The Effectiveness of Temporary Driving Restrictions: Evidence from Air Pollution, Vehicle Flows, and Mass-Transit Users in Santiago

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Abstract

Driving restrictions are common strategies to curb local air pollution in many developing countries. In this study, I use high frequency data on air pollution, vehicle flows, and users of mass-transit systems to evaluate the effectiveness of strengthening short-term driving restrictions in Santiago, Chile. Every winter in Santiago, a permanent driving restriction bans light vehicles from driving during specific days of the week. This base restriction is complemented with short-term bans triggered with the official announcement of environmental episodes on days of critical air pollution. I take advantage of the discontinuity in the air quality indexes used to announce these episodes to estimate the causal effect of these incidences and their bans on pollution. For identification, I employ a fuzzy regression discontinuity design that uses the thresholds in the air quality indexes as instruments of the episodes' announcement. The use of high frequency data on traffic flows and users of mass-transit systems allows me to isolate the impacts of short-term driving restrictions from other abatement actions on air pollution also triggered by these episodes that do not necessarily affect mobile source emissions.

Keywords: Driving Restriction, Air Pollution, Pollution Alerts.
JEL Classification: Q52, Q53, R41

1. Introduction

Airborne pollution is a main concern in major cities of developing countries (Greenstone and Hanna, 2014; Greenstone and Jack, 2015). The lack of adequate access to basic health care makes individuals in these nations particularly vulnerable to environmental contamination (Bell et al., 2006), leading to significant costs on both human health and productivity (Greenstone and Jack, 2015). In Latin America, poor air quality put at risk the health of more than 80 million inhabitants generating annual losses of about 65 million working days (Programme, 2002). Among countries in the region, Chile ranks second only after Mexico in exposure of urban areas to PM_{10}, and first in exposure to $PM_{2.5}$, with Santiago as one of the most contaminated cities in this country (WHO, 2014). Concentrations of particulate matter in Santiago are related to a 0.6% rise in daily mortality from respiratory causes, and to a 4,000 annual deaths from long-term exposure to this type of pollution (OECD, 2005).

Poor air quality in Santiago is primarily due to mobile source pollution. Emissions from mobile sources in this city account for 60-95% of total emissions for pollutants such as nitrogen oxides (NO_X, generic term for nitrogen oxide (NO) and nitrogen dioxide (NO_2) that in combination with sunlight produce the formation of ground-level ozone (O_3)), fine particulate matter ($PM_{2.5}$), coarse particulate matter (PM_{10}), carbon monoxide (CO), and sulfur dioxide (SO_2).[1] These emissions are intensified as the average age of vehicles on the road increases, or as the city expands beyond public transit's capacity, augmenting the needs of private transportation. Over the last decade, the number of vehicles driving in Santiago increased by 78%, with light-duty vehicles standing for 72% of that increase.[2]

In this study, I evaluate Santiago's main policy aimed at reducing emissions from mobile sources during days of critical air contamination. Starting in 1990, a permanent driving restriction based on cars' license plates began prohibiting light-duty vehicles without a cat-

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[1] Data from the Register on Pollutant Release and Transfer (Registro de Emisiones y Transferencias de Contaminantes - RETC).

[2] Information from the Annual Reports on Road Vehicles (Anuario del Parque Vehicular de Vehículos en Circulación) for 2005 and 2015, available at the National Institute of Statistics (INE)'s website.

alytic converter -without a *green sticker* (hereafter dirty vehicles)- from driving from 7:30am to 9:00pm on winter weekdays. This base restriction is complemented with temporary driving bans on all light-duty vehicles -including vehicles with a *green sticker* (hereafter clean vehicles)- depending on the severity of airborne contamination.[3,4] These short-term driving bans are part of a 24-hour set of preventive measures called *environmental episodes* activated in Santiago whenever the authorities foresee high levels of the Air Quality Index for Particulates (ICAP) in the city. Different ICAP thresholds lead to a three-tier system of episodes (i.e. alert, pre-emergency, and emergency) whose temporary driving bans may add two or four more digits to the dirty vehicles restriction, and impose up to a six-digit restriction on clean vehicles.

I take advantage of the exogenous variation in the issuance of these episodes to empirically evaluate the effectiveness of these incidences -and their short-term driving restrictions- in curbing Santiago's airborne pollution. Whether mobile source pollution is reduced in this city is analyzed using hourly ambient concentrations from 2000 to 2015 on four major pollutants from mobile sources: PM_{10}, $PM_{2.5}$, CO, and NO_X. Effective driving bans reduce mobile source pollution by getting cars off the roads and pushing their drivers towards cleaner forms of transportation. This study delves into this idea by using evidence on urban transit flows. I particularly look at the number of vehicle trips recorded by counting stations in Santiago between 2004 and 2015, and at the number of trips taken in Santiago's mass-

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[3] A *green sticker* is a mandatory self-adhesive sticker added to the windshields of all fuel-efficient vehicles (e.g. eco-diesel, electric cars, etc.), and vehicles with catalytic converters, which certifies vehicles' compliance with the emission standards needed to drive in Santiago's Metropolitan Region. Vehicles earning a *green sticker* are brand new vehicles sold after September 1st, 1992 and emitting less than $0.25 g/km$ of hydrocarbons, less than $2.11 g/km$ of CO, less than $0.62 g/km$ of NO_X, and less than $0.125 g/km$ of particulate matter. Drivers obtain these stickers when getting their vehicle permits, issued after annual mandatory cars inspections that certify their gas emissions. During 2005, 30% of Santiago's vehicles were classified as dirty vehicles, and responsible for 54% and 24% of CO and PM_{10} emissions from mobile sources, respectively (Atal, 2009). Since then, however, the number of dirty vehicles has dropped dramatically. Previous calculations in 2015 numbers reveal that dirty vehicles are responsible for approximately 3.6% of current CO and 1.6% of current PM_{10} emissions from mobile sources.

[4] A long-term restriction only on dirty vehicles might have significant impacts on fleet turnover. Barahona et al. (2016) show that Santiago's permanent driving restriction pushes the city's vehicle composition toward vehicles with a green sticker that are not affected by this policy. Indeed, 56% of 2001 registered cars in Santiago had a *green sticker*. These cars represent now 98% of registered cars in the city (INE, 2015).

transit system which includes subway trips between 2000 and 2015, and transit buses trips between 2007 and 2015. The use of hourly data on urban transit flows allows me to isolate the effects of short-term driving restrictions from other abatement actions also triggered by the episodes, which do not necessarily affect pollution from mobile sources. The empirical analysis of driving restriction using evidence on urban transit flows constitute one of the main contributions of this study.

To identify the effects, I develop on the form of random variation in the data in a fuzzy regression discontinuity (RD) approach that uses the ICAP index as the running variable. The RD identification design exploits the knowledge of the arbitrary ICAP cutoffs that determine three different episodes, which I pool together to evaluate the overall effectiveness of these treatments. Local FRD designs and flexible polynomial trends for the main equation are specified and estimated through a GMM procedure that considers the serial correlation in the data. Weather variables, and several fixed effects are used to control for confounding factors. The time span between the issuance of an episode and the beginning of driving bans allows me to rule out the possibility of unobservables simultaneously affecting both the forcing and the outcome variable.

Preliminary findings show that temporary driving restrictions effectively push drivers off the roads, although with small effects on pollution. Results from a pooling fuzzy RD with a flexible polynomial approach reveal that the issuance of an episode decreases CO concentrations in around 46-56%. Similar effects are also found for other pollutants, although these results are not statistically different from zero. Results for urban transit flows suggest that the episodes' announcement decrease the number of vehicle trips in around 17-19%. No effects are found, however, for mass-transit ridership, which suggest that air quality episodes not only keep drivers off the roads, but also people off the streets.

This study contributes to the ongoing discussion on the effectiveness of driving bans at curbing mobile source pollution. Driving restrictions are a common governmental strategy to reduce airborne pollution and traffic congestion in major cities of Latin America (e.g.

Bogota, Mexico City, San Jose, Sao Paulo, Quito), Asia (e.g. Beijing, Tianjin, New Delhi), and Europe (e.g. Milan, Athens, Berlin). Mixed findings on their causal impacts, however, still raise concerns about their effectiveness either because of the shifting of driving towards hours -or days- not affected by these policies, or because of the purchasing of a second car to fully avoid the restriction. Eskeland and Feyzioglu (1997) highlight the failure of Mexico City's Hoy No Circula (HNC) driving restriction program by showing an increase in total driving since HNC's implementation. Davis (2008) reinforces this conclusion showing both a shift in traffic towards non-rush hours and an increase in the total number of vehicles, particularly high-emission vehicles in circulation.[5] Similar conclusions are in Zhang et al. (2017) for Bogota's driving restriction plan where the authors find that the policy might increase air pollution. Yet, many other studies highlight the success of driving bans in improving air quality. Analyzing Quito's Pico y Placa (PyP) program, Carrillo et al. (2016) find that driving bans reduce CO concentrations by 9-11%, and in contrast with studies on HNC, the authors find no evidence of shifts in traffic towards off-peak hours. Similar conclusions are in Viard and Fu (2015) for Beijing's driving restriction program where the authors report an 18% and a 21% reductions in particulate matter due to every-other-day and one-day-a-week restrictions in this city, respectively. Positive effects for Beijing's policies are also found by Chen et al. (2013) for the particular case of short-term driving restrictions in place during the 2008 Olympic games. Finally, Wolff (2014) attributes a 9% emission reduction to the low-emission zones (LEZ) program in Germany emphasizing the program's efficacy. This paper complements this discussion by providing empirical evidence on Santiago's temporary driving restriction and its effects on mobile source pollution and urban transit flows, helping therefore to unravel substitution patterns of drivers affected by

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[5] Davis (2008) empirical strategy considers a RD design in time around the HNC's implementation. Salas (2010) revisits Davis' (2008) estimations and finds that both the sign and significance of the HNC impacts are highly sensitive to the time window and the length of the time trend polynomial of the RD specification. Particularly, smaller time windows around the HNC implementation reveal positive and significant effects of the program on several air pollutants, unveiling a potential distinction between short-term and long-term drivers' adaptation behaviors to this policy. However, the order of the time trend polynomial used to control for time-varying factors affecting pollution levels compromises all HNC's significant impacts.

this policy. In doing so, this work represents one of the few studies on driving restrictions that simultaneously reviews data on air pollution, traffic flows, and users of mass-transit systems.

