Journal of Business and Economics, ISSN 2155-7950, USA
November 2020, Volume 11, No. 11, pp. 1255-1262
DOI: 10.15341/jbe(2155-7950)/11.11.2020/007

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Analysis of the Policy to Reduce Ozone Emissions in Mexico City

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Abstract: This paper analyzes the effectiveness of the policy to reduce and control tropospheric ozone emissions in Mexico City. We analyze the institutional structure of this policy, which consists of restricting the circulation of some vehicles according to the rate at which they emit certain pollutants, but does not seek to determine the social cost of those emissions. The empirical estimation of maximum concentrations of ozone concerning the determinants indicated by the three official programs of this policy shows that the factors of the environment (maximum temperature mainly, and to a lesser degree rainfall), explain the formation of this gas, while gasoline and diesel consumption are not significant determinants of it. We concluded that the policy is ineffective in achieving its objectives of reducing and controlling ozone pollution. The reevaluation of Mexico City development policy is required to address environmental pollution issues.

Key words: local government; environmental health and safety; air pollution; emission control

JEL codes: H700, Q510, Q530, Q580

1. Introduction

The objective of this work is to study the effectiveness of the Mexico City government policy to control the environmental pollution generated by the mobile sources that circulate in the city and its conurbation area. This policy is established in a wide range of legislation and operates primarily through the three programs analyzed here. To achieve the proposed objective, the following section presents a review of the literature on the programs that restrict vehicular traffic in Mexico City. Section 3 analyzes the institutional structure to regulate the environmental pollution produced by motor vehicles in Mexico City. In particular, it examines whether the content and linkage of the three programs as well as the and the Mexican Official NORM NOM-020-SSA1-2014 can identify some social cost of pollutants monitored by the Ministry of the Environment of Mexico City. Section 4 presents the empirical analysis, which runs from January 2008 to July 2016, finds that the generation of ozone, measured by the maximum values at IMECA air pollution index points, of this pollutant (which trigger the activation of environmental contingencies program), follows a stationary behavior, so, any intervention of public policy can only, at best, modify emission levels in the short term but in the long run, the mean and variance of the series will not be altered. The consumption of gasoline and diesel, measured by the volume of sales in cubic meters in the same period, also shows a stationary behavior. This situation contrasts with the significant increase in the number of motor vehicles registered in Mexico City during the period. This apparent contradiction suggests that the increase of vehicles has been made to avoid the restrictions on the circulation of the vehicles determined

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by the programs analyzed here because this does not translate into greater consumption of fuels. Thus, in estimating the generation of ozone, according to the approaches of the three programs, it is found that temperature, and to a lesser extent rainfall, are significant determinants in the formation of this pollutant, while consumption of gasoline and diesel are not. This evidence shows that vehicle pollution control programs are ineffective, since the maximum ozone values remain, on average, constant during the period. Section 5 presents the final comments.

2. Literature Review

Previous research found unexpected and contradictory effects on the purposes of the program: greater car use without increases in the use of public transport and no impact on pollutant emissions. Davis (2008), using several periods previous to 2005, finds no evidence to claim that the program has improved air quality in Mexico City. Nor does he find evidence that car drivers have replaced the use of their vehicles by greater use of other forms of transport of low emission of pollutants. On the contrary, the author finds evidence of an increase in car sales and registered cars in Mexico City. Davis (2017) finds that the expansion of the "Hoy No Circula" program to include Saturdays does not generate a significant reduction in the levels of eight pollutants monitored by the Mexico City Environment Ministry. Eskeland, G., and Feyzioglu (1997) found that the program turned cars into "driving licenses" so that households could purchase an additional car to increase their "permits" to drive, which increased the use of old cars and increased traffic during the week and weekends. Gallego et al. (2013), using hourly concentrations of carbon monoxide, found that programs to restrict the circulation of automobiles in Mexico City and Santiago de Chile have, in the short term, caused an increase in the number of vehicles and pollution levels in the environment.

3. The Institutional Structure of the Policy to Regulate Atmospheric Pollution Produced by Automotive Vehicles in Mexico City

Although this policy has a more complex structure, in this paper we will limit ourselves to analyze the *Mandatory Vehicle Verification, Hoy No Circula, and Atmospheric Environmental Contingencies* programs, as well as the Official Mexican NOM-020-SSA1-2014.

