	2,597	5,490	3,135	6,673	3,135	6,673	3,337	7,024
Adjusted R^2	0.923	0.913	0.862	0.866	0.930	0.936	0.935	0.933
Number of monitoring stations	20	20	24	24	24	24	24	24

* p-val<0.1; ** p-val<0.05; *** p-val<0.01; Y is for included variables; - is for variables not statistically significant.

Source: Iracheta, J.A. using MCMA's Automatic Network of Atmospheric Monitoring data.

Note: The models estimations consider all variables, but only statistically significant coefficients are included in the table.

Table 9. MCMA 2015. Main results for specification one, mean daily concentrations

2015 Control: Previous years Mean daily concentrations	CO		NO_X		NO_2		O_3	
	60 Days	125 Days	60 Days	125 Days	60 Days	125 Days	60 Days	125 Days
Variable	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)
Impact size	0.117***	0.116***	0.073***	0.065***	0.139***	0.131***	0.238***	0.081***
Eligibility dummy	-0.136***	-0.078***	-0.103***	-0.066***	-0.068***	-0.079***	-0.140***	0.017*
After implementation period dummy	-0.168***	-0.103***	-0.132***	-0.034***	-0.242***	-0.201***	-0.244***	-0.219***
Maximum average temperature	0.032***	-	0.078***	0.118***	-	-	0.600***	0.525***
Minimum average temperature	-	-0.014**	-0.014*	-0.389***	-	-0.037***	-0.093***	-0.065***
Average rain	-	-	-	-	-	-	-	-
Wind speed during peak hours	-0.338***	-	-0.306***	-	-0.323***	-0.390***	-	-
Dow Jones Index closing value	-	-	-	-	-	-	-	-
Mexican Stock Exchange closing value	0.054***	-	-	-	-	0.078***	0.070***	-0.062***
Mexican National Price Index biweekly value	-	-0.024***	0.118***	0.038***	0.085***	-	-	-
Spatial correlation vector	Y	Y	Y	Y	Y	Y	Y	Y
N	7,077	14,982	7,996	16,798	8,314	16,845	8,709	17,508
Adjusted R^2	0.937	0.903	0.934	0.906	0.956	0.947	0.945	0.930
Number of monitoring stations	29	20	25	24	25	24	31	24

* p-val<0.1; ** p-val<0.05; *** p-val<0.01; Y is for included variables; - is for variables not statistically significant.

Source: Iracheta, J.A. using MCMA's Automatic Network of Atmospheric Monitoring data.

Note: The models estimations consider all variables, but only statistically significant coefficients are included in the table.

Table 10. MCMA 2015. Main results for specification one, maximum daily concentrations

2015 Control: Previous years Maximum concentrations	CO		NO_X		NO_2		O_3	
	60 Days	125 Days	60 Days	125 Days	60 Days	125 Days	60 Days	125 Days
Variable	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)
Impact size	0.076***	0.086***	0.002	0.046***	0.091***	0.100***	0.172***	0.015
Eligibility dummy	-0.097***	-0.049***	-0.102***	-0.036***	-0.046***	-0.063***	-0.071***	0.073***
After implementation period dummy	-0.162***	-0.114***	-0.106***	-0.097***	-0.212***	-0.136***	-0.147***	-0.085***
Maximum average temperature	0.151***	0.043***	0.320***	0.253***	0.220***	0.193***	0.544***	0.530***
Minimum average temperature	-0.026***	-	-0.068***	-0.356***	-	-0.400***	-0.061***	-0.126***
Average rain	-	-	-	-	-	-	-	-
Wind speed during peak hours	-0.299***	-	-0.211***	-0.222***	-0.283***	-	-0.242***	-
Dow Jones Index closing value	-	-	-	-	-	-	-	-
Mexican Stock Exchange closing value	0.061***	-	-	-	-	0.023***	0.091***	-0.084***
Mexican National Price Index biweekly value	-	-0.041***	0.152***	0.028***	0.048***	-	-	-
Spatial correlation vector	Y	Y	Y	Y	Y	Y	Y	Y
N	7,069	14,966	8,176	16,798	8,176	16,191	8,709	17,508
Adjusted R^2	0.928	0.888	0.870	0.860	0.939	0.922	0.464	0.924
Number of monitoring stations	29	20	25	24	25	24	31	24

* p-val<0.1; ** p-val<0.05; *** p-val<0.01; Y is for included variables; - is for variables not statistically significant.

Source: Iracheta, J.A. using MCMA's Automatic Network of Atmospheric Monitoring data.

Note: The models estimations consider all variables, but only statistically significant coefficients are included in the table.

Table 11. MCMA 2015. Main results for specification two, mean daily concentrations

2015 Control: Sundays Mean daily concentrations	CO		NO_X		NO_2		O_3	
	60 Days	125 Days	60 Days	125 Days	60 Days	125 Days	60 Days	125 Days
Variable	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)
Impact size	0.066***	0.164***	0.046**	0.124***	0.071***	0.089***	0.109***	0.027
Eligibility dummy	0.183***	0.101***	0.305***	0.191***	0.256***	0.250***	-0.189***	-0.157***
After implementation period dummy	-0.150***	-0.145***	-0.092***	-0.065***	-0.129***	-0.101***	-0.066**	-0.127***
Maximum average temperature	0.034***	-0.048***	0.077***	0.078***	-	-0.044***	0.460***	0.498***
Minimum average temperature	-	-	-	-0.354***	-	-	-0.155***	-0.041***
Average rain	-	-	-	-	-	-	-	-
Wind speed during peak hours	-0.344***	-	-0.327***	-	-0.344***	-0.402***	-0.45***	-
Dow Jones Index closing value	-	-	-	-	-	-	-	-
Mexican Stock Exchange closing value	0.043***	-	0.053***	0.089***	0.059***	0.084***	-0.064**	-0.055***
Mexican National Price Index biweekly value	0.073***	0.002**	-	-0.003**	-	-	-	-0.009***
Spatial correlation vector	Y	Y	Y	Y	Y	Y	Y	Y
N	3,522	6,850	3,064	6,116	3,195	6,373	3,723	7,357
Adjusted R^2	0.955	0.907	0.948	0.915	0.967	0.957	0.960	0.940
Number of monitoring stations	29	20	25	24	25	24	31	24

* p-val<0.1; ** p-val<0.05; *** p-val<0.01; Y is for included variables; - is for variables not statistically significant.

Source: Iracheta, J.A. using MCMA's Automatic Network of Atmospheric Monitoring data.

Note: The models estimations consider all variables, but only statistically significant coefficients are included in the table.

Table 12. MCMA 2015. Main results for specification two, maximum daily concentrations

2015 Control: Sundays Maximum concentrations	CO		NO_X		NO_2		O_3	
	60 Days	125 Days	60 Days	125 Days	60 Days	125 Days	60 Days	125 Days
Variable	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)	Std. coeff. (Beta)
Impact size	0.029	0.109***	-0.019	-0.061***	0.031	0.086***	-0.014	-0.012
Eligibility dummy	0.241***	0.163***	0.344***	0.329***	0.272***	0.169***	0.045***	-0.053***
After implementation period dummy	-0.116***	-0.139***	-0.115***	0.036**	-0.163***	-0.094***	0.085***	-0.054**
Maximum average temperature	0.153***	0.020**	0.276***	0.223***	0.098***	0.113***	0.433***	0.466***
Minimum average temperature	-0.031***	-	-0.070***	-0.354***	-	-0.321***	-0.107***	-0.107***
Average rain	-	-	-	-	-	-	-	-
Wind speed during peak hours	-0.315***	-	-0.264***	-0.224***	-0.319***	-	-0.331***	-
Dow Jones Index closing value	-	-	-	-	-	-	-	-
Mexican Stock Exchange closing value	0.045***	-	0.045***	-	0.060***	0.083***	-	-0.036***
Mexican National Price Index biweekly value	-	-0.004***	0.079***	-0.012***	0.061***	-	-	-
Spatial correlation vector	Y	Y	Y	Y	Y	Y	Y	Y
N	3,521	6,849	3,064	6,116	3,064	6,116	3,723	7,357
Adjusted R^2	0.947	0.895	0.895	0.879	0.952	0.926	0.432	0.929
Number of monitoring stations	29	20	25	24	25	24	31	24

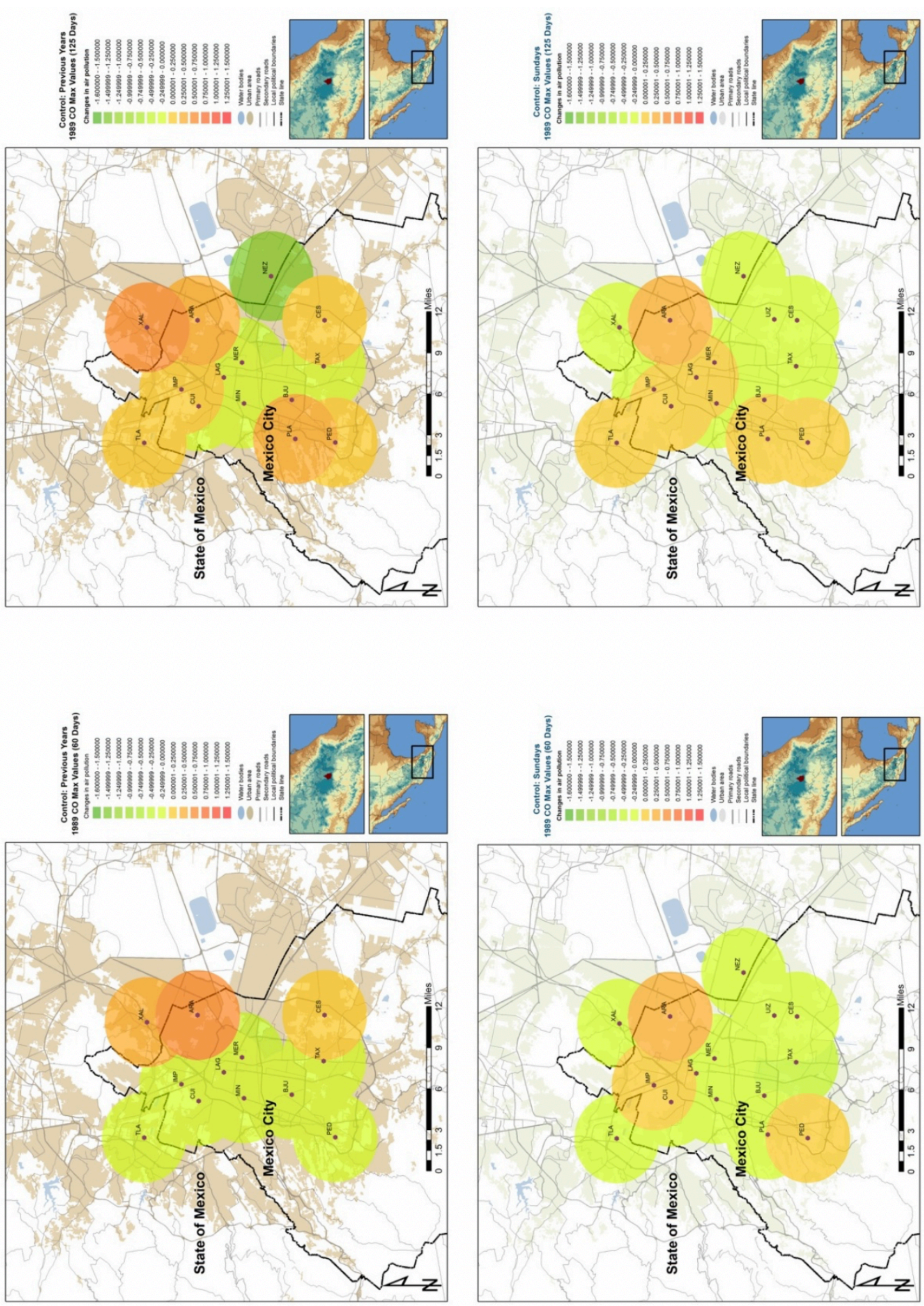
* p-val<0.1; ** p-val<0.05; *** p-val<0.01; Y is for included variables; - is for variables not statistically significant.

Source: Iracheta, J.A. using MCMA's Automatic Network of Atmospheric Monitoring data.

Note: The models estimations consider all variables, but only statistically significant coefficients are included in the table.

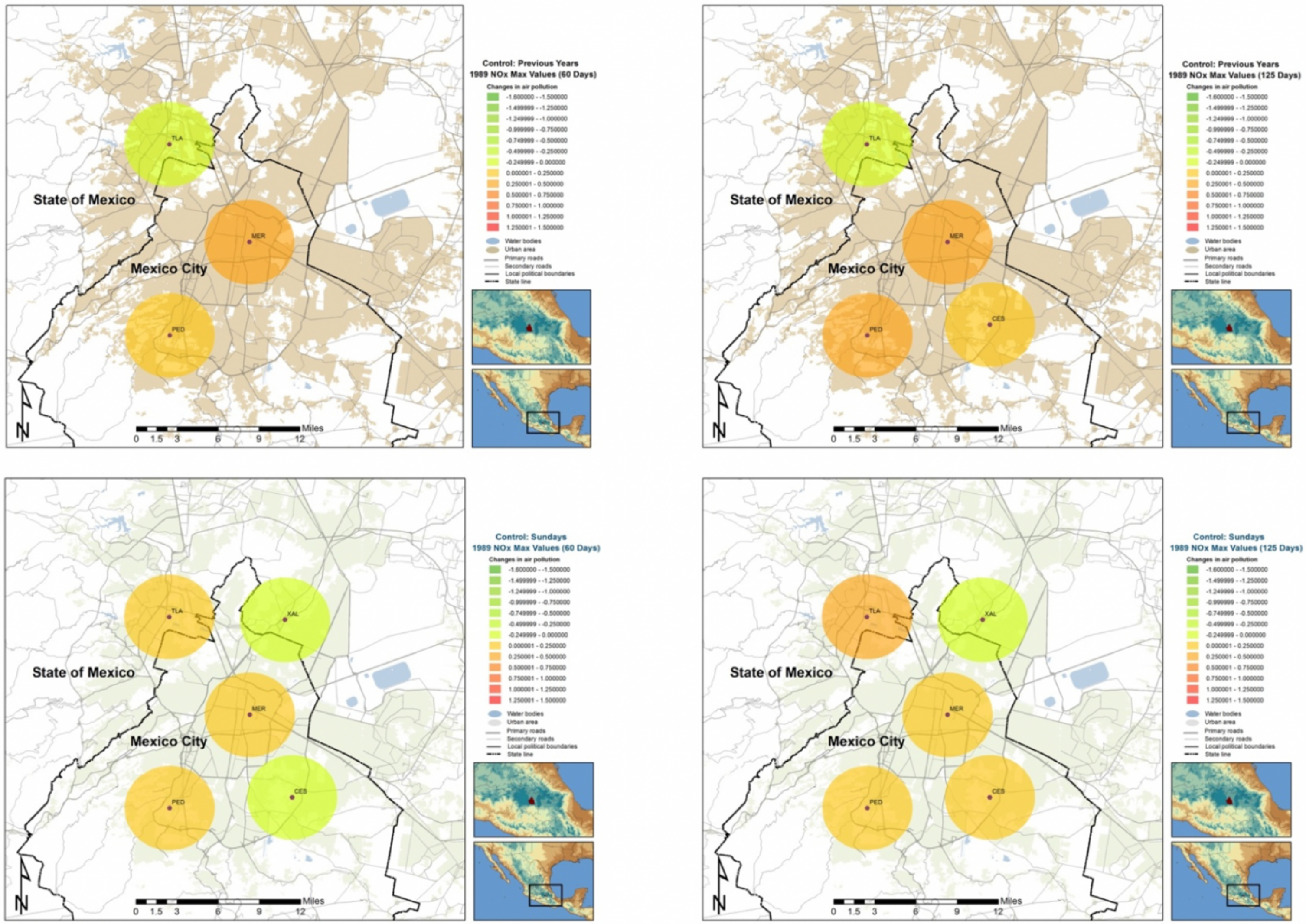
APPENDIX 2. STATISTICAL RESULTS SUMMARY MAPS

Map 1. MCMA 1989. CO maximum daily concentrations, 60 and 125 days



Source: Iracheta, J.A. using MCMA's Automatic Network of Atmospheric Monitoring data.

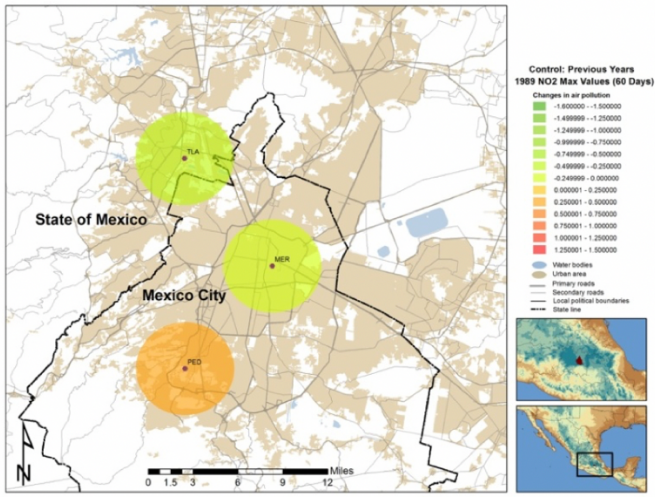
Map 2. MCMA 1989. NO_X maximum daily concentrations, 60 and 125 days



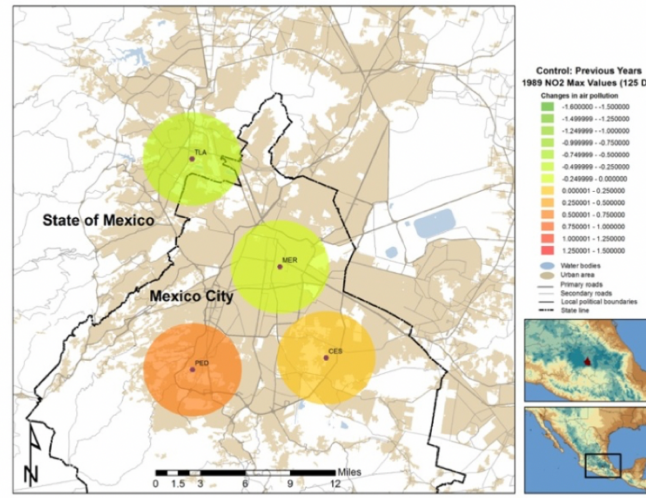
Source: Iracheta, J.A. using MCMA's Automatic Network of Atmospheric Monitoring data.

Map 3. MCMA 1989. NO_2 and O_3 maximum daily concentrations, 60 and 125 days

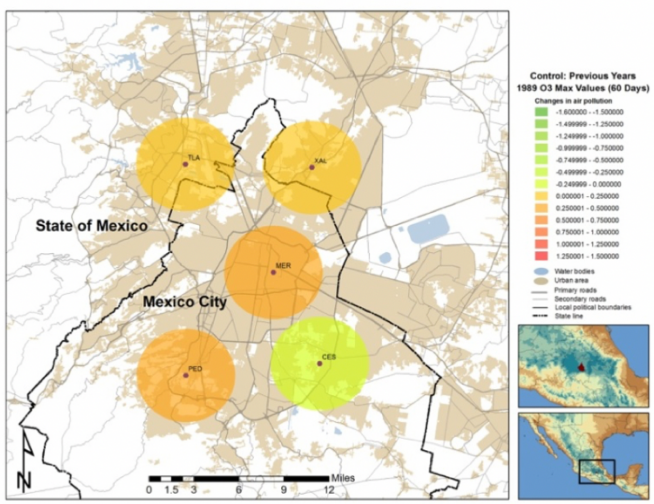
NO_2



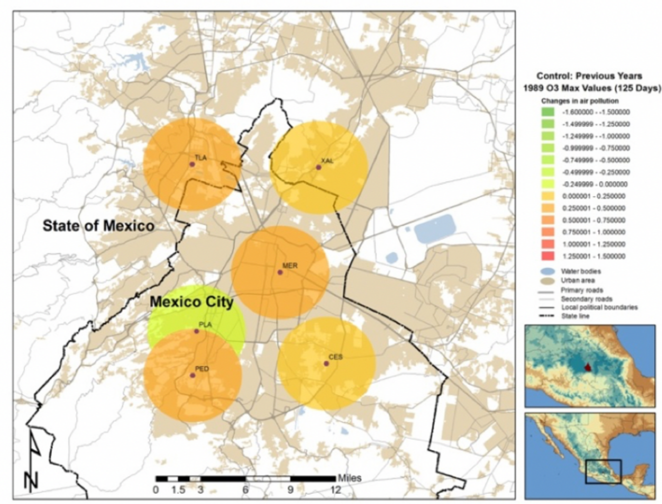
NO_2



O_3

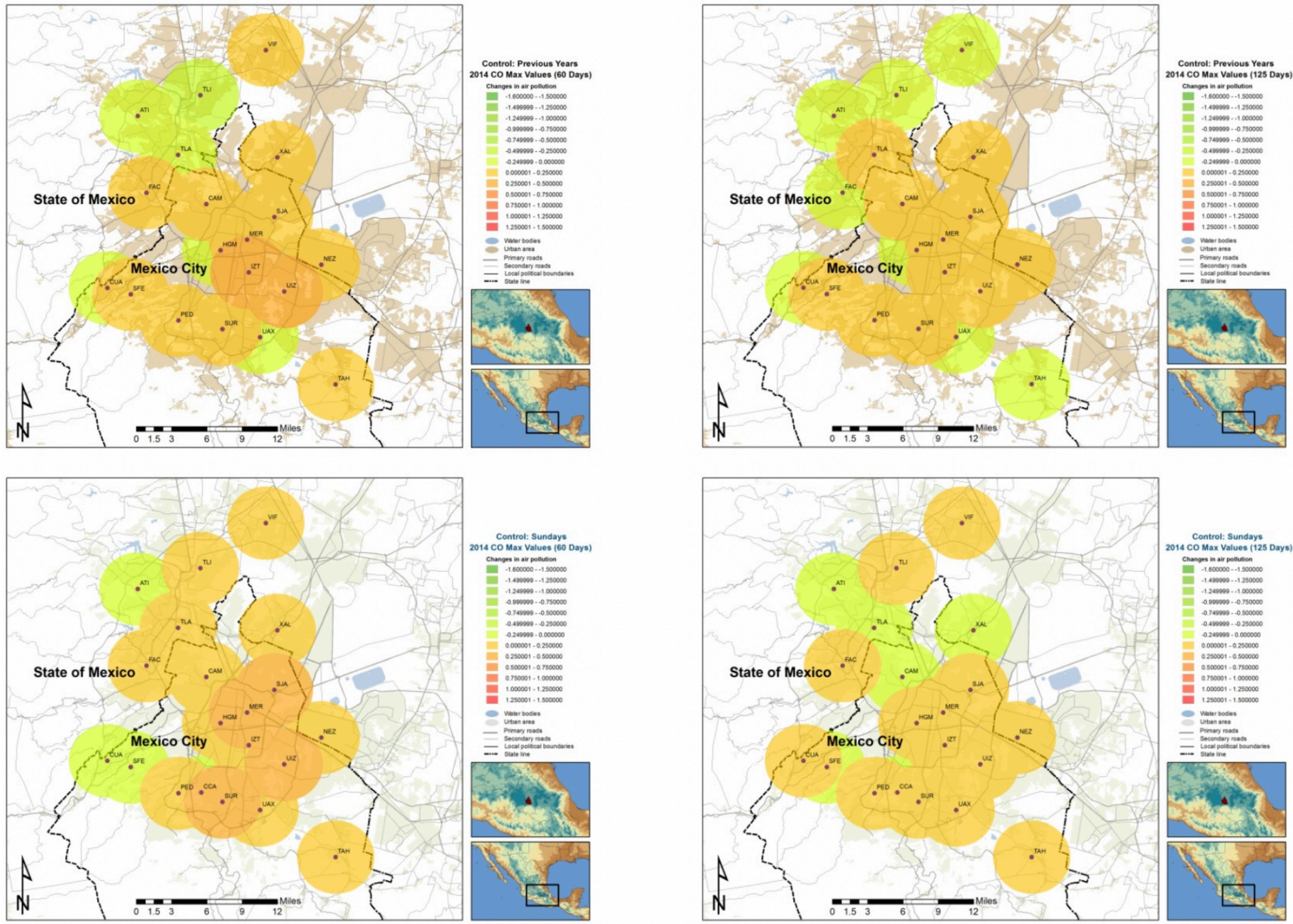


O_3



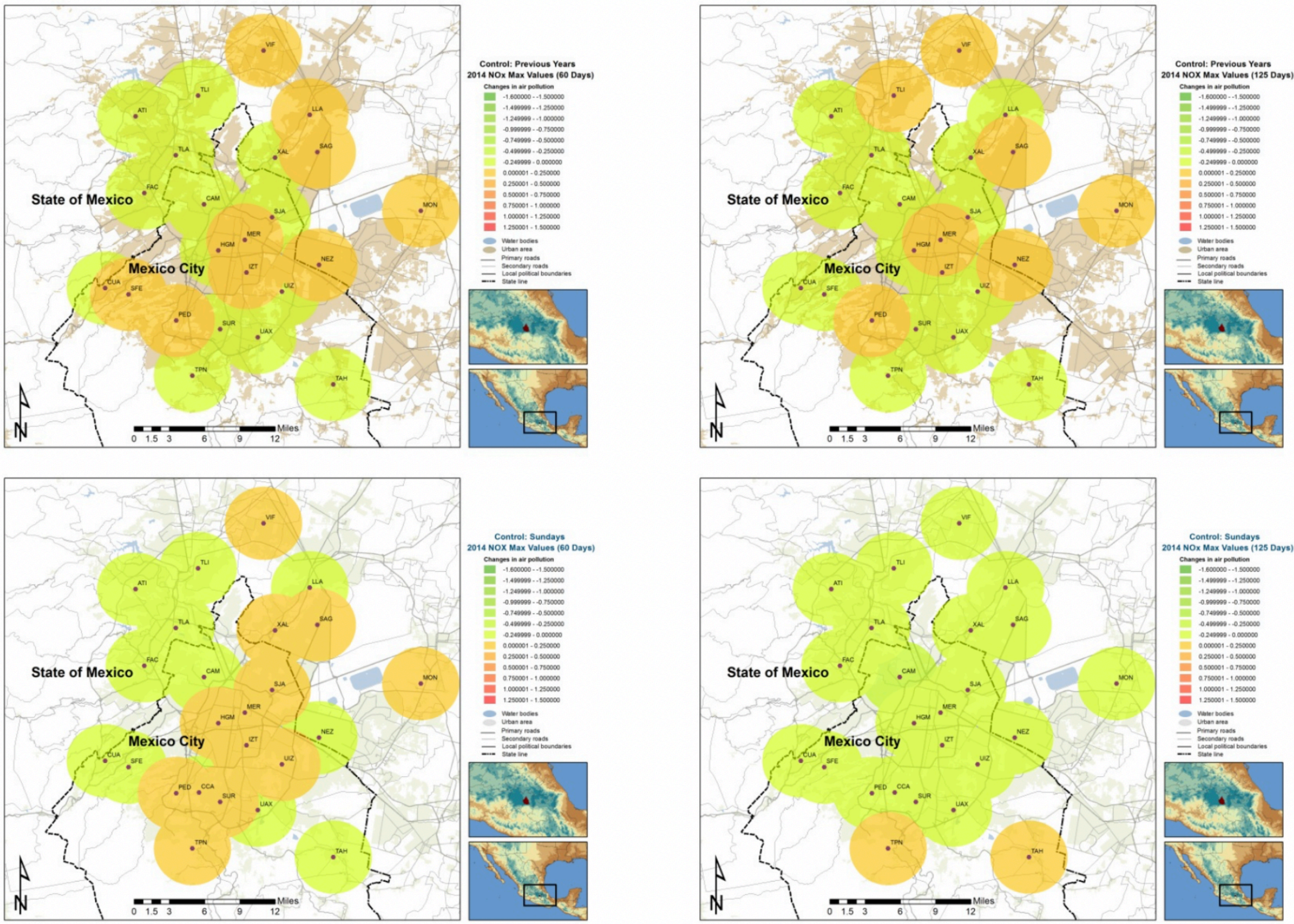
Source: Iracheta, J.A. using MCMA's Automatic Network of Atmospheric Monitoring data.