This paper also builds on previous studies on Santiago's environmental episodes. Prior studies highlight the effectiveness that these warnings have in either reducing air pollution (Atal, 2009; Troncoso et al., 2012; Mullins and Bharadwaj, 2015), or in discouraging the use of private cars in the city (de Grange and Troncoso, 2011). However, most of them fail to prioritize causal inference to estimate the impacts of short-term driving restrictions on air pollution. [6] This work fills in this gap by evaluating the causal impacts that several reinforcements to these short-term driving bans generate on several pollutants.

The plan of this paper is laid out as follows. Section 2 provides background details on the permanent and the temporary driving restriction schemes used in Santiago, and on the specifics of the air quality episodes. Section 3 presents the data and section 4 describes the empirical strategy and the preliminary impacts on the outcome variables.

2. Background Information

The severity of air contamination has motivated several mitigation actions to improve air quality in Chile, especially in the metropolitan area of Santiago -home of almost half of the country's population. Santiago locates in the central part of Chile, in a basin surrounded by the mountains with an altitude that ranges between 1,500 and 4,500m. These mountains prevent strong winds formation, which in combination with thermal inversions decrease the dispersion of pollutants, particularly during winter months i.e. from April to August (WHO, 2006). Figure 1 exhibits the hourly average ambient concentrations of both heavy (PM_{10})

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[6] de Grange and Troncoso (2011) estimate the daily percentage difference in the conditional expectation of urban flows between days with and without a pre-emergency episode. A similar approach is taken in Troncoso et al. (2012) for air pollution. An exception is Mullins and Bharadwaj (2015) who use a successful strategy to identify causal effects of environmental episodes on heavy particulate matter concentrations. Yet their estimations do not disentangle the effects of temporary driving restrictions from other actions also triggered by these episodes.

and fine ($PM_{2.5}$) particulate matter during the summer and winter seasons, obtained from the Air Quality Information System (Sistema de Información de Calidad del Aire -SINCA), a Ministry of Environment's division (Ministerio de Medio Ambiente -MMA) in Chile. Over summer months, both PM_{10} and $PM_{2.5}$ concentrations peak daily at 8:00am, time after which they decrease steadily throughout the end of the day. It is during winter, however, that daily concentrations of particulate matter peak not only at 8:00am but also around 8:00-9:00pm due to the thermal inversion process that during this time of the year controls the air exchange in the city reducing the diffusion of air pollutants.

During the late 80s and early 90s, the Special Decontamination Commission of the Metropolitan Region and the Air Pollution Prevention and Clean-up Plan (PPDA) introduced several actions aimed at targeting emissions from both stationary and mobile sources in Santiago (OECD, 2005). Concretely, the PPDA targets emissions from stationary sources through the setting of emission standards, tradable permits, and emissions taxes, while mobile source pollution is addressed through the Critical Episodes Management (Gestión de Episodios Críticos -GEC) program that establishes permanent and temporary driving restrictions on private cars. These driving bans -based on the last digits of vehicles' license plates- prohibit the use of light-duty vehicles during winter days between April 1st and August 31st. The permanent restriction, fully in operation since 1990, affects dirty vehicles driving in Santiago during weekdays from 7:30am to 9:00pm.[7,8] This restriction is complemented since 1997 with short-term bans on both dirty and clean vehicles that are activated whenever meteorological conditions prevent the dispersion of pollutants in Santiago leading to extreme air quality conditions that exceed the PPDA tolerable ceilings.[9] When this is true, the PPDA considers the issuance of a 24-hour air quality episode, also called environmental episode, intended to both recommend the avoidance of human exposure to outdoor

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[7] I use *permanent restriction* and *seasonal restriction* interchangeably throughout.

[8] Specifically, driving bans affect cars circulating in Santiago's province plus cars driving in Puente Alto and San Bernardo *communes*. In total, 34 communes are affected by these bans. Santiago's metropolitan area is administratively divided in 6 provinces and 52 communes.

[9] Despite these short-term actions were established by the PPDA during the early 90s, their full enforcement did not start until 1997 (Mullins and Bharadwaj, 2015).

pollution, and activate the set of short-term abatement actions including additional driving restrictions.

Since the PPDA creation, air quality in Santiago has shown an improvement in terms of particulate pollution. Figure 2 displays Santiago's daily PM_{10} (panel a) $PM_{2.5}$ (panel b), along with CO (panel c), and NO_X (panel d) concentrations since the start of the PPDA enforcement (when available). Panels a and c of figure 2 show a decreasing pattern over time in terms of both PM_{10} and CO concentrations, respectively. Concentrations of $PM_{2.5}$ and NO_X concentrations, however, have remained stable over time, probably due to the rapid urban growth of this city during the last 30 years (Romero et al., 1999). This situation complicates anticipating the effectiveness of the PPDA in terms of reduced emissions in general, especially when annual average concentrations for particulate matter in Santiago are still well above the WHO guideline levels of 20 micrograms per cubic meter ($\mu g/m^3$).

2.1 Environmental Episodes

The air quality episodes' issuance is based on a daily forecasting system of Santiago's particulate matter concentrations used by the MMA since 2000. This forecasting model, called the *Cassmassi* model, consists in a set of linear equations -one per station- that weight patterns of particle concentrations together with 24-hour forecasts of a categorical variable associated with meteorological features linked to atmospheric stability in the city (i.e. the Meteorological Potential of Atmospheric Pollution Index - PMCA) (Saide et al., 2011). From these equations, the authorities get 24-hour moving average predictions of expected PM_{10} and $PM_{2.5}$ concentrations in Santiago for the next day (Perez, 2008; Salini, 2009).[10] An example of the weights used by the *Cassmassi* model in the prediction of 24-hour PM10 concentrations is displayed in Appendix A for the *Pudahuel* station -the station that generally records the highest levels of particle concentrations in the city.

Outputs from the *Cassmassi* model correlates with the Air Quality Index from Partic-

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[10] Predictions of 24-hour $PM_{2.5}$ concentrations did not start until 2011.

ulates (ICAP), inspired by the former US EPA Air Quality Index and created to easily correlate different levels of pollutants on the same scale. This index transforms measures of either PM_{10} or $\mathrm{PM}_{2.5}$ into a convenient and comparable scale, so that the higher the ICAP value the greater the particulate concentration, and so the health concern. Levels reached by this index are considered in the issuance of air quality episodes, which based on different thresholds lead to a three-tier label system of air quality events (i.e. alert, pre-emergency, and emergency). When ICAP values exceed these thresholds in at least one of the SINCA's monitoring stations, the Environment Superintendent (Superintendencia del Medio Ambiente -SMA) recommends Santiago's mayor to issue an episode for the next day starting at 0:00am. These official air quality forecast reports take place every winter day at 8:00pm. The episodes' announcement goes through evening newspapers, the SMA's official website, smartphone apps, newscast TV, and radio shows airing between 9:00pm and 0:00am.

Table 1 displays ICAP thresholds for both PM_{10}- and $\mathrm{PM}_{2.5}$-based index, their 24-hour average particulate matter correlations, and the corresponding episode. Forecast of good air quality are equivalent to ICAP values below 100, while predictions of regular air conditions relate to ICAP values between 100-199. Air quality episodes are announced whenever ICAP values reach the 200-threshold. The mildest episode called *alert* is announced whenever the ICAP is between 200-299, which is equivalent to 195-239$\mu g/m^3$ PM_{10} concentrations, or to 80-109$\mu g/m^3$ $\mathrm{PM}_{2.5}$ concentrations. The 300-threshold leads to an environmental *pre-emergency* that is called for ICAP values between 300-499, equivalent to 240-329$\mu g/m^3$ PM_{10} concentrations, or 110-169$\mu g/m^3$ $\mathrm{PM}_{2.5}$ concentrations; while the 500-threshold leads to an environmental *emergency* with ICAP values equivalent to PM_{10} concentrations $\geq 330\mu g/m^3$, or $\mathrm{PM}_{2.5}$ concentrations $\geq 170\mu g/m^3$.

Despite the description by official reports of the air quality index as the key variable for the episodes' issuance, some evidence highlights the possibility that other parameters will also be playing a role in this process. As stated by Saide et al. (2011), this decision might sometimes involve experienced air quality forecasters, and in some cases it might merely be a political decision. The possibility that the ICAP indexes might not be the only variables considered for the episodes' announcement is relevant for the empirical design, as these indexes might be affecting the probability of declaring an air quality episode instead of actually triggering its issuance. How this distinction affects the empirical design is explained in section 4.

2.2 Temporary Driving Restrictions

Air quality episodes in Santiago trigger several short-term abatement actions that affect emissions from both stationary and mobile sources, and whose severity varies according to the type of episode declared. Emissions from stationary sources are in general addressed with shutdowns of industrial facilities and with the prohibition of wood burning stoves, while emissions from mobile sources are targeted with temporary driving bans aimed at complementing the permanent restriction. A detailed description of the actions triggered by these episodes is in table B1 of Appendix B.

In order to match the permanent ban, short-term restrictions ban cars off the roads between 7:30am and 9:00pm. These bans vary by day of the week, and depending on the air quality episode in place, they can also affect clean cars. Table 2 summarizes the different versions of these bans applied in Chile since 1990, along with the number of digits and the type of cars affected. Originally, the permanent restriction was a 2-digit policy on dirty cars affecting thus 20% of them. This policy was tightened up in 2008 with the addition of two more digits leading to a 40% of dirty cars daily banned from driving.[11] Clean cars are instead curtailed only by temporary bans. Particularly, air quality alerts extend the 2-digit permanent restriction on dirty vehicles to Saturdays and Sundays. Air quality pre-emergencies add two more digits to the ban on dirty cars, and impose a 2-digit restriction on clean vehicles, during both weekdays and weekends. Finally, air quality emergencies trigger an 8-digit restriction on dirty vehicles, and impose a 4-digit restriction on clean cars.

