VEHICLE RESTRICTIONS AND VARIATION IN FLOWS: A MULTIMODAL ANALYSIS FOR SANTIAGO

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Abstract

In this paper, we estimate the impact of vehicle restrictions imposed on nearly 20% of vehicles (two-digit patent) on the flow of cars, bicycles, and public transport use in the city of Santiago. This restriction applies during days when high environmental pollution is projected. We estimate that on the days of vehicular restriction, the increase in the use of public transport is not significant. On the other hand, the traffic flow on a motorway and on the 26 streets analyzed drops approximately 13% during the days of restriction. We also estimate a nearly 3% increase in motorway flow at times when traffic restriction does not apply, caused by the change in schedules in which some motorists travel to avoid the restriction. Furthermore, we estimate that the flow of bicycles in cycle lanes falls by 9% during the vehicle restriction days, possibly due to the greater environmental contamination that is projected for restriction days and public warnings to avoid physical activity.

Keywords: vehicular restriction, car flow, public transport, highways, bicycle, multiple regression models, panel data.

1. INTRODUCTION

Previously, in de Grange and Troncoso (2011), through multiple regression analysis (longitudinal and panel data), we estimated the effects that sporadic (non-permanent) vehicular restrictions generate on the flows of cars, Metro, and buses in the city of Santiago, using data for the year 2008. In the present work, we update the estimates using data for the year 2015 and extend the analysis considering the impact on the flows of bicycles on bicycle lanes and on vehicles in an important urban highway of Santiago (Highway Costanera Norte).

Vehicle restriction is implemented only on days when, on the previous night, high levels of pollution in the city were expected (e.g., environmental pre-emergencies and emergencies). On environmental pre-emergency days, two digits of restriction are implemented on vehicles with a catalytic converter, and on environmental emergency days, four digits of restriction are implemented on vehicles with a catalytic converter. This restriction applies between 7:30 and 9:00 p.m. Vehicles with a catalytic converter represent practically the entirety of the automobile group for Santiago (only vehicles previous to 1993 do not have a catalytic converter, for which reason they face permanent vehicular restriction between April and August of each year).

Some of the main conclusions in the previous work presented in de Grange and Troncoso (2011), when implementing two-digit vehicle restriction (pre-environmental emergency), were: (i) there was a 5% decrease in flow on the main streets of the city; (ii) there were significantly low changes in the use of public transport, particularly buses; and (iii) some motorists modify the schedules of their trips to avoid the hours in which the vehicle restriction rules. The environmental emergency was not implemented during the year 2008; thus, it was omitted from the analysis.

In updating this analysis with data from 2015, we find that although the restrictions translate into less car use, this decrease does not translate into greater use of public transport. On the other hand, the traffic restriction of approximately 20% of the vehicular park is translated into a decrease of approximately 13% of the flows observed in the streets of the city and in the studied highway. This figure is higher than the 5.5% estimated in de Grange and Troncoso (2011) with data from 2008, which would be explained in part by the increase in the value of fines for not abiding by the restriction and the additional prohibition for cars on circulating in some important city streets. We also find that on the days when a double-digit restriction is declared, the flows on the highway studied increase by almost 3% in the hours during which this measure does not apply due to a substitution effect: some travelers tend to change their travel schedule to avoid the traffic restriction (they travel before 7:30 a.m. and after 9 p.m.). Finally, bicycle flows on the cycle lanes studied decrease by approximately 9% on two-digit restriction days, most likely due to poor air quality and public warnings to abstain from physical activity during these days.

In section 2 of this article, we present relevant antecedents to understand the vehicle restriction policy that is implemented in Santiago, Chile, accompanied by an updated literature review. In section 3, we present a summary of the data used and the methodology considered for the empirical analysis. In section 4, we present the main results, and in section 5, we end with a discussion and the conclusions of the work developed.

2. WORLDWIDE VEHICLE RESTRICTION CASES AND REVIEW OF EMPIRICLE STUDIES

2.1 Cities in which Vehicle Restriction has been Implemented

Vehicle restriction is a regulatory policy for automobile use that has been in force for decades and mainly implemented in cities of Latin American countries (Bull, 2003) and, to a lesser extent, in European and Asian cities.