Map 4. MCMA 2014. CO maximum daily concentrations, 60 and 125 days



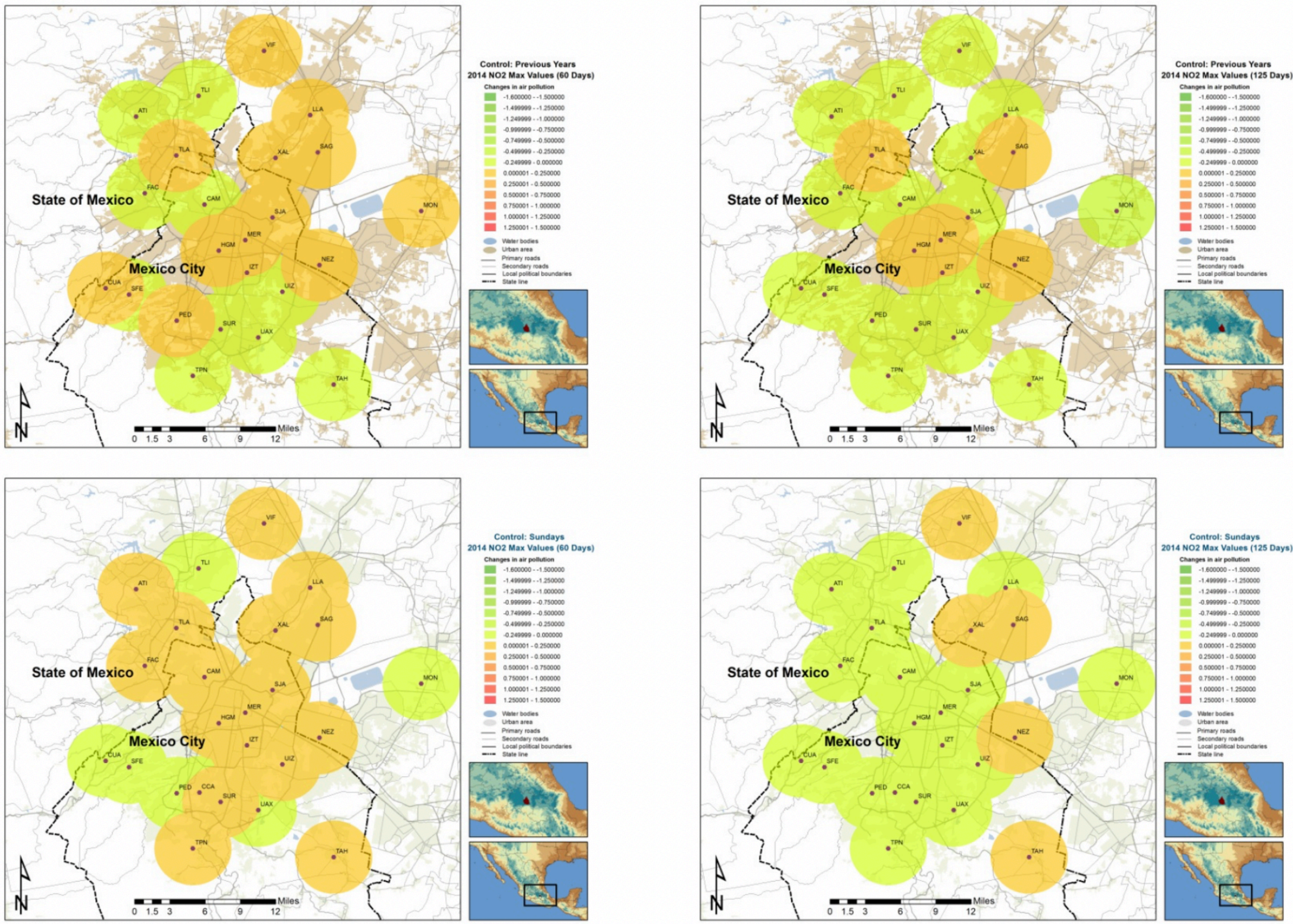
Source: Iracheta, J.A. using MCMA's Automatic Network of Atmospheric Monitoring data.

Map 5. MCMA 2014. NO_X maximum daily concentrations, 60 and 125 days



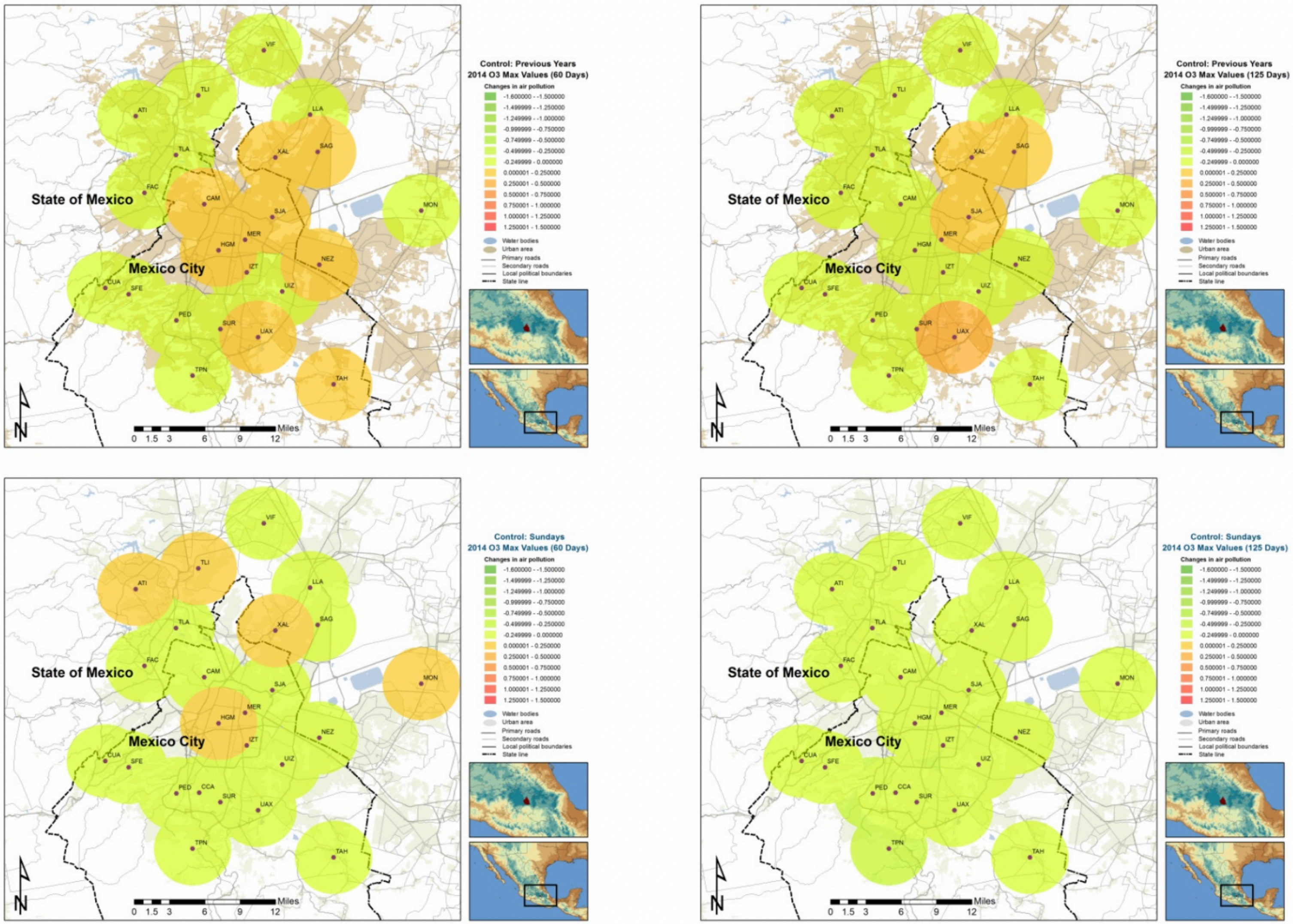
Source: Iracheta, J.A. using MCMA's Automatic Network of Atmospheric Monitoring data.

Map 6. MCMA 2014. NO_2 maximum daily concentrations, 60 and 125 days



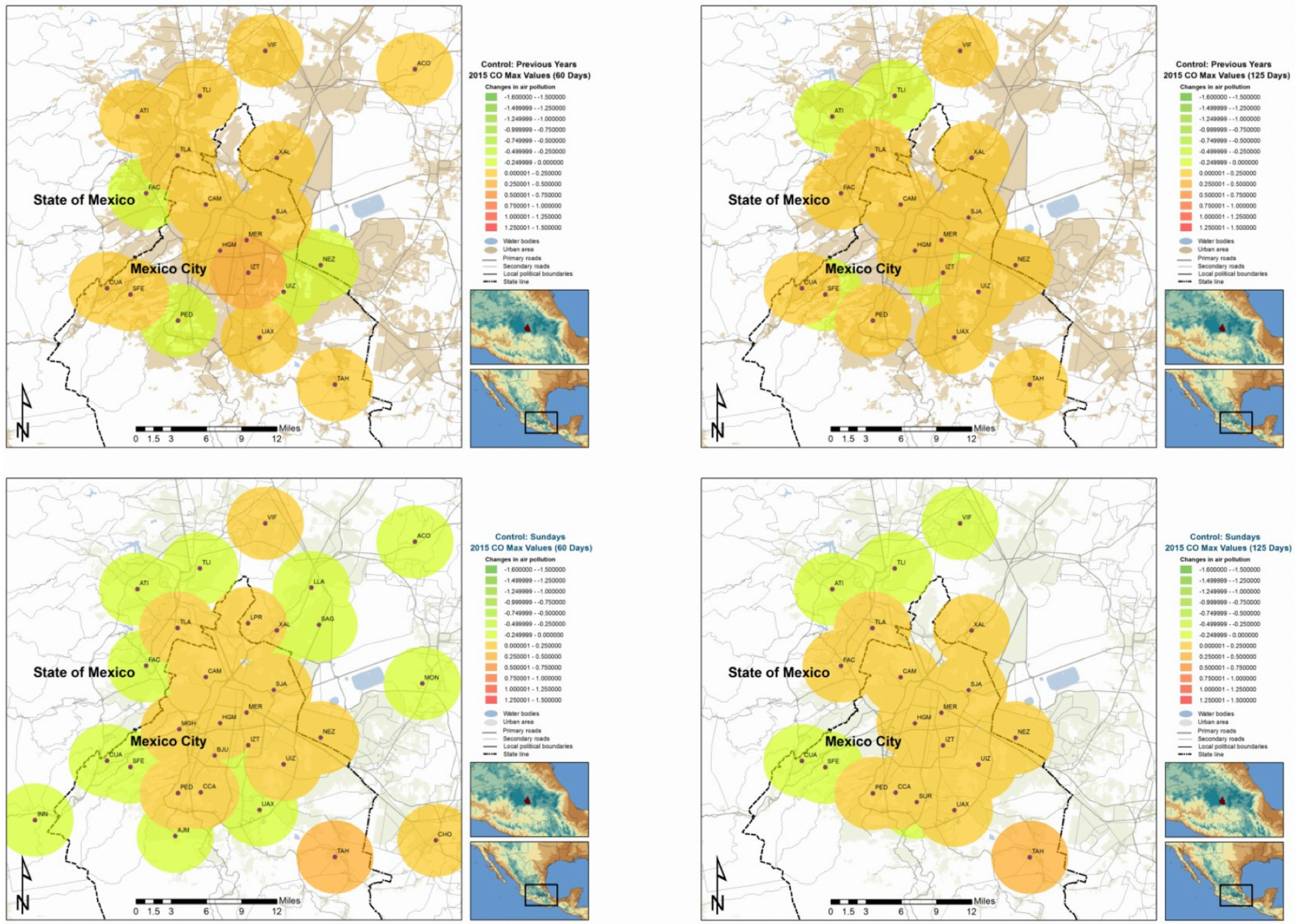
Source: Iracheta, J.A. using MCMA's Automatic Network of Atmospheric Monitoring data.

Map 7. MCMA 2014. O_3 maximum daily concentrations, 60 and 125 days



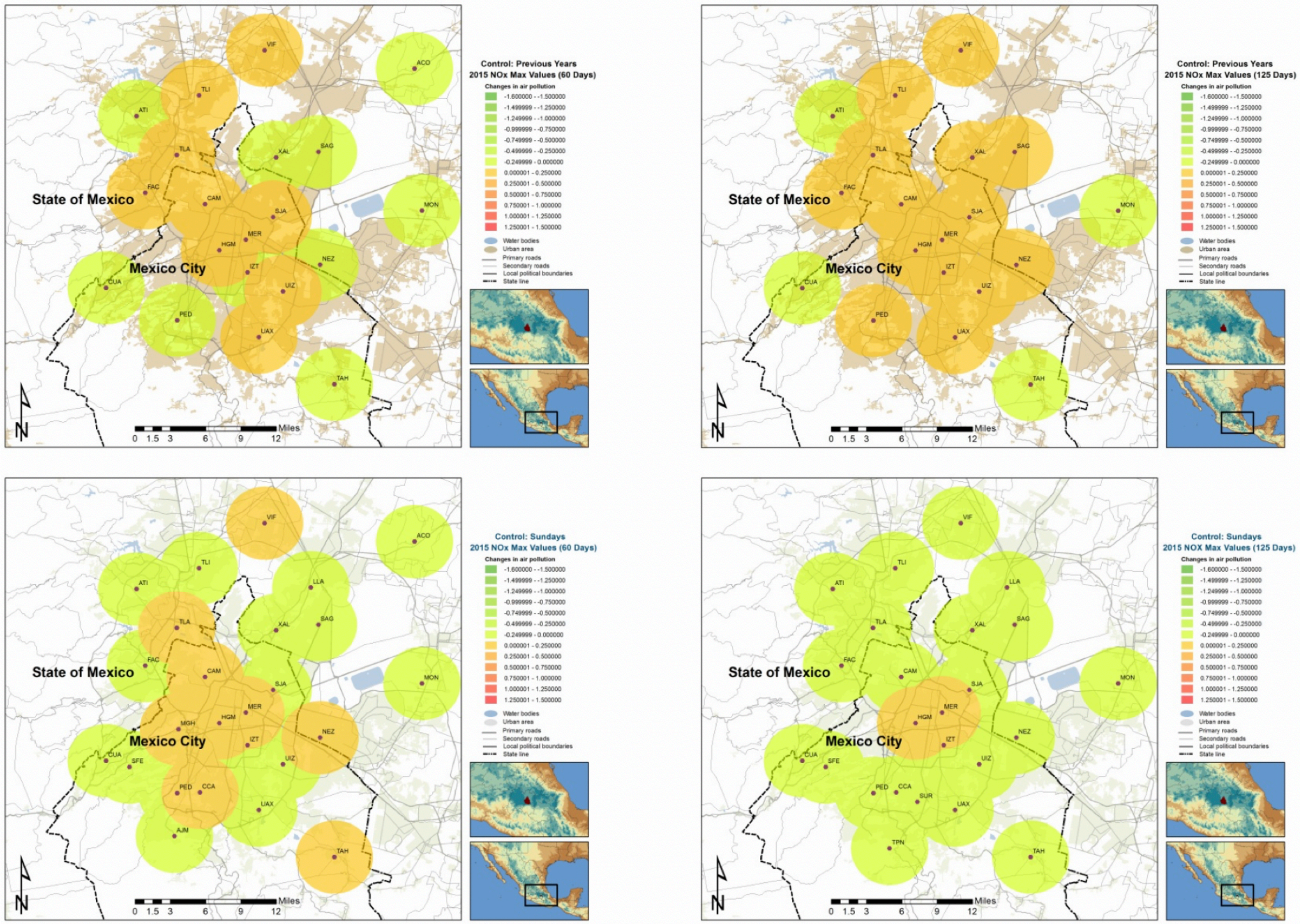
Source: Iracheta, J.A. using MCMA's Automatic Network of Atmospheric Monitoring data.

Map 8. MCMA 2015. CO maximum daily concentrations, 60 and 125 days



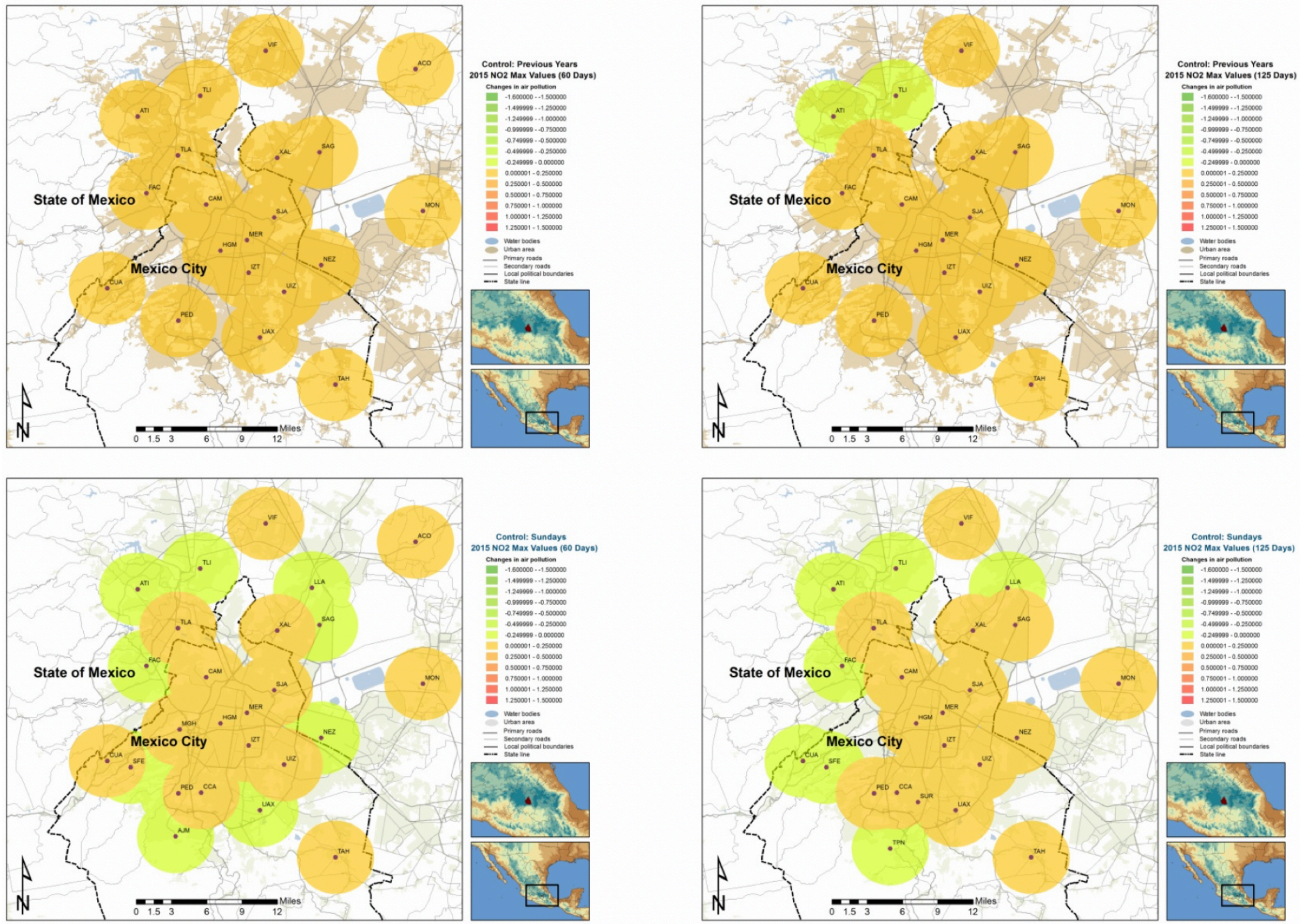
Source: Iracheta, J.A. using MCMA's Automatic Network of Atmospheric Monitoring data.

Map 9. MCMA 2015. NO_X maximum daily concentrations, 60 and 125 days



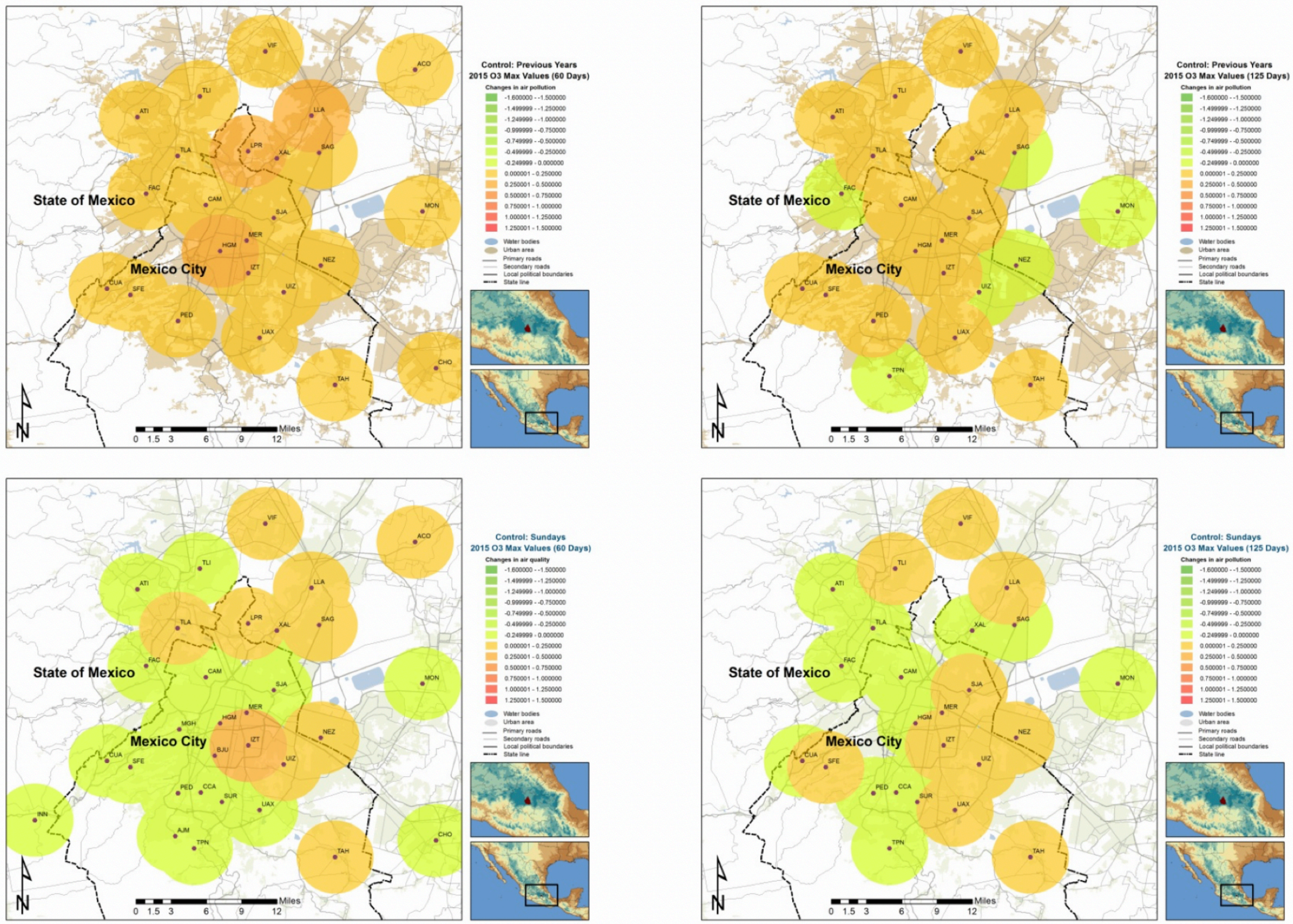
Source: Iracheta, J.A. using MCMA's Automatic Network of Atmospheric Monitoring data.

Map 10. MCMA 2015. NO_2 maximum daily concentrations, 60 and 125 days



Source: Iracheta, J.A. using MCMA's Automatic Network of Atmospheric Monitoring data.

Map 11. MCMA 2015. O_3 maximum daily concentrations, 60 and 125 days



Source: Iracheta, J.A. using MCMA's Automatic Network of Atmospheric Monitoring data.

CHAPTER 2:

ROAD-RELATED INVESTMENTS AND INDUCED TRAVEL IN METRO AREAS: THE CASE OF MEXICO CITY

Abstract

There is a large body of literature that addresses the relationship between road capacity, and the use of private vehicles, mainly reflecting that building additional road capacity tends to affect decisions about driving. In the short term this could mean shifting hours, routes, transportation modes, distance traveled, or making additional trips to take advantage of the improved infrastructure, on what has been broadly called "induced travel". In the long term, added road capacity could mean overall increases in vehicle ownership, as well as reallocation of activities, and shifts in urban development patterns. The main concern behind induced travel is that public policy that aims at improving transit, i.e. increasing travel speed and reducing commuting time by increasing road capacity, may end up reducing the overall efficiency of the transit system. Furthermore, this relationship is also affected by the availability of public transportation, since it may be an actual alternative for vehicle use, and increasing road capacity represents an opportunity cost to increasing public transportation capacity. While there is strong evidence suggesting the existence of both short- and long-term effects, there are relevant variations on the size of the effects, as well as on the methods used for estimating them.