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[11] So far, clean cars are not affected by the permanent restriction. Yet, current plans consider a permanent ban on clean cars starting in 2018.

The implementation of these restrictions requires planning ahead the numbers banned from driving for a full year (see table B2 in Appendix B for a 2016 example). The enforcement of these bans is a national police force task, which increasing vehicle inspections during days with episodes. Penalties for violations include fines between US$70 and US$150, together with driving license suspensions (de Grange and Troncoso, 2011).[12] In the rest of this work, I explore the data and the empirical strategy to address whether short-term driving restrictions effectively contribute to reduce the number of cars in circulation and so mobile source emissions.

3. Data

3.1 Environmental Episodes

The empirical analysis in this work considers historical information on air quality episodes issued in Santiago from the Operative Unit of Traffic Control (Unidad Operativa de Control de Tránsito -UOCT). Since 1997, a total of 473 episodes have been declared in the city, averaging to 26 episodes per year (see table 3). Nevertheless, given the availability of air pollution data, this study only uses episodes issued between 2000 and 2015, which add up to 397 episodes available. Among these, air quality alerts are the most common episode with a total of 318 issuances, followed by pre-emergencies with 78 issuances. Air quality emergencies are, however, a rare event -only 1 emergencies declared since 2000.

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[12] The 2016 GEC report from the MMA indicates that 5,578 vehicles were ticketed for driving restriction violations during morning rush hours in 2016. Most these violations occurred during June and July, months during which 16 air quality pre-emergencies and 1 emergency were issued. The same report indicates that only a 0.3% of these violations (3 tickets) correspond to violations of the permanent driving restriction. According to Atal (2009), vehicles' inspections are significantly visible in the city during air quality pre-emergencies.

3.2 Air Pollution and Weather Variables

Hourly data on air pollution from vehicle emissions comes from the network of monitoring stations located in Santiago's metropolitan area, SINCA. This network has 11 stations continuously tracking air quality and weather conditions in the city. Figure B1 (Appendix B) shows the spatial location of these stations (red dots). Daily commuting flows in the area move from suburban belts towards the region's center, which allows these stations to read pollution records from most of the daily economic activity taking place in the region. I particularly look at ambient concentrations of PM_{10}, $PM_{2.5}$, CO, and NO_X. Particulate matter concentrations are important to study as the calling of air quality episodes is exclusively based on these records, while CO and NOX concentrations are used as they constitute the main pollutants from light-duty vehicles.[13] As driving restrictions are in place in 34 out of the 52 communes in Santiago's metropolitan region, I only use the readings of 10 stations located in the affected area (highlighted area in figure B1). Descriptive statistics for these variables and so years with available information are depicted in table 4 (panel A).

Weather information comes from two main sources. I gather hourly information on humidity and wind speed from 10 stations of the SINCA network, which I complement with data on Santiago's daily precipitations and temperature from the National Oceanic and Atmospheric Administration (NOAA). Descriptive statistics for these variables are also displayed in table 4 (panel B).

Values for 24-hour average and 24-hour maximum particulate matter concentrations during summer and winter days, with and without episodes are displayed in table 5. As expected, average and maximum both PM10 and PM2.5 concentrations are substantially lower during summer, and during days without air quality episodes relative to days with extreme events. Average particulate matter concentrations of 24-hour reach $56.866\mu g/m^3$ during summer days and $78.727\mu g/m^3$ during winter days without episodes for PM_{10}, and $21.798\mu g/m^3$ and

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[13] The transportation sector is also a main responsible of volatile organic compounds (VOCs) emissions. However, data availability prevents the use of this pollutant in this work.

$38.142 \mu g/m^3$ respectively for $PM_{2.5}$. These concentrations increase steadily for days with episodes. A similar situation occurs for 24-hour maximum concentrations. Values displayed in table 5 reflect first the critical situation of air contamination in Santiago, as particulate pollution reaches levels far above the WHO guidelines of $50 \mu g/m^3$ and $25 \mu g/m^3$ 24-hour mean for heavy and fine particulate matter respectively; and second, consistently indicate higher records of pollution in this city during days with episodes.

3.3 Index of Air Quality from Particulates (ICAP)

Information on daily values for the Index of Air Quality from Particulates (ICAP) for both PM_{10} and $PM_{2.5}$ is provided by the MMA at the station level for 2000 to 2015. From this information, I construct daily maximum ICAP values for both pollutants as the calling of episodes occurs whenever values for these indexes reach levels above regular air quality conditions in at least one of the reading stations. Additional specifications may include ICAP values recorded at the station with the highest records, or daily averages when including more than one station with the higher records.

A relationship between the time series of daily max ICAP values (based on PM_{10} and $PM_{2.5}$) and the episodes' issuance during winter 2015 is depicted in figure 7. Dashed lines are drawn to depict the different ICAP-thresholds considered for the episodes' issuance, while days with air quality episodes are shown in colors. According to the GEC program, days before an episode are expected to show daily max ICAP values above the 200-threshold for at least one of the two indexes. This, however, is not always the case. Days with an air quality episode preceded for days with daily max ICAP values below the 200-threshold reflect at some extent the discretion embedded in this issuance. This situation affects the empirical strategy chosen to evaluate the impact of this issuance. More details are provided in the next section.

3.4 Urban Flows

Three different datasets on urban flows are gathered in this study. The first one is obtained from the UOCT and consists in hourly readings on vehicle trips from 2004 to 2015 captured by several traffic-control stations located in Santiago. These traffic-control stations are counting stations connected to Santiago's road network placed under some of the main roads of the city. Despite these counting stations are not capable of distinguishing between either public and private transportation, or between light-, medium-, and heavy-duty vehicles, their counting represents a good proxy on car use whenever unobservable factors affecting this counting occur at random.

A second dataset comes from Metro S.A. and contains hourly information on subway trips taken between 2000 and 2015. Santiago's subway consists of 5 lines with an extension of 103km operating daily from 5:30am to 0:00am during weekdays, from 6:30am to 0:00am during Saturdays, and from 8:00am to 0:00am during Sundays and holidays. Daily average ridership in Santiago's subway add to more than 1,750,000 trips since 2007, year in which Santiago's bus rapid transit system -called *Transantiago*- started operations. Transantiago policy was aimed to persuade drivers off the roads by improving the quality of the city's public transportation. However, its results were the exact opposite due to inexactitudes in routes designs and in buses schedules that increased commuting times across the city pushing public buses users towards the subway instead. Before 2007, daily average ridership in this city was around 640,000 trips. Daily trips taken in Transantiago from 2007 to 2015 constitute the third dataset considered here and obtained from the Ministry of Transportation and Telecommunications (MTT). Table 6 displays the descriptive statistics for these variables along with the number of observations, and the years covered.[14]

Driving restrictions that work get drivers off the roads and push them towards cleaner forms of transportation. Thus, mass-transit systems ridership is expected to increase during days with air quality episodes. To have a sense of this effect, table 5 displays 24-hour aver-

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[14] Similar datasets are used in de Grange and Troncoso (2011) but for 2008 only.

age and maximum trips by transportation mode during summer and winter days, with and without episodes. Consistently with effective temporary bans, average vehicle trips decrease during days with air quality episodes. Similarly, subway trips increase during days with air quality alerts, although they decrease during days with pre-emergencies. A similar pattern is observed for transit buses trips. At first, this pattern in mass-transit systems ridership can be explained by individuals responding positively to the authorities' recommendations of avoiding outdoor exposure during days with episodes. As air quality alerts are a common episode, individuals may be sensitive to these recommendations for air quality pre-emergencies only. In this case, the average mass-transit ridership is expected to decrease during air quality pre-emergencies. Air quality emergencies, instead, might reverse this situation given the severity of their bans. In any case, the number of air quality emergencies during the period of analysis is limited to only one observation, which prevents more accurate conclusion.

4. The Effects of Short-Term Driving Restrictions

4.1 Empirical Model

This study addresses the overall effectiveness of temporary driving restrictions in keeping drivers off the roads. These short-term bans are triggered by the announcement of environmental episodes whenever authorities predict high levels of pollution measured by the ICAP indexes. A natural quasi-experimental mechanism to empirically exploit this feature is to use a sharp regression discontinuity (SRD) design that exploits the discontinuity embedded in the different cutoffs of this index used to call an episode, and relies on the standard smoothness assumptions of pollution and urban flows during days with no episodes. However, due to the authorities' discretion embedded in the episodes' issuance (see section 2), the calling cannot be defined as deterministic function of ICAP values, meaning that the issuance's probability jumps not necessarily from 0 to 1 at the ICAP cutoffs. This situation makes a SRD design an unpractical option as other variables might also affect the treatment assignment. Yet, ICAP values might still affect the conditional expected value of treatment, in which case is it possible to exploit the discontinuity on the conditional probability of treatment by means of a fuzzy regression discontinuity (FRD) design, feasible whenever the incentives to treat change discontinuously at the threshold (Imbens and Lemieux, 2008). As a result, the discontinuity becomes an instrument for the episodes issuance instead of deterministically calling for it (Angrist and Pischke, 2008).