Already in the 1970s, an entrance restriction to central sectors of the city of Buenos Aires was implemented, based on the last digit of the license plate of private cars. Another one of the first cities to ban the circulation of cars in its central area was Athens in the 1980s. The main objective of the measure was to reduce the high levels of air pollution caused by the high traffic congestion existing in that area. The restriction was called "Dactylios" in Greek, and it coincided with the inner circumferential ring of the metropolitan area. The main objective of this measure was to decrease the high levels of air pollution produced by the levels of traffic congestion at the time and by the meteorological conditions of the valley in which the city is located. The system restricted circulation from Monday to Friday in alternating form for vehicles with registration finishing in even and odd numbers.

In Santiago de Chile, the vehicle restriction began to be applied in 1986 due to the high levels of air pollution. The system consisted of prohibiting the transit of automobiles whose last vehicle plate numbers end in one of the two predetermined digits for each business day.

Originally, the restriction applied to most private vehicles except those equipped with a catalytic converter to decrease the coarse particulate material (PM10) produced by combustion. Over the years, the number of cars equipped with a catalytic converter exceeded the number of traditional cars, and at present, the latter represent a very low percentage of the total (less than 4%). From 2001, on the days in which a pre-emergency or environmental emergency is declared, due to the high levels of contamination, vehicular restriction is also implemented for cars with a catalytic converter. Under pre-emergency, the restriction of catalytic cars is a two-digit restriction, and on emergency days, it is a four-digit restriction. Since 2014, pre-emergencies or environmental emergencies are declared considering fine particulate matter (PM2.5) instead of PM10. The environmental impact of the different policies implemented during environmental emergency and pre-emergency days in Santiago can be found in Troncoso and de Grange (2012).

In Caracas, the capital of Venezuela, between 1979 and 1990, a traffic restriction plan was implemented one day a week, called "Stop Day" (*Día de Parada*). This implementation was performed to mitigate the constant traffic jams in the city. The then-Ministry of Transport and Communications (now the Ministry of Popular Power for Infrastructure) allocated a number according to which they were banned from circulation one day a week.

In Mexico City, in November 1989, the program called "No Circulation Today" (*Hoy no Circula*) was begun, with the main objective of combating the problems of air pollution. The program became officially mandatory for cars from March 1990 and for all public transport vehicles from January 1991. Subsequently, the program has been extended to Pachuca, Puebla, and Toluca. In 2008, the program was expanded in Mexico City to restrict circulation on one Saturday a month.

In 1997, the city of Sao Paulo implemented a vehicular restriction, known as "Vehicle Rotation" (*Rodízio Veicular*). The traffic restriction applied to private cars based on the last digit of the registration number, restricting two numbers per day, from Monday to Friday, during morning and afternoon rush hours (7:00-10:00 a.m.; 5:00-8:00 p.m.). From 2003, the municipal government decided to extend the traffic restrictions for heavy vehicles, and from June 30, 2008, commercial vehicles were included. In May 2014, the Municipality of Sao Paulo passed a law provisioning that electric vehicles, electric hybrids, and those based on a hydrogen cell will be free from the vehicle restriction.

In 1998, in the city of Bogotá, a restriction measure for the entrance of cars to roads, called "Rush and Plate" (*Pico y Placa*), was first applied. This measure was applied to mitigate congestion at peak times. The restriction was exercised, as is customary, with the last number of the license plate, restricting the entry of 4 digits per day, which means that each car should be barred from circulating two days per week. The city implemented the annual rotation of the numbers to prevent permanently fixing the days of the week of the restriction. Thus, vehicles restricted on Tuesdays and Thursdays of this year would change to being restricted on Wednesdays and Fridays for the following year and so on. From 2008, "Rush and Plate" was expanded to 14 hours in Bogota, from 6:00 to 8:00 p.m. As of December 2012, "Rush and Plate" in Bogota increased the ban on circulation to 50% of vehicles every day, depending on whether the last digit of the plate is even or odd, and the restriction lasts from 6:00 to 9:00 a.m. and from 5:00 p.m. to 7:30 p.m.

In Managua, Nicaragua, as of 2001, a restriction is applied to the circulation of half of all taxis to avoid the congestion caused by the excess of existing vehicles. Those that have even-numbered plates circulate between 6:00 and 2:00 p.m., whereas those with odd-numbered plates can do so between 2:00 and 10:00 p.m.

In the city of La Paz, the capital of Bolivia, a restriction program to access a 10 km² area of the old city center entered into force in January 2003. The measure has three restriction schedules: from 8:00 to 9:30 a.m., from 12:00 to 1:00 p.m., and from 6:00 to 8:00 p.m.