Most of the studies rely on vehicle-miles traveled (VMT) for measuring the actual driving; however, there are several shortcomings to this approach. One is that this variable can be measured for specific road projects, but not necessarily for the overall transit system. Also, if the goal is to look at the entire system, then VMT needs to be obtained through surveys,

forcing a frequent tradeoff between using time-series vs cross-sectional data. Finally, some models fail to consider a measure of public transportation, and overlook the environmental implications of adding road capacity. Methodologically, modeling the effects of adding road capacity necessarily involves endogenous variables (road congestion induces adding capacity, that in turn induces more road congestion). This research uses a recursive equations system for Mexico City Metro Area, for a 17-year period (2000-2016), at the delegation/municipality, and metro area levels. This research builds upon previous models, but explicitly addresses the short and long run effects, as well as some of the observed shortcomings. First, investment in roads-related infrastructure is used as a measure for its availability at the local level. Second, total registered vehicles are used as a proxy measure for the amount of driving taking place in each jurisdiction. Finally, changes in the extension of the urban area are utilized as a measure for changes in land use over the long term. This research is relevant for metro areas since it presents an alternative way for looking at the short and middle run effects of adding road capacity, shedding additional light on metropolitan transit systems. For Mexico this is one of the very few studies of this nature, and likely the most comprehensive so far.

1. Introduction

Metropolitan areas are vast urban spaces characterized by large, diverse, and heterogeneous populations, distributed unevenly in the territory across multiple political and administrative jurisdictions. These mega cities are regional centers for economic and social activity, providing urban services such as access to larger markets, high quality basic services, education, public space, infrastructure, and cultural, and recreational activities. Metro areas share physical and functional links across these jurisdictions, therefore making governance an extremely challenging task. In addition, the complex nature of metro areas, coupled with the concentration of population and economic activities, imposes severe environmental stress, affecting air, water, and land. This concentration demands large amounts of energy and other resources, with a corresponding generation of waste and problems of visual and noise pollution.

Embedded in such complexity, the metropolitan transit subsystem is a key component, since it allows for most of the economic and social interactions to occur. Transit systems take different shapes depending on the availability of transportation modes, although some broad categories can be readily defined by who and how many are able to have access: private (based on private vehicles), public (based on public individual vehicles, such as buses), mass public (based on public linked vehicles over exclusive lanes/routes, such as trams, subways, or BRT), or non-motorized transportation (such as pedestrians, or bicycles). Most metro areas have combinations of all these modes; however, there is usually a predominant one.

In this research, I explore the relationship between private transportation and road-related infrastructure, also considering the public and mass public transportation alternatives. The goal is to test and measure the “induced travel” hypothesis; i.e., the claim that there is a feedback effect between the availability of roads (private transportation infrastructure) and the use of vehicles in a metro area. This feedback effect results from large concentrations of people with a need to move from one place to another, creating pressure over the entire transportation system. If we assume that the public and mass public transportation subsystems remain unchanged (constant), then these pressures will be absorbed by the private transportation subsystem, which will translate into traffic congestion, increased commuting time, and lower air quality.

A common response from the public sector to relieve traffic is to improve/expand the road network, facilitating vehicle flow. However, when such improvements/expansions occur, several signals and incentives are created for vehicle owners to increase the use of their private vehicles. First, an improved road infrastructure will tend to reduce private vehicle commuting time in the short run, making it more appealing for users to shift routes, times, and/or transportation modes in order to take advantage of the enhanced infrastructure. This effect has been termed “triple convergence” (Downs, 1992). However, as more vehicles enter the subsystem, the capacity limit is met and commuting times increase, but with a larger total vehicle fleet that puts additional pressure on the entire sub system. This revisited problem of traffic congestion is again addressed by adding capacity, starting the cycle over and generating an upward spiral of private vehicle-based congestion.

Second, given that public budgets are limited, any road-related investment represents a direct opportunity cost to investing in alternative transportation modes, such as public and/or mass public transportation. This means that investment decisions on roads are not only incentivizing the use of private vehicles, but they are also creating negative incentives to using alternative modes of transportation. Third, as the two previous elements take effect, the overall metropolitan infrastructure becomes more difficult and costlier to transform, enhancing the two effects and making them more likely to remain in place.

With these ideas in mind, using yearly data from 2000 to 2016 for three metro areas, I explore the two-way causal effect of investing in road-related projects over the size of the vehicle fleet, and how that vehicle fleet in turn affects investment decisions. This chapter focuses on investigating this two-way causal effect in Mexico City Metro Area, whereas the next chapter applies the same principles to investigate the two-way causal effects in Los Angeles and San Francisco metro areas. The country distinction is proposed for three reasons. The first one is that U.S. cities follow different growth patterns than Mexican cities. This is particularly relevant for the cases of California cities, where the elements that affect urban expansion and transportation are considerably different than those observed for the average Mexican city, therefore it is to be expected that such differences will shed light on how these different patterns affect the two-way causal relationship. The second is that there are several studies that measure induced transit from different approaches for Los Angeles and San Francisco. Such studies should be useful to calibrate the results of the models used in this research, however that is not the case for Mexico City where, to the best of my knowledge, there are no studies that measure induced transit, thus there are no references to compare the results. Finally, it is critical to understand this phenomenon in Mexico, since almost 60% of its population lives in metropolitan areas that have expanded without necessarily respecting the principles stated in their urban planning instruments in the past three decades. (CONAPO, 2010)

In terms of the methods, for Mexico City and Los Angeles, the urban area variable turned out to be non-statistically significant in all of the specifications, and it was excluded from both simultaneous systems. To address this shortcoming, a recursive system of equations was used instead of a simultaneous one. Nonetheless, it was possible to successfully estimate a simultaneous equations system for San Francisco Metro Area.

2. Literature Review

There is a large body of literature that addresses the relationship between traffic congestion, road capacity, and the use of private vehicles, mainly reflecting changes in road capacity that increase travel speed, travel distance, and the number of trips. Behind the induced travel literature there is the theory that improvements in road capacity produce behavioral changes in favor of a more intense usage of vehicles. The rationale behind this two-way causality is that under improved road infrastructure conditions, a “triple convergence” will occur where vehicle users will shift their routes, hours, and transportation modes to take advantage of such infrastructure. (Downs, 1992) The triple convergence gives way to the “Law of Peak-Hour Traffic Congestion,” which states that on urban commuter expressways, peak-hour traffic congestion will rise to meet maximum capacity. (Downs, 1962) However, the triple convergence does not consider other changes in the pattern of vehicle use that result from improvements in road infrastructure and that may affect traffic. “Induced travel” (Cervero & Hansen, 2002) or “generated traffic” (Litman & Colman, 2001) encompasses five such changes: 1) newly generated trips (also called latent demand), 2) longer journeys, 3) changes in modal splits, 4) route diversions, and 5) changes in commute hour. More restrictively, the concept of “induced demand” (Cervero & Hansen, 2002) includes only the first three categories. This same concept of induced demand is called induced travel by Litman and Colman (2001). However, the term “induced travel” entails different concepts depending on the author. For the sake of clarity, I will use the Cervero and Hansen (2002) definition of “induced travel” since it encompasses the five elements that have a role for explaining this phenomenon.

It is important to note that all these hypothesized effects occur over the short term, i.e., these behavioral changes are likely to be an immediate response to increases in road capacity. However, there are two additional effects that are expected to occur over the long haul. The first is an increase in household auto ownership levels, as a way to adjust to the improved road conditions. The second is a reallocation of activities through changes in land use and urban development patterns, where additional road capacity allows for higher speeds and longer commutes, making new developments possible. (Noland & Lem, 2002)

Another potential consequence of induced travel is that increasing road capacity may reduce the overall efficiency of the private transportation network, making road congestion worse. This effect has been called the Downs-Thomson Paradox (Noland & Lem, 2002) or Braess' Paradox (Litman & Colman, 2001). This paradox is rooted in two elements. The first is the opportunity cost of increasing road capacity at the expense of public transportation, where lack of investments or actual disinvestment may reduce public system capacity, thus reducing the number of users and causing fares to rise. This effect, in turn, causes further shifts in mode from public to private transportation. (Noland & Lem, 2002) The second element accounts for shifts in land use patterns, where additional road capacity induces more dispersed automobile-dependent developments. (Litman & Colman, 2001) These hypothesized effects are considered to occur in the long run, whereas the five changes of induced travel occur in short periods of time. (Litman & Colman, 2001; Noland & Lem, 2002)

The total travel time budget is also a relevant element to consider when discussing induced travel. Several studies show that, on the aggregate, time budgets tend to remain constant in the long run, although with some variations dependent on individual and household characteristics, destination, and type of residential area. (Gunn, 1981; Metz, 2008; Mokhtarian & Chen, 2004; Zahavi & Ryan, 1980) Furthermore, there is evidence suggesting that, under more favorable travel conditions such as faster speeds, these time budgets tend to be fully or almost fully used in the form of longer distance travel. (Goodwin, 1996) If, on average, travel time remains constant, higher road capacity translates into higher speeds and greater distance traveled, at least partially off-setting the potential time savings. (Noland & Lem, 2002)

Goodwin (1996) reviews a large number of empirical studies addressing induced travel in the United Kingdom (UK). He identifies two categories of research that measure the effects of improved road infrastructure based on the costs of vehicle use due to fuel consumption and travel time. The first category is characterized by empirical studies that show consistent results on the relationship between fuel cost and vehicle use. These studies derive fuel cost elasticities close to -0.1 in the short run, increasing to around -0.5 in the long term. The second category shows a larger effect, with a travel time elasticity of about -0.5 in the short term and -1.0 in the long term. The differences in the magnitude of the resulting elasticities show that the response for changes in travel time tends to be larger than the response to changes in fuel costs. Using comparable parameters for the US (mainly reflecting a different gasoline price, which is considerably lower than in the UK), the resulting elasticities would range from -0.56 in the short run, to -1.18 in the long run. (Noland & Lem, 2002)

Goodwin (1996) also looks at the evidence provided by vehicle counts on specific road projects. When comparing traffic forecasts prior to the execution of a project with the actual resulting traffic once the project is in full operation, vehicle counts are underestimated on average by 10%. For the relieved roads (roads that would reduce their traffic load due to a near-by project) this underestimate is approximately 16%. In principle, these miscalculations could be attributed to unexpected induced travel, considering that the forecast errors tend to increase over time, consistent with what fuel and time cost studies show. However, these findings have been challenged since most of these traffic forecasts fail to properly address economic growth rates that, in turn, effect changes in traffic levels (regardless of road capacity). Rodier and Johnston (2002) looked at the potential sources of forecasting error and found that while personal income and fuel price did not play a relevant role, population and employment growth had a significant effect.

Noland and Lem (2002) make a comprehensive review of the empirical literature on induced travel in the US. Several studies look at the relationship between vehicle-miles traveled (VMT) and lane-miles at different geographical levels. Early studies used both time series and panel data with fixed effects models, controlling for variables such as population, income, population density, gasoline prices, and type of facility. (Hansen & Huang, 1997; Noland, 2001) All these variables had a significant effect on explaining changes in VMT. The authors were able to estimate elasticities of lane miles (additional road capacity) with respect to VMT, which ranged from 0.3 to 0.7 at the county level and between 0.5 and 0.9 at the metropolitan level. (Hansen & Huang, 1997) They also estimate short run elasticities between 0.3 and 0.6, and long run elasticities from 0.7 to 1.0. (Noland, 2001) Despite these efforts, the ability to draw causal inferences about induced travel is highly constrained, especially considering that there is a two-way endogenous causal relationship between road capacity and use of vehicles.

A second set of studies addressed this shortcoming by using instrumental variables. Noland and Cowart (2000) find weak evidence of a causal link between changes in lane miles and increased VMT; however, they believe that the relative weakness of their instruments (total urbanized area and the inverse of population density, i.e., area divided by population) is likely to affect their results. Fulton, Noland, Meszler, and Thomas (2000) use aggregate data at the state level for their IV models (using two and three year-lagged growth in lane-miles as instrument), and find statistically significant short-run elasticities of between 0.3 and 0.5.

Even though the instrumental variables approach is more robust than previous statistical analysis and allows for identifying causal relationships, the choice of the instruments is usually challenged, thus undermining the findings. To address this limitation, as well as the issue of causality when dealing with endogenous variables, a third set of studies used systems of simultaneous equations. Cervero and Hansen (2002) use a 15-year time series in California to look at specific facilities (roads) and find an elasticity for lane miles with respect to VMT of 0.5. Fulton et al. (2000) look at county level data from Maryland, Virginia, North Carolina, and Washington, DC, and find similar results. Using California data, Cervero (2003) develops a more advanced "path model" accounting for supply and demand of road infrastructure in the short run, including its effects over urban development in the long run. His results are somewhat consistent with previous findings; however, he points out that there is evidence that previous estimates have overstated the magnitude of the short-term induced travel. In the long-term, he finds evidence that additional lane-miles induced changes in land use and urban development. The results show more-than-proportional additional building activities along new or improved corridors, particularly of housing developments, taking place over periods of two to three years after the road work ended.

Strathman, Dueker, Sanchez, Zhang, and Riis (2000) and Barr (2000) use household data with a large variety of exogenous and endogenous variables for their simultaneous equation systems. The former study finds an elasticity of 0.29 for lane miles with respect to VMT, whereas the latter finds time elasticities of between -0.3 and -0.4. In both cases, the findings are consistent with previous studies.

Studies addressing induced travel have provided relatively consistent evidence about the direction (sign) of the gasoline price, time travel, and VMT elasticities. These findings represent a strong theoretical and empirical base. Nonetheless, this literature seems to be particularly focused on the effects of adding road capacity over the amount of driving that takes place but, by relying on VMT as a measure of the actual driving, previous research is subject to several shortcomings. One is that VMT can be measured for specific road projects, but not necessarily for the overall transit system. Also, if the goal is to look at the entire system, then VMT needs to be obtained through surveys, forcing a tradeoff between using time series and cross-sectional data. Finally, some models fail to fully capture the effect of relevant variables, such as the availability of public transportation or alternative transportation modes, and overlook the environmental implications of adding road capacity.

For most of the studies that use a simultaneous equation system (at least for those that have been mentioned in the literature review), the availability of alternative transportation modes (mainly public transportation) is usually considered an exogenous variable, serving as a control rather than an actual structural component of the system (endogenously determined). This allows inclusion of different measures of alternative transportation modes as policy variables, which then can be used for estimating their effects on the endogenous variables of the system.

In summary, there are two major contributions of the proposed research. The first one is to include alternative transportation modes (in this case by using modal split) as a way to control for its effects on the variables of interest. Such a specification should inform how alternative modes of transportation affect investments in road infrastructure and the usage of vehicles. The second is the choice of metropolitan areas to be studied. A large proportion of past research has focused on California, with other relevant metro areas neglected. In addition, such a model has not been estimated for Mexico City, which has unique characteristics that distinguish it from U.S. cities. Thus, findings for Mexico City may be quite different and have the potential for a significant impact on the policy debate that is currently taking place about the national environmental crisis that is affecting large cities, and in particular Mexico City.

3. Data and Methods

a) Data

For the **public investment in road-related infrastructure variable**, yearly reporting of public expenditures on road-related projects for each metropolitan area were used. The data are obtained at the city, county/municipality, state, and federal levels. Expenditures include construction of new roads and related projects (such as junctions, overpasses, etc.), maintenance of existing ones, installment and maintenance of signaling, and acquisition of rights of way. The data were obtained from a variety of sources: 1) Public accounts reports (informes de la cuenta pública) at the state- and municipal-level for each jurisdiction of the Mexico City Metro Area from 2000 to 2016, 2) state of the government reports (informes de gobierno) and supporting documents for Mexico City and the State of Mexico from 2000 to 2016, 3) investment reports for specific funds such as the Metropolitan Fund (Fondo Metropolitano) or the Federal District Communication Infrastructure Improvement Fund (Fideicomiso para el Mejoramiento de las Vías de Comunicación del Distrito Federal, FIMEVIC).

For the **registered vehicles variable**, yearly data on the number of private and total vehicles registered at local jurisdictions within metropolitan areas were used, and were obtained from the Statistic Yearbook for Mexico City and for the State of Mexico from 2000 to 2016 published by the Mexican National Institute of Statistics and Geography (INEGI). The **modal split variable** used yearly data on the proportion of trips made using the public transportation system. The data were obtained from Mexico City' and State of Mexico's transportation agencies. A relevant drawback is that these agencies do not keep track of the modal split in a systematic way. They keep global point estimations on the distribution of trips across modes, but they are not specific to political jurisdictions or time frames; thus, they are not adequate for statistical inference. Due to these issues, the models use the number of users of mass public transport for each system. In particular, for Mexico City delegations (municipalities equivalent), this variable includes the users of the subway system (metro), the BRT system (*Metrobús*), and light rail (*transportes eléctricos*). For the State of Mexico municipalities, it includes the users of the BRT system (*Mexibús*), and the cableway system (*Mexicable*). For each system and route, the number of daily users per station was obtained and, according to the station's location, was assigned to its corresponding political jurisdiction.

The **urban area variable** used yearly data on the total size of the urban area by county/municipality. The measurements relied on GIS remote sensing procedures for the total size of the urban area and for each year using end-of-year satellite imagery (usually December of the corresponding year), although close time ranges were used in some cases in order to obtain the clearest images possible. The satellite imagery was obtained from the United States Geological Survey, using Landsat 7 imagery for the years 2000 to 2012, and Landsat 8 for 2013 to 2016. Finally, the **total population variable** used yearly data on total population size obtained from the Mexican National Institute of Statistics and Geography (INEGI), and the Mexican National Population Commission (CONAPO).

b) Methods

This research is intended to measure the effect that three endogenous variables subject to reverse causality have over each other, therefore it is necessary to address the issue of endogeneity. A simultaneous equation system is proposed since it is a method that adequately addresses this issue. The system, in this form, would be estimated independently for each city; however, following the same structure. The structural equations that theoretically would be estimated via two-stage least squares (TSLS) are the following:

$$Eq\ A: Vehicles_i = \alpha_0 + \alpha_1 Invest_{i,t-n} + \alpha_2 ModalSplit_i + \alpha_3 Vehicles_{i,t-1} + \alpha_4 UrbanArea_i + X_i\alpha + \varepsilon_{1i}$$

$$Eq\ B: Invest_i = \beta_0 + \beta_1 Vehicles_{i,t-n} + \beta_2 ModalSplit_i + \beta_3 Invest_{i,t-1} + \beta_4 UrbanArea_i + X_i\beta + \varepsilon_{2i}$$

$$Eq\ C: UrbanArea_i = \delta_0 + \delta_1 Vehicles_{i,t-n} + \delta_2 Invest_{i,t-n} + \delta_3 ModalSplit_{i,t-n} + \delta_4 UrbanArea_{i,t-1} + X_i\delta + \varepsilon_{4i}$$

Where:

$Vehicles_i$ is the total number registered vehicles.

$Invest_i$ is the total investment in road-related infrastructure.

$UrbanArea_i$is the total size of the urban area.

$ModalSplit_i$ is the proportion of trips made using the mass public transportation system.

$X_i\alpha, X_i\beta$ and $X_i\delta$ are vectors of exogenously determined covariates, such as total population.

Additionally, lagged versions of the endogenous variables are included, since they strongly depend on their past behavior. Since these lagged variables are predetermined within the system in prior periods, it is assumed that they are exogenously predetermined.[3] It is important to note that, even though there are three structural equations in the theoretical model, for reasons that are explained later in this section, it was only possible to estimate equations A and B.

For these models, the common practice is to keep the modal split or public transportation variables on the right-hand side of the equations in order to allow using them as a policy variable. (Cervero & Hansen, 2002; Strathman et al., 2000) This means that one could exogenously alter its value to reflect policy goals and forecast its effects over the system.

Mexican cities show a different urban expansion pattern than US cities. While it can be argued that the latter grow in large part due to the availability of better and faster roads that push out the urban limits, the former do not necessarily follow that same development pattern. One of the most important reasons for the expansion of Mexican cities is the emergence of informal settlements and new developments in the outskirts that occur due to lack of affordable land located within the urban areas (Salazar, 2012). Such urbanizations take place regardless of the existence of adequate transportation infrastructure and, in many cases, they suffer from a relevant lack of connectivity to the main city. In the Mexico City Metro Area, much of the transportation infrastructure to service the expansion areas of the city was built as a response to growing urban pressure to connect distant communities, rather than the opposite (Iracheta, 2009). This is not to say that the availability of roads does not have an effect on urban expansion. Rather, such effects are not as strong in Mexican cities in comparison to US cities.

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[3] The lagged variables were constructed by hand, independently from the SAS and Stata LAG functions to avoid bringing values from one urban area into the data points for the next one, since the database uses a combination of cross-section and time series data points for each jurisdiction and each year. Additionally, not all jurisdictions have information for all years, thus the manual construction of the lagged variables prevented from using data for years that, otherwise, would be missing.

This pattern became evident when putting together the variable for the size of the urban area. It was evident, from inspection of the data for the municipality-level yearly values, that there was little variation, with no variation at all in some cases. This was particularly the case for several Mexico City delegations, where the totality of their territory has been fully occupied even for decades. Hence, when estimating the system of equations for its different specifications, the effect of urban expansion was systematically insignificant. This was also true for the variables of interest in equation C (where urban area is the left-hand variable). Because of these anomalies, the equation and the variable for urban expansion was excluded from the model, resulting in a two-equation system.

The system of equations then becomes recursive, with the lagged endogenous variables providing the interaction across time periods. The main implication for this methodological change is that the parameters are estimated sequentially, rather than in a jointly way. In order to meet the no serial correlation assumption $cov(u_{1t}, u_{2t}) = 0$, which is required to obtain unbiased estimators, all right-hand side variables must be exogenous. (Gujarati, 2004) Since lagged variables are considered predetermined within the model, (Gujarati, 2004; Pindyck & Rubinfeld, 1998) the above condition is met by using lagged versions of the variables of interest (Number of registered vehicles and investment in roads infrastructure) which are considered predetermined in the model since they took their values on prior time periods. With these conditions in mind, the models can be estimated using OLS, however there is a tradeoff in that the equations are no longer interdependent, but rather they have a unilateral causal dependence. In other words, Y_1 affects Y_2, but Y_2 does not affect Y_1. (Gujarati, 2004) The equations are then:

$$Eq\ A: Vehicles_i = \alpha_0 + \alpha_1 Invest_{i,t-n} + \alpha_2 ModalSplit_i + \alpha_3 Vehicles_{i,t-1} + X_i\alpha + \varepsilon_{1i}$$

$$Eq\ B: Invest_i = \beta_0 + \beta_1 Vehicles_{i,t-n} + \beta_2 ModalSplit_i + \beta_3 Invest_{i,t-1} + X_i\beta + \varepsilon_{2i}$$

Since the equations are no longer simultaneous, but recursive, they can be estimated using OLS.

4. Results and Discussion

There are several considerations for specifying the system of equations. Firstly, the system is estimated separately for Mexico City Metro Area and for Mexico City. The latter includes all 16 delegations of Mexico City only, and the former includes these delegations in addition to 28 of the 59 municipalities of the State of Mexico that are part of the Metro Area. These municipalities are only those physically contiguous to Mexico City that have had investment in roads infrastructure as well as access to mass public transport. Secondly, for Equation A, the models utilize separately the number of registered private vehicles (those used for private transport) and the total number of vehicles (vehicles used for private and public transport, such as taxis, and the like), since it is reasonable to expect different effects for each group. Finally, for Equation B, the models are divided into two groups. The first uses total investment in roads (construction of new roads, as well as extension or enlargement of existing ones) and overpasses (including the construction or improvement of overpasses, underpasses, tunnels and elevated intersections). The second group utilizes these two measures in addition to investments in street pavement and rolling surface maintenance. This separation responds to the systematic inconsistencies that have been reported in news media about the misuse of public resources destined to pavement and rolling surface maintenance, therefore being subject to potential bias. For each section, a total of 12 models were estimated, with a grand total of 24 models that consider all the relevant equation permutations about the variable time-frames (as stated in the theoretical model), using current time-periods, as well as one- and two-year lagged values. The specifications summary is as follows:

Table 1. Specifications summary

Specification 1: Mexico City Metro Area			**Specification 2:** Mexico City (excluding State of Mexico's metropolitan municipalities)		
	Equation A	**Equation B**		**Equation A**	**Equation B**
1.1	Number of private vehicles	a. Total investment in roads and overpasses b. Total investment in roads, overpasses and pavement	2.1	Number of private vehicles	a. Total investment in roads and overpasses b. Total investment in roads, overpasses and pavement
1.2	Total number of vehicles	a. Total investment in roads and overpasses b. Total investment in roads, overpasses and pavement	2.2	Total number of vehicles	a. Total investment in roads and overpasses b. Total investment in roads, overpasses and pavement

Source: Iracheta, J.A.

After running Breusch-Pagan tests for the two dependent variables on the corresponding independent variables for each model, a problem of heteroskedasticity was found on all the variations of both specifications. Thus, all the models utilized robust standard errors in order to correct for standard deviation bias, and to properly test for the significance of each variable. The variance inflation factors were also estimated to prevent the occurrence of a problem of Multicollinearity, and the corresponding corrections were made for each model individually. Once the best possible model was identified for each equation, it was included in the recursive equations system.

a) Mexico City Metro Area

Specification 1.1

Equation A is intended to model the effects that road-related infrastructure investments have over the size of the vehicle fleet in the city (using the number of vehicle registrations as a proxy variable), and Equation B is intended to model the effect that the size of the vehicle fleet (using the number of registered vehicles that in this case work as a proxy for road congestion) have over the public decisions about road-related infrastructure investments. Specification 1.1 estimates the recursive system of equations for the Mexico City Metro Area considering the number of private vehicles on the left-hand side of Equation A, and total investment in road infrastructure (in its two variations excluding and including expenditures in pavement) for Equation B. For a recursive model to be properly estimated using OLS, all right-hand side variables must be exogenous, which means that the variables of interest must be lagged so they can be predetermined in the model. Therefore, no model using current time periods for the total investment in roads infrastructure variable or the total number of the registered vehicles variable on the right-hand side of the equation was estimated.

The results show that, for every MX$100 million (US$11.3 million as of the 2016 purchase parity power -PPP- factor of 8.869) (BANXICO, 2018; OECD, 2018) invested in road infrastructure (roads and overpasses), a little over 1,900 private vehicles are added to the metropolitan vehicle fleet in the first year after the investment takes place, and about 3,400 private vehicles are added two years after the investment takes place. If expenditures in pavement are included in the road infrastructure investment variable, the number of additional registered private vehicles increases to approximately 2,130 for every MX$100 million investment in the first year, and remains steady around 3,440 additional private vehicles in the second year after the investment takes place. All these coefficients are statistically significant at 99% percent confidence.