Despite Santiago's policy considers three different air quality episodes, much of the historical episodes issued correspond to the mildest one: an alert. Due to this situation, the empirical strategy considers a pooling FRD aimed at increasing the statistical power of the RD design. A pooling FRD normalizes the running variable so that the cutoff is zero for all the days with values above regular air quality conditions. Let T_t be a random variable representing the treatment of interest during day t. In the pooling FRD, the treatment of interest is defined as whether there is an episode called during day t, regardless of the type of episode. Using this definition, the probability of calling an episode is defined to jump as follows:

$$P(T_t = 1|\bar{x}_{t-1}) = \begin{cases} g_1(\bar{x}_{t-1}) & \text{if } \bar{x}_{t-1} \geq 0 \\ g_0(\bar{x}_{t-1}) & \text{otherwise.} \end{cases}$$

where $g(\cdot)$ is any function with $g_1(0) \geq g_0(0)$, and $\bar{x}_{t-1}$ is the ICAP variable during day $t-1$ normalized as follows:

$$\bar{x}_{t-1} = x_{t-1} - 200. \tag{1}$$

Using this normalization of the ICAP index, is easy to see that days with ICAP values equal or higher than 0 are more likely to have an environmental episode.[15] The FRD leads to a two-stage estimation where running variable, $\bar{x}_{t-1}$, is used as an instrument for the

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[15] As the episodes are called only during winter, equation 1 can also be complemented with a dummy variable for the respective season. In other words, the conditional probability of having an episode is defined as $g_1(\bar{x}_{t-1})$ if $\bar{x}_{t-1} \geq 0$ and $t-1$ is a winter day.

episodes' announcement. The equation relating the episodes' announcement and $\bar{x}_{t-1}$ is:

$$T_t = \alpha_0 + \alpha_1 D_{t-1} + \sum_{j=1}^{p} \gamma_{lj} \bar{x}_{t-1}^{j} + \sum_{j=1}^{p} \gamma_{rj} [D_{r,t-1} \times \bar{x}_{t-1}]^{j} + \mathbf{X}_t \delta + \nu_t \tag{2}$$

where T_t is equal to one if an episode was announced on day t, and zero otherwise; D_{t-1} is an indicator variable taking one for values $\bar{x}_{t-1} \geq 0$, and zero otherwise; p indicates the order of a polynomial fit; $\mathbf{X}_t$ is a vector of covariates including humidity, temperature, precipitation, wind speed, and dummies for year, month and day-of-the-week (dow); and ν_t is an error term. Subscripts l and r identify coefficients predicting the relationship between the ICAP variable and the treatment below and above the 200 threshold, respectively. The coefficient on D_{t-1}, α_1, indicates the discontinuity in the episodes' announcement at the threshold.

Fitting a similar structure on the outcome variables, the second-stage estimation equation takes the following form:

$$y_t = \beta_0 + \beta_1 T_{t-1} \sum_{j=1}^{p} \eta_{lj} \bar{x}_{t-1}^{j} + \sum_{j=1}^{p} \eta_{rj} [T_{r,t-1} \times \bar{x}_{t-1}]^{j} + \mathbf{X}_t \zeta + \epsilon_t \tag{3}$$

where y_t is the log of the outcome of interest (i.e. air pollution, or urban flows) during day t; and ϵ_t is an error term. Under the assumption that the discontinuity in 2 induces the discontinuity in 3, the episode impact is defined as:

$$\tau = \frac{\beta_1}{\alpha_1}. \tag{4}$$

Given the time series characteristics of the outcome variables, equations 2 and 3 are fitted using a GMM procedure that accounts for potential serial correlation in the data. Moreover, as the issuance of episodes is not only based on the ICAP index on PM_{10} but also on the ICAP index on $PM_{2.5}$, this last index is used as an additional instrument in equation 2. Finally, for outcome variables on air pollution, equation 3 will also include one lag of the response variable to control for pollutants persistence (Gibson and Carnovale, 2015).

4.2 Preliminary: Pooling Fuzzy Regression Discontinuity Results

As a manner of observing the relationship between the running variable and the different outcomes, figure 4 and figure 5 present a sharp discontinuity fit using a local polynomial approach on air pollution and urban traffic flows respectively. In terms of air pollution, figure 4 suggests the existence of a sharp drop for all the pollutants after the zero threshold, with higher drops for CO and NO_X. In terms of urban flows, figure 5 suggests the existence of a similar effect on vehicle trips, and on mass-transit trips -although not as strong as in the first case. A negative jump on air pollution and vehicle trips around the cutoff is consistent with air quality episodes being an effective policy to curb mobile source emissions, while a similar jump in mass-transit trips after the zero cutoff suggests the possibility that individuals decide to stay at home during air quality warnings.

Table 8 and 9 depict the results for the estimated episodes impact on daily average pollution and urban transit flows respectively using a fuzzy RD design with a flexible polynomial fit. Each of the columns represent different specifications. Richer specifications in table 8 suggest that the issuance of air quality episodes generates negative impacts on CO concentrations only. The issuance of episodes decreases CO daily concentrations in around 46-56%. There is some evidence of a negative impact of air quality episodes on other pollutants, although these findings are not statistically different from zero.

Instead, findings in table 9 suggest the effectiveness of temporary driving restrictions triggered by air quality episodes. Results from a global polynomial fit (columns 4-6) suggest that the episodes' announcement decrease vehicle trips by 17-19%. Temporary driving restrictions seem to effectively affect drivers' behaviors by keeping them off the roads during days with air quality episodes. This intuition is consistent with results for mass-transit trips. The announcement of episodes generates negative impacts on subway's trips and buses trips, although this evidence is not statistically significant. Air quality episodes not only trigger temporary driving bans, but also recommend population to avoid outdoor exposure to pollution. Negative effects on mass-transit ridership suggest that people reacts positively to these recommendations and decides to reduce daily trips.

Tables 10 and 11 present results of a pooling fuzzy RD using a local approach. Different bandwidths around the zero cutoff are considered following Imbens and Lemieux (2008) recommendations of an alternative to a global polynomial estimation. Results from these tables suggests no evidence of episodes on the outcome of interests. Despite the sign of the coefficients is as expected, none of these estimations is statistically different from zero. Yet, these findings could be driven by the reduced number of observations around the cutoff.

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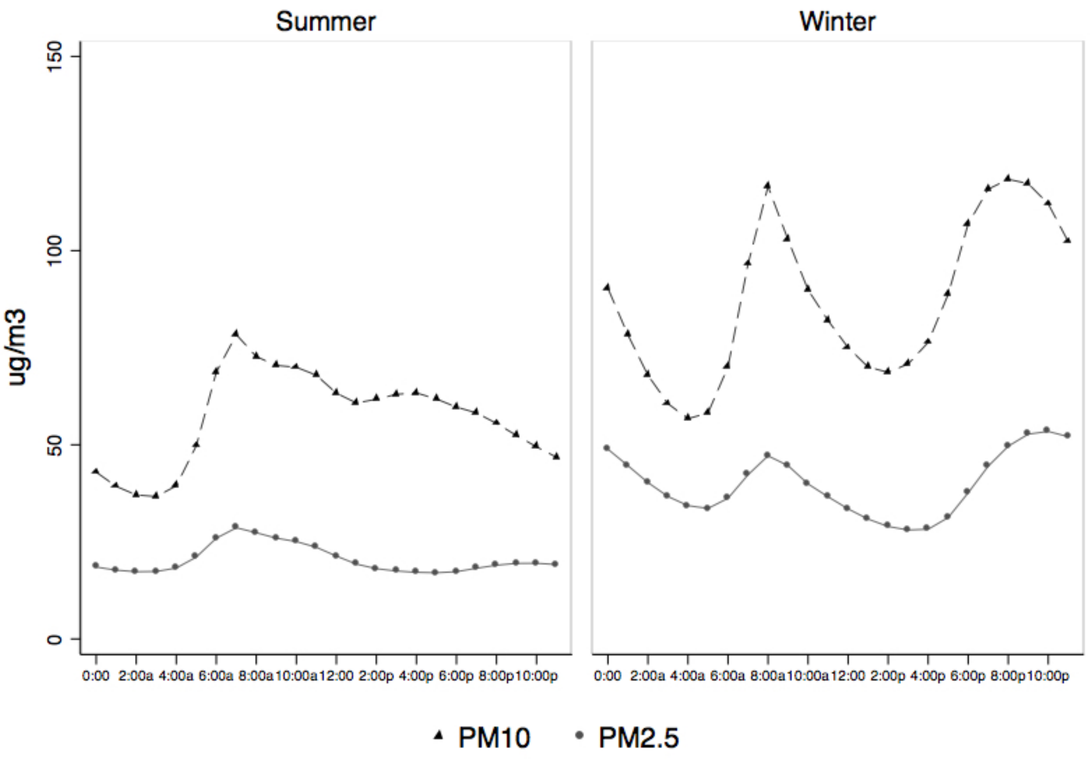
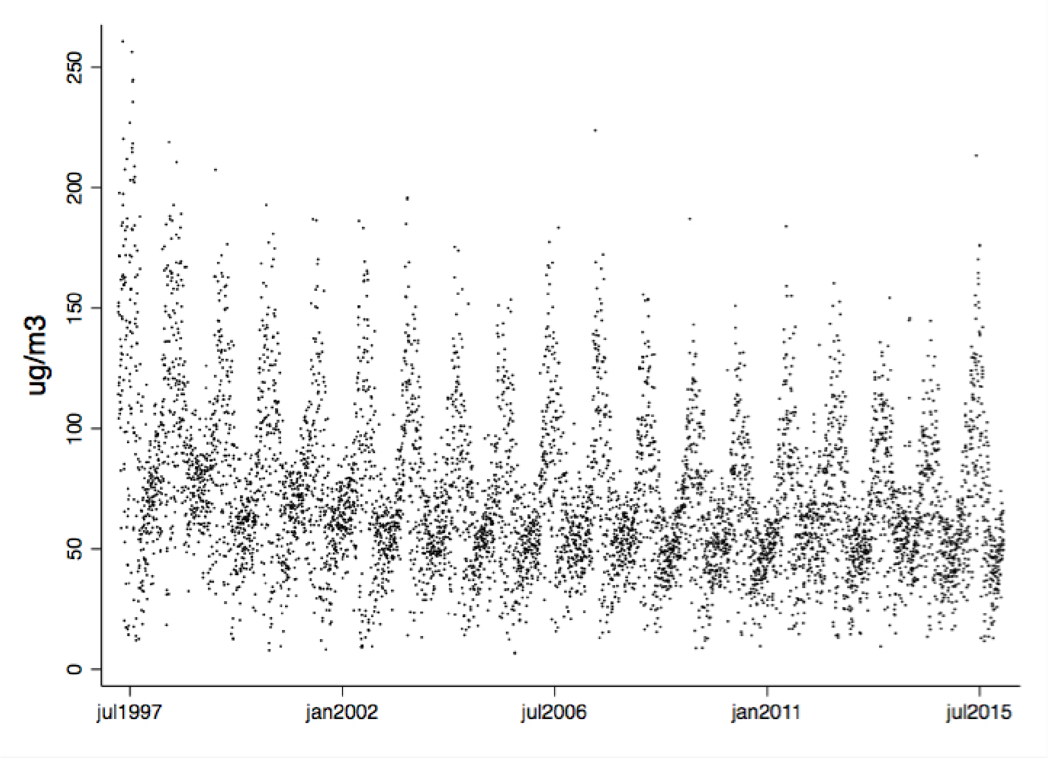
Figures and Tables

Figure 1: Hourly PM_{10} and $PM_{2.5}$ Average Concentrations in Santiago. Summer and Winter months.