Thus, the Hoy No Circula Program limits the circulation of vehicles that, according to the Compulsory Vehicle Verification Program, have a poor environmental performance according to the rate of their pollutant emissions, since according to the program of Atmospheric Environmental Contingencies these emissions have a harmful effect on health. Mexican Official NORM NOM-020-SSA1-2014 defines that pollutants have a threshold effect for ozone; i.e., the negative effects of that gas on health start from the concentrations indicated by the norm, lower concentrations appear to be innocuous (according to the Norm).

This scheme presents the following inconsistencies. First. The verification program measures, every six months, the emission rates of hydrocarbons, carbon monoxide, nitrogen oxides, the sum of monoxide and carbon dioxide ($CO + CO_2$) and oxygen from motor vehicles, but the contingency program is set up according to concentrations of ozone and PM10 particles recorded in the atmosphere at some point in a day. Although NOM-020-SSA1-2014 indicates that the generation of ozone depends on the emissions of nitrogen oxides and hydrocarbons, it also points out that other factors such as solar radiation and the environment are determinants of ozone generation [ozone = f (nitrogen oxides, hydrocarbons, and solar and environment radiation)], but nitrogen oxides are two gases, nitrogen dioxide (NO_2), which acts as a precursor in the *formation* of ozone and nitric oxide

(NO), that acts as precursor in the *destruction* of ozone. Girard (2005). Second. By measuring only pollution rates, the Compulsory Vehicle Verification Program does not measure the pollution volumes of each motor vehicle, so it cannot identify the social cost of such emissions. Measuring these costs is a necessary condition to establish a policy that can actually "*prevent, minimize and control the emission of pollutants from mobile sources circulating...*" according to the objective of the Hoy No Circula program. Third. By not measuring the volumes of pollution emitted by motor vehicles, it is not possible to know the effect that said emissions have on "health". Fourth. Although the volume of pollution of each motor vehicle were known, since "health" is not defined or quantified, it is not possible to establish, identify or quantify the — adverse — effects of pollution on "health", that is, the policy does not allow to identify the social cost of ozone pollution that automobiles indirectly "emit" on health. Fifth. Accepting that the emission of pollutants (especially ozone and PM10) into the atmosphere has a negative effect on "health", even if it is not measured, then an empirical analysis of the trajectory of the concentrations of these pollutants is required to determine if the public policy contained in the documents analyzed here has managed to reduce the concentrations of pollutants emitted into the atmosphere and then, even by mere association, to accept that it has had an effect on "health". Although it is not possible to determine the meaning of this effect since the norm NOM-020-SSA1-2014 contradicts itself in that pollution has both, increased and decreased at the same time.

Thus, to prevent, minimize and control the emission of pollutants, the Hoy No Circula Program is applied, which limits the circulation of vehicles that, according to the Compulsory Vehicle Verification Program, have a poor environmental performance giving the result of the verification of their pollutant emissions, since according to the program of Atmospheric Environmental Contingencies these emissions harm health. Mexican Official NORM NOM-020-SSA1-2014 defines that pollutants have a threshold effect for ozone; i.e., the negative effects of that gas on health start from the concentrations indicated by the norm, lower concentrations appear to be innocuous (according to the Norm).

4. Empirical Analysis

The Official Mexican Norm NOM-020-SSA1-2014 states that "health" is a function of ozone and other atmospheric pollutants and in turn that the formation of ozone, which does not come directly from internal combustion engines, is a function of some of the emissions of these and other factors. The effect of ozone on health and the effect of car pollution on ozone creation, could be estimated by a simultaneous equations model. But while there are daily and even hourly measurements for concentrations of pollutants in the atmosphere, there is no similar information to measure "health" daily, much less in hourly, terms.

As mentioned above, there is no data or definition corresponding to the concept of "health" so in this work it will be assumed that in some way the effect of ozone on health is fulfilled, then, only the effect of car pollution on ozone creation will be estimated to analyze the behavior over time of ozone concentrations in Mexico City and to determine if there are changes in the indicated concentrations and whether these changes can be connected to the programs analyzed here.

The Data. The Ministry of the Environment of Mexico City publishes, in IMECA index, the maximum hourly and daily concentrations of ozone, among other pollutants, in five regions of the city; Northwest (No), Northeast (Ne), Center (Ce) Southwest (So) and Southeast (Se). CONAGUA (Federal Government Water Commission) provides rainfall data measured in total accumulated concentrations per month in mm and the average monthly maximum temperature of the Mexico City. The Ministry of Energy presents the volume of sales of gasoline and diesel in cubic meters per month in Mexico City. For the empirical analysis of this work, the monthly average of the maximum daily concentrations of ozone in each zone is taken since the maximum concentrations determine the activation of the environmental contingencies according to the corresponding program.