On Equation B of the system, for every 1,000 registered vehicles, there is an approximate MX$943 thousand (US$106.3 thousand PPP) investment in roads infrastructure (considering roads and overpasses only, at 95% confidence) in the first year after the vehicle registration, and about MX$918 thousand (US$103.5 thousand PPP) two years after the registration at 90% confidence. When pavement expenses are included, the investment amount increases to MX$1.325 million (US$149.4 thousand PPP) after the first year, and to MX$1.369 million (US$154.4 thousand PPP) two years after the registration of the vehicles. The latter coefficients are significant at 99% confidence.

These models also show that total population has a direct positive effect on the total number of private vehicle registrations. For every million additional inhabitants in the Mexico City Metro Area, between 157 and 160 thousand additional vehicles enter the vehicle fleet. The number of mass public transport users also affects the total number of registered private vehicles. In Equation A, the sign of the results for the number of mass public transport users is the opposite of what was expected, and for every additional million users of the mass transport system, between 718 and 721 additional private vehicles are registered. Even though these effects are relatively small, they still reflect a counterintuitive result. A possible explanation for this effect is that Mexico City's mass transit system is not efficient enough as to absorb all current and additional users, thus when a large enough number of additional regular users enter the system, they overcrowd current users, pushing some of them to shift mode from public to private transportation.

For Equation B, the number of mass transport system users reduce the amount of investment destined to roads infrastructure. For the case of investment in roads and overpasses only, the results show that, for every million additional mass transport users, there is a reduction in roads infrastructure investment of between MX$970 thousand and 1.01 million (US$109.4 thousand and 113.9 thousand PPP). When pavement expenditures are included, for every million additional mass transport users, there is a reduction in roads infrastructure investment of between MX$1.03 and 1.05 million (US$116.1 and 118.4 thousand PPP). A summary of the main results is presented in Table 4.

Table 2. Main results summary for specification 1.1

Variable	Coefficient (Significance level) / Standardized coefficient							
	Model 1		Model 2		Model 3		Model 4	
	EQUATION A: Total Number of Private Vehicles							
Total investment in roads and overpasses (t-1) (MX$ Millions)	**19.32*** **	0.099						
Total investment in roads and overpasses (t-2) (MX$ Millions)			**34.07*** **	0.155				
Tot. invest. in roads, overpasses and pavem. (t-1) (MX$ Millions)					**21.34*** **	0.110		
Tot. invest. in roads, overpasses and pavem. (t-2) (MX$ Millions)							**34.4*** **	0.157
Total population (Millions)	159,230***	0.508	157,410***	0.502	157,620***	0.503	155,110***	0.495
Users of mass public transport (Millions)	721***	0.486	718***	0.484	719***	0.485	716***	0.483
Constant	31,913***		31,144***		31,396***		30,896***	
N	407		407		407		407	
Adjusted r^2	0.649		0.663		0.651		0.663	
	EQUATION B: Total Investment in Roads and Overpasses				**EQUATION B: Total investment in Roads, Overpasses and Pavement**			
Total number of private vehicles (t-1) (Vehicles)	**942.7** **	0.167			**1,325.0*** **	0.234		
Total number of private vehicles (t-2) (Vehicles)			**917.8* **	0.151			**1,369.4*** **	0.226
Total population (Millions)	-19,595,790	-0.012	-3,285,780	-0.002				
Users of mass public transport (Millions)	-1,011,530***	-0.131	-970,080***	-0.126	-1,054,140***	-0.136	-1,030,930***	-0.133
Constant	136,755,845***		138,666,565***		133,241,772***		138,915,968***	
N	407		407		407		407	
Adjusted r^2	0.008		0.006		0.028		0.024	

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

Source: Iracheta, J.A.

Specification 1.2

Specification 1.2 estimates the recursive equation system for the Mexico City Metro Area considering the total number of vehicles on the left-hand side of Equation A, and total investment in road infrastructure (in its two variations excluding and including expenditures for pavement) for Equation B. The main findings are as follow. For every MX$100 million (US$11.3 million PPP) invested in road infrastructure (roads and overpasses), approximately 1,870 vehicles (for private and public use) are added to the metropolitan vehicle fleet one year after the investment is made, and about 3,340 vehicles are added two years after the investment takes place. If expenditures in pavement are included in the road infrastructure investment variable, similar to Specification 1.1, the number of additional registered vehicles increases to approximately 2,100 for every MX$100 million (US$11.3 million PPP) investment in the first year, and remains steady around 3,400 additional vehicles in the second year after the investment takes place. All these coefficients are statistically significant at 99% percent confidence.

For every 1,000 registered vehicles, there is a MX$881 thousand (US$99.3 thousand PPP) investment in roads infrastructure (considering roads and overpasses only, at 90% confidence) in the first year after the vehicle registration, and MX$848.5 thousand (US$95.7 thousand PPP) two years after the registration. When pavement expenses are included, the investment amount increases to MX$1.27 million (US$143.2 thousand PPP) after the first year, and to MX$1.31 million (US$147.7 thousand PPP) two years after the registration of the vehicles. The latter coefficients are significant at 99% confidence. Table 5 presents a summary of these results.

Table 3. Main results summary for specification 1.2

Variable	Coefficient (Significance level) / Standardized coefficient							
	Model 1		Model 2		Model 3		Model 4	
	EQUATION A: Total Number of Vehicles							
Total investment in roads and overpasses (t-1) (MX$ Millions)	**18.73*** **	0.094						
Total investment in roads and overpasses (t-2) (MX$ Millions)			**33.42*** **	0.149				
Tot. invest. in roads, overpasses and pavem. (t-1) (MX$ Millions)					**20.93*** **	0.105		
Tot. invest. in roads, overpasses and pavem. (t-2) (MX$ Millions)							**33.95*** **	0.151
Total population (Millions)	165,470***	0.516	163,660***	0.510	163,870***	0.510	161,360***	0.503
Users of mass public transport (Millions)	742***	0.489	740***	0.487	740***	0.488	738***	0.486
Constant	31,949***		31,160***		31,407***		30,893***	
N	407		407		407		407	
Adjusted r^2	0.660		0.674		0.663		0.674	
	EQUATION B: Total Investment in Roads and Overpasses				**EQUATION B: Total investment in Roads, Overpasses and Pavement**			
Total number of vehicles (t-1) (Vehicles)	**881.21** **	0.160			**1,277.44*** **	0.232		
Total number of vehicles (t-2) (Vehicles)			**848.52***	0.144			**1,314.32*** **	0.223
Total population (Millions)	-15,923,240	-0.010	919,480	0.001				
Users of mass public transport (Millions)	-988,580***	-0.128	-942,440***	-0.122	-1,050,250***	-0.136	-1,022,990***	-0.132
Constant	138,812,207***		140,879,277***		134,525,007***		140,500,603***	
N	407		407		407		407	
Adjusted r^2	0.007		0.005		0.027		0.023	

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

Source: Iracheta, J.A.

b) Mexico City (Excluding State of Mexico's Metropolitan Municipalities)

Specifications 2.1 and 2.2 follow the same logic as specifications 1.1 and 1.2, however they include information for Mexico City only. In other words, these models consider only data from the 16 Mexico City delegations, excluding State of Mexico's municipalities that are part of the Mexico City Metro Area.

Specification 2.1

Specification 2.1 utilizes the number of private vehicles on the left-hand side of Equation A, and total investment in road infrastructure (in its two variations excluding and including pavement expenditures) for Equation B. A summary of the main results is presented in Table 6.

The results show that, for every MX$100 million (US$11.3 million PPP) invested in road infrastructure (roads and overpasses), approximately 1,680 additional private vehicles enter Mexico City's vehicle fleet in the first year after the investment takes place, and about 2,130 additional private vehicles enter the fleet two years after the investment takes place. When pavement expenditures are considered in the road infrastructure investment variable, the number of additional registered private vehicles increases to approximately 1,930 for every MX$100 million (US$11.3 million PPP) investment in the first year, and 2,050 additional private vehicles in the second year. All these coefficients are statistically significant at 99% percent confidence.

Looking at Equation B, for every 1,000 registered vehicles, there is an approximate MX$875 thousand (US$98.7 thousand PPP) investment in roads infrastructure (considering roads and overpasses only) in the first year after the vehicle registration, and about MX$929 thousand (US$104.7 thousand PPP) two years after the registration, however these coefficients are not statistically significant. When pavement expenses are included, the investment amount increases to a little under MX$1.1 million (US$124 thousand PPP) after the first year, and to around MX$1.14 million (US$128.5 thousand PPP) two years after the registration of the vehicles. The latter coefficients are significant at 99% confidence.

Similar to what was observed under Specification 1.1, both total population and total users of mass public transport have a positive and statistically significant effect on the total number of registered private vehicles. The case of increments in total population also increasing the total number of registered vehicles is straightforward; however, that is not the case for increments in total users of mass public transport which, one would expect, would reduce the total number of registered private vehicles; however, the results show the opposite effect. These results are consistent with what was observed for Mexico City Metro Area and, as mentioned before, a possible explanation for such counterintuitive result is that, when a large enough number of additional mass public transport users enter the system, they overcrowd current users, pushing those that are able to rely on private transportation to shift mode from public to private.

Table 4. Main results summary for specification 2.1

Variable	Coefficient (Significance level) / Standardized coefficient							
	Model 1		Model 2		Model 3		Model 4	
	EQUATION A: Total Number of Private Vehicles							
Total investment in roads and overpasses (t-1) (MX$ Millions)	**16.81*** **	0.085						
Total investment in roads and overpasses (t-2) (MX$ Millions)			**21.33*** **	0.107				
Tot. invest. in roads, overpasses and pavem. (t-1) (MX$ Millions)					**19.26*** **	0.097		
Tot. invest. in roads, overpasses and pavem. (t-2) (MX$ Millions)							**20.52*** **	0.104
Total population (Millions)	147,690***	0.470	147,990***	0.471	145,830***	0.465	145,780***	0.464
Users of mass public transport (Millions)	619***	0.492	618***	0.491	619***	0.493	620***	0.493
Constant	59,263***		58,492***		58,388***		58,316***	
N	240		240		240		240	
Adjusted r^2	0.576		0.580		0.578		0.579	
	EQUATION B: Total Investment in Roads and Overpasses				**EQUATION B: Total investment in Roads, Overpasses and Pavement**			
Total number of private vehicles (t-1) (Vehicles)	**874.9**	0.160			**1,098.8*** **	0.199		
Total number of private vehicles (t-2) (Vehicles)			**929.3**	0.158			**1,136.9*** **	0.192
Total population (Millions)	-166,305,410	-0.105	-165,089,970	-0.105				
Users of mass public transport (Millions)	-505,600**	-0.079	-509,120*	-0.081	-683,480***	-0.107	-665,930**	-0.104
Constant	135,390,049***		134,684,796***		112,377,375**		115,640,474**	
N	240		240		240		240	
Adjusted r^2	-0.001		-0.002		0.017		0.014	

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

Source: Iracheta, J.A.

Specification 2.2

Specification 2.2 utilizes the total number of vehicles on the left-hand side of Equation A, and total investment in road infrastructure (in its two variations excluding and including pavement expenditures) for Equation B. The results are as follow:

For every MX$100 million (US$11.3 million PPP) invested in road infrastructure (roads and overpasses), approximately 1,700 vehicles (for private and public use) enter the metropolitan vehicle fleet one year after the investment is made, and about 2,100 vehicles enter two years after the investment takes place. If pavement expenditures are included in the road infrastructure investment variable, the number of additional registered vehicles increases to approximately 1,900 for every MX$100 million (US$11.3 million PPP) investment in the first year, and remains steady around 2,000 additional vehicles in the second year after the investment takes place. All coefficients are statistically significant at 95% percent confidence.

When looking at Equation B, for every 1,000 registered vehicles, there is about MX$845 thousand (US$95.3 thousand PPP) investment in roads infrastructure (considering roads and overpasses only) in the first year after vehicle registration, and a bit over MX$898 thousand (US$101.3 thousand PPP) two years after registration; however, none of these coefficients is statistically significant. When pavement expenses are included, the investment amount increases to MX$1.04 million (US$117.3 thousand PPP) after the first year, and to MX$1.07 million (US$120.6 thousand PPP) two years after the registration of the vehicles. The latter coefficients are significant at 99% confidence. Table 7 presents a summary of the main results.

Table 5. Main results summary for specification 2.2

Variable	Coefficient (Significance level) / Standardized coefficient							
	Model 1		Model 2		Model 3		Model 4	
	EQUATION A: Total Number of Vehicles							
Total investment in roads and overpasses (t-1) (MX$ Millions)	**16.55***	0.081						
Total investment in roads and overpasses (t-2) (MX$ Millions)			**21.11***	0.103				
Tot. invest. in roads, overpasses and pavem. (t-1) (MX$ Millions)					**19.02***	0.094		
Tot. invest. in roads, overpasses and pavem. (t-2) (MX$ Millions)							**20.28***	0.099
Total population (Millions)	158,510***	0.491	158,800***	0.492	156,670***	0.486	156,620***	0.485
Users of mass public transport (Millions)	628***	0.486	627***	0.485	629***	0.487	629***	0.487
Constant	59,357***		58,579***		58,482***		58,411***	
N	240		240		240		240	
Adjusted r^2	0.593		0.597		0.595		0.596	
	EQUATION B: Total Investment in Roads and Overpasses				**EQUATION B: Total investment in Roads, Overpasses and Pavement**			
Total number of vehicles (t-1) (Vehicles)	**844.5**	0.159			**1038.8***	0.194		
Total number of vehicles (t-2) (Vehicles)			**898.2**	0.157			**1072.3***	0.186
Total population (Millions)	-171,050,010	-0.108	-170,270,890	-0.108				
Users of mass public transport (Millions)	-495,890*	-0.078	-500,420*	-0.079	-661,080**	-0.104	-642,920**	-0.101
Constant	137,136,482***		136,364,223***		114,558,410**		117,932,089**	
N	240		240		240		240	
Adjusted r^2	-0.002		-0.003		0.015		0.013	

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

Source: Iracheta, J.A.

5. Conclusions

The findings of this research are consistent both with other studies and the expected results of the theoretical model. The evidence provided here points out the existence of the induced travel phenomenon in Mexico City.

Equation A measures the impact of investment on roads infrastructure on the number of registered vehicles (which can be assumed to add up to the vehicle fleet of the city). The theoretical model considers that increments in investment for roads infrastructure would create a positive incentive for the use of private vehicles, as opposed to the use of mass public transport or other alternative modes. When looking at the entire metro area (Mexico City and the State of Mexico), the evidence suggests that, for every additional MX$100 million (US$11.3 million PPP) of investment in roads infrastructure, there is an increase in the size of the vehicle fleet (as measured by vehicle registration) of between 1,900 and 2,130 vehicles one year after the investment takes place (depending on if the investment considers roads and overpasses only, or the latter plus pavement expenditures), and about 3,400 two years after the investment takes place. When looking at Mexico City only, the effects are smaller, but nonetheless significant. For every additional MX$100 million (US$11.3 million PPP), the number of additional registered range from 1,680 to 1,930 on the first year, and between 2,050 and 2,130 after two years of the investment.

In order to put these numbers in perspective, in 2016 there was an overall investment in roads infrastructure, including roads, overpasses and pavement, of about MX$8.7 billion (US$980.9 million PPP) in the Mexico City Metro Area. This investment, according to the results, would have induced an increment in the vehicle fleet of between 165,000 and 185,000 additional private vehicles one year after the investment took place. The 2016 overall investment for Mexico City was of about MX$6.8 billion (US$767 million PPP), which would have induced an increment of between 114,000 and 131,000 private vehicle registrations, one year after the investment took place, representing about one third of all additional registered vehicles in Mexico City for that year.

Figure 1. Main results for the Mexico City Metro Area

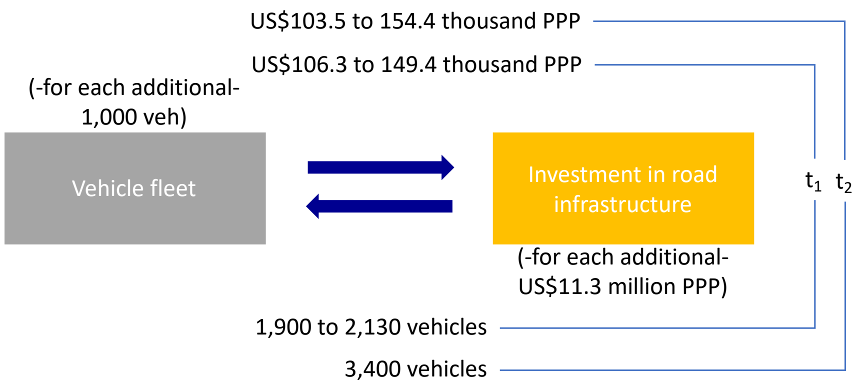
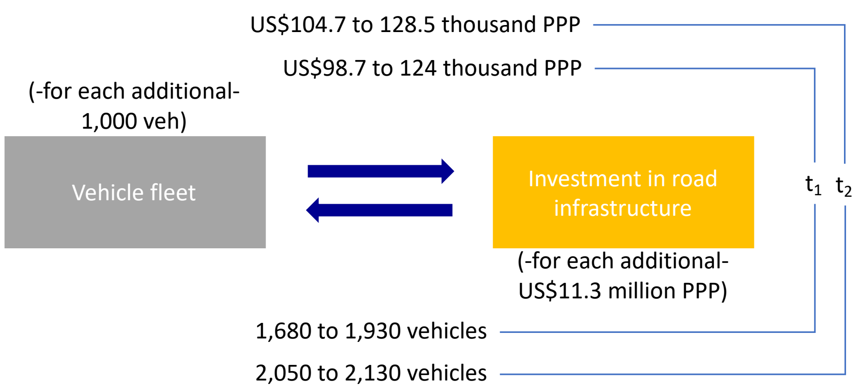


Figure 2. Main results for Mexico City



Source: Iracheta, J.A.

Equation B measures the impact that the number of registered vehicles (a proxy variable for road congestion) has on the amount of investment that is directed to roads infrastructure, as an effort to reduce such congestion. The evidence points out that, in the Mexico City Metro Area, for every thousand additional vehicles that are registered, there is an investment in roads of between MX$943 thousand (US$106.3 thousand PPP) and MX$1.325 million (US$149.4 thousand PPP) after one year, and between MX$918 thousand and MX$1.369 million (US$103.5 and 154.4 thousand PPP) two years after the vehicle registration.

For Mexico City alone, the evidence suggests that, for every MX$100 million (US$11.3 million PPP), there is an induced increment in private vehicle registrations of between 1,680 and 1,930 after one year, and of between 2,050 and 2,130 registrations two years after the investment in roads infrastructure takes place. In terms of Equation B, the evidence points out at the occurrence of investments that range from MX$875 thousand to MX$1.1 million (US$ 98.7 to 124 thousand PPP) in the first year for every thousand additional registered vehicles, and investments of between MX$929 thousand to MX$1.14 million (US$104.7 to 128.5 thousand PPP) for every thousand additional registered vehicles in the second year after the registrations take place.

These results suggest that induced travel is observable in Mexico City, and the results are consistent with what has been observed in other cities. This evidence also suggests that the transportation strategy that has been implemented historically in Mexico City and in the entire country, which has relied mainly on developing road infrastructure, may have been counterproductive, increasing the severity of the problem of road congestion. Additionally, investing in roads infrastructure represents an opportunity cost to investing in alternative transportation modes, mainly mass public transport. But the problems of induced travel are not only related to congestion, but also to pollution emission increments and environmental quality loss, impacts on public health, increments in travel time and an overall reduction of quality of life.

There are several implications in terms of environmental and transportation policy that are readily present from these results. The first one is that Mexico City's authorities, local, city wide and metropolitan, urgently require to engage into a profound revision of the measures that are being taken for tackling the air pollution and road congestion problems from an integrated perspective, and relying on different policies than those that have been implemented so far. Chapter one showed that the flagship air pollution control program in

Mexico City, the *Hoy No Circula* (HNC), has had serious unintended consequences, such as substantially increasing the size of the vehicle fleet, however with mixed results regarding improvements in air quality. Nonetheless, when looking at the long-term pollution concentrations in Mexico City, it is possible to observe some mild improvements on air quality. The main causes for those long-term improvements remain elusive, since many factors have a role to play such as reduction in gasoline lead contents and improvements in engines' fuel efficiency. Also, it has been claimed by the local authorities that the *HNC* has been determinant for keeping air pollution from spiraling out of control, however there is no causal evidence to support such claim, since the effects of the *HNC* program evaluations are only valid for a short period of time afterwards its implementation and policy changes.

As mentioned, the *HNC* implementation had the effect of increasing the size of the vehicle fleet, but also have the road-related infrastructure investments, as the evidence suggests. Thus, these policies have not been effective for addressing these issues, and furthermore, it is reasonable to say that they have actually worsen the problem of road congestion, and restrained the potential for stronger improvements in air quality, making the case for a different kind of debate about measures to be taken and policies to be implemented in Mexico City.

Some of the most salient alternative policies are congestion pricing, such as London' or Stockholm's congestion charges, that have proved to be effective, (Albalate & Bel, 2009) and tradable driving permit systems, which have not been implemented in any city so far, but have been widely discussed, particularly for Chinese cities. Both of these policies rely on economic incentives, which are powerful tools for shifting public's behavior, in addition to having the potential to attain economic efficiency, if properly designed, by internalizing the congestion- and air pollution-related externalities imposed on all citizens by drivers and their vehicles, at the socially-efficient price.

Even though these policies represent a way forward and a departure from traditional command-and-control approaches, such as those based on driving restrictions, they have also raised equity concerns about the distribution of their costs and benefits. Accessibility differences across areas of the city to mass public transportation or non-motorized alternatives will determine how these costs and benefits are distributed. In the case of Mexican cities, one must be cautious, since these transportation alternatives tend to shrink and disappear as one moves further away from city centers. And these city outskirts tend to be the least developed, where most of low-income families live, therefore imposing a double charge, one for being forced to rely on fewer, and proportionally more expensive transportation alternatives, and a second one derived from the congestion-related charges or permits that might be put in place.

It is also important to acknowledge that tradable permit-based programs have been implemented mostly for regional air pollution control for point sources, and there are no real-world references as to how they would work if implemented for mobile sources and road congestion control. These considerations are relevant, since one would expect that such a program would carry a steep learning curve, both for the enforcing authorities, as well as for regular citizens that would be subjected to the policies.

Based on the evidence presented here, it should be paramount to further evaluate the effects of public investment decisions, in order to reverse the problems posed by the phenomenon of induced travel and to shift the transportation model that persists in Mexico City and the rest of Mexican cities. However, such revisions should occur within a much broader public debate, relying on a careful analysis of policy alternatives, paying special attention to the design features and equity concerns, as well as the technological, operational and enforcement mechanisms that are used.

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CHAPTER 3:

ROAD-RELATED INVESTMENTS AND INDUCED TRAVEL IN METRO AREAS: THE CASES OF LOS ANGELES AND SAN FRANCISCO

Abstract

Induced travel is a phenomenon in which the problem of road congestion is tackled by increasing road capacity that, in turn, causes a series of unintended behavioral changes in the short run, in terms of new trips, longer travel distance, route changes, shifts in transportation modes and travel hours, that end up increasing the number of vehicles circulating and thus offsetting the benefits obtained from these infrastructure investments. In the long run, the additional road infrastructure may induce increases in vehicle ownership, reallocation of economic activities, and transformation of the urbanization patterns toward city expansion. Furthermore, induced travel may be enhanced by the allocation of public investment for road infrastructure, mostly used by private vehicles, becoming an opportunity cost for public transport or alternative transportation modes. The main policy implication of induced travel is that the public efforts for reducing road congestion, reducing commuting time or increasing travel speed, by increasing road capacity, may be actually reducing the overall efficiency of the entire transit system.

The induced travel hypothesis has been observed in many cities of the world, and there is strong evidence that suggests the existence of both short- and long-term effects. The literature relies in a variety of methods and spatial configurations, mostly focusing on specific road projects using vehicle-miles traveled (VMT) as a measure for the amount of driving at the project and its immediate area of influence. Such approach is very appealing, since it provides results traceable to specific projects and areas of the city, however there are several shortcomings to it. The most important is that it is constrained to well defined city

areas since the data are obtained from local surveys, and they are not available to the rest of the city on a systematic and timely fashion as to allow for statistical inference.

Modeling the induced travel phenomenon necessarily involves the inclusion of endogenous variables (road congestion induces decisions to increase road capacity that, in turn, induces more road congestion). For overcoming this potential problem, this research estimates a simultaneous equations system for the San Francisco Metro Area, and a recursive equations system for the Los Angeles Metro Area using county data for a 17-year period (2000 to 2016). The goal of this research is to model induced travel at the metropolitan level, as opposed to the local dimension that is usually found in the literature. In that sense, it builds upon previous research and sheds light on the effects of induced travel on the city-wide transit system. In order to attain such goal, this research uses investment in road-related infrastructure, as opposed to mile-lane or similar variables, as a proxy measure of road capacity; and total registered vehicles instead of VMT, as a proxy variable for total driving in each political jurisdiction. Finally, the urbanization pattern is measured through yearly changes in the urban area size. This research is relevant for the induced travel literature because it presents a more integrated way for understanding the short- and long-term effects of the public decisions related to road infrastructure and the metropolitan transit system.

1. Introduction

Induced travel is a phenomenon that has been well documented in the transportation literature using different approaches, including statistical studies and quasi-experimental research with a variety of methods, such as instrumental variables and simultaneous equations systems. Recall from chapter two that induced travel encompasses, in the short run, five types of behavioral change due to additional road capacity, that may take the form of improvements or enlargement of road infrastructure: 1) new trips that otherwise would not have happened, 2) longer travel distance, 3) changes in modal split, usually from public to private transportation, 4) changes in routes, and 5) changes in commute hour. (Cervero & Hansen, 2002; Downs, 1992; Litman & Colman, 2001).

The endogeneity of the two-way causal relationship that exists between the construction of additional road capacity as a measure to tackle road congestion, which may end up inducing even more driving and road congestion, makes the task of modeling and measuring this phenomenon a highly complex one. In chapter two, a recursive equations system model was used to identify the existence and the magnitude of the induced travel phenomenon in Mexico City. The relevance of that research lies in the fact that no study has ever estimated an effect size of the induced travel problem in Mexico, at the project-specific level or otherwise, but rather, induced travel has been only addressed hypothetically by the mobility and transportation opinion-makers, or as a matter of perception and discourse, but with no quantitative evidence.