With the purpose of mitigating the effect on the economy of high oil prices, in August 2005, the vehicle restriction on accessing the central area of San José, Costa Rica, was implemented considering the last number of the license plate, restricting two numbers per day. The vehicle restriction was initially applied only at peak times, from Monday to Friday between 7:00 and 8:30 a.m. and between 4:00 and 5:30 p.m. In June 2008, the vehicle restriction area was expanded, and from July 10, 2008, the rationing of road space was extended to 13 hours for private cars and light-duty vehicles, from 6:00 a.m. to 7:00 p.m. Heavy vehicles were also subject to vehicle restriction but only during peak hours. To boost the use of clean energy in the country, since October 2012, electric hybrid vehicles and 100% electric vehicles are exempt from vehicle restriction.

Beijing temporarily implemented a vehicle restraint system during the 2008 Olympic Games. Its aim was to improve air quality. The restriction came into effect on July 20, 2008, and was implemented for two months, given that the Olympics were followed by the Paralympic Games September 6-17 that same year. Police control of the measure was performed with the aid of a network of 10,000 automatic traffic surveillance devices. The restriction was 50% and applied on alternate days, depending on whether the final number of the number plate was even or odd. The results of the vehicle reduction during the Olympics were considered a success, which is why the measure was made permanent beginning in October 2008 but restricting the circulation of only 20% of vehicles from Monday to Friday instead of half of all vehicles, as was the case during the 2008 Olympics.

In Paris, during the month of March 2014, automobile circulation was temporarily restricted due to a high level of suspended particles. On March 17, 2014, a partial restriction on traffic circulation was declared in and around Paris based on license plate numbers. Vehicles with odd-numbered license plates, including private cars and commercial vehicles weighing more than 3.5 tons, were banned from entering the city between 5:30 am and midnight. Electric vehicles, electric hybrids, natural gas-powered cars, and carpools with three or more passengers were exempt from the restriction. It was not necessary to extend the vehicle restriction the following day because the air quality improved. Another case of air pollution affected Paris during the third week of March 2015. At the request of the mayor of Paris, Anne Hidalgo, the national government ordered a traffic restriction in Paris and 22 cities in the administrative region of Île-de-France for Monday, March 23. All motor vehicles with license plates ending in odd numbers, including private cars and commercial vehicles weighing more than 3.5 tons, were prohibited from entering the capital and other cities of the metropolitan area within the restricted area. Similar to the episode in 2014, during the restriction, taxis, ambulances, vehicles with three passengers or more, electric cars, and other environmentally friendly vehicles were allowed free transit.

2.2 Literature Review of Empirical Analysis and Results

According to Kornhauser and Fehlig (2003), road space rationing is a street demand management technique that, instead of charging for driving (such as road pricing), restricts the days or hours in which a driver can use congested roads. Although in the opinion of these authors vehicular restriction is a more equitable measure than road pricing to mitigate the problem of vehicular congestion, we must also consider that vehicle restriction, as it exists in Santiago, affects users in a somewhat heterogeneous manner. Some reasons for this situation are (i) for some users (such as those who live near the Metro network or close to work), replacing the car trips is easier; (ii) some users have a second car that they can use during those days; and (iii) the measure does not distinguish the importance (willingness to pay) of different trips.

On the other hand, some technicians have opposed this measure, defining it as unfair and inefficient. Within this group, through a time series analysis, Eskeland and Feyzioglu (1995) find that in the long run, vehicle restriction increases congestion and pollution because those affected tend to acquire an additional vehicle, which normally corresponds to an older and, therefore, more polluting vehicle and tend to drive more during the days when they are not affected by the measure, negatively offsetting any benefits sought. The measure would mainly affect lower-income drivers who do not have an additional vehicle.

For the "No circulation today" program implemented in Mexico City, studies indicate that the negative impacts of this measure are greater than the positive impacts, among other causes, due to the acquisition of a second vehicle; thus, in practice, many end up not being affected by the restriction. Indirect evidence also suggests that environmental pollution has been exacerbated due to the restriction (Tovar, 1995). Davis (2008) concludes that the environmental pollution sensors (hourly) in Mexico City did not show improvement; the author also finds that passengers did not increase the use of public transport. In addition, Davis (2008) observes an increase in purchases of gasoline (above expectations) and, therefore, in pollution. In conclusion, households harmed by the expropriation of their vehicles from traffic flow react defensively to the measure, neutralizing it almost completely. It is argued that the "No circulation today" program has led families to purchase additional old vehicles to solve the problem of circulation caused by the restriction; it is further noted that these vehicles were generally manufactured with worse technology and that their environmental impact would be more severe. According to the Environmental Authority of the Metropolitan Zone of the Valley of Mexico, this phenomenon is partially true, and it is estimated that 22% of the vehicles purchased at the start of the "No circulation today" program were of the type described (Cifuentes, 2007).