Tables 2 and 3 present results from the Diky Fuller test for ozone and PM10 emissions for each of the five regions examined respectively. The tests were repeated even with 6 delays, and in all cases, the same result was obtained: the null hypothesis is rejected. There is no evidence to accept that the series are non-stationary. The same test was applied to other reported contaminants (sulfur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO)) and similar results were obtained and omitted.

Table 2 Results of the Diky Fuller Test for Ozone Emissions

Zones	Statistical value ofTest (z_t)	Critical value at 1%	MacKinnon P-valuefor (z_t)
Northwest	-29.980	-3.430	0.0000
Northeast	-28.238	-3.430	0.0000
Center	-29.577	-3.430	0.0000
Southwest	-29.366	-3.430	0.0000
Southeast	-30.444	-3.430	0.0000

Source: own elaboration with data of the Ministry of the Environment of the City of Mexico. n = 3117

Table 3 Diky Fuller Test Results for PM10 Particle Emissions

Zones	Statistical value ofTest (z_t)	Critical value at 1%	MacKinnon P-valuefor (z_t)
Northwest	-14.602	-3.430	0.0000
Northeast	-16.956	-3.430	0.0000
Center	-14.737	-3.430	0.0000
Southwest	-16.889	-3.430	0.0000
Southeast	-14.910	-3.430	0.0000

Source: own elaboration with data of the Ministry of the Environment of the City of Mexico. n = 3117

As for ozone determinants, since the amount of pollutants generated by motor vehicles is not established by the Vehicle Verification Program measurements, only their rate is measured as explained above, the volume of sales of gasoline and diesel is used to approximate the volume of pollutants. The number of cars registered in the City is not used because it is not possible to determine how many of the registered cars circulate, or in what periods they do. The data from the State and Municipal Database System (SIMBAD) of INEGI provide the number of motor vehicles registered by Municipality. On the other hand, the number of cars registered in the City shows a significant growth in the study period, so the Dicky Fuller test, which is done by adding a trend term for this variable, does not provide evidence to accept that this series is stationary (that is, their mean and variance are constant over time). As for the other determinants of ozone formation, environmental conditions, the monthly averages of the maximum temperature in °C and rainfall, measured in mm, are used. Table 4 shows the corresponding results from the Dicky Fuller test.

Except for the number of registered cars, there is no evidence to accept that the other series are non-stationary. According to Enders (1995), a stationary series has a constant mean and variance in the long run, so a policy intervention (such as Hoy No Circula and the Atmospheric Environmental Contingencies) can only have a transitory effect in the short term, which will disappear in the long run. On the other hand, a policy intervention will change the mean and variance of the series in the short and long terms in a non-stationary series, such as the number of motor vehicles in Mexico City. When analyzing the ozone time series published by the Mexico City

Environment Department, it is observed that the maximum daily concentrations of ozone recorded in each of the five zones of the city (Northwest, Northeast, Center, Southwest, and Southeast) follow a stationary behavior, which means that the corresponding public policy has not changed, nor can it change its mean or its variance in the long term.

Table 4 Results of the Diky Fuller Test for the Series of Rain, Maximum Temperature, Gasoline, Diesel, and Cars in Mexico City

Variables	Statistical value ofTest (z_t)	Critical value at 1%	MacKinnon P-valuefor (z_t)
Rainfall	-4.192	-3.509	0.0007
Maximum Temperature	-5.269	-3.509	0.0000
Gasoline	-10.001	-3.509	0.0000
Diesel	-6.803	-3.509	0.0000
Cars	-2.546	-3.160 (critical value at 10%)	0.3051

Source: own elaboration with data from CONAGUA, Secretaría de Energía (n = 102) and INEGI (n = 83)

Estimation. The Mexico City government's policy to reduce environmental pollution caused by motor vehicles known as the "Hoy No Circula" Program, defines the determinants of ozone formation and it is specified in this section. The dependent variable is Oit, the ozone in region i during period t. Where i are five regions in which the City is divided, Northwest, Northeast, Center, Southwest, and Southeast and t has a monthly frequency that runs from January 2008 to July 2016. According to (1), Oit is a function of Y a vector of environmental variables defined by the average monthly rainfall in the city measured in mm (rainfall) and the average maximum monthly temperature in the city measured in °C (tempmax), as well as a vector of variables of precursors of the formation of ozone X defined by the monthly sales of gasoline and diesel in the City.