The case presented in this chapter, corresponding to the metro areas of Los Angeles and San Francisco is different from the case of Mexico City, but it is also relevant for other reasons. In the first place, the urbanization patterns of U.S. cities are very specific, with California cities further possessing their own specificity. These patterns show expansive cities, where inhabitants of the wealthy suburbs commute to the city center and back, taking advantage of dense freeway networks that allow to live further away with relatively low negative effects in terms of financial costs or driving time budget. Mexican cities, on the contrary, have mixed patterns, where the wealthy areas tend to concentrate near the urban core, and the outskirts tend to be where the lower-income families live. However, it is also true that newer urban developments for higher income families usually locate further away from the city centers, creating a complex and heterogeneous mosaic with stark differences among neighboring areas.

In second place, Los Angeles and San Francisco have been widely studied in the past, and several quasi-experimental studies support a series of overall consistent results. (Cervero & Hansen, 2002; Noland & Lem, 2002) Nonetheless, these studies have focused mainly on specific road projects and the impacts on their immediate influence radio, but they do not address the problem from the perspective of the city as a whole. This research addresses the induced travel phenomenon from a metropolitan perspective by implicitly assuming that the effects of specific road infrastructure projects that may be causing a locally observable problem of induced travel, may also be causing a city-wide effect, since drivers usually do not limit their driving to the specific areas where projects are built, but rather they only pass by these infrastructures and move further to other parts of the city, therefore affecting a larger area, and potentially the entire city.

This research contributes to further the understanding of the induced travel phenomenon by studying a seemingly local problem of road congestion that is addressed by constructing additional road capacity that is, however, potentially having an effect at the metropolitan level and, therefore, affecting the entire metropolitan transit system. This is relevant for the cases of Los Angeles and San Francisco, since there is no readily available evidence of the magnitude of the problem at the metropolitan level.

As mentioned before, chapters two and three test the induced travel hypothesis from a metropolitan perspective and, therefore, they share the same theoretical framework. This approach is applied to three different metro areas, that can be grouped together into two cases: 1) Mexico City in Mexico (chapter two), and 2) Los Angeles and San Francisco in California (chapter three). Since the theoretical framework is the same, the Literature Review is also the same for both chapters, however the remaining sections are different for each one.

2. Data and Methods

a) Data

The **public investment in road-related infrastructure variable** used yearly reporting of public expenditures on road-related projects for each metro area. The data were obtained from the California State Controller and the California Department of Transportation at the city, county and state levels. Expenditures include construction of new roads, reconstruction of existing ones, installment of signals, and overall maintenance of roads, in the form of patching and sealing. The **registered vehicles variable** uses yearly data on the number of total autos registered at local jurisdictions within metropolitan areas. The data were obtained from the Bureau of Transportation Statistics at the Department of Transportation.

The **modal split variable** uses yearly data on the number of trips made using the public transportation system. The data were obtained from the Bureau of Transportation Statistics at the Department of Transportation. The **urban area variable** uses yearly data on the total size of the urban area by county. The total size of the urban area was obtained by GIS remote sensing procedures for each year using end-of-year satellite imagery (usually December of the corresponding year), although close time ranges were used in some cases in order to obtain the clearest images possible. The imagery was obtained from the United States Geological Survey. Analysis of the years 2000 to 2012 used Landsat 7 imagery, and Landsat 8 was used for the years 2013 to 2016. Finally, **total population** data at the county level were obtained from the US Census Bureau.

b) Methods

This research is intended to measure the effect that three endogenous variables subject to reverse causality have over each other, therefore it is necessary to address the issue of endogeneity. A simultaneous equations system using two-stage least squares (TSLS) is proposed since it is a method that adequately addresses this issue. The system, in this form, would be estimated independently for each metro area; however, following the same structure. The theoretical structural equations are the following:

$$Eq\ A: Vehicles_i = \alpha_0 + \alpha_1 Invest_{i,t-n} + \alpha_2 ModalSplit_i + \alpha_3 Vehicles_{i,t-1} + \alpha_4 UrbanArea_i + X_i\alpha + \varepsilon_{1i}$$

$$Eq\ B: Invest_i = \beta_0 + \beta_1 Vehicles_{i,t-n} + \beta_2 ModalSplit_i + \beta_3 Invest_{i,t-1} + \beta_4 UrbanArea_i + X_i\beta + \varepsilon_{2i}$$

$$Eq\ C: UrbanArea_i = \delta_0 + \delta_1 Vehicles_{i,t-n} + \delta_2 Invest_{i,t-n} + \delta_3 ModalSplit_{i,t-n} + \delta_4 UrbanArea_{i,t-1} + X_i\delta + \varepsilon_{4i}$$

Where:

$Vehicles_i$ is the total number of registered vehicles.

$Invest_i$ is the total investment in road-related infrastructure (in its different variations).

$UrbanArea_i$ is the total size of the urban area.

$ModalSplit_i$ is the number of unlinked passenger trips using the mass public transportation system.

$X_i\alpha$, $X_i\beta$ and $X_i\delta$ are vectors of exogenously determined covariates.

Additionally, lagged versions of the endogenous variables are included, since they strongly depend on their past behavior. Since these lagged variables are predetermined within the system in prior periods, it is assumed that they are exogenously predetermined.[4]

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[4] The lagged variables were constructed by hand, independently from the SAS and Stata LAG functions to avoid bringing values from one jurisdiction into the data points for the next one, since the database uses a combination of cross-section and time series data points for each city and each

For these models, the common practice is to keep the modal split or public transportation variables on the right-hand side of the equations in order to allow using them as a policy variable. (Cervero & Hansen, 2002; Strathman et al., 2000) This means that one could exogenously alter its value to reflect policy goals and forecast its effects over the system.

Order condition of identification:

To test if the equations system is identified, we can look at the following matrix of endogenous and exogenous covariates, where Y_1 is vehicles, Y_2 is roads investments, Y_3 is the urban area size, X_1 is the modal split and X_2 is a pre-determined exogenous variable.

Table 1. Endogenous and exogenous covariates matrix

Endogenous left-hand variables			Endogenous right-hand variables			Predetermined (exogenous) right-hand variables				
Y_{1i}	Y_{2i}	Y_{3i}	Y_{1i}	Y_{2i}	Y_{3i}	$Y_{1i,t-n}$	$Y_{2i,t-n}$	$Y_{3i,t-n}$	$X_{1i,t-n}$	X_2
1	0	0	0	0	1	1	1	0	1	1
0	1	0	0	0	1	1	1	0	1	1
0	0	1	0	0	0	1	1	1	1	1

The order condition is a necessary, but not sufficient condition for identification of the system. If $K - k \geq m - 1$, the model is identified, where K is the number of predetermined variables in the model, k is the number of predetermined variables in a given equation, and m is the number of endogenous variables in a given equation. (Gujarati, 2004, p. 748)

On structural equations one and two, K=13, k=4, and m=2, therefore the order condition is met since $K - k = 9$ and $m - 1 = 1$ for each of them. For the third structural equation, K=13, k=5 and m=1, thus $K - k = 8$ and $m - 1 = 0$, therefore meeting the order condition, and having the system identified as a whole.

year. Additionally, not all jurisdictions have information for all years, thus the manual construction of the lagged variables prevented from using data for years that, otherwise, would be missing.

Rank condition of identification:

The rank condition provides a sufficient condition for identifying the system of equations. If in a model of M equations with M endogenous variables is possible to construct at least one nonzero determinant of order *(M-1)(M-1)* from the coefficients of both endogenous and predetermined variables excluded from that particular equation, then the equation is identified. (Gujarati, 2004, p. 752) To check if the rank condition is met, we use the structural equations solving for the error term, and substituting the names of the endogenous variables for Y_i, and the predetermined variables by $Y_{i,t-n}$, or X_i, and then looking at their corresponding matrices:

$$Eq\ A: Y_1 - \alpha_0 - \alpha_1 Y_{2,t-n} - \alpha_2 X_1 - \alpha_3 Y_{1,t-1} - \alpha_4 Y_3 - \alpha_5 X_2 = \varepsilon_1$$

$$Eq\ B: Y_2 - \beta_0 - \beta_1 Y_{1,t-n} - \beta_2 X_1 - \beta_3 Y_{2,t-1} - \beta_4 Y_3 - \beta_5 X_2 = \varepsilon_2$$

$$Eq\ C: Y_3 - \delta_0 - \delta_1 Y_{1,t-n} - \delta_2 Y_{2,t-n} - \delta_3 X_{1,t-n} - \delta_4 Y_{3,t-1} - \delta_5 X_2 = \varepsilon_3$$

Table 2. Coefficients matrix

Eq.	Coefficients								
	1	Y_1	Y_2	Y_3	$Y_{1,t-n}$	$Y_{2,t-n}$	$Y_{3,t-n}$	X_1	X_2
A	$-\alpha_0$	*1*	*0*	$-\alpha_4$	$-\alpha_3$	$-\alpha_1$	*0*	$-\alpha_2$	$-\alpha_5$
B	$-\beta_0$	0	1	$-\beta_4$	$-\beta_1$	$-\beta_3$	0	$-\beta_2$	$-\beta_5$
C	$-\delta_0$	0	0	1	$-\delta_1$	$-\delta_2$	$-\delta_4$	$-\delta_3$	$-\delta_5$

Equations matrices for excluded coefficients:

$$A = \begin{bmatrix} 1 & 0 \\ 0 & -\delta_4 \end{bmatrix} \text{ where } DetA = \begin{vmatrix} 1 & 0 \\ 0 & -\delta_4 \end{vmatrix} = -\delta_4$$

$$B = \begin{bmatrix} 1 & 0 \\ 0 & -\delta_4 \end{bmatrix} \text{ where } DetB = \begin{vmatrix} 1 & 0 \\ 0 & -\delta_4 \end{vmatrix} = -\delta_4$$

$$B = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \text{ where } DetB = \begin{vmatrix} 1 & 0 \\ 0 & 1 \end{vmatrix} = 1$$

Therefore, assuming that the coefficients are nonzero, the system meets the rank condition, hence it can be estimated. It is expected that not all the predetermined variables will have a nonzero coefficient, in which case the structural equations will be adjusted to reflect the best possible fit.

3. Results and Discussion

The results are presented separately for the two metro areas. In the case of the Los Angeles Metro Area, no specification using the urban area turned out to be statistically significant; therefore, all results were estimated using recursive equations systems, and are presented in terms of Equations A and B only. For the case of the San Francisco Metro Area, it was possible to estimate most specifications using simultaneous equations systems.

After running Breusch-Pagan tests for the two or three dependent variables (depending on the type of system) on the corresponding independent variables for each model, a problem of heteroskedasticity was found on all the variations of all specifications. Thus, all models utilized robust standard errors in order to correct for standard deviation bias and to properly test for the significance of each variable. The variance inflation factors were also estimated to prevent the occurrence of a problem of multicollinearity, and the corresponding corrections were made for each model individually. Once the best possible model was identified for each equation, it was included in the recursive or simultaneous equations systems. The specifications summary is as follows:

Table 3. Specifications summary

<table>
<tr><th colspan="2">Los Angeles Metro Area</th><th colspan="3">San Francisco Metro Area</th></tr>
<tr><th>Equation A</th><th>Equation B</th><th>Equation A</th><th>Equation B</th><th>Equation C</th></tr>
<tr><th colspan="2">Recursive Equation System</th><th colspan="3">Simultaneous Equation System</th></tr>
<tr><td rowspan="2">Total number of vehicles (registered vehicles)</td><td>Total investment in new roads, reconstruction and signals</td><td rowspan="2">Total number of vehicles (registered vehicles)</td><td rowspan="2">Total investment in new roads, reconstruction and signals</td><td rowspan="2">Urban area</td></tr>
<tr><td>Total investment in new roads, reconstruction, signals, patching and sealing</td></tr>
</table>

Source: Iracheta, J.A.

a) Los Angeles Metro Area

For the case of the Los Angeles Metro Area, the urban area variable, which measures the size of the total urban area for each county and each year, turned out to be non-statistically significant on all variations of equations A and B. Therefore, it was not possible to include Equation C, which utilizes urban area on the left-hand side of the equation since no interactions with equations A and B would occur. Therefore, a recursive equations system was used. The main results summary is presented in Table 4.

Equation A models the effects that investments on road-related infrastructure have over the size of the vehicle fleet in the city, in this case measured by the total number of registered vehicles working as a proxy variable. Equation B is intended to show the effect the vehicle fleet size has over the amount of resources that are dedicated to road-related infrastructure. In this equation there are two variations for its dependent variable: models one through three use total investment in new roads, roads reconstruction and signaling, whereas models four through six use investment in patching and sealing, in addition to new roads, reconstruction of existing ones and signaling.

Table 4. Recursive equations systems main results summary

Variable	Model 1		Model 2		Model 3		Model 4		Model 5		Model 6	
	Coefficient (Significance level) / Standardized coefficient											
EQUATION A: Total Number of Vehicles												
Total investment in new roads, reconstruction and signals (t) (US$)	0.0089***	1.0221										
Total investment in new roads, reconstruction and signals (t-1) (US$)			0.0094***	1.0292								
Total investment in new roads, reconstruction and signals (t-2) (US$)					0.0098***	0.9992						
Total investment in new roads, reconstruction, signals, patching and sealing (t) (US$)							0.0077***	1.027				
Total investment in new roads, reconstruction, signals, patching and sealing (t-1) (US$)									0.0081***	1.0351		
Total investment in new roads, reconstruction, signals, patching and sealing (t-2) (US$)											0.0084***	1.0062
Mass public transportation total unlinked (t) (Rides)	-0.0016	-0.1117	-0.0017**	-0.1168	-0.000895	-0.0612	-0.0015*	-0.1012	-0.0016**	-0.1104	-0.000866**	-0.0592
Intercept	-43,352	0	-109,183	0	-137,931**	0	-33,475	0	-86,406	0	-99,556	0
N	75		75		75		75		75		75	
Adjusted r^2	0.9244		0.9332		0.9351		0.9473		0.9534		0.9517	
	EQUATION B: Total Investment in New Roads, Reconstruction and Signals						**EQUATION B: Total Investment in New Roads, Reconstruction, Signals, Patching and Sealing**					
Total number of vehicles (t) (Vehicles)	101.613***	0.8857					120.7621***	0.9094				
Total number of vehicles (t-1) (Vehicles)			103.0377***	0.8878					122.5565***	0.9123		
Total number of vehicles (t-2) (Vehicles)					104.3807***	0.8897					124.2376***	0.9149
Total investment in roads and overpasses (t-1) (US$)												
Mass public transportation total unlinked rides (t) (Rides)	0.25697**	0.1531	0.2488**	0.14826	0.2398*	0.1429	0.2505**	0.1290	0.2401**	0.1236	0.2288*	0.1178
Intercept	24799452***	0	25,910,911***	0	27,258,148***	0	20,338,275**	0	21473195***	0	22924717***	0
N	75		75		75		75		75		75	
Adjusted r^2	0.9345		0.9342		0.9328		0.9533		0.9541		0.9536	

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

Source: Iracheta, J.A.

In Equation A, model one shows that for every additional dollar invested in new roads, reconstruction of existing ones and installation of roads signaling, there is an additional registration of 0.0089 vehicles the same year of the investment. In a more understandable scale, these coefficients show that, for every additional one million dollars of investment in road-related infrastructure (construction of new roads, reconstruction of existing ones, signals, patching and sealing), there is an increment of 8,400 registered vehicles that will take place in that year as well as in the two coming years (model six). This figure is of 8,100 If we look at one year after the investment (model five), and of 7,700 if we look at the year in which the investment takes place (model four). All coefficients are statistically significant at 99% confidence. These results point out that investments on road-related infrastructure have a persistent effect over time in terms of the number of vehicles that are registered, and such effect seems to be incremental as time goes by. Such results are consistent with what was expected, since improvements in road infrastructure appear to have a positive effect on decisions about driving, or at least about having a registered vehicle that allows for the possibility of choosing a private vehicle as transportation mode.

Regarding Equation B, the results show that for every additional registered vehicle, there is an increase in roads infrastructure investment of about 102 dollars, which is equivalent to saying that, for every 10,000 additional registered vehicles, there is an increment of 1.02 million dollars in investments for new roads, reconstruction of existing ones, and signaling. When looking at the effects of vehicles that are registered in previous years, there are no relevant changes, since the invested amount increases to 103 and 104 dollars when the vehicle registration takes place one and two years prior to the investment respectively. All the coefficients are statistically significant at 99% confidence. These results point out that there is a relatively steady relationship between vehicle registrations and the financial resources destined to building roads infrastructure. These results are also consistent with what was expected, since it has been claimed that, as the size of the vehicle fleet increases, road congestion, especially during rush hours, also increases, influencing decision-makers to dedicate more resources to expand or improve road-related infrastructure, thus fueling the endogenous cycle of induced travel.

In Equation B, public transportation ridership is a relevant variable to consider. For every additional thousand public transportation rides, there is an increment of between 240 and 257 dollars in investment for roads infrastructure. If we consider that, only in Los Angeles County there were 569.2 millions of unlinked passenger trips (rides) during 2016, this amount would have an effect on investment of between 136 and 146 million dollars during that year, which represents between 14 and 15% of the 953.7 million dollars that were invested in Los Angeles County in construction of new roads, reconstruction of existing ones and signaling. These effects seem counterintuitive since one would expect that public transportation additional trips would reduce the need for additional investments in road-related infrastructure; however, such effect might be only reflecting increments in the overall metropolitan number of trips made, which would use all transportation modes available.

The results for models four through six, corresponding to investment in patching and sealing, in addition to investment in new roads, reconstruction of existing ones and signaling; are similar to what was observed in models one through three. In Equation A, for every additional one million dollars invested on roads infrastructure, there is a 7,700 increase in registered vehicles in the year that the investment takes place (model four). When the investment happens one year before, the number of registered vehicles increases to 8,100 (model five), and when the investment takes place two years before (model six), the increment is of 8,400 registered vehicles. All coefficients are statistically significant at 99% percent confidence.

In Equation B, the results show that for every additional registered vehicle, there is a 121 dollar increase in roads infrastructure investment. This means that, for every 10,000 additional registered vehicles, there is a 1.21 million dollar increase to the amount destined for roads infrastructure. In terms of the registrations that took place one year before, the investment amount for every 10,000 additional registered vehicles increases to $1.23 million, and for registrations that took place two years before, the investment in roads infrastructure is of $1.24 million. All coefficients are statistically significant at 99% confidence.

Public transportation ridership has statistically significant effects on both equations. For Equation A, an increment of 10,000 additional unlinked passenger trips (rides) has an effect of reducing the number of vehicle registrations between 9 and 16 units. If we assume that one person takes two trips every one of the 260 workdays (for example, to go to work, or school, and back), per year; then one person would be taking around 520 trips yearly. Hence, 10,000 trips would be the approximate number of total trips that 19.2 (~20) people would take, on average, over the year. One could say that a reduction of between 9 and 16 vehicle registrations might be due to shifts in transportation mode from private vehicles to public transportation. In terms of Equation B, for every additional thousand public transportation rides, there is an increment of between 229 and 250 dollars in investment for roads infrastructure. Again, if we consider the total number of unlinked passenger trips (rides) in Los Angeles County for 2016 (569.2 millions), this amount would mean an investment of between 130 and 142 million dollars during that year, which represents between 12 and 14% of the 1.053 billion dollars that were invested in Los Angeles County in construction of new roads, reconstruction of existing ones, signaling, sealing and patching. As mentioned before, these effects might reflect an overall increment in the number of trips made throughout the metropolitan area, on all transportation modes available.

b) San Francisco Metro Area

In contrast to what was observed for Los Angeles, it was possible to estimate most specifications using simultaneous equations systems for the San Francisco Metro Area. On all specifications, the road-related infrastructure investment variables include investment in construction of new roads, reconstruction of existing ones and signaling. The main results summary is presented in Table 5 (5.1 through 5.3).

Equation A is intended to model how the number of registered vehicles is affected by road-related infrastructure investment decisions, as well as by changes in the size of the urban area. The results show that, for each additional one million dollars of investment in roads infrastructure, there is a vehicle registration increase of 3,683 units the year in which the investment takes place, and there is an increment of 3,588 vehicles registered for investments that are realized one year before. However, there is an unexpected result when looking at investment taking place two years prior to the vehicle registration, in which for each additional one million dollars of investment in road-related infrastructure, there is a reduction of between 1,080 and 1,090 vehicle registrations in the current year, which is the opposite effect than what is expected. In terms of the relationship between the size of the urban area and the number of registered vehicles, for each increment of one hectare in the size of the urban area there is an associated effect of between 10.9 (~11) and 19.8 (~20) additional registered vehicles, which means that, for every additional 100 hectares in the size of the urban area, there are between 1,100 and 2,000 new registered vehicles. These results are consistent with the theoretical model, since it is to be expected that, given a more extended city, families will require additional vehicles to meet their transportation requirements, especially because newer urbanized areas tend to gain access to the public transportation networks (if they ever gain access) after the urbanization occurs.

Table 5.a. Simultaneous equations systems main results summary (1 of 3)

Variable	Coefficient (Statistical significance) / Standardized coefficient					
	Equations System 1		Equations System 2		Equations System 3	
EQUATION A: TOTAL NUMBER OF VEHICLES						
Total investment in new roads, reconstruction and signals (t) (US$)	0.003683*	0.35022	-0.00053	-0.05087	-0.00054	-0.05147
Total investment in new roads, reconstruction and signals (t-1) (US$)						
Total investment in new roads, reconstruction and signals (t-2) (US$)						
Mass public transportation total unlinked rides (t) (Rides)	-0.00013	-0.01744	0.000669***	0.09404	0.00067***	0.09422
Mass public transportation total unlinked rides (t-1) (Rides)						
Mass public transportation total unlinked rides (t-2) (Rides)						
Urban area (t) (Has)	11.31869***	0.62357	19.02984***	1.04670	19.03912***	1.04721
Urban area (t-1) (Has)						
Urban area (t-2) (Has)						
Total number of vehicles (t-1) (Vehicles)						
Total number of vehicles (t-2) (Vehicles)						
Intercept	39,695.99**	0	27,586.09**	0	27,624.35**	0
Adjusted r^2	0.8894		0.9480		0.9479	
EQUATION B: TOTAL INVESTMENT IN NEW ROADS, RECONSTRUCTION AND SIGNALS						
Total number of vehicles (t) (Vehicles)	-8.93323	-0.09394	12.24632**	0.12875	11.94326**	0.12556
Total number of vehicles (t-1) (Vehicles)						
Total number of vehicles (t-2) (Vehicles)						
Mass public transportation total unlinked rides (t) (Rides)	0.033737	0.04855	0.056983**	0.08425	0.05672**	0.08386
Mass public transportation total unlinked rides (t-1) (Rides)						
Mass public transportation total unlinked rides (t-2) (Rides)						
Urban area (t) (Has)						
Urban area (t-1) (Has)						
Urban area (t-2) (Has)						
Total investment in new roads, reconstruction and signals (t-1) (US$)	1.006187**	0.97269	0.806462***	0.78135	0.809217***	0.78402
Total investment in new roads, reconstruction and signals (t-2) (US$)						
Intercept	4,594,186	0	2,326,331	0	2,354,916	0
Adjusted r^2	0.8240		0.8393		0.8393	
EQUATION C: URBAN AREA						
Total number of vehicles (t) (Vehicles)	0.055566***	1.00861				
Total number of vehicles (t-1) (Vehicles)			0.05168***	0.9259		
Total number of vehicles (t-2) (Vehicles)					0.05251***	0.92768
Total investment in new roads, reconstruction and signals (t) (US$)						
Total investment in new roads, reconstruction and signals (t-1) (US$)						
Total investment in new roads, reconstruction and signals (t-2) (US$)			0.000042**	0.06761	0.00004**	0.06507
Mass public transportation total unlinked rides (t) (Rides)						
Mass public transportation total unlinked rides (t-1) (Rides)	-0.00003***	-0.06305	-0.00003***	-0.07182	-0.00003***	-0.07205
Mass public transportation total unlinked rides (t-2) (Rides)						
Urban area (t-1) (Has)						
Urban area (t-2) (Has)						
Intercept	-1,850.53**	0	-1,420.74**	0	-1,433.95**	0
Adjusted r^2	0.92711		0.94962		0.94891	
N (for the equations system)	154		144		144	

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

Source: Iracheta, J.A.

Table 5.b. Simultaneous equations systems main results summary (2 of 3)

Variable	Coefficient (Statistical significance) / Standardized coefficient					
	Equations System 4		Equations System 5		Equations System 6	
EQUATION A: TOTAL NUMBER OF VEHICLES						
Total investment in new roads, reconstruction and signals (t) (US$)						
Total investment in new roads, reconstruction and signals (t-1) (US$)	0.003588*	0.32980	-0.0006	-0.05502	-0.00051	-0.04715
Total investment in new roads, reconstruction and signals (t-2) (US$)						
Mass public transportation total unlinked rides (t) (Rides)	-3.10E-06	-0.00042	0.000662***	0.09316	0.000649***	0.09127
Mass public transportation total unlinked rides (t-1) (Rides)						
Mass public transportation total unlinked rides (t-2) (Rides)						
Urban area (t) (Has)	10.95817***	0.60371	19.1857***	1.05527	19.01663***	1.04597
Urban area (t-1) (Has)						
Urban area (t-2) (Has)						
Total number of vehicles (t-1) (Vehicles)						
Total number of vehicles (t-2) (Vehicles)						
Intercept	54,812.13***	0	26,389.4**	0	26,988.06**	0
Adjusted r^2	0.8887		0.9484		0.9490	
EQUATION B: TOTAL INVESTMENT IN NEW ROADS, RECONSTRUCTION AND SIGNALS						
Total number of vehicles (t) (Vehicles)						
Total number of vehicles (t-1) (Vehicles)	13.6448**	0.14144	12.48606**	0.12936	12.48606**	0.12936
Total number of vehicles (t-2) (Vehicles)						
Mass public transportation total unlinked rides (t) (Rides)	0.05363**	0.07718	0.056867**	0.08408	0.056867**	0.08408
Mass public transportation total unlinked rides (t-1) (Rides)						
Mass public transportation total unlinked rides (t-2) (Rides)						
Urban area (t) (Has)						
Urban area (t-1) (Has)						
Urban area (t-2) (Has)						
Total investment in new roads, reconstruction and signals (t-1) (US$)	0.799994***	0.77336	0.805617***	0.78053	0.805617***	0.78053
Total investment in new roads, reconstruction and signals (t-2) (US$)						
Intercept	2,570,544	0	2,329,646	0	2,329,646	0
Adjusted r^2	0.84099		0.83923		0.83923	
EQUATION C: URBAN AREA						
Total number of vehicles (t) (Vehicles)	0.05557***	1.00861				
Total number of vehicles (t-1) (Vehicles)			0.05168***	0.92591		
Total number of vehicles (t-2) (Vehicles)					0.05251***	0.92768
Total investment in new roads, reconstruction and signals (t) (US$)						
Total investment in new roads, reconstruction and signals (t-1) (US$)						
Total investment in new roads, reconstruction and signals (t-2) (US$)			0.000042**	0.06761	0.00004*	0.06507
Mass public transportation total unlinked rides (t) (Rides)						
Mass public transportation total unlinked rides (t-1) (Rides)	-0.00003***	-0.06305	-0.00003***	-0.07182	-0.00003***	-0.07205
Mass public transportation total unlinked rides (t-2) (Rides)						
Urban area (t-1) (Has)						
Urban area (t-2) (Has)						
Intercept	-1,850.53**	0	-1,420.74**	0	-1,433.95**	0
Adjusted r^2	0.92711		0.94962		0.94891	
N (for the equations system)	154		144		144	

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

Source: Iracheta, J.A.