In the metropolitan region of São Paulo, Brazil, since 1995, several vehicular restriction experiences have been performed. The so-called "rotation" program was implemented, restricting the use of vehicles according to plate number (Viegas, 2001). First, the vehicle restriction was applied voluntarily for a week; the Environmental Agency suggested leaving cars at home, with cars taking turns every day based on the two final digits of the license plate. On the first two days, membership was relatively high: approximately 50%, falling the following days to an average of 38% (Bull, 2003).

In other contexts, in Manila (Philippines), there is a restriction scheme in which the circulation of certain vehicles, identified by the plate number, is prohibited in high-flow arteries during peak periods (GTZ, 2002).

A short-term empirical analysis of the effect of restricting 20% of the totality of vehicles during each day of the week is discussed in Wang et al. (2014). Using data from household surveys and travel journals for Beijing, they analyze the short-term effect of the vehicle restriction policy on the choice of mode of transport, and they identify which demographic groups are most likely to disregard this restriction. Estimates reveal that vehicle restriction does not have a significant influence on individuals' choice of mode and that almost 48% of car owners did not follow the rules and "illegally" drove to their destinations. However, in the study by Gu et al. (2017), also for Beijing, it is concluded that the effect would be significant in terms of reducing the number of vehicle-miles.

In a theoretical paper, Cantillo and Ortúzar (2014), using a simple microeconomic analysis supported by evidence gathered in some of the cities where vehicle restriction policies have been implemented, conclude that such approaches are only feasible in the very short term and that ultimately they do not meet the desired objectives. In another paper based on a theoretical approach, supported by simulations, Nie (2017) concludes that vehicle restriction is not a good policy, mainly due to the medium-term behavior of motorists. Using a mathematical model that explicitly considers the transport mode choice and user heterogeneity, he concludes that there is no guarantee that vehicle restrictions end up reducing system costs, due to the acquisition of new vehicles by the population, and that it can also jeopardize the implementation of other more efficient regulatory policies, such as road pricing or specific taxes (see Litman, 2013).

3. DATA AND METHOD

The data used correspond to measurements of vehicle flows (in major city streets and on an urban highway), passengers in public transport (buses and Metro), and bicycles from different sources, all for the year 2015. These were:

(i) The daily flows of bicycles for seven bicycle lanes in Santiago measured by the Municipality of Providencia, which is a central commune of Santiago de Chile.

(ii) The daily and hourly flows, measured by the Traffic Control Operational Unit (Unidad Operativa de Control de Tránsito, UOCT), for 26 measurement points distributed in different streets of the city. The UOCT is the entity in charge of traffic management within the cities.

(iii) The daily and hourly flows measured in nine ramps of the urban highway Costanera Norte. This 35-km highway crosses all of Santiago from east and west, with three lanes per direction.

(iv) The daily validations of Transantiago and Metro system buses provided by the Metropolitan Public Transportation Directorate (Dirección de Transporte Público Metropolitano, DTPM), an entity under the Ministry of Transport and Telecommunications of the Chilean government.

The measurements of bicycle flows published by the Municipality of Providencia have an hourly frequency. However, because there is no reason to suppose a change in the pattern of bicycle trips during the day of restriction (hourly substitution), we add these data to obtain a daily frequency.

Additionally, we eliminated from the sample the only day (in all of 2014 and 2015) in which the authority declared an Environmental Emergency and restricted the circulation to practically 40% of the totality of vehicles. Because this event occurred on a single day and was the first time this restriction was declared, changes in observed flows may be attributable to factors other than the measure. The inclusion of this day practically does not modify the estimates of the effects of pre-emergency days.

Table 1 shows the general descriptive statistics of the data for each mode analyzed, considering only the observations included in the regression models. In the cases of panel data (9 highway ramps, 26 streets and 7 cycle paths), the aggregate descriptive statistics are shown, without distinguishing by measurement point. The annex shows the descriptive statistics of bicycles, Costanera Norte, and UOCT per measurement point.