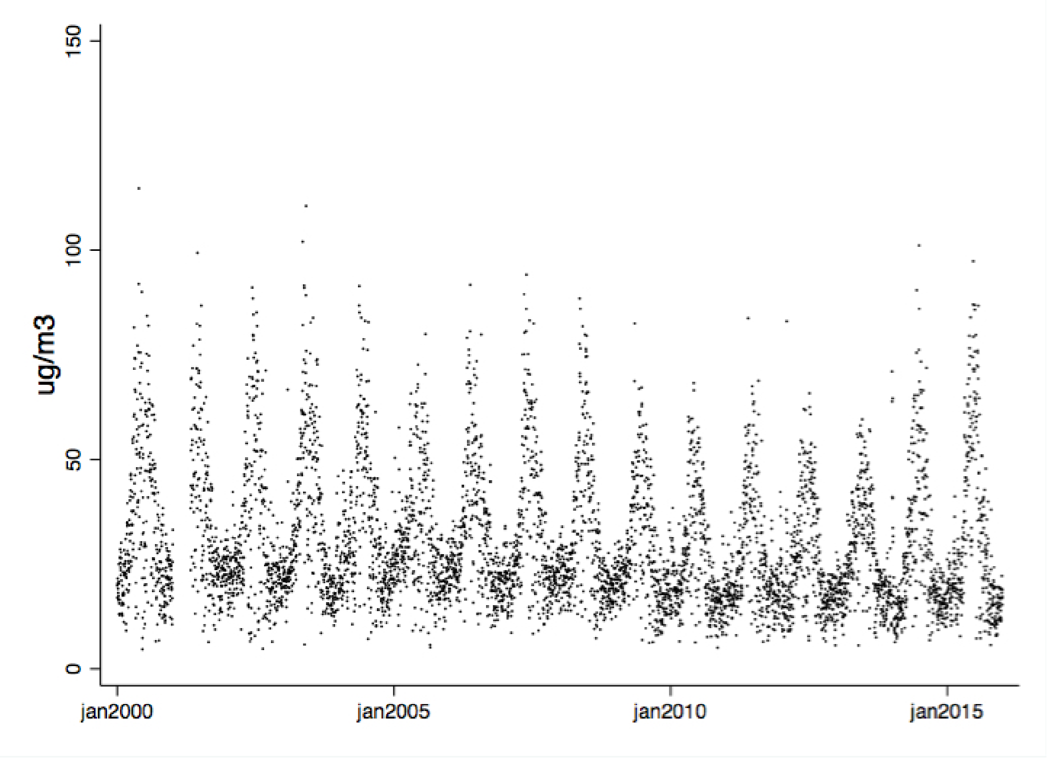


Notes: Winter months include from April to August. Summer months include from September to March.

Figure 2: Daily Pollutant Concentrations in Santiago.

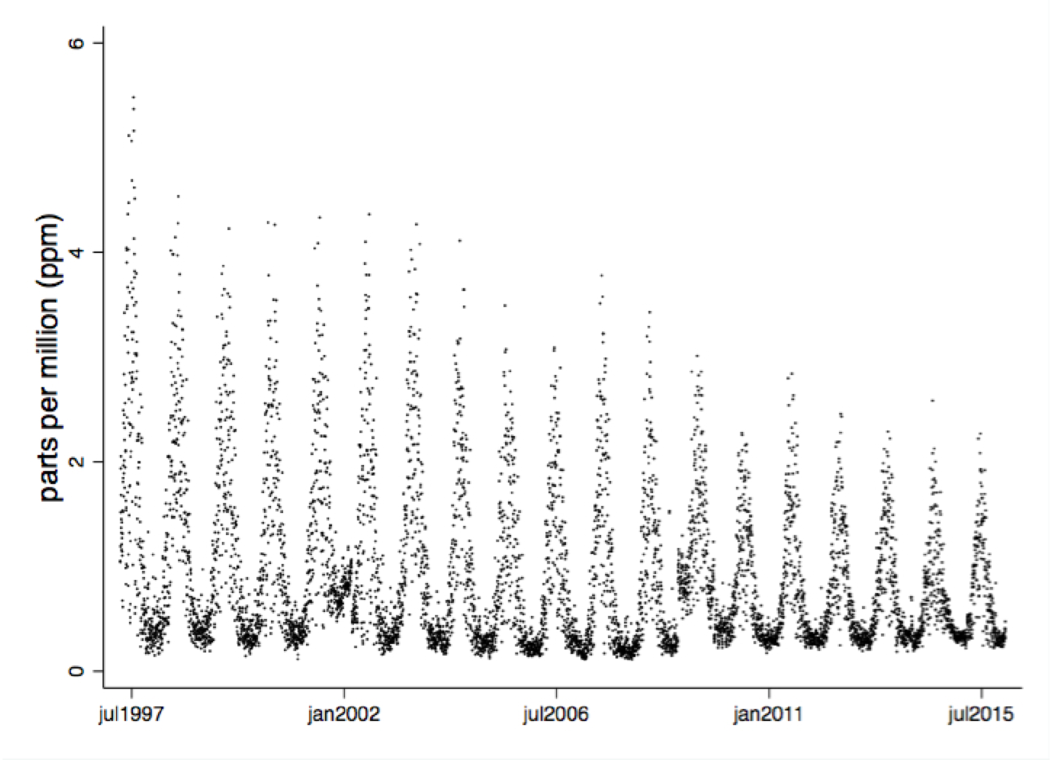


(a) PM_{10}

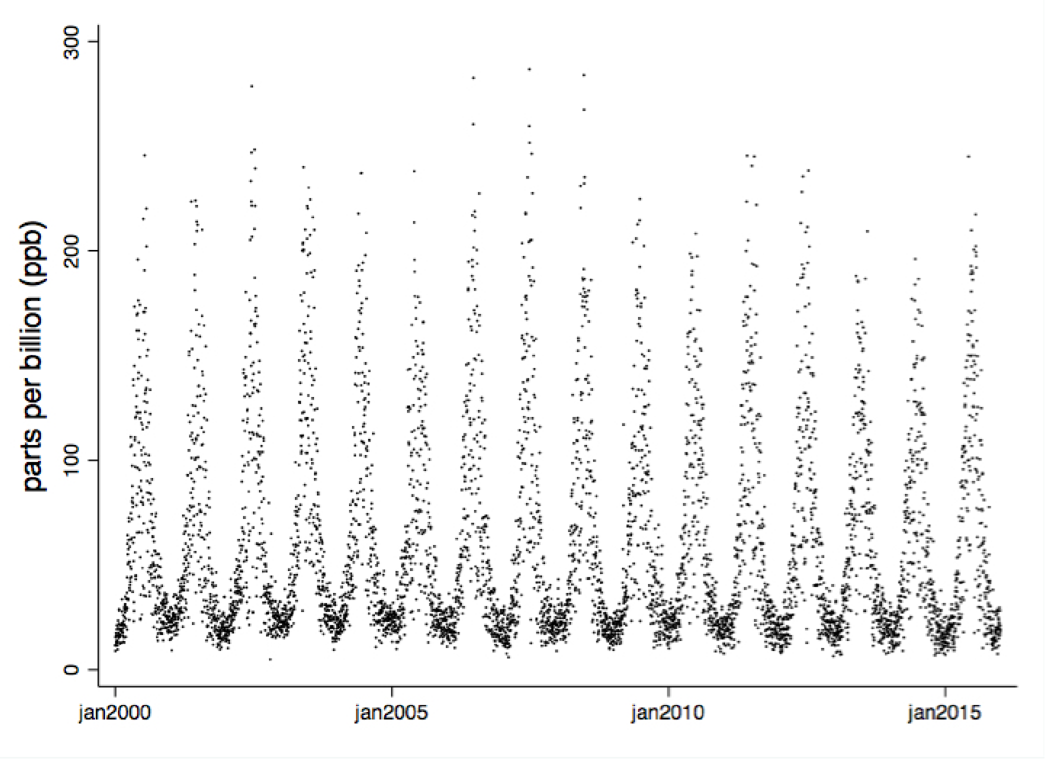


(b) $PM_{2.5}$

Figure 2: Daily Pollutant Concentrations in Santiago (continued)



(c) CO



(d) NO_X

Table 1: Index of Air Quality from Particulates (ICAP)

ICAP	24-hour PM_{10} Concentration ($\mu g/m^3$)	24-hour $PM_{2.5}$ Concentration ($\mu g/m^3$)	Air Quality Condition	Environmental Episode
0 - 99	≤ 149	≤ 49	Good	-
100 - 199	150 - 194	50 - 79	Regular	-
200 - 299	195 - 239	80 - 109	Bad	Alert
300 - 399	240 - 284	110 - 139	Critical	Pre-emergency
400 - 499	285 - 329	140 - 169	Dangerous	Pre-emergency
+500	≥ 330	≥ 170	Exceeding	Emergency

Notes: Adapted from Morales (2006).