Table 5.c. Simultaneous equations systems main results summary (3 of 3)

Variable	Coefficient (Statistical significance) / Standardized coefficient			
	Equations System 7		Equations System 8	
EQUATION A: TOTAL NUMBER OF VEHICLES				
Total investment in new roads, reconstruction and signals (t) (US$)				
Total investment in new roads, reconstruction and signals (t-1) (US$)				
Total investment in new roads, reconstruction and signals (t-2) (US$)	-0.00109**	-0.09665	-0.00108**	-0.09604
Mass public transportation total unlinked rides (t) (Rides)	0.000725***	0.10195	0.000724***	0.10182
Mass public transportation total unlinked rides (t-1) (Rides)				
Mass public transportation total unlinked rides (t-2) (Rides)				
Urban area (t) (Has)	19.8107***	1.08965	19.7982***	1.08896
Urban area (t-1) (Has)				
Urban area (t-2) (Has)				
Total number of vehicles (t-1) (Vehicles)				
Total number of vehicles (t-2) (Vehicles)				
Intercept	31,271.34**	0	31,298.02**	0
Adjusted r^2	0.9468		0.9469	
EQUATION B: TOTAL INVESTMENT IN NEW ROADS, RECONSTRUCTION AND SIGNALS				
Total number of vehicles (t) (Vehicles)				
Total number of vehicles (t-1) (Vehicles)				
Total number of vehicles (t-2) (Vehicles)	12.35018**	0.12618	12.35018**	0.12618
Mass public transportation total unlinked rides (t) (Rides)	0.056798**	0.08398	0.056798**	0.08398
Mass public transportation total unlinked rides (t-1) (Rides)				
Mass public transportation total unlinked rides (t-2) (Rides)				
Urban area (t) (Has)				
Urban area (t-1) (Has)				
Urban area (t-2) (Has)				
Total investment in new roads, reconstruction and signals (t-1) (US$)	0.808262***	0.78309	0.808262***	0.78309
Total investment in new roads, reconstruction and signals (t-2) (US$)				
Intercept	2,351,715	0	2,351,715	0
Adjusted r^2	0.8389		0.8389	
EQUATION C: URBAN AREA				
Total number of vehicles (t) (Vehicles)	0.053967***	0.98116		
Total number of vehicles (t-1) (Vehicles)			0.051681***	0.92591
Total number of vehicles (t-2) (Vehicles)				
Total investment in new roads, reconstruction and signals (t) (US$)				
Total investment in new roads, reconstruction and signals (t-1) (US$)				
Total investment in new roads, reconstruction and signals (t-2) (US$)			0.000042**	0.06761
Mass public transportation total unlinked rides (t) (Rides)				
Mass public transportation total unlinked rides (t-1) (Rides)	-0.00003***	-0.06104	-0.00003***	-0.07182
Mass public transportation total unlinked rides (t-2) (Rides)				
Urban area (t-1) (Has)				
Urban area (t-2) (Has)				
Intercept	-1,048.67	0	-1,420.74**	0
Adjusted r^2	0.9484		0.9496	
N (for the equations system)	144		144	

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

Source: Iracheta, J.A.

Regarding public transportation, for every 10,000 additional unlinked passenger trips, there is an increment of between 6 and 7 new vehicle registrations. These results are somehow counterintuitive, since one would expect that a larger number of public transportation trips would reflect a reduction in the number of vehicle registrations. However, these results might actually be showing that large increments in public transportation ridership negatively affect the quality of the service, causing some users to shift from public to private transportation.

Equation B is intended to model the effect that vehicle registrations and the size of the urban area have over investment decisions on road-related infrastructure. The results show that, for every additional one thousand vehicle registrations, there is an increment of between \$11,900 and \$12,246 dedicated to road-related infrastructure in the year in which the registration takes place. The investment in roads-related infrastructure increases in an amount of between \$12,486 and \$13,645 for every one thousand additional vehicles registered one year before the investment takes place, and about \$12,350 for vehicle registration occurring two years before the investments take place. These results suggest that the number of vehicle registrations affects road-related investment decisions of the current year, but also of subsequent years, which is consistent with the theoretical model.

Public transportation ridership also has an effect over infrastructure investment decisions. Equation B shows that, for every additional 10,000 unlinked passenger trips, or in a more understandable scale (as pointed out for Los Angeles), for the yearly trips made by 19 people, there is an increment of between \$530 and \$570 investment in road-related infrastructure. These results seem counterintuitive, since one would expect that the more trips are made using public transportation, the smaller the amount that would be destined to road-related infrastructure; however, given the relatively small effect size, it is possible to say that this relationship reflects increments in the overall trips made within the metro area, regardless of the mode used for those trips.

Total investment in roads infrastructure is also affected by past investments. The results suggest that past investments represent around 80% of current investment decisions, i.e. for every 80 cents invested in road-related infrastructure in t_0, there is one-dollar investment in t_1. A limitation of the simultaneous equation specification and of the data, is that it was not possible to model the relationship between the expansion of the urban area and increments in investment for road-related infrastructure. In all models strong multicollinearity was observed between the size of the urban area and other variables of interest, hence urban area size was excluded from this equation to avoid potential problems.

Equation C models the effect that vehicle registrations and investments in road-related infrastructure have over the size of the urban area. The results show that, for every additional one thousand vehicle registrations, there is an increment of between 54 and 56 hectares in the size of the urban area on the same year that the registration takes place. But vehicle registration also affects the size of the urban area in subsequent years. For example, for every one thousand registered vehicles, urban size grows by around 51 hectares the following year, and by around 52 hectares two years after the registration. In other words, the number of vehicle registrations has relatively strong short- and long-term effects over the size of the urban area. If we consider that in 2016, there were 5,491 additional vehicle registrations in San Francisco County, the corresponding increase in the urban area would be of about 286 hectares directly related to the changes in the size of the vehicle fleet of the city. To put in perspective, during the period of analysis for this research (2000-2016) there was an increment of 62,639 vehicle registrations in San Francisco County, which would represent an enlargement of the urban area of about 3,257 hectares, representing 27.4% of the total urban area as of 2016.

In terms of the effects of investments in road-related infrastructure over urban area size, the results showed that these investments have a two-year delayed effect on the urban area size. For every additional one million dollars investment, there was an increment in the size of the urban area of between 40 and 42 hectares two years after the investment took place, which is what is expected according to the theoretical model. In 2014, there was an additional road-related infrastructure investment of $30.5 million compared to 2013. If the results are accurate, such investment would have pushed the urban area to grow about 1,218 hectares in the two following years.

The results regarding public transportation show that, for every 10,000 additional unlinked passenger trips, there is a reduction of 0.3 hectares in the size of the urban area. Again, assuming that 10,000 trips represent, on average, the total yearly trips made by 19 people, these results would mean that, if 100 additional people shifted mode in favor of public transportation, the urban area would be reduced in about 1.6 hectares. Such result is, of course, impossible since the urban area does not shrink, but rather shows how shifting modes from private to public transportation reduces the pressure over enlargement of the urban area.

4. Conclusions

This research is intended to produce and measure the existence of the induced travel phenomenon in the metropolitan areas of Los Angeles and San Francisco. Past studies have focused on specific road-related infrastructure projects, such as construction of additional lanes, or major infrastructure projects, however, there is not much evidence on if and how the phenomenon takes place at the metropolitan level. The metropolitan level of analysis is relevant, since people use the infrastructure built within specific projects only for a fraction of their entire trips, since they still need to make it to their final destination, regardless of whether there is adequate infrastructure to support the number of vehicles circulating in the area. Therefore, it is to be expected that the problems of induced travel not only affect the areas where the infrastructure projects are developed, but also the entire metropolitan area.

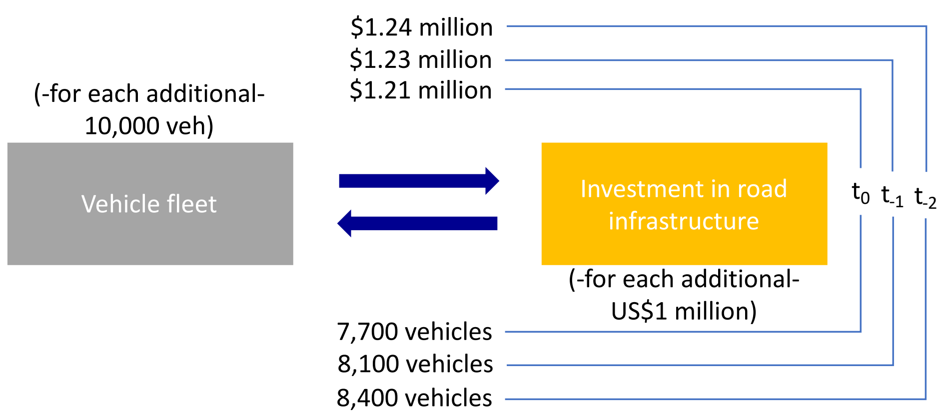
In broad terms, induced travel can be explained as follows: When a city suffers from road congestion and increasing travel time, there is an incentive for public decision-makers to dedicate resources to enlarge or improve road-related infrastructure. In turn, when such infrastructure is constructed, there are strong positive incentives for private vehicle users to increase the usage of their vehicles, and for non-private vehicle users to shift mode from public transportation (or other modes) to private vehicles. In turn, the increment in trips made using private vehicles overwhelms the capacity of existing infrastructure, again creating problems of road congestion and travel time, further inducing government decision-makers to dedicate additional financial resources to enlarge or improve road-related infrastructure. This results in a descending spiral where road congestion creates the need for increasing infrastructure spending. At this point, it is important to consider that all of this road-related spending represents an opportunity cost to improving the public transportation system as well as other modes different than private vehicles.

Finally, to fully elucidate the idea of induced travel, one must consider that the expansion of the road-related infrastructure, i.e. additional lanes, bypasses, freeways, junctions, and the like, tends to facilitate access to farther-away urban developments. This, in turn, creates an incentive for urban expansion, which is more difficult to address via public transportation, limiting the alternatives of transportation modes to private vehicles which again exacerbates the problems of road congestion and the need for additional road-related infrastructure.

For the Los Angeles Metro Area it was only possible to estimate equations A and B of the three-simultaneous equation system, thus a recursive equations system was used. The excluded equation (Equation C) was intended to model the effects of the size of the urban area over road-related infrastructure investment and the number of registered vehicles.

The results for Los Angeles show that increments in the size of the vehicle fleet, as measured by the number of registered vehicles, has an effect of increasing public spending for road-related infrastructure that, in turn, has an effect of increasing the number of vehicle registrations, thus suggesting the existence of induced travel. According to the results, each additional $1 million investment in construction of new roads, reconstruction of existing ones, signaling, sealing and patching, increases by 8,400 the number of vehicle registrations starting the year of the investment and for up to two years after. Considering that, in the period from 2000 to 2016 there was a total investment in road-related infrastructure of $26.7 billion for the entire metropolitan area, this figure would have induced a total of 5.1 million vehicle registrations, representing approximately 48.4% of the entire vehicle fleet.

Figure 1. Induced travel in the Los Angeles Metro Area



Source: Iracheta, J.A.

For every additional 10,000 vehicle registrations there was an effect of increasing the amount dedicated to road-related infrastructure of about $1.21 millions. Considering that the total number of vehicle registrations in the entire metropolitan area was of 10.6 million vehicles as of 2016, the total amount of road-related infrastructure investment that would have been induced by the change in the size of the vehicle fleet would have been of a little under $1.3 billion, representing 12.3% of the total investment.

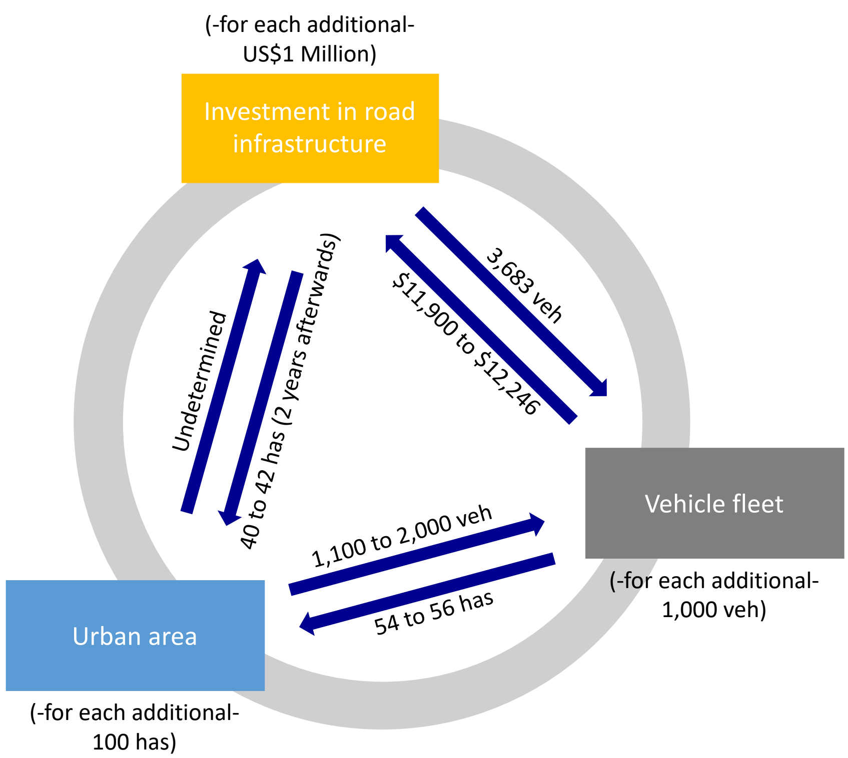
For the San Francisco Metro Area, it was possible to estimate the complete theoretical model using a simultaneous equations system of three equations. The results show that increments in the number of registered vehicles increase public spending for road-related infrastructure. In turn, this has the effect of increasing the number of vehicle registrations. Also, the results demonstrate that the number of registered vehicles increases the size of the urban area, which in turn has a positive effect on the number of registered vehicles. Additional spending in road-related infrastructure also has an effect of increasing the size of the urban area; however, it was not possible to estimate the effect that changes in the size of the urban area has over the amount of resources dedicated to road-related infrastructure. Similar to what was observed for Los Angeles, these results clearly suggest the existence of induced travel, with the additional positive feature of being able to estimate the complete theoretical model.

According to the results, each additional $1 million investment in construction of new roads, reconstruction of existing ones and signaling increases by 3,683 the number of vehicle registrations. For example, if we consider that in the period from 2000 to 2016 there was a total investment in road-related infrastructure of $8.1 billion for the entire metropolitan area, the expected number of induced registered vehicles due to such investment is of 469,735 vehicles, representing approximately 8.4% of the total vehicle fleet as of 2016.

For every additional 1,000 vehicle registrations there was an effect of $11.9 to $12.2 thousand increase in the amount dedicated to road-related infrastructure. Considering that the total number of vehicle registrations in the entire metropolitan area as of 2016 was of 5,894,661 vehicles, the total amount of road-related infrastructure investment that would have been induced by the change in the size of the vehicle fleet would have been of between $1.05 and $1.08 billion, representing between 13 and 13.4% of the total investment.

In terms of the size of the urban area, both variables have a positive effect. In the first case, each additional 1,000 vehicle registrations increases the size of the urban area between 54 and 56 hectares. In the second case, an additional $1 million investment in road-related infrastructure also increases the urban area between 40 and 42 hectares, but two years after the investment takes place. In other words, there is a positive long-term effect of investment decisions about road-related infrastructure over the size of the urban area. Considering that the increment in size of the urban area from 2013 to 2014 was of 220.5 hectares, it is possible to say that around 43% of such enlargement can be traced to the induced travel phenomenon, as explained by the bidirectional relationship of investment in road-related infrastructure and the size of the city's vehicle fleet.

Figure 2. Induced travel in the San Francisco Metro Area



Source: Iracheta, J.A.

The evidence presented in this research provides arguments to fuel the public debate about how cities are shaping their transportation systems, and how the private vehicle-based model is creating negative feedback effects that work against the well-being of citizens for several reasons:

1) Road congestion and longer travel time may cause stress and emotional discomfort,
2) Longer commutes both in time and distance have a negative effect over human health and, by depriving people of alternative transportation modes, also deprive people of a more active way of life,
3) A private vehicle-based system, under current circumstances, has a negative effect over local and global environment due to increasing the amount of pollution emissions, including greenhouse gases that fuel climate change,
4) Non-private vehicle-based systems may have a positive effect over the construction of communities, since they allow an expansion of public spaces and city features that would be unavailable otherwise when there is a dependence on private vehicles and, finally
5) A private vehicle-based system pushes out the boundaries of the cities, causing land use changes and larger environmental footprints, with the consequence of losing natural areas and endangering natural ecosystems.

The findings of this research confirm the existence of induced travel in both the Los Angeles and San Francisco metro areas. These results are consistent with past research; however, it provides a wider perspective on this phenomenon and additional evidence on the forms that induced travel may take, especially when considering that the effects can be felt across the entire metropolitan area and not only around the influence area of particular road-related infrastructure projects.

The findings clarify how investment decisions affect other relevant variables with an impact on the development of urban areas. This is particularly relevant when looking at the opportunity costs of infrastructure investment for private transportation modes as opposed to investing in public transportation or other transportation alternatives. Probably the most important lesson is that a new, more integrated approach about urban development and its transit system is required. As long as there is a need to commute from home to the working place, or to access all kinds of public services, such as education, health care, leisure, etcetera, there is going to be increasing pressure over the transit system. Furthermore, an ever-expanding city restrains the possibilities to provide quality public transportation due to drops in population density, and consequently, reduction of the public transport system financial feasibility.

Therefore, the debate should be about how to balance out the costs and benefits of the desired model of city. “Business as usual” will only deepen road congestion problems, will have a larger negative impact on environmental quality, and will raise travel time. Probably, one of the few alternatives that would prevent the continuation of the downward spiral of induced travel has to do more with looking back at revitalizing city cores by regaining, and even increasing population density and taking advantage of the already installed infrastructure, than looking at ways to tackle road congestion. Such a turn in the urbanization pattern would reduce the amount of driving in several ways: 1) by shifting transport modes from private to public transport or non-motorized alternatives, due to its relatively higher availability and shorter travel distances, 2) by reducing travel distance since employment alternatives and services would be available in the surrounding areas; and 3) by reducing travel time due to a more efficient road system.

If these conditions were met, it is reasonable to expect general efficiency gains in the transport system in the short run, including reductions in roads usage that, in turn, would create a positive incentive to go back to driving a private vehicle. In order to prevent this from happening, and bouncing back to a previous and less efficient state of affairs, any urban policy should be accompanied by a shift in the transportation system. In the first place, it should be a priority to look for ways to account for the externalities that driving, in terms of road congestion, air pollution or noise, among others, imposes on society. There are many approaches to internalizing those externalities, such as congestion charges (congestion Pigouvean taxes) or tradable driving permits (analogous to cap-and-trade systems), which are based on the economic instruments for point source air pollution control, and that are potentially capable of attaining the road congestion goal at the most cost-effective way while imposing the lowest overall costs to society. (Kolstad, 2011) Finally, all measures should aim at expanding the transport alternatives for all types of users, in such way that every individual may assess their ability or willingness to shift mode or face the additional costs for covering the externalities they impose on other citizens.

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CHAPTER 4:

ROAD CONGESTION AND AIR QUALITY MANAGEMENT IN MEXICO CITY: POLICY ALTERNATIVES

Abstract

In chapter one, the *Hoy No Circula* program for Mexico City was evaluated in three moments in time, and the results showed limited effects for the improvement of Mexico City's air quality. An unintended effect of this program was a substantial increment in the size of the vehicle fleet that circulates in the city. Chapters two and three discussed the Induced Travel phenomenon and estimated the effect size for the Mexico City, Los Angeles and San Francisco metro areas. On all cases, the evidence suggested the existence of Induced Travel, and made clear that adding road capacity in these metro areas, induces a larger number of vehicle registrations, hence worsening the problem of road congestion.

This chapter takes the findings from the previous ones in order to frame the discussion about some of the most salient policy alternatives that would be available to deal with the problems of road congestion and air pollution in Mexico City. The need to redefine the policy approach stems from two facts. The first one is that, even though there has been a long-term reduction in air pollution, current concentrations have stabilized at a relatively high level in a way that negatively affects human health. On its part, road congestion has worsened to the point that Mexico City has been regarded in past years as the city with the worst traffic in the world.

With these considerations in mind, two market-based policy instruments, congestion charges and tradable driving permit programs, are discussed in terms of their efficiency characteristics, as well as in terms of their political feasibility and equity concerns. Finally, in the last section of this chapter, several versions of these market-based alternatives are put

forward within the context of Mexico City's features. These alternatives include proposals made by other authors (a fuel tax and a congestion charge), as well as one new proposal (a tradable driving permit system) and, on all cases, they are analyzed in order to assess their viability from a technical, as well as from a political standpoint.

Each of the analyzed policy alternatives have important advantages and drawbacks. The results of the analysis suggest that the tradable driving permit system is the most viable alternative, especially since it would create a supporting coalition that would move forward its implementation; however, it would also face a steep learning curve that would require an intense training process and a progressive implementation.

1. Introduction

The goal of this chapter is to look into the broader policy implications that emerge from the relationship between air quality and road congestion in metropolitan areas, which were discussed in chapters one through three, in terms of the *Hoy No Circula* (*HNC*) program on air quality in Mexico City, and the Induced Travel phenomenon for the cases of the Mexico City, Los Angeles and San Francisco metro areas. Such discussion should help to understand how those policies affect Mexico City's environmental quality and its relationship to road congestion, and be the foundation for a new policy approach on how to tackle these two issues from a comprehensive perspective. This chapter starts by discussing some of the contextual features of Mexico City considered for the analysis of the policy alternatives. Then the discussion addresses market-based instruments, which are the most salient policy alternatives and, finally, the last section of the chapter puts forward a set of policy alternatives for tackling road congestion and the loss of air quality in Mexico City. These policy alternatives consider the evidence and findings that were obtained in all previous chapters, but with special interest in chapters one and two that specifically address the case of Mexico City.

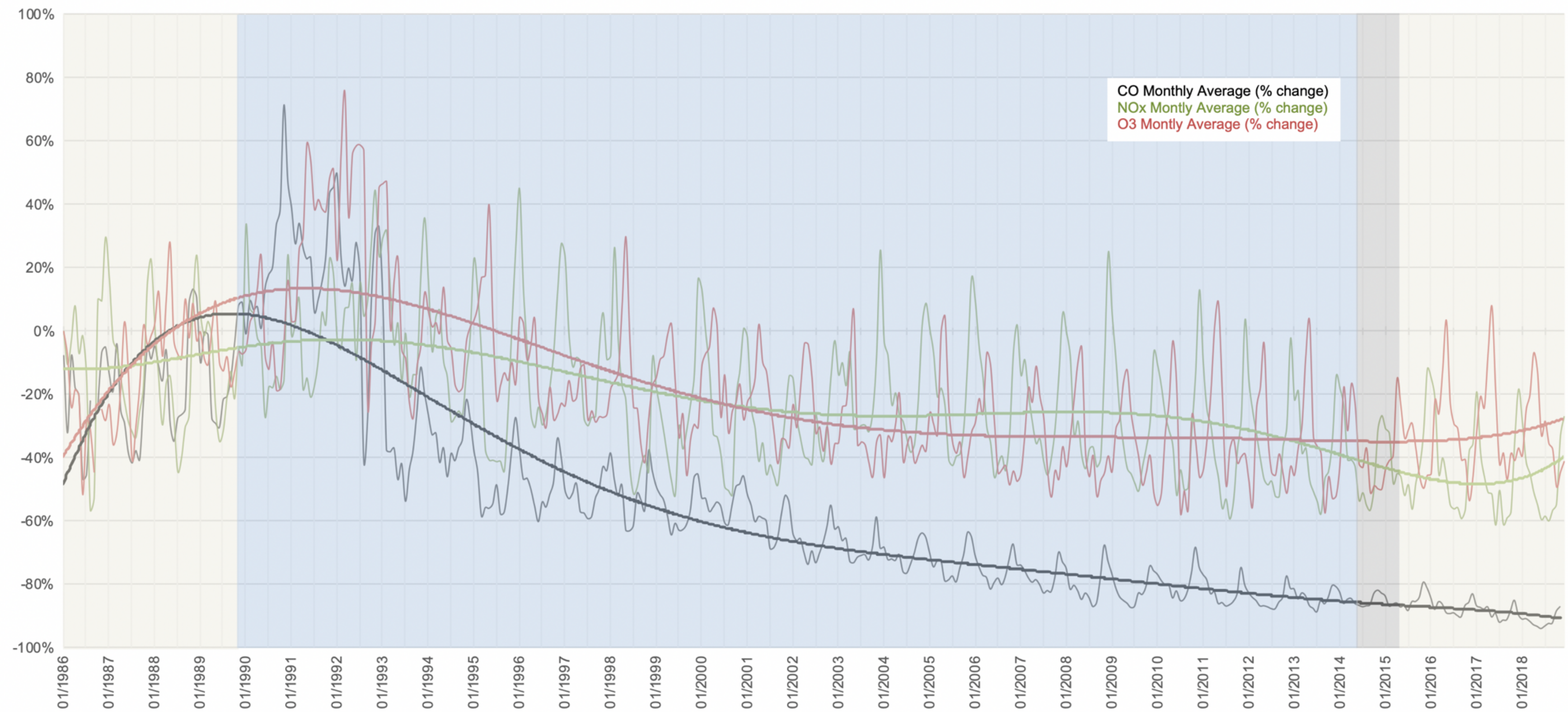
The road congestion and air pollution problems of the Mexico City Metropolitan Area (MCMA) impose high public, private and social costs. Public budgets suffer from an ever-increasing pressure to maintain the existing infrastructure and meet the demand for additional infrastructure, for private, public and non-motorized transportation. The costs citizens face are also increasing, due to losses in productive time, travel comfort and low-quality roads and public transportation infrastructure. But the most important loses are faced by the society in general, since the problems of road congestion and air pollution have relevant negative effects on human health, in the form of congestion-related stress, accidents, respiratory affections and cardio-vascular diseases, among others. Cravioto, Yamasue, Okumura, and Ishihara (2013) estimate the total external costs of road transport in Mexico for 2006 to be between the range of 4.71 to 7.7% of that years' nominal GDP. Note that these costs were estimated at the national level, and they consider accidents (37.6% of total costs), road congestion (28.5%), air pollution (17.8%), infrastructure (9.6%), noise (3.4%) and greenhouse gas emissions (2.9%). The Mexican Institute for Competitiveness IMCO (2019) used the productive value of time lost in traffic to estimate the congestion costs for 32 Mexican cities, including Mexico City's Metro Area in 2019. They found that about 0.25% of the national GDP was lost due to losses of productive time, which represented a per capita cost of approximately US$621 PPP (MX$5,827).