Table 1
Descriptive statistics of flows according to mode

Mode	No. Obs.	Mean	St. Dev.	Min	Max	Frequency
Bicycle	640	2,557	999	150	5,424	Daily
Metro	103	2,312,637	214,633	669,187	2,536,264	Daily
Bus	103	3,121,973	292,589	1,035,400	3,384,824	Daily
Costanera Norte	927	46,610	16,648	8,915	87,730	Daily
UOCT	2,168	17,436	10,229	9	39,866	Daily
Costanera Norte	22,248	1,942	1,571	18	6,764	Hourly
UOCT	44,855	851	663	2	2,964	Hourly

Following de Grange and Troncoso (2011), we consider working days (excluding Saturdays, Sundays, and holidays) between April and August, which are the months in which the authorities may declare Environmental Emergencies and, therefore, vehicular restriction.

In the econometric model, similar to that recently used in LV et al. (2015) to evaluate other public transport policies, we include groups of dichotomous variables by year, month of the year, day of the week, and time of day (the latter only for hourly data) as control variables. In addition, we include among the explanatory variables a dichotomous variable that indicates the day on which the pre-emergency occurs (restriction to 20% of all vehicles).

Additionally, to analyze the substitution of flows between schedules that governs and does not govern the vehicular restriction, particularly for the UOCT flows and the Costanera Norte highway, we performed an additional regression that included two dichotomous variables for pre-emergency days: (i) one for the hours in which the restriction applies on pre-emergency days (between 7:00 a.m. and 9:00 p.m.) and (ii) one for the hours in which the restriction does not apply during pre-emergency days (between 9:00 p.m. and 7:00 a.m.). This is due to the possibility that motorists have to advance or postpone their trips to avoid the restriction. Because the data for Costanera Norte (CN) and the UOCT have hourly frequency (and not every half hour), we define the dichotomous variables as though the measurement were from 7:00 a.m. on.

In all models, the dependent variable corresponds to the natural logarithm of the observed flow for each period, which can be daily or hourly, depending on the case.

During the year 2015, 16 environmental pre-emergencies were declared, 10 of which fell on working days. This measure restricts the circulation of 20% of vehicles with a catalytic converter between 7:30 a.m. and 9:00 p.m. in the city of Santiago. At present, vehicles with a catalytic converter represent approximately 95% of the total cars in Santiago. The percentage of vehicles without a catalytic converter is close to 4% (vehicles prior to 1993) and face a permanent 4-digit vehicular restriction between April and August.

In the cases of bicycles and flows in the UOCT and in the Costanera Norte, the data have a panel data structure, whereas in the case of buses and Metro, the data are longitudinal. In addition, UOCT and Costanera Norte data are used with hourly frequency to distinguish the hours of day in which the restriction applies from those in which it does not.

In this manner, we define three regression models. For the case of the panel data for bicycles, CN, and UOCT, the model is as follows:

$$y_{it} = \gamma' X_{it} + \beta D_{it} + \mu_i + \varepsilon_{it} \qquad (1)$$

where X_{it} is the spatial control variables (bicycle path, highway entry ramp, or street *i*) and temporal variables (day *t*), and D_{it}^{R} is equal to 1 if during the restriction day, the restriction is at time *t*, otherwise 0. Then, the estimation of the parameter β (its sign and significance) that accompanies this last dichotomous variable will make it possible to determine the effect of vehicle restriction on the daily flows for these five modes of transport. We also include an individual control μ_i.

In the case of the hourly flows of vehicles in the CN and UOCT, the model is as follows:

$$y_{it} = \gamma' X_{it} + \beta_R D_{it}^{R} + \beta_{NR} D_{it}^{NR} + \mu_i + \varepsilon_{it} \qquad (2)$$

where X_{it} is the variables of spatial control (highway entry, or i) and temporal variables (time t), D_{it}^{R} is equal to 1 if during the restriction day, it is activated at time t, otherwise 0, and is equal to 1 if during the restriction day, it is not activated at time t, otherwise 0. Observe that in model (2), the variable D_{it} incorporated in (1) is omitted in the model but the variables D_{it}^{R} and D_{it}^{NR} are added to analyze the hourly substitution of the flows for CN and UOCT. Again, we include an individual control μ_i.