Table 2: Number of Digits Restricted by Permanent and Temporary Driving Restrictions. 1990-2015

Stage	Type of Light Vehicle	Day of the Week	Permanent Restriction	Temporary Restrictions		
				Alert	Pre-emergency	Emergency
1990-1996	Dirty	Weekdays	2	-	-	-
		Weekends	0	-	-	-
	Clean	Weekdays	0	-	-	-
		Weekends	0	-	-	-
1997-2000	Dirty	Weekdays	2	4	6	8
		Weekends	0	2	4	6
	Clean	Weekdays	0	0	0	0
		Weekends	0	0	0	0
2001-2007	Dirty	Weekdays	2	4	6	8
		Weekends	0	2	4	6
	Clean	Weekdays	0	0	2	4
		Weekends	0	0	2	4
2008-2015	Dirty	Weekdays	4	4	6	8
		Weekends	0	2	6	8
	Clean	Weekdays	0	0	2	4
		Weekends	0	0	2	4

Notes: Permanent and temporary driving restrictions are in place only between 7:30am to 9:00pm and from April 1st to August 31st. Temporary driving restrictions show the total number of digits restricted during days with environmental episodes (*i.e.* number of digits restricted under the permanent restriction plus additional digits). Dirty = Vehicles without a *green sticker*. Clean = Vehicles with a *green sticker*.

Table 3: Historical Issuance of Environmental Episodes. 1997-2015

Year	Environmental Warnings			
	Alerts	Pre-emergencies	Emergencies	Total
1997	7	12	0	19
1998	19	11	1	31
1999	11	14	1	26
2000	27	11	0	38
2001	21	4	0	25
2002	22	11	0	33
2003	21	5	0	26
2004	13	2	0	15
2005	7	2	0	9
2006	21	3	0	24
2007	27	4	0	31
2008	21	8	0	29
2009	23	0	0	23
2010	7	2	0	9
2011	19	7	0	26
2012	23	2	0	25
2013	6	0	0	6
2014	22	1	0	23
2015	38	16	1	55
Episodes Since 1997	355	115	3	473
Episodes Since 2000	318	78	1	397

Notes: Data from the Unidad Operativa de Control de Tránsito (UOCT). Currently, environmental episodes are announced during winter days between April 1st-August 31st. Yet, five episodes were announced on March and September during 1997 and 1998. These episodes are not listed in this table.

Table 4: Descriptive Statistics on Pollution and Weather Variables.

Variables	Obs.	Mean	Std. Dev.	Min	Max	Years
Panel A: Pollutants						
PM_{10}	1,257,005	71.065	54.864	0	998.0	1997-2015
$PM_{2.5}$	956,161	28.975	24.578	0	901.9	2000-2015
CO	1,385,954	0.891	1.309	0	49.0	1997-2015
NO_X	816,772	59.762	80.378	0	1374	2000-2015
Panel B: Weather Variables						
Humidity (%)	980,343	59.592	21.715	0	105.0	2003-2015
Wind Speed (m/s)	972,641	1.426	1.148	0	17.3	2003-2015
Precipitation (in)	4,117	0.034	0.173	0	3.8	2000-2015
Temperature (°F)	5,836	58.934	9.192	36.5	80	2000-2015

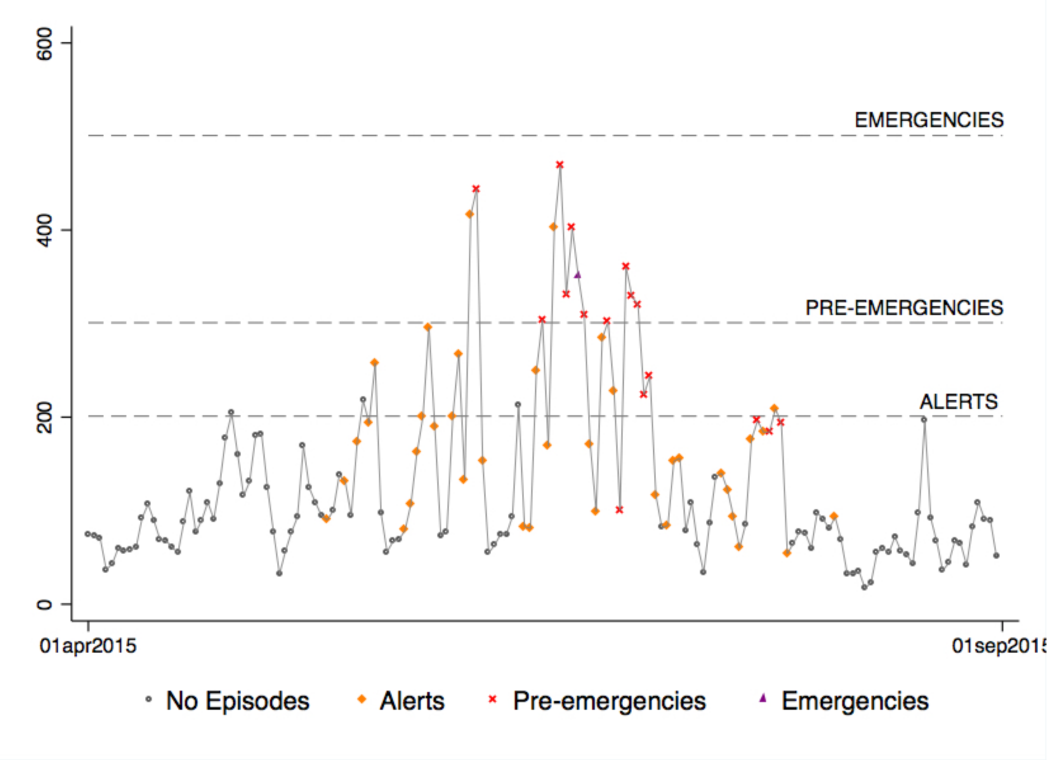
Notes for Panel A: Observations are station-hour. Particulate matter is in micrograms per cubic meter, CO is in parts per millions, and the other pollutants in parts per billions. *Notes for Panel B*: Observations are station-hour for humidity and wind speed. Observations are days for precipitation and temperature.

Table 5: Pollutant Concentrations During Environmental Episodes

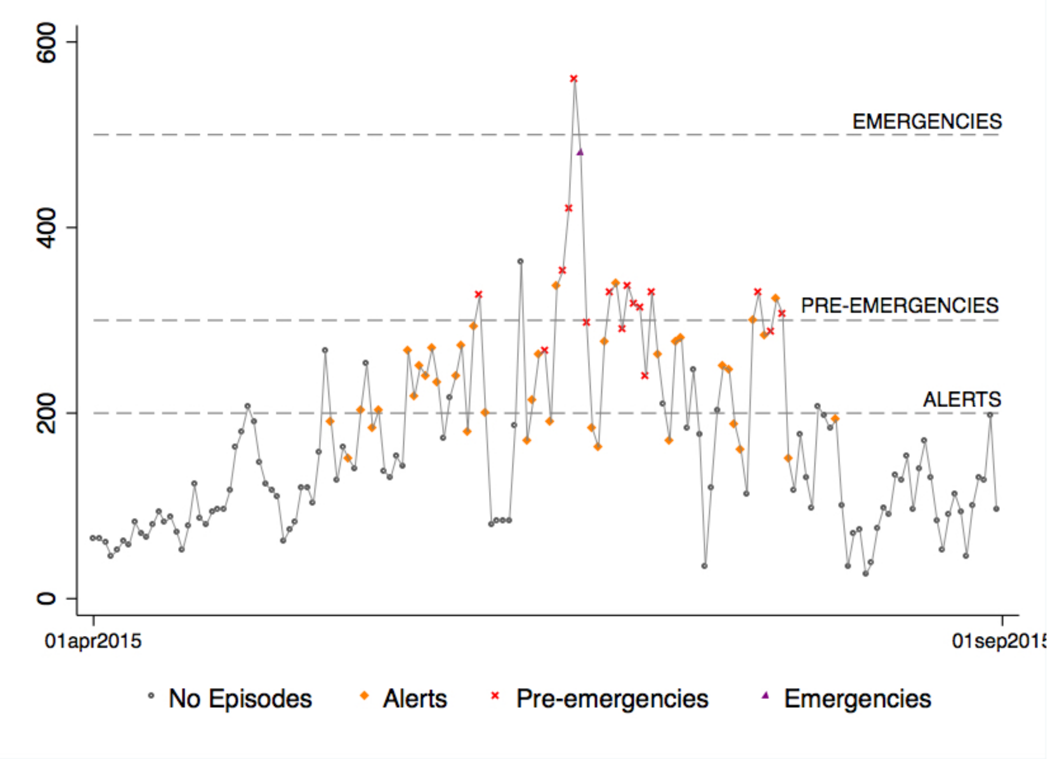
Pollutant	Type of Episode	Season	24-Hour Average	24-Hour Maximum
PM_{10} ($\mu g/m^3$)	Without Episodes	Summer	56.866	187.116
		Winter	78.727	260.010
	Alerts	Winter	120.377	380.545
	Pre-emergencies	Winter	129.851	418.661
	Emergencies	Winter	148.070	440.833
$PM_{2.5}$ ($\mu g/m^3$)	Without Episodes	Summer	21.798	65.215
		Winter	38.142	116.895
	Alerts	Winter	57.305	179.655
	Pre-emergencies	Winter	62.439	213.591
	Emergencies	Winter	79.912	149.000

Notes: Data from the UOCT and the NOAA. Winter considers days between April 1st-August 31st.

Figure 3: Daily Maximum ICAP_{10} and $\text{ICAP}_{2.5}$ during Winter 2015



(a) ICAP based on PM_{10}



(b) ICAP based on $\text{PM}_{2.5}$

Notes: Using daily maximum ICAP. Winter considers days between April 1st-August 31st.