The problem of road congestion has worsened in time and no solution seems to be at hand, whereas the problem of air pollution has been merely managed in order to obtain moderate concentration reductions in the past three decades, but without actually reaching a fair degree of air quality. The most concerning issue is that these non-solutions are embedded within the actual policies that have been implemented so far to address such problems; therefore, they have reached a plateau where it is unlikely that they will be able to improve the conditions without a substantial policy transformation.

The evidence presented in chapter one about the impacts of the *Hoy No Circula* program, showed that it had limited effects for the improvement of Mexico City's air quality, however it had important side effects that partially offset those improvements, and generated more severe road congestion in the long run. The evidence also showed that the policy changes of 2014 and 2015 had mild positive and negative effects respectively. Recall that these impact evaluations are limited to brief periods (between six and 24 months) before and after the policy implementation and the rules changes, and they are not designed to address the entire period that falls between the first implementation of 1989 to date.

The long-term pollution concentration trends for Mexico City clearly show important improvements in air quality for the past 30 years. These results might be due to the existence of *HNC*, but they could also be the result of improvements in vehicle's fuel efficiency, the implementation of the Comprehensive Program for Air Pollution in the MCMA (*PICCA* by its Spanish acronym) and subsequent environmental programs, other unobserved factors, or a combination of all of the above. CO is the pollutant that had the largest improvement, with concentration levels at around 10% of those observed in 1986, with a downward trend which seems to continue to date. NO_X and O_3 concentrations have also experienced an overall reduction. Today the former is about 60% of the levels of 1986, and the latter is about 70%, and both seemed to have stabilized around 2005, with a very slight downward trend. Nonetheless, the important point is that, there is a variety of factors that might have helped reduce pollution emissions, and there is no evidence to specifically pinpoint *HNC*'s overall impact on air quality in the long-run trend. Furthermore, one cannot rule out the possibility that *HNC* has actually contributed to limit the potential improvements in Mexico City's air quality. Figure 1 depicts the overall pollution concentrations from 1986 to 2018.

Figure 1. Long term pollutants concentrations trend



Source: Iracheta, J.A. using MCMA's Automatic Network of Atmospheric Monitoring data.

Moving forward, the evidence presented in chapters two and three suggests the existence of the Induced Travel phenomenon in the metro areas of Mexico City, Los Angeles and San Francisco. Particularly in chapter two, where Mexico City is analyzed, the evidence showed that a relevant percentage of each year's additional vehicle registrations can be traced directly to road-related infrastructure investment (for 2016, about one third of all additional vehicle registrations in the Mexico City Metro Area were induced by the road-related infrastructure investments), due to the incentives of adding road capacity or improving existing conditions over individual decisions, favoring the usage of private vehicles as the main transportation mode, rather than shifting to other modes.

If these policies were to remain unchanged for the coming years, the above arguments portray a negative scenario for the city's road congestion and air quality, that would continue to hamper the chances of attaining a higher quality of life, as well as social and economic development at all levels. These arguments also work for asserting the existence of a downward spiral that will continue to move down unless some substantial policy redefinitions are set in motion. In the first place, the *HNC* maintains a somehow stable status quo in terms of air quality and mobility. However, it does not provide a solution in the long run, but rather it only manages the problem, allowing for the implementation of emergency measures such as for episodes of air quality crisis (the so called *contingencia ambiental*). In second place, there is a continued effort to add road capacity, and to build additional road infrastructure to improve vehicles' flow which will aggravate the road congestion, as it was argued in chapters two and three. On the other hand, this is happening at the opportunity cost of having a higher capacity and quality public and non-motorized transportation systems.

Keep in mind that these programs deal with two different, however self-reinforcing problems: road congestion and air quality loss. Given the existing conditions of the vehicle fleet, where the vast majority of vehicles depend on fossil fuel, the policy goals should be to reduce road congestion as a mean for reducing emissions, but also as a goal in itself. (Raux, 2007) Furthermore, increasing fuel efficiency and moving toward hybrid and electric vehicles would have a positive impact on air quality, but it is unlikely that it would reduce road congestion. Empirical studies have showed that, on the aggregate, driving time budgets tend to remain constant over time, although with some variations depending on individual and household characteristics, destination, and type of residential area. (Gunn, 1981; Metz, 2008; Mokhtarian & Chen, 2004) Also, it has been argued that increasing fuel efficiency may increase travel time and/or distance, (Duncan & Graham, 2013) due to the lower fuel costs (Metz, 2008), and due to the perception of having a lower driving-related individual carbon footprint. Therefore, policies that focus on more fuel-efficient vehicles only, might actually increase the amount of driving and aggravate the problem of road congestion, even if they have an individual positive impact on air quality.

Moving forward to the policy alternatives that are available to address road congestion, Grant-Muller and Xu (2014) classify the management instruments and measures into five categories[5]:

1. Infrastructure: These measures expand the available road capacity, by enlarging roads, adding lanes, building solutions for bottlenecks and so on. These may also include the organization and mixture of land use types, and manage residential density in order to reduce personal travel.
2. Public transport: These measures are intended to increase the public transportation mode share by increasing its coverage and improving the quality of its service. Public transport is dedicated to passengers' transit; therefore, it does not reduce the sources of congestion related to freight transport, and dedicated public transport

[5] These categories are an adaptation and do not exactly coincide with Grant-Muller and Xu (2014) classification.

infrastructure may actually reduce capacity for freight and the other transportation modes.

3. Physical restrictions on vehicle use: These instruments consider government regulations to attain policy goals by imposing conditions on transportation policy, such as restrictions on vehicle ownership or restrictions on the allowed day, time or distance for driving; allocation of pedestrian areas, limited access zones, parking restrictions, dedicated lanes or similar restrictions, among others. These instruments might be packed within the command-and-control category that is used in the environmental economics literature.
4. Technology instruments: These measures aim at optimizing transit by relying on information and communications technology. These measures include intelligent transport systems, demand-responsive transit signaling and lane allocation, and in-vehicle navigation systems, among others.
5. Economic (market-based) instruments: These instruments rely on the use of economic incentives and market principles to guide behavior change. These instruments could be tradable credit schemes, Pigouvean taxes and subsidies on emissions, on fuel or on vehicle use; and congestion charges.

There is, of course, the option of not doing anything about traffic, and allowing cities to grow congested without making relevant efforts. However, when road congestion becomes a more salient issue for city governments and transportation authorities, the traditional first response usually consists in expanding the current infrastructure to release existing traffic conflict points, such as main road crossings or merging sections. However, these first responses usually result in the worsening of the problem, engaging decision-makers into the first steps of the Induced Travel vicious circle.

2. Discussion of Market-Based Instruments

Based on the environmental policy literature, market-based instruments for pollution control possess several advantages over other policy alternatives since they rely on economic incentives and disincentives to drive behavioral change toward the attainment of environmental goals; however, they also face some shortcomings that need to be addressed in order to be considered as viable alternatives. From an economic standpoint, market-based instruments are capable of attaining a higher degree of efficiency, and even an optimal allocation of resources, minimizing the social costs of implementing these instruments; therefore, being the preferred option over prescriptive alternatives. When properly designed, they are able to meet the environmental goal in the most cost-effective way. (Keohane, 2007) This means that environmental regulation using market-based instruments will impose the lowest overall costs to society, since they create incentives for those firms that have the lowest (pollution) abatement cost to make the largest pollution emissions reduction. (Stavins, 2007) This cost minimization is attained because market-based instruments equate the marginal costs of abatement per unit of output for all regulated entities (equi-marginal principle), rather than equating their actual abatement level. (Goulder & Parry, 2008) If there were a perfectly competitive market with no transaction costs (theoretical), there would be a symmetry between a Pigouvean tax and a tradable credit system in terms of costs and the environmental goals.

Going back to the instruments to address road congestion and its related air pollution, economists prefer market-based instruments since they account for the heterogeneity of drivers, their needs and the nature of their trips. This is an analogous interpretation of the equi-marginal principle, where those vehicle users with relatively lower costs for driving abatement or shifting transportation mode (from private to public or non-motorized modes), make the largest contribution to the overall reduction in the amount of driving and its consequent reduction of road congestion and pollution emissions. In this case, the costs would be related to the availability of alternative transportation modes, the capacity to use them, and the overall willingness to reduce driving by the means that are available to the user. These elements are overlooked by command-and-control instruments, such as driving restrictions; therefore, they increase the individual and social costs of the policy, and loose effectiveness for attaining their congestion and environmental goals. (Mahendra, 2008)

Some of the most important arguments against the implementation of market-based instruments for addressing environmental problems or, as in this case, road congestion and its corresponding air quality loss, are several. They range from political limitations, to equity concerns and ethical considerations. These issues are addressed further down this section for each specific case.

a) Congestion Charges

A congestion charge is an instrument intended to put a price on the costs that drivers impose on other road users in terms of time and delays. (Albalate & Bel, 2009) The charge may be conceptually broaden to also put a price on the environmental costs that drivers impose on all citizens by reducing air and ecosystems quality, as well as affecting human health. Following the same principle of a Pigouvean tax, the economic rationale behind a congestion charge is that the maximum net benefit for society will occur when the marginal social cost of driving (the average cost of having an additional vehicle entering the city's roads), and not only the individual cost, is internalized; (Thomson, 1998) or, in different terms, when drivers, by means of paying a tax, assume the cost they are imposing on the rest of society, due to the congestion of public space (roads) and its related air pollution.

Singapore was the first city to ever implement a congestion charge scheme in the world, beginning in 1975. At first, the system relied on paper permits and manual enforcement, but in 1998, it started using in-vehicle electronic smart cards to automatically charge whenever a vehicle crossed a gantry. (Santos, Fraser, & Newbery, 2006) This program had positive results considering that it reduced traffic volume in 45% during peak hours; (Willoughby, 2000) nonetheless, it also had unexpected results by causing congestion to substantially increase right before and after the restricted hours. (Santos et al., 2006)

The most salient case of a congestion charge is that of London's downtown area, which was first implemented in 2003. Several authors consider this program to be successful in terms of its congestion reduction goal, as well as from the indirect impacts on economic activity. (Albalate & Bel, 2009; Quddus, Carmel, & Bell, 2007; Santos et al., 2006) The number of vehicles circulating in London's downtown dropped between 15 and 20% two weeks after implementation, and up to 30% after several months. Of those reductions, about 50% shifted mode to public transport, 10% shifted to taxis, motorcycles or bicycles, 25% shifted route to avoid passing through the congestion charge area, and the remaining 15% adjusted their trip to free-of-charge hours or simply avoided making trips. (Albalate & Bel, 2009; Santos et al., 2006). These estimations show that a relevant portion of the reductions (25%) were trips diverted from the downtown to other parts of the city, and mainly to London's Inner Ring Road, which saw an increment of 4% in the vehicle flow. (Santos et al., 2006) This side effect shows that, similar to what was observed in Singapore, where the congestion shifted to the hours where no restriction was in place, the congestion charge in London moved the vehicle flow to different areas of the city.

Another relevant case of successful implementation of a congestion charge is that of Stockholm, Sweden, where a traffic volume reduction of 19% was observed, and around 6% of drivers shifted mode to public transport. (Albalate & Bel, 2009) One feature that is unique to the Stockholm case is that the congestion charge was tested first for a temporary exercise, after which the program was subjected to a referendum, where citizens decided to maintain the charge. There is evidence suggesting that the support for the congestion charge reflected the benefits obtained from reductions in time travel, showing that Stockholm citizens highly valued their time. (Quigley & Hårsman, 2010) An interesting feature of the Stockholm case, observed in a cost-benefit analysis, is that, according to the evidence, the congestion charge did not actually produce an overall welfare gain, even though the level of the charge (the tax level) was near optimal. (Kopp & Prud'homme, 2010) Three features seem to be the main drivers of the negative results of the cost-benefit analysis. The first one is that Stockholm's road congestion problem was not as high as, say London's; therefore, the lesson to be learned is that in order for a congestion charge to have a positive outcome, it is necessary to have a relevant road congestion problem. The second is that enforcement costs (particularly when it is necessary to control potentially millions of trips) tend to be high. Even though these costs were half in Stockholm than those observed in London, it was not sufficient to make the welfare gains larger than the losses. The third feature is that imposing a congestion charge caused some drivers to shift modes from private to public transport, and affected public transport capacity and quality. In order to make a congestion charge a viable option, one must evaluate the public transport alternative and its ability to meet the expected increased demand, which involves potentially high costs for the infrastructure development and operation. (Kopp & Prud'homme, 2010)

The city of Edinburgh, Scotland, worked for over a decade on the design of a congestion charge, replicating London's model. Before putting it into effect, the city held a referendum to decide if such a program should be implemented; however, differently than the path that Stockholm followed, in Edinburgh, no temporary trial was put in place in order to test the efficacy of the measure. The result of the referendum was a generalized reject of the policy proposal, eliminating any chance to move forward for its implementation. (Albalate & Bel, 2009)

Most policy instruments tend to create winners and losers when they are implemented. Pigouvean taxes, regardless of whether they take the form of a carbon tax for pollution emissions or a charge for road congestion, face relevant political feasibility issues since they seem to create losers only, (Albalate & Bel, 2009; Downs, 1992; Farrow, 1995) even when some stakeholders may benefit from the measure, or in this case, some drivers who highly value their time, may end up better off than before the tax. (Thomson, 1998) For the case of congestion charges, drivers must pay for what many assume to be the right for a “free” use of roads, even though it is hardly free if one considers the externalities that are imposed on other citizens, and society in general. (Albalate & Bel, 2009) Drivers also have to take driving reduction measures that may involve additional costs in the form of travel comfort, or other indirect costs.

Albalate and Bel (2009) identify three features that need to be considered when designing a congestion charge system. The first one is what fee structure and operational technology will be used. In particular, it is relevant to assess if the congestion charge is to be applied with variations depending on the time and place, or if it will be constant. While the latter is simpler to implement, it may face inefficiencies on trip allocations. The second is what the purpose of the tax revenues will be. Such purpose is relevant since it may bring upfront benefits of the tax, e.g. to improve the road or public transport infrastructure, in order to balance up the negative perception of the tax. (Harrington, Krupnick, & Alberini, 2001) The third is related to the political impacts of imposing a tax under conditions of loss aversion and free-ridership. The former implies that the perceived loss from an already enjoyed benefit (free use of roads) is greater than the expectation of a future gain (reduced congestion and improved air quality), thus creating a strong opposing coalition against a policy measure such as the implementation of a congestion charge. The latter phenomenon implies that, when the costs of policy decisions are distributed among a diffuse group (such as drivers), there are incentives to avoid incurring in such costs (providing political support for an unpopular measure), while enjoying the benefits from the decision. In the case of the congestion charge, it is reasonable to expect a low degree of active support, even when there are clear gains for specific groups. (Albalate & Bel, 2009)

In terms of equity and distributional concerns, depending on the design, a congestion charge may be regressive in the sense that there is a proportionally higher negative monetary impact for lower-income drivers than for those with higher income, (Thomson, 1998) which would end up being the ultimate winners. This effect, however, would be inversely proportional to the extent that there are quality transportation alternatives to driving, in which case the negative effects would decrease, and would become positive as the alternatives equally or better satisfy the mobility needs. A congestion charge could also affect public transport users if a mode shift from private to public transport occurs as a consequence of the charge, by reducing its relative capacity and quality. In such scenario, there would be relevant concerns since public transport users have a relatively lower, or even neutral contribution to the road congestion and air quality loss; however, they would be forced to assume some of the costs of tackling those problems. In general, it is not possible to assert that a congestion charge would have negative equity or distributional outcomes, since the net effect depends on the policy design, as well as on the characteristics of the mobility system as a whole, with special consideration of the mass public transport. Nonetheless, these issues must be accounted for in order to have the best possible design and attain the congestion and environmental goals, but not at the expense of specific population groups.

b) Tradable Driving Permits

There is a large body of literature addressing various alternatives of tradable driving permit instruments. (Fan & Jiang, 2013; Goddard, 1997; Verhoef, Nijkamp, & Rietveld, 1997; Yang & Wang, 2011) This literature is mainly based on the development of environmental policy instruments that have been around since the early seventies and, in particular, this literature takes its foundations from the tradable emissions markets, otherwise known as cap-and-trade programs. These systems consist on allocating pollution rights to firms and allow them to trade those permits. Firms with higher marginal costs for pollution abatement would purchase permits from lower marginal cost firms within the total pollution allowance (cap) which is set as the program's yearly goal, and that would be tightened progressively in time until reaching the ultimate goal. This in turns creates a market for pollution permits, and eventually the determination of a price for the right to pollute. The economic logic behind these systems is that, under competitive market conditions, firms will have an incentive to reduce their emissions to the point in which they minimize their marginal costs of pollution abatement, creating an optimal level of pollution at the firm level, and meeting the environmental goal at the aggregate level. (Hanley, Shogren, & White, 2007) By allowing firms with high marginal abatement costs to purchase allowances, and low marginal abatement cost firms to sell them, overall costs are minimized both at the firm and at the industry levels (Kolstad, 2011) and, again, under competitive market conditions, this would also allow to price the permits at the optimal level. The environmental logic of this instrument, is not only about internalizing the cost of the pollution externality, but it is also about a progressive reduction on the emissions cap, that will allow to reach the environmental goal by incentivizing firms to innovate and improve pollution reduction technologies.

A tradable driving permit system is analogous to a cap-and-trade pollution control system, however there are some differences. While the goal for a cap-and-trade program is to reduce point source pollution emissions, a tradable driving permit system has a double goal: reducing road congestion and reducing mobile source's (vehicles) pollution emissions. Therefore, the externalities in this case are the congestion that vehicles cause by their use of public space (roads) and that should be available to everyone, and the externality caused by their pollution emissions affecting the city-wide air quality. It is important to consider that there might be ways of reducing one externality without changing the other, such as driving electric vehicles, which would reduce pollution emissions, but would be neutral in terms of road congestion.

Rather than having polluting firms or industries under a tradable driving permit system, there are drivers that, instead of abating their emissions, take measures to reduce their amount of driving, which would reduce their pressure on the overall road infrastructure and would also reduce their emissions. Their “abatement” alternatives would be to cut down their trips in number and/or distance, shifting modes (from private vehicles to public transport or non-motorized alternatives) or sharing vehicles. In such scenario, those drivers with higher marginal costs (for instance, because of a lack of alternatives to driving a vehicle, or because of having a lower willingness to reduce their driving), would purchase the permits; while those drivers with lower marginal costs to reduce their driving would be permit sellers. Finally, rather than having an environmental goal measured in terms of total pollution emissions, under a tradable driving permit system there would be a maximum number of vehicles allowed to circulate at any given time, which would reflect the relationship between road capacity, travel time and pollution emissions. Fan and Jiang (2013) define five elements that should be considered when designing a tradable driving permit program: 1) the permit quota, which is usually pre-determined, 2) the initial permit allocation to selected recipients, 3) the permit trading mechanisms at the marketplace or at road access controls, 4) the operational rules for permit usage, that may be differentiated by time, place and vehicle’s characteristics, and 5) the enforcement mechanisms to ensure compliance.

Moving past the economic efficiency argument that supports a tradable permit system, there are several elements that would favor the implementation of such a program. In the first place, a tradable permit program accounts directly for the public problem that it intends to address, in this case, road congestion and air pollution. Secondly, a tradable permit program creates an incentive for the participating agents to be vigilant about other players complying with the program, since the permit value depends on its proper use; and thirdly, tradable permit programs allow that some agents with a low permit usage receive benefits from selling their permits. (OECD, 2001) This feature is important from two perspectives. From a political standpoint, a tradable driving permit would generate a group of permit sellers that would financially benefit, hence potentially becoming a supporting coalition of the program. (Colby, 2000) If we consider that political agents tend to favor conferring benefits rather than imposing costs, (Barthold, 1994) a decisive factor might be the final balance between perceived winners and losers of the program. Second, a tradable driving permit program might also improve the distribution of income if we consider that higher-income agents with lower willingness to reduce their driving would dedicate a larger amount of financial resources in order to maintain their driving status, transferring resources to those with lower income and/or financial capacity, whose expected willingness to shift transportation mode would be higher. (Goddard, 1997)

This argument, however, has a flip side for the case of Mexican cities, where the areas in which the lowest income families live, tend to be farthest away from city centers, and with the least accessibility to mass public transport or non-motorized alternatives. Therefore, a tradable driving permit program that do not consider these limitations would impose a disproportionately large cost to lower income families, further reducing their available income and quality of life. This equity issue would not only be applicable to lower income families since public transport accessibility differences affect many areas of Mexico City, and all income ranges. Additionally, there is a group that would not be able to shift transport mode, even if they were willing to do it. This group includes the elderly, people with disabilities, and other people with specific characteristics whose case would have to be addressed in the design and implementation of the program.

Another potential drawback is that the group that would most likely oppose such a system is the one with the lowest willingness to shift transport mode, which tends to have a higher financial and lobbying capacity, thus posing a relevant political obstacle. Furthermore, two socio-economic characteristics that affect the willingness to shift driving patters in order to reduce the carbon footprint are age and income. Several studies found that as age and income increase, the willingness to participate in a tradable driving permit program is lower. (Dogterom, Bao, Xu, & Ettema, 2018; Gehlert, Kramer, Nielsen, & Schlag, 2011) Therefore, it is reasonable to expect opposition from groups that share these characteristics to the implementation of a tradable driving permit program. Finally, there are some controversies between economists and environmentalist groups since the latter argue that a permit trading system is privatizing a natural resource that should be available freely and openly. (Tietenberg, 2007). Furthermore, a tradable permit system would turn pollution into a commodity, thus moving the pollution problem into doing "business as usual", instead of taking a more direct action to tackle the problem. (Auer, 2000; Pesci, Pérez, & Pesci, 2007)

The empirical studies about tradable driving permits have considerable limitations, since there are no actual real-life programs being applied in the world. This literature relies on perception and self-reported data about hypothetical situations, on computer-based laboratory experiments, or on games and computer simulations. (Dogterom, Ettema, & Dijst, 2017) Even with these limitations, these studies have commonly found that, in terms of their potential to change individual behavior (the willingness to reduce their carbon footprint by changing driving patterns), tradable driving permit programs would have a similar, or even larger effect for reducing the amount of driving, than imposing a tax (on fuel or on carbon). (Aziz, Ukkusuri, & Romero, 2015; Capstick & Lewis, 2010; Dogterom et al., 2018; Raux, Croissant, & Pons, 2015; Wallace, Irvine, Wright, & Fleming, 2010; Zanni, Bristow, & Wardman, 2013) Nonetheless, the option of maintaining the current driving patterns, or even the option of paying in order to keep the status quo is, in general, preferred rather than any other policy alternative. (Raux et al., 2015)

In general, it is not possible to assert that a tradable driving permit program would outperform a congestion charge, since there is no real-life evidence to support such a claim. Nonetheless, there is positive evidence from the environmental policy field regarding the results of cap-and-trade programs, even when considering the wide degree of variation in terms of relative success. (Colby, 2000; Schmalensee & Stavins, 2013; Solomon, 1999) In any case, the previous paragraphs underline several aspects that must be taken into account when designing and implementing a tradable driving permit system, and these elements will determine its viability and success.

3. Policy Alternatives and Conclusions

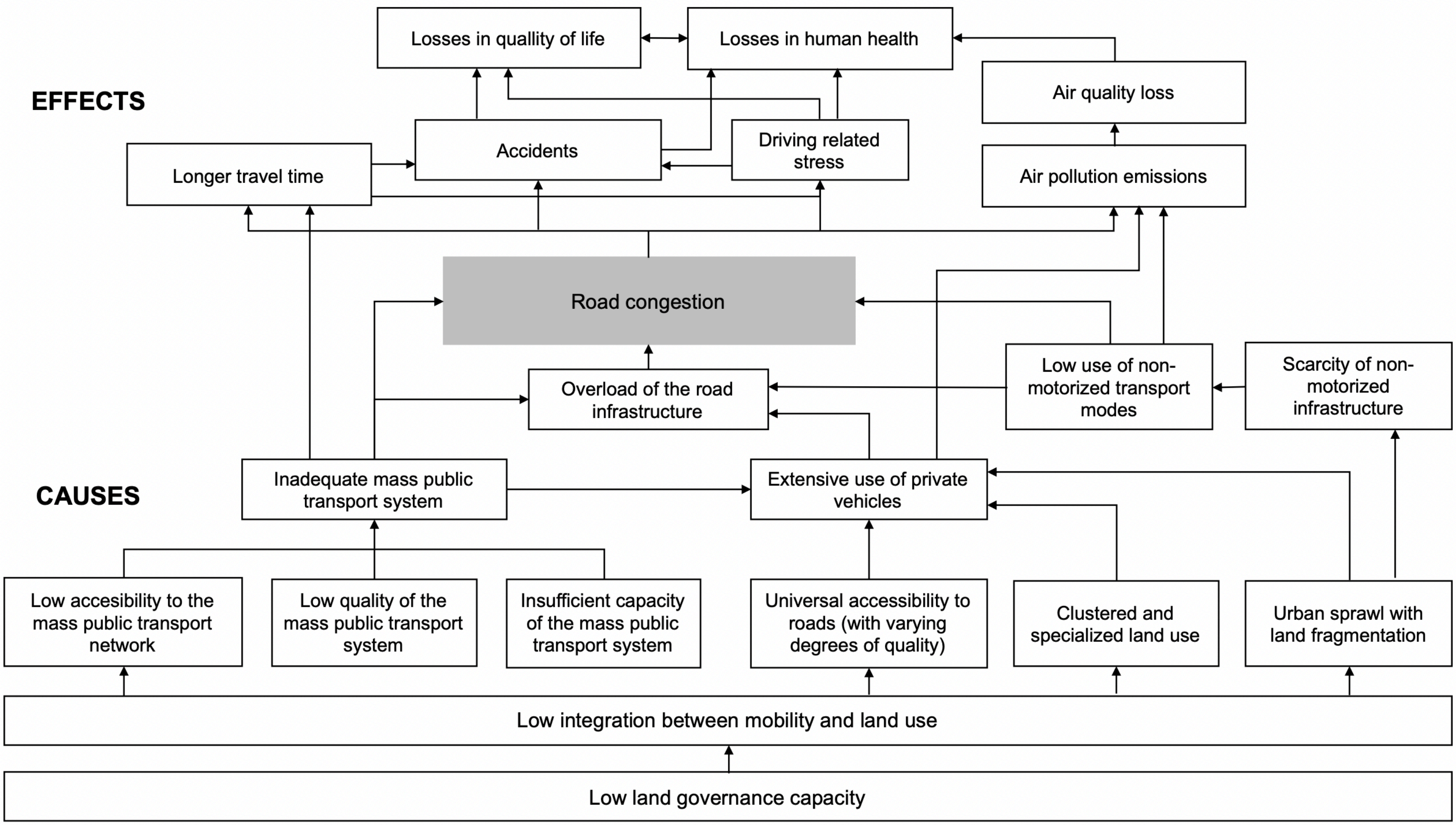
Mexico City and its metropolitan area face an immense challenge for tackling the problems of road congestion and poor air quality. According to the evidence presented in previous chapters, current policies are not properly designed to provide a long-term solution to these interrelated problems and, in particular, the continued decisions for investing in additional road capacity have proven to be counterproductive to the goal that they intend to solve. These conditions call for an in-depth redefinition of these policies from a comprehensive perspective. Therefore, we start this section by stating a proposed definition of the public problem, as well as the policy goals, and then we move forward to the discussion of the means to attain the latter.