Finally, for bus and Metro trips, the model corresponds to the following:

$$y_t = \gamma' X_t + \beta D_t + \varepsilon_t \tag{3}$$

where X_t are the temporal control variables and D_t corresponds to the dichotomous variable for the pre-emergency days. In all models, ε represents the random error.

The estimation of the models with panel data (1) and (2) was performed using fixed effects estimators, whereas in the case of the longitudinal cut (3), we used Ordinary Least Squares (OLS). In all cases, we used the robust estimation of the heteroscedasticity of the variance matrix and covariance of the estimators to ensure the consistency of the hypothesis tests.

4. RESULTS

Tables 2 and 3 show the main results of the estimation of models (1), (2), and (3), using, when appropriate, daily data or hourly data. To improve the presentation, the coefficients γ associated with the control variables X are not shown.

Table 2
Regressions using daily data

Dep: Ln (Flow)	Bicycle	Bus	Metro	CN	UOCT
Pre-emergency $\left(\hat{\beta}\right)$	-0.092***	-0.071	-0.093	-0.130***	-0.125***
	(0.013)	(0.113)	(0.128)	(0.015)	(0.032)
R^2	0.2823	0.2011	0.1487	0.2494	0.1001
No. of Observations	640	103	103	927	2168

Standard errors in parentheses. *** indicates significance at 1%

In the estimates with daily data in Table 2, we found that the measured bicycle flows decreased by slightly more than 9% on pre-emergency days. This result is mainly explained by the greater pollution that is estimated for these days and by the recommendations of the authorities regarding avoiding physical activities.

On the other hand, we did not find significant marginal effects for bus and Metro use as a result of the restriction; that is, on vehicle restriction days, there would be no significant transfer of car users to public transport, similar to the conclusion of Wang et al. (2014). In the study by de Grange and Troncoso (2011), the same conclusion regarding buses was reached; however, there was a slight increase for the Metro. We now estimate that there is no significant increase in Metro ridership, which can be explained by the high permanent saturation that this means of transport has experienced, particularly in recent years.

Finally, for the daily flows of CN and UOCT, we obtain in both cases a very similar result: on vehicular restriction days, in which circulation is restricted to 20% of vehicles, the flow is reduced by approximately 13% for both. In de Grange and Troncoso (2011), only UOCT data were analyzed, estimating an average daily reduction of 5.5%. This increase from 5.5% to 12.5% is presumably explained by the fact that, in 2008, the fine for not complying with the vehicle restriction was approximately US$ 35 (0.5 Chilean monthly tax units, UTM)) whereas, in 2015, the fine was approximately US$ 105 (1.5 UTM). Another additional reason that would explain the increase of 5.5% to 12.5% is that, in 2015, the so-called "environmental axes" were implemented, which are road axes in which traffic is prohibited during peak periods (between 7:30 and 10:00 a.m. and between 5:00 p.m. and 9:00 p.m.) on pre-emergency environmental days, further discouraging the use of cars.

Table 3 shows the estimates of the impact of vehicle restriction on the CN and UOCT flows on pre-emergency days, distinguishing the hours in which the vehicle restriction is in effect from the hours in which it does not apply.

Table 3
Regressions using hourly data

Dep: Ln (Flow)	CN	UOCT
Pre-emergency in effect	-0.161***	-0.133***
	(0.016)	(0.012)
Pre-emergency not in effect	0.029**	0.011
	(0.011)	(0.016)
R^2	0.9487	0.7382
No. of Observations	22248	44855

Standard errors in parentheses. ** indicates significance at 5% and *** at 1%

We found that the CN flows decreased by 16.1% and the UOCT flows by 13.3% during the hours in which the vehicle restriction (between 7:00 a.m. and 9:00 p.m.) was in force. In contrast, in the hours in which it was not in effect (between 9:00 pm and 7:00 a.m.), we estimate an increase of close to 3% in CN flows and a non-significant increase in UOCT flows.

5. DISCUSSION AND CONCLUSIONS

By restricting the use of private vehicles, affected users face three alternatives: (i) evading or circumventing the measure, (ii) using public transport or other alternative means, and (iii) postponing activities for another day. Concerning the expected effect of restrictions on the use of public transport, there may be two opposing effects: (i) on one hand, some car users use public transport that day, and (ii) on the other hand, some activities are postponed for another day, and therefore, some trips on public transport are not performed the day of the restriction.