Table 6: Descriptive Statistics on Urban Traffic Flows

Variables	Obs.	Mean	Std. Dev.	Min	Max	Years
Vehicle Trips	2,579,679	714	714	0	11,269	2004-2015
Subway Trips	116,880	63,294	56,420	0	282,664	2000-2015
Transit Buses Trips	3,247	2,921,347	967,754	10,453	4,468,663	2007-2015

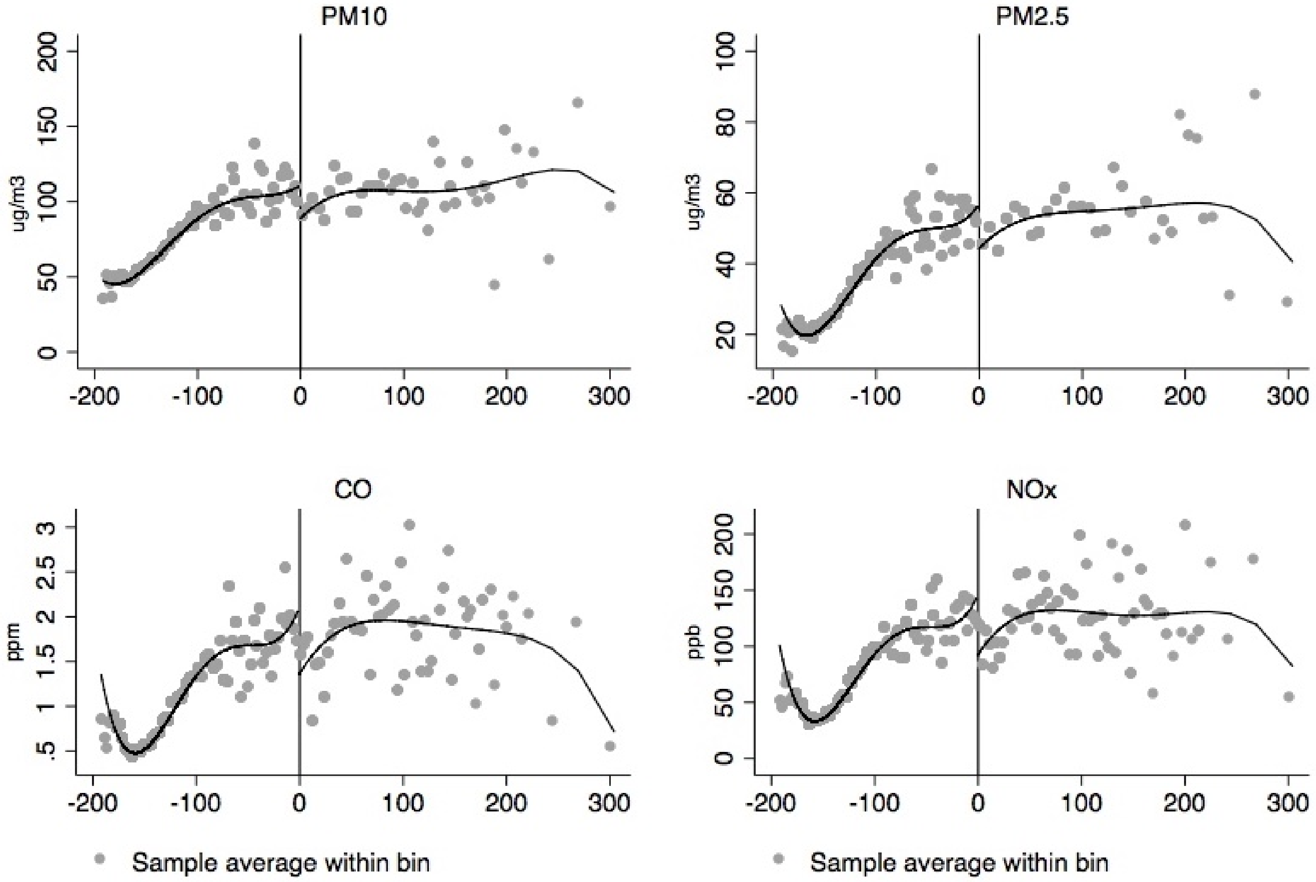
Notes: Observations are station-hours for traffic flows; hours for metro riderships; and days for transit buses trips. Statistics for transit buses trips consider daily totals.

Table 7: Urban Flows During Environmental Episodes

Urban Flow	Type of Episode	Season	24-Hour Average	24-Hour Maximum
Vehicle Trips	Without Episodes	Summer	711.02	2,828.22
		Winter	733.88	2,959.15
	Alerts	Winter	726.63	2,887.87
	Pre-emergencies	Winter	692.23	2,695.72
	Emergencies	Winter	617.88	2,516.00
Subway Trips	Without Episodes	Summer	61,334.93	119,941.97
		Winter	65,661.96	133,098.92
	Alerts	Winter	69,113.05	139,633.24
	Pre-emergencies	Winter	61,845.75	124,842.69
	Emergencies	Winter	120,602.90	265,590
Transit Buses Trips	Without Episodes	Summer	120,098.70	-
		Winter	123,919.32	-
	Alerts	Winter	125,261.55	-
	Pre-emergencies	Winter	117,647.58	-
	Emergencies	Winter	137,549.42	-

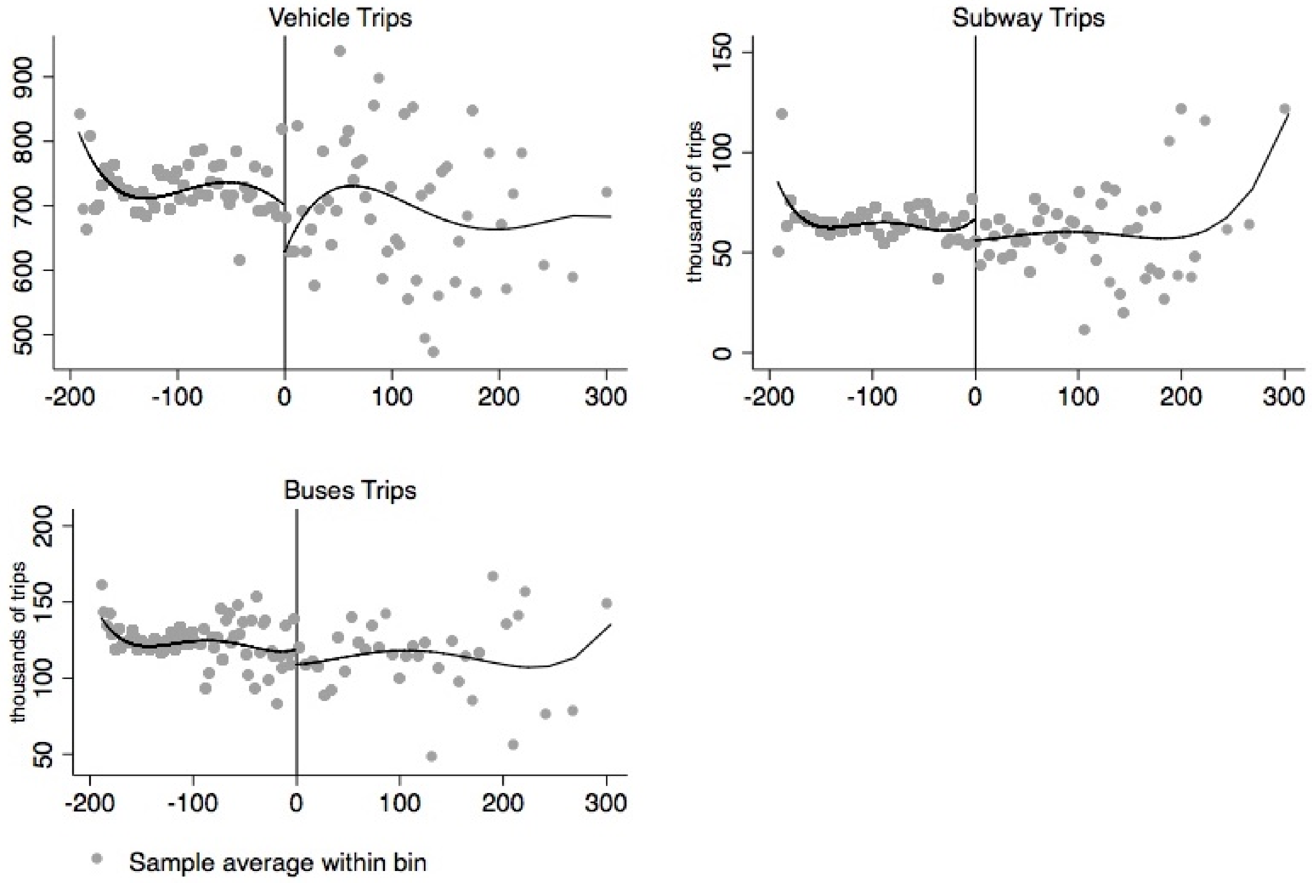
Notes: 24-hour average for buses is obtained by dividing daily totals on 24. Winter considers days between April 1st-August 31st.

Figure 4: Pooling Sharp RD on Air Pollution - Local Polynomial Approach



Notes: 4th degree local polynomial fit using $ICAP_{10}$ as the running variable. Outcome variables in levels. Observations are daily averages.

Figure 5: Pooling Sharp RD on Urban Transit Flows - Local Polynomial Approach



Notes: 4th degree local polynomial fit using ICAP_{10} as the running variable. Outcome variables in levels. Observations are daily averages.