Adequately defining a public problem is probably the most relevant part of the policy process, since the definition will determine the lines of action that will be utilized. For Moore (1976), one should keep in mind three considerations: 1) the interests that will be affected by the persistence of the problem or by the policy instruments that are used, 2) the instruments that are available, and 3) the causal variables that will determine the effectiveness of the instruments. Furthermore, the definition of the problem will determine the extent to which there are policy instruments to address the public problem in question. (Moore, 1976) For the problems that have been discussed throughout this research, there are at least three alternatives to guide the public problem definition. The first one is in terms of the air quality loss as a consequence of emissions by internal combustion engine vehicles. The *Hoy No Circula* program follows this logic; however, there could be other instruments, such as launching an intensive program to substitute fossil fuel for hybrid or electric vehicles. Such a program would significantly reduce pollution emissions from mobile sources, however, if a one to one substitution occurred, it would be neutral in terms of road congestion.

A second alternative would be the definition of the problem in terms of insufficient road capacity that causes congestion, which has two implications. The first one is that urban mobility loss is a problem in itself, and the second is that the air quality loss is a byproduct of the road congestion. Infrastructure investments in road-related infrastructure, even with the unintended and counterproductive effect of increasing traffic, follow this logic.

Finally, the third alternative would be to define the problem in terms of the interrelation that exists between these two problems and other conditions that create a complex problem which, consequently, require a similar set of solutions in order to address multiple causes. Figure 2 portrays the problem tree, where multiple causes and interactions work toward shaping the problem. Note that, even though air pollution is a significant issue in terms of air quality and human health, it is not necessarily the main problem to address, but rather a consequence of a different set of problems.

Figure 2: Problem tree diagram



Source: Iracheta, J.A.

An adequate policy should aim at addressing the causes of the problem; however, it is necessary to differentiate between those structural causes that would require an overarching systemic transformation, and those that may be addressed by means of a public program. In this case, the causes related to land governance, urban planning and control of land use would be out of the scope of this analysis, but the conditions of the public transportation system, as well as the conditions that drive the overload of the road infrastructure, particularly the extensive use of private vehicles as the main transportation mode for a relevant portion of Mexico City's population, are the causes that are subject to a public policy redefinition. In order to address these public problems, some proposals have been put forward in the past.

Eskeland (1994) proposed the implementation of a two-pronged air pollution control program, with one component aiming at the enforcement of a stricter emissions abatement requirement for vehicles coupled with a gasoline tax, which together would mimic the incentives produced by an emissions fee. He developed a formal model for the estimation of the optimal level of the Pigouvean gasoline tax, which could be reduced according to the attainment of the environmental goal, but it could also be increased if the tax did not induce the expected behavioral changes in the gasoline demand.

This two-pronged proposal was intended to address air pollution, but not necessarily road congestion. One feature of the model is that it differentiates between polluting and non-polluting goods, but it does not differentiate between private or public transportation modes. Such difference is relevant since the individual marginal costs of abatement would strongly vary depending on the availability of alternative and less pollutant transportation modes, such as non-motorized, subway or light rail systems. Even if the social marginal costs of abatement were minimized, there would be strongly differentiated effects at the individual level that would disproportionately affect lower income families or people living in lower accessibility areas. Another potential way of abating individual emissions would be the substitution of internal combustion engine vehicles with electric ones. Even if this possibility were viable given the relative mismatch between average income and the price of electric vehicles in Mexico City, if all vehicles were substituted, the mobile source air pollution problem would be solved, but the road congestion would remain the same.

Additionally, a proposal partially based on a gasoline tax in Mexico City raises several concerns about its political viability, as well as its equity effects. In the first place, gasoline price in Mexico is fixed and determined by the national oil company Pemex, which possesses monopolistic powers, and suffers from very low productivity and high production costs. Furthermore, the gasoline price has gotten decades of subsidies, which keeps its price artificially lower than what it would be given the domestic production costs, the international oil prices and the heavy fiscal regime that falls upon Pemex. It is worth noting that there has been a progressive reduction of the subsidy over the past two decades, known as *gasolinazo* (gasoline price gouge), which has substantially increased the price and has been highly unpopular causing social protests. Under such scenario, a gasoline tax would mean not only the elimination of the subsidy, but also the imposition of a tax which would further increase the gasoline price. As it was mentioned in the previous section, taxes seem to create losers only, thus it is only reasonable to expect a very intense social and political opposition to such measure.

From an equity perspective, fuel prices are among the most sensitive factors that affect quality of life, for at least two reasons. The first one is that transportation is one of the most important social and economic activities, since it allows families to go to school, to the work place, and satisfy every need that cannot be satisfied at home. Keeping all other variables constant, a gasoline price hike would make transportation costlier, thus reducing the disposable income and the quality of life, and disproportionally affecting lower income families. The second reason is that a tax-related fuel price hike has the potential of generating inflation across the board, again reducing disposable income and quality of life with a disproportionate negative effect over the lowest income groups.

In terms of Moore's (1976) design considerations, a fuel tax would be readily available in the policy maker's tool kit and would have the potential to address the causal variables that determine the road congestion problem. However, the interests that would be affected are so large and distributed across policy makers and social groups, that it is highly unlikely that this policy would move to its actual implementation.

An alternative to a fuel tax would be the imposition of a congestion charge. Such a policy would be less controversial than a fuel tax, since it would not directly affect the overall energy and fuel markets; nonetheless, it would still face the same negative perception of creating losers only, and disproportionally affecting lower income groups. Mahendra (2008) studied the perception of transportation experts from academia, consulting firms and practitioners, regarding a hypothetical congestion charge that would be implemented in four Latin American cities, including Mexico City. When experts were asked about the *Hoy No Circula* program, only 44% considered that it had a positive effect for relieving road congestion, and when asked about the alternative solutions to road congestion, the highest ranked response was expanding, improving and integrating the public transport system, followed by the introduction of physical restraints to driving, such as restricted lanes and pedestrian zones. Among the lowest ranked solutions were the imposition of a fuel or a vehicle ownership tax, as well as increasing road capacity. About the latter, if we consider that Mexico City authorities have invested in massive road infrastructure projects for decades, and continue to do so to this day, it is worth noting how disconnected the public investment decisions are from the experts' opinions. (Mahendra, 2008)

The obstacles that a congestion charge would face, according to the respondents, are lack of public knowledge and information about such a program at the decision-making level, as well as a lack of political will; but most importantly, it would face important opposition from most drivers, regardless of the income group to which they pertain. For affluent car owners, the respondents argue, a congestion charge would have no sizeable effect, since they would not be sensitive to the charge; while lower income drivers would face a disproportionally large negative effect on their disposable income. Finally, respondents considered that the revenues obtained from a hypothetical congestion charge should be used to improve the public transportation system, since low- and middle-income drivers would likely shift mode if public transport were an actual quality alternative to driving. (Mahendra, 2008) Nonetheless, as long as there is no universally available transportation alternative that services the entire city, the effects of a congestion charge would disproportionally affect the lowest income groups.

Again, looking at Moore's (1976) design considerations, a congestion charge would be available in the policy makers' tool kit, however it would require to take several steps before moving into an implementation phase. In the first place, further quantitative analysis to estimate the optimal level of the charge would be required; followed by a more precise identification of daily vehicle flows, restriction areas, entry points and potential areas that would likely receive the diverted trips. Nonetheless, this information could be produced and analyzed without much problem. As per the second consideration, a congestion charge would address the causal variables that determine the nature of the problem, since it would aim at reducing road congestion and, consequently, would also reduce pollution emissions. In order to enhance the effectiveness of the charge, the collected revenues should be directed to improving the public transportation system. The third consideration about the interests that the policy will affect is more problematic. Taxes are usually not well received and there are few politicians that would be willing to risk imposing a brand-new tax. Also, the lowest income population would be disproportionally affected, and so the program would have to go through a progressive implementation, and making sure that alternative transportation modes become available to cover underserviced areas.

One final alternative is the implementation of a tradable driving permit system. The most important issue to be resolved in order to make this type of program viable, would be attaining a balance between the perceived winners and losers, and the political interests that those agents would be supporting.

In regards to the technical part, current and already available technology makes relatively simple to track any vehicle's mileage, as well as implementing an application to link the mileage to a hypothetical driving credit market and bank accounts. The challenging part would likely be the system integration between drivers and monitoring and enforcement authorities. Let us not forget that the current *Hoy No Circula* program is "manually" enforced, and police officers are continuously monitoring vehicles to make sure that only those meeting the check-up requirements are on the streets. This type of enforcement has proven to be effective in Mexico City, but also to impose relatively high costs, that could be substantially reduced by having an automated technology-based monitoring and enforcement system. Nonetheless, driving-related automated systems of this type, such as for freeway toll payments, are not widely used in Mexico; and even less common is the use of direct trading applications to participate in the financial markets. Finally, since no similar program has been implemented in any city so far, there are multiple gray areas that would potentially challenge the implementation, amplifying the learning curve for fully understanding and controlling the tradable driving permit system. Similar to what was observed by Mexican experts about a congestion charge, it is reasonable to expect the same lack of knowledge and information about the program and its implementation at the decision-making level. (Mahendra, 2008)

As mentioned before, the most important strength of a tradable driving permit system is that it has the ability to create a supporting coalition by those drivers whose driving abatement costs would be lower, thus willing to shift mode or undertake measures to reduce their driving, and become permit sellers. Additionally, it is reasonable to expect that some of the lowest income drivers would pertain to such a coalition, since the gains from the permit trading would be higher than the costs of abating the amount of driving, thus having net disposable income gains. To obtain the support from such varied and diverse coalition would be highly desirable from a political standpoint, and would increase the chances of the program to move forward to its actual implementation.

Nonetheless, as with any other policy that arises from the need to internalize the costs of an externality, at first it will require all agents to incur into additional direct or indirect costs, such as acquiring a permit, stepping out of their comfort zone in order to shift mode, or letting go some travel comfort. In the case of a tradable driving permit system, the distribution of these costs might be highly unequal, particularly when no viable transport alternatives are readily available. Of special interest would be the lowest income families that would be forced to face these additional costs, since they would be disproportionally affected. In order to address these limitations, any tradable driving permit system should be enforced with a relatively lenient goal in terms of the number of allowed permits, to be tightened over the course of a long enough time period as to sufficiently reduce the accessibility differences across the city, until reaching the desired goal.

The initial permit allowance distribution would be determinant to reduce, and even eliminate any equity concern. One alternative would be grandfathering a significant proportion of permits, say 80%, where half of that percentage would be randomly allocated, and the other half would be allocated considering an index of geographical accessibility to alternative modes of transport, as well as the relative financial capacity of the typical family by geographical area. The remaining 20% would be auctioned and the revenues could be used to improve the public transport system and the non-motorized infrastructure. Of course, there is an infinite number of possible allocation combinations, thus a more in-depth study would be required to determine the specific figures. On all cases, and regardless of the source of the funding (revenues obtained via the auctions or public funds), the system must be accompanied by an infrastructure investment program for public transportation and non-motorized alternatives, aiming at having an equal accessibility and service quality throughout the city.

In terms of Moore's (1976) design considerations, this alternative is the strongest and possesses the highest level of viability. In the first place, it is the only one with the potential to actually create a supporting coalition that would be politically desirable, and that would balance the debate with other opposing groups. Secondly, the availability of technological instruments to implement the program would not be an issue since they already exist, however their social understanding and ability to use would potentially be a problem, particularly for police officers who would be the enforcement authorities. Therefore, a program of this complexity would require to be tested, preceded by a long period of socialization and training, similar to what Stockholm did to implement their congestion charge. Finally, the causal variables of road congestion and air pollution would be fully addressed, thus potentially providing a long-term comprehensive solution.

Each of the above-mentioned policy alternatives is capable of substantially reducing road congestion and air pollution; however, they all would require complementary programs in order to tackle the expected equity issues that would accompany them. All alternatives would require to improve the quality and coverage of the mass public transport system, but also to provide adequate infrastructure for non-motorized alternatives and short-distance commutes. Additionally, each alternative should go hand in hand with campaigns to raise awareness on the positive long-term effects of air quality, relief of road congestion and the overall people's wellbeing, as well as ongoing training for police officers and public servants.

One advantage of these alternatives is that they are capable of generating potentially large revenues, although with important variations among programs, which would provide resources to invest in public transport and non-motorized infrastructure. Additionally, considering that the expected gradual reduction in the overall amount of driving in the city would reduce the financial pressure to invest in new road-related infrastructure projects, as well as the pressure to maintain and update the existing infrastructure; a large batch of resources would be released, and could be used to further improve the public and non-motorized transportation systems. At the end, the aim of the chosen alternative should be to break and turn the current vicious circle of Induced Travel and *Hoy No Circula*, into a virtuous one, where individuals, based on their own values and abilities, decide which transportation mode is best for them, and whether they are willing to reduce their amount of driving, while generating the means to self-sustain the program. This would allow to transform the entire transportation system, and would substantially reduce pollution emissions and their impact on air quality, human health, and the overall quality of the city-wide urban ecosystem.

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CURRICULUM VITAE

Jose Alfonso Iracheta Carroll, PhD

Director General of Mexico National Institute of Sustainable Land
(*Instituto Nacional del Suelo Sustentable* -INSUS-)

Education

August 2011 to April 2020. PhD in Public Affairs. Specialized in Environmental Policy and Policy Analysis with a focus on metropolitan environmental policy. School of Public and Environmental Affairs –SPEA–, Indiana University, Bloomington, Indiana, USA.

February 2010 – December 2011. Sustainable Development, Master's Degree (candidate). Foro Latinoamericano de Ciencias Ambientales –FLACAM– (Latin American Forum of Environmental Sciences), La Plata, Argentina.

May 2007 – June 2009. Public Administration and Public Policy, Master's Degree. Centro de Investigación y Docencia Económicas –CIDE– (Center for Research and Teaching in Economics), Mexico City, Mexico.

August 1998 – December 2002. Economics, B.A. Graduated with honors (academic excellency). Universidad Iberoamericana campus Santa Fe (Ibero-American University), Mexico City, Mexico

Professional experience

December 2018 to date. Mexico National Institute of Sustainable Land Policy (Instituto Nacional del Suelo Sustentable -INSUS-), Mexico City, Mexico. Director General.

- Responsible for conducting Mexico's National Land Policy.
- Responsible for conducting Mexico's National Property Regularization Program.

August 2016 – September 2018. Centro Eure. Estudios Territoriales y Políticas Públicas (Eure Center. Land Studies and Public Policy), Lerma, Mexico. Public Policy Consultant / Project Manager.

- **2018.** UN-Habitat Mexico Office: Estimation of geographic, socioeconomic and housing indicators for the City Prosperity Index (CPI) for 186 urban municipalities in Mexico.
- **2017-2018.** Municipal Institute of Planning of Los Cabos, Mexico: Development of land policy instruments and a monitoring and evaluation system to assess the 2040 Urban Development Plan.
- **2017-2018.** Government of the State of Jalisco: Process evaluation of the Metropolitan Fund for Guadalajara and Ocotlan Metropolitan Areas
- **2017-2018.** Government of the State of Jalisco: Process evaluation of the Complementary Fund for Regional Development of Jalisco (FONDEREG).
- **2016-2017.** Centro Eure: Study about Smart Cities for Latin America. The project included an evaluation and certification instrument to qualify different aspects of "smartness" on cities decision making and achievements.

- **2016-2017.** Friedrich Ebert Stiftung: Study about the challenges of Latin America sustainable urban development considering all major metro areas. The study will conclude with the publication of one book, part of a series of studies regarding Latin America process of development.
- **2016.** UN-Habitat: Development of the City Prosperity Index for 17 cities of Saudi Arabia, this is chapter 5 for the UN-Habitat Saudi Arabia National Report.

January 2013 – July 2016. Centro Eure. Estudios Territoriales y Políticas Públicas (Eure Center. Land Studies and Public Policy), Lerma, Mexico. Public Policy Consultant / Advisor.

- **2014-2016.** UN-Habitat: Development of the City Prosperity Index for 136 cities of Mexico, quantitative analysis of underlying relationships between indicators, and formulation of the local and national reports.
- **2014-2015.** Mexico National Institute of Affordable Housing for the Workers (Instituto del Fondo Nacional de la Vivienda para los Trabajadores -INFONAVIT-): Development of an affordable housing deterioration indicators system, application on 36 selected housing developments, and development of the intervention proposal.
- **2013.** Mexico Department of Environment and Natural Resources (Secretaría de Medio Ambiente y Recursos Naturales -SEMARNAT-): Development of a metropolitan sustainable development indicators system for Mexican metropolis, and its methodology. The project included a literature review of all major current systems around the world, and the development of a proposal for Mexico.

May 2009 – August 2011. Centro Eure. Estudios Territoriales y Políticas Públicas (Eure Center. Land Studies and Public Policy), Lerma, Mexico. Public Policy Consultant / Project Manager.

- **2010-2011.** Mexico Department of the Treasury (Secretaría de Hacienda y Crédito Público -SHCP-) and Inter-American Development Bank: Evaluation of the objectives, operating rules and efficiency of the usage of resources of the Metropolitan and Regional federal funds.
- **2010-2011.** Metropolitan Commission of Merida, and Mexico National Council for Science and Technology (Consejo Nacional de Ciencia y Tecnología -CONACYT-): Formulation of the Metropolitan Program of Sustainable Development of Merida.
- **2011.** Government of the Municipality of Chimalhuacan, State of Mexico: Development of the land use, and economic development master plan of the Strategic Center for Environmental Recovery of Eastern Chimalhuacan.
- **2009-2010.** Government of the Municipality of Metepec, State of Mexico: Formulation of the land use policies, strategies and project proposals to manage water deficit, land use, and urban growth in Metepec (Metropolitan Area of Toluca).
- **2009-2010.** Government of the State of Hidalgo, Hidalgo: Formulation of the land use policies and strategies of the region of Tula for the construction of a petroleum refinery and a competitiveness cluster.
- **2009.** Municipal Institute of Planning of Leon, and Mexico Department of Social Development (Secretaría de Desarrollo Social -SEDESOL-), Mexico. Formulation of policy proposals to control peripheral urban growth and consolidation of the urban core in Leon, Guanajuato

April 2004 – July 2007. Universidad Autónoma del Estado de México –UAEM– (Autonomous University of the State of Mexico), Toluca, Mexico. Chair of the Programming Department.

- Responsible for the formulation of the Operative Annual Program (ISO 9001-2000 certified process) as well as reviewing and assessing the development plans of the schools and departments of the University under a methodology of Strategic Planning.

March 2004 – April 2004. Government of the State of Mexico, Mexico. Member of the organization committee for the Reunion of the Administration Council of the World Association of Large Metropolis and Tasks Commissions, Ixtapan de la Sal, Mexico.

October 2003 – March 2004. BBVA-Bancomer Bank. Market risks consultant. Responsible for the supervision and measurement of the market risk of a couple of the bank's portfolios, Mexico City, Mexico.

Research

2015 – 2019. School of Public and Environmental Affairs, Indiana University, Bloomington, Indiana, USA. PI: Jose A. Iracheta. Estimation of the Induced Travel phenomenon at the metropolitan level for Mexico City, Los Angeles and San Francisco.

2015 – 2019. School of Public and Environmental Affairs, Indiana University, Bloomington, Indiana, USA. PI: Jose A. Iracheta. Impact evaluation of the flagship air pollution control program in Mexico City (*Hoy No Circula*) for the time of the first implementation of the program (1989), and for the policy changes of 2014 and 2015.

2016 – 2017. School of Public and Environmental Affairs, Indiana University, Bloomington, Indiana, USA. PI: Jose A. Iracheta. Research on the environmental policy instrument choice for pollution control in the Lerma River, Mexico, which crosses the Metropolitan Area of Toluca, and provides a substantial percentage of drinking water for the Mexico City Metropolitan Area (in progress).

2014 – 2015. School of Public and Environmental Affairs, Indiana University, Bloomington, Indiana, USA. PI: Lisa Blomgren Amsler, and Jose A. Iracheta. Research on the effects of the conflict mediation processes in the USPS on perception of fairness by USPS employees using survey data (in progress).

2013 – 2014. School of Public and Environmental Affairs, Indiana University, Bloomington, Indiana, USA. PI: Prof. Douglas Noonan, Prof. Abdul-Akeem Sadiq, and Jose A. Iracheta. Research on how U.S. urban communities located in floodplain areas undertake preventive and corrective actions for flooding risks according to the incentives provided by FEMA´s Community Rating System program.

2012 – 2013. School of Public and Environmental Affairs, Indiana University, Bloomington, Indiana, USA. PI: Jose A. Iracheta. Research on metropolitan governance in Mexico. The research aims at analyzing the adequacy of the outcomes and decision-making process of sixteen metropolitan areas based on the differences of the corresponding institutional arrangements between them.

2012 – 2013. School of Public and Environmental Affairs, Indiana University, Bloomington, Indiana, USA. PI: Prof. Evan Ringquist. Research on identifying what characteristics predispose international environmental agreements (IEAs) to effectively address environmental problems based on a meta-evaluation of European IEAs.

2009. Centro de Investigación y Docencia Económicas –CIDE– (Center for Research and Teaching in Economics), Mexico City, Mexico. PI: Jose A. Iracheta. Research on the effects of crisis perception in the decision-making process applied to the case of the 2008 legal reform of the oil industry in Mexico. (Thesis for obtaining the degree of Master in Public Administration and Public Policy).

Publications

2016. UN-Habitat, Kenya. Ndugwa, Robert, Vigier, François, Iracheta, Jose A., and El-Sheik, Tarek**.** Report: Saudi Arabia National Report (in press).

2014. CLEAR, CIDE, IADB, SHCP, Centro Eure, El Colegio Mexiquense, Mexico. Iracheta, Alfonso X. and Iracheta, Jose A. Book: Evaluación de los Fondos Metropolitano y Regional del Gobierno Federal Mexicano (Evaluation of the Mexican Federal Metropolitan and Regional Funds).

Non-professional experience

January – May 2008. Centro de Investigación y Docencia Económicas –CIDE– (Center for Research and Teaching in Economics), Mexico City, Mexico. Policy analysis about the smoking forbiddance in non-vented public places in Mexico City.

August – December 2007. Centro de Investigación y Docencia Económicas –CIDE– (Center for Research and Teaching in Economics), Mexico City, Mexico. Policy analysis about the incentive program for commercial forest plantations of the National Forest Commission (CONAFOR).

October 2001. Universidad Iberoamericana campus Santa Fe (Ibero-American University), Mexico City, Mexico. Chairman of the Organization Committee of the XXVI Economics Seminar (elective office).

August – December 1999. Universidad Iberoamericana campus Santa Fe (Ibero-American University), Mexico City, Mexico. Academic assistant for the course of Econometrics II

Fellowships and awards

August 2011 – 2014. Fulbright-Garcia Robles scholarship for the PhD program in Public Affairs.

August 2011 – 2013. Indiana University tuition and fees waiver for the PhD program in Public Affairs.

August 2011 – 2015. Central Bank of Mexico Fund for the Development of Human Resources (FIDERH) student loan for the PhD program in Public Affairs.

February 2010. Latin American Forum for Environmental Sciences scholarship for the Master in Sustainable Development Program.

May 2007 – June 2009. Mexican National Science and Technology Council (CONACYT) fellowship for the Master in Public Administration and Public Policy program.

Activism and professional organizations

August 2014 to date. Latin America Policy Association (LAPA), Bloomington, Indiana, USA. Founding member.

2014 to date. Association for Public Policy Analysis and Management (APPAM). Member.

August 2013 – August 2014. Association of SPEA PhD Students (ASPS), Bloomington, Indiana, USA. Board member. Chair of the 2014 ASPS Conference.

August 2010 to date. Foropolis, Mexico City, Mexico. Founding member. Foropolis is a policy network focused in Urban Sustainable Development. It´s objective is to summon Mexican specialists to dialogue with public authorities of all levels, to propose supported alternatives and to effectively impact the decision-making process about Mexico´s Urban Development.

August 2008 to date. Tlaloc Foundation, Toluca, Mexico. Activist and project leader. Active participant in varied initiatives and leader of a project looking for the foundation of a Sustainability Policy network in the region of the Metropolitan Area of Toluca.

March 2001 – April 2002. Universidad Iberoamericana campus Santa Fe (Ibero-American University), Mexico City, Mexico. President of the Students Association of Economics (elective office).

March 2001 – April 2002. Universidad Iberoamericana campus Santa Fe (Ibero-American University), Mexico City, Mexico. Member of the Students Representatives Council (elective office).

May – August 2000. Kfar-Hanassi Kibbutz, Israel. Volunteer for community work.

Languages

Spanish (native language).

English (advanced).

French (beginner).

Software

Microsoft Office (advanced).

Stata (intermediate).

SAS (intermediate).

ArcGIS (beginner).

Hobbies

Interpretation of music (piano, drums, guitar and bagpipes).

Literature and writing.

Filmmaking.

Indoors rowing, rock climbing, jogging, and football (soccer).