Our estimate of the effect of restricting vehicle traffic on urban surface flows (UOCT) by 20% in 2015 was higher than that reported for 2008 (a decrease of 12.5% vs. 5.5%), although it is still less than the theoretical 20%. This increase could be explained by the fact that, in 2015, the fine for not complying with the vehicle restriction was three times higher than the existing fine in 2008. In addition, in the year 2015, part of the road was restricted, prioritizing the circulation of buses over automobiles.

Similarly, the decrease in the flows in the CN urban highway because of the vehicular restriction was of an order of magnitude similar to that of the streets of the city (13%), for which reason the hypothesis that they are equal for usual levels of significance is rejected.

Regarding the changes in the travel schedule, we found that on pre-emergency days, the flows increase by 2.9% on the CN highway in the hours during which the measure does not apply; however, there would be no significant changes of schedule in the UOCT flows.

For its part, it was expected that the reduction in the use of private transport would translate, to some extent, into greater use of public transport. However, consistent with the 2008 estimates, we do not observe that restrictions on the use of private vehicles translate into greater use of public transport, for neither buses nor Metro.

Bicycles could be a substitute for car restriction days for some users. However, we find that their use decreases by 9% during those days. This could be explained in part by the authorities' recommendation to not engage in physical activity during pre-emergency periods, which are declared precisely when poor air quality is recorded in the city.

According to our estimates, in 2015, there would be a lower propensity to avoid or circumvent the restriction on the part of motorists, compared to 2008. However, the decrease in the use of private transport would not necessarily translate into a greater use of alternatives such as public transport or bicycles. This finding suggests that the effect of the lower activity in the city on the use of public transport would be of a similar magnitude to the transfer of users of private transport.

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Annex

Vehicle Flows by UOCT Measurement Station (26 streets)

Station	No. Obs.	Mean	St. Dev.	Min	Max
E005P0	2367	1426.88	850.0512	31	2639
E011O0	1912	1635.085	926.974	52	2964
E042O0	2367	915.0237	539.2391	42	2173
E057N0	168	299.2738	184.3346	15	784
E057S0	168	1178.679	693.4602	53	2278
E061N0	2272	928.0748	506.5942	39	2439
E061S0	2272	983.3341	577.4589	49	2115
E064O0	1899	653.9421	395.8551	21	1749
E064P0	2368	691.8568	425.0847	17	1643
E068O0	59	184.339	110.8447	3	368
E073O0	2260	697.2681	499.7738	2	1724
E073O1	336	898.1935	387.3358	2	1503
E073P0	2122	750.4255	519.6822	2	1705
E073P1	496	474.3649	295.4769	2	1011
E078N0	1713	644.829	368.7592	18	1220
E078S0	1713	727.2493	422.6032	20	1452
E080O0	2177	237.7841	203.1054	3	2085
E080P0	2177	802.5792	496.5917	14	1653
E089O0	2309	1282.049	768.9392	23	2411
E094N0	1649	258.473	180.8139	2	682
E094N1	1329	140.4801	230.6587	2	704
E094S0	1915	418.3305	222.2413	8	784
E113O0	2238	1474.517	659.9923	5	2291
E114O0	2283	1245.636	623.7366	2	2518
E116N0	2143	596.2128	367.4823	2	1114
E116S0	2143	881.6351	570.2441	10	1781

Bicycle Path Flows (7 cycle paths)

Bike path	No. Obs.	Mean	St. Dev.	Min	Max
ANDRES BELLO	103	3290.049	847.1138	167	4702
ANTONIO VARAS	103	1997.922	539.9798	150	2925
BUSTAMANTE	101	1952.941	497.9223	166	3224
MARIN	103	2015.495	481.805	182	2716
MIGUEL CLARO	24	1168.958	346.8284	172	1585
POCURO	103	3643.777	1073.48	235	5424
RICARDO LYON	103	2754.932	622.1203	268	3719

Vehicle Flows by Costanera Norte Entryway (9 entryways)

Entryway	No. Obs.	Mean	St. Dev.	Min	Max
P2.1OP	2472	1477.428	1182.589	25	4819
P2.1PO	2472	1699.021	1253.011	23	4530
P22OP	2472	1281.346	1113.371	18	4965
P22PO	2472	1284.51	944.5274	22	3878
P3O-P	2472	2429.212	1666.436	57	5443
P3PO	2472	3372.732	2251.743	90	6764
P4P-O	2472	2631.523	1757.78	56	5524
P5O-P	2472	1609.935	1002.383	87	4192
P5P-O	2472	1693.165	1046.233	69	4089