Table 8: Episode Impact on Daily Average Pollution - Global Polynomial Approach

$\log(y_t)$	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
PM_{10}	0.183	-0.086	-0.192	-0.200	-0.329	-0.365
	(0.140)	(0.123)	(0.138)	(0.201)	(0.237)	(0.265)
N (days)	5,812	3,480	3,480	3,480	3,480	3,480
$PM_{2.5}$	0.258^{*}	0.053	-0.085	-0.209	-0.409^{*}	-0.434
	(0.139)	(0.121)	(0.141)	(0.213)	(0.247)	(0.280)
N (days)	5,722	3,480	3,480	3,480	3,480	3,480
CO	0.258^{*}	-0.119	-0.216	-0.457^{*}	-0.556^{**}	-0.556^{*}
	(0.153)	(0.123)	(0.151)	(0.242)	(0.271)	(0.303)
N (days)	5,812	3,480	3,480	3,480	3,480	3,480
NO_X	0.523^{**}	0.194	-0.0035	-0.0592	-0.140	-0.176
	(0.179)	(0.146)	(0.170)	(0.224)	(0.242)	(0.263)
N (days)	5,812	3,480	3,480	3,480	3,480	3,480
Weather		×	×	×	×	×
Time fixed effects			×	×	×	×
Order Polynomial Fit				2^{nd}	3^{rd}	4^{th}

Notes: Response variables in logs. GMM estimations using the normalized versions of both $ICAP_{10}$ and $ICAP_{2.5}$ as instruments. Weather covariates include humidity, precipitation, temperature, and wind speed. Time fixed effects include dummies for year, month, and dow. Estimations include the response variable lagged one period. Standard errors robust to a 3-week serial correlation in parentheses. Significance levels: $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.001$

Table 9: Episode Impact on Daily Average Urban Transit Flows - Global Polynomial Approach

$\log(y_t)$	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Vehicle Trips	0.0143	-0.126	-0.0896	-0.168*	-0.183*	-0.191*
	(0.109)	(0.111)	(0.0779)	(0.101)	(0.105)	(0.114)
N (days)	4,259	3,398	3,398	3,398	3,398	3,398
Subway Trips	-0.176	-0.597**	-0.175	-0.238	-0.255	-0.265
	(0.222)	(0.268)	(0.155)	(0.191)	(0.197)	(0.212)
N (days)	5,812	3,480	3,480	3,480	3,480	3,480
Transit Buses Trips	-0.183	-0.259	-0.100	-0.130	-0.118	-0.127
	(0.168)	(0.175)	(0.107)	(0.130)	(0.132)	(0.148)
N (days)	3,247	2,857	2,857	2,857	2,857	2,857
Weather		×	×	×	×	×
Time fixed effects			×	×	×	×
Order Polynomial Fit				2^{nd}	3^{rd}	4^{th}

Notes: Response variables in logs. GMM estimations using the normalized versions of both ICAP_{10} and $\text{ICAP}_{2.5}$ as instruments. Weather covariates include humidity, precipitation, temperature, and wind speed. Time fixed effects include dummies for year, month, and dow. Standard errors robust to a 1-week serial correlation in parentheses. Significance levels: $^*p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.001$

Table 10: Episode Impact on Daily Pollution - Local Approach

	Daily Average			
Bandwidth h	**120**	**90**	**60**	**30**
PM_{10}	-0.112	-0.331	-0.0798	0.917
	(0.245)	(0.333)	(0.322)	(0.802)
$PM_{2.5}$	-0.148	-0.338	0.161	0.628
	(0.302)	(0.346)	(0.494)	(1.095)
CO	-0.304	-1.055	-1.164	0.0718
	(0.264)	(0.646)	(1.083)	(0.685)
NO_X	0.128	-0.355	-0.379	-0.00582
	(0.293)	(0.429)	(0.569)	(0.650)
N (days)	932	378	225	113

Notes: All regressions include weather variables and time fixed effects. Standard errors robust to a 3-week serial correlation in parentheses. Significance levels: $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.001$

Table 11: Episode Impact on Urban Transit Flows - Local Approach

	Daily Average			
Bandwidth h	**120**	**90**	**60**	**30**
Vehicle Trips	-0.120	-0.0954	-0.118	-0.0703
	(0.111)	(0.131)	(0.182)	(0.352)
Subway Trips	-0.310	-0.233	-0.201	-0.531
	(0.234)	(0.274)	(0.345)	(0.506)
Transit Buses Trips	-0.148	-0.311	0.657	-0.542
	(0.159)	(0.681)	(1.091)	(2.059)
N (days)	932	378	225	113

Notes: All regressions include weather variables and time fixed effects. Standard errors robust to a 1-week serial correlation in parentheses. Significance levels: $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.001$

A. Appendix A

The following equation describes the weights used by the *Cassmassi* model to forecast PM_{10} concentrations in the *Pudahuel* station:

$$y_{t+1} = 39.4\nu_t + 0.33y_t + 2.06x_t + 0.21h_t - 21.7 \tag{5}$$

where y_{t+1} is the expected 24-hour moving average of PM_{10} for day $t + 1$; ν_t is the forecasted atmospheric stability for the following day taking discrete values from 1 to 5; y_t is the 24-hour moving average of PM_{10} measured during day t at 10:00am (local time); x_t is the temperature (°C) of the 925 hPa level registered by monitoring station *Santo Domingo* (located at 80km west from Santiago) at 12:00pm UTC of day t, and h_t is 24-hour change in height measured at 500 level registered by monitoring station *Santo Domingo* during day t at 12:00pm UTC. The inclusion of x_t and h_t as part of the equations in the *Cassmassi* model are intended to control for the expected strength of thermal inversions in Santiago Perez (2008).

B. Appendix B

Episode	Protocols
Alert	• Temporary driving restriction on 20% (weekends) of dirty vehicles • Prohibition in the use of wood and other biomass for residential heating
Pre-emergency	• Temporary driving restriction on 60% (all days) of dirty vehicles • Temporary driving restriction on 20% (all days) of clean vehicles • Temporary suspension of stationary emissions sources responsable for 30% of total stationary emissions of particulate matter. This is equivalent to the shutdown of 750 facilities. • Elementary and high-school physical education classes and community sports are suspended by the Ministry of Education • Prohibition in the use of wood and other biomass for residential heating
Emergency	• Temporary driving restriction on 80% (all days) of dirty vehicles • Temporary driving restriction on 40% (all days) of clean vehicles • Temporary suspension of stationary emissions sources responsable for 50% of total stationary emissions of particulate matter. This is equivalent to the shutdown of 2,461 facilities. • Recommendation by the Ministry of Education of classes cancellations in elementary schools and high-schools • Prohibition in the use of wood and other biomass for residential heating

Table B1: 2015 Protocols in Environmental Warnings

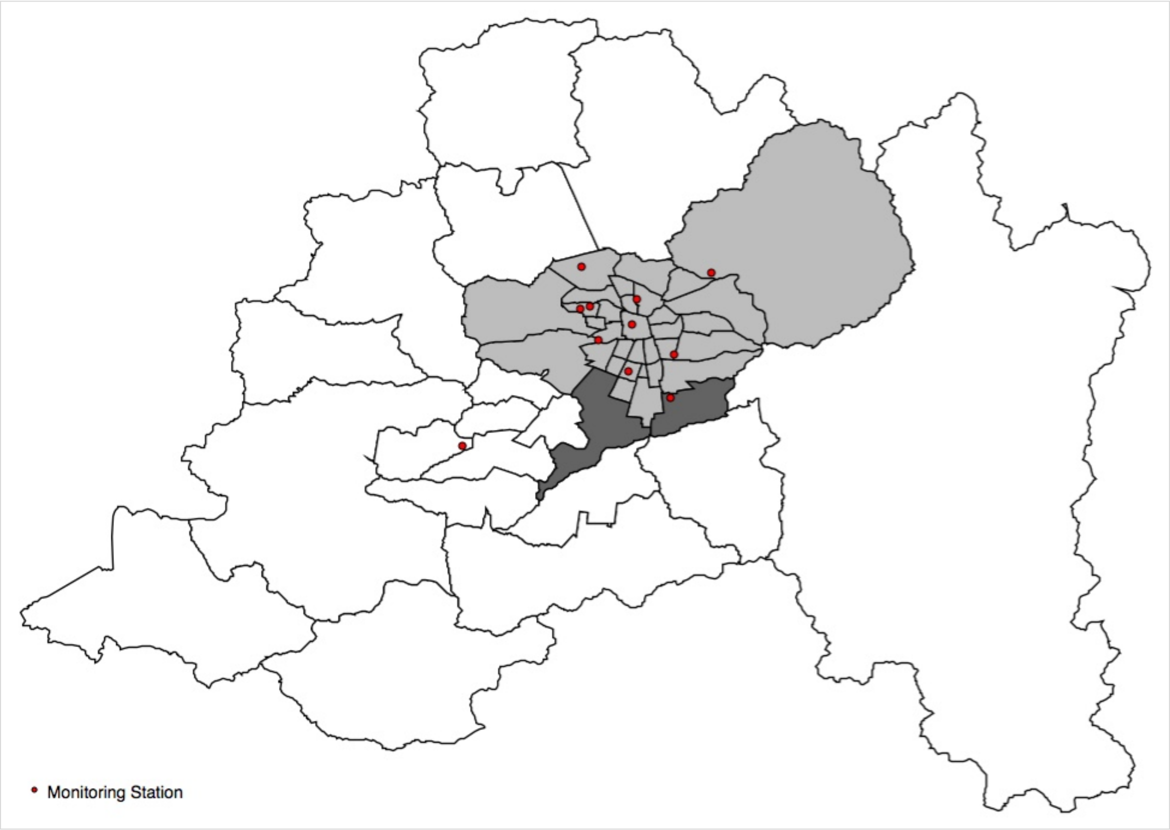
Note: Adapted from Mullins and Bharadwaj (2015).

Table B2: 2016 Calendar of Driving Restrictions for Santiago

Type of Restriction	Day/Episode	Digits Affected
Permanent Restriction	Monday	3-4-5-6
	Tuesday	7-8-9-0
	Wednesday	1-2-3-4
	Thursday	5-6-7-8
	Friday	9-0-1-2
Temporary Restrictions	First Episode	0-1
	Second Episode	2-3
	Third Episode	4-5
	Fourth Episode	6-7
	Fifth Episode	8-9

Note: Permanent restrictions on dirty vehicles only.

Figure B1: Spatial Location of Santiago's Monitoring Stations



Note: Areas affected by driving restrictions in color. Only one monitoring station is outside this range -Talagante station. Borders represent communes' limits.