The model to be estimated is:

$$Oit = Yit\alpha i + Xit\beta i + \varepsilon it \tag{1}$$

The independent variables in Y and X are the same for the five regions, but the parameters and residues are specific for each region (α, β, ε). Since both the dependent variable, the maximum values of ozone, and its determinants: use of fuels and environmental conditions, present stationary behaviors, it is possible to use the Ordinary Least Squares method to estimate the effect of these determinants on the dependent variable. The results are presented for each of the five geographic regions of Mexico City in Table 5.

Table 5 Determinants of Ozone, O_{it}, Expression (3), by Region of Mexico City

	Northwest	Northeast	Center	Southwest	Southeast
rainfall	-0.0394** (-2.87)	-0.0857*** (-5.67)	-0.0386* (-2.58)	-0.0113 (-0.72)	-0.0271 (-1.91)
tempmax	5.326*** (12.53)	4.570*** (9.79)	5.873*** (12.69)	6.256*** (12.87)	5.157*** (11.72)
gasoline	-0.0000220 (-0.54)	-0.0000832 (-1.84)	0.00000747 (0.17)	0.0000608 (1.29)	0.0000433 (1.02)
diesel	0.000157 (1.65)	0.000112 (1.07)	0.0000157 (0.15)	-0.0000247 (-0.23)	0.0000394 (0.40)
_cons	-57.22* (-2.58)	-1.055 (-0.04)	-66.41** (-2.75)	-90.52*** (-3.57)	-66.46** (-2.89)
N	103	103	103	103	103
R-sq	0.661	0.597	0.648	0.645	0.610
F Prob >F	0.0000	0.0000	0.0000	0.0000	0.0000

t statistics in parenthesis

*p < 0.05, ** p < 0.01, *** p < 0.001

To eliminate autocorrelation problems of type AR(1) that could be presented due to the use of time series, it was estimated (5) again under the Prais-Winsten correction. The results are presented in Table 6. When estimating the Durbin-Watson statistic for n = 103 and k = 5, lower and upper critical values of 1.441 and 1.647 respectively are obtained.

Table 6 Determinants of Ozone, O_{it}, (Expression 3) by Region of Mexico City with Correction by First-order Autocorrelation

	Northwest	Northeast	Center	Southwest	Southeast
rainfall	-0.0299 (-1.86)	-0.0603** (-3.37)	-0.0304 (-1.76)	-0.00959 (-0.53)	-0.0263 (-1.78)
tempmax	5.428*** (11.93)	4.732*** (9.52)	5.699*** (11.30)	6.190*** (11.72)	5.152*** (11.38)
gasoline	-0.0000226 (-0.59)	-0.0000362 (-0.88)	-0.00000251 (-0.06)	0.0000388 (0.84)	0.0000404 (0.94)
diesel	0.0000963 (0.95)	0.0000425 (0.39)	0.0000274 (0.24)	0.00000383 (0.03)	0.0000432 (0.43)
_cons	-52.29** (-2.76)	-20.95 (-1.03)	-59.06** (-2.65)	-81.54*** (-3.44)	-65.43** (-2.86)
N	103	103	103	103	103
R-sq	0.641	0.566	0.600	0.605	0.596
F Prob >F	43.72	31.97	36.68	37.48	36.16
Original Durbin-Watson Statistic	1.156560	1.139427	1.379247	1.436707	1.85273
transformed Durbin-Watson Statistic	2.078755	2.020961	2.015732	2.0278424	1.970905

t statistics in parenthesis
* p < 0.05, ** p < 0.01, *** p < 0.001
Durbin-Watson critical values (5,103): $d_L = 1.441$, $d_U = 1.647$.

5. Results

Tables 5 and 6 show that environmental conditions are the main determinants of ozone formation in the five regions of Mexico City analyzed here. In all cases, the coefficients of the maximum temperature are statistically significant at 99% confidence. These coefficients indicate that for each centigrade that the temperature increases, ozone increases between 4.73 and 6.19 IMECA points depending on the region (Table 6). The effect of rain on ozone formation is small in magnitude and not significant. In Table 5 rainfall appears to have a negative effect on the Northwest, Northeast, and Central regions, but once the correction is performed by autocorrelation, Table 6, only in the Northeast region has a significant effect at 95% confidence. For each additional mm of rain, the generation of ozone is reduced by 0.06 IMECA points. On the other hand, the consumption of gasoline and diesel has zero effect on the generation of maximum levels of ozone, in all cases on both tables the coefficients have a magnitude close to zero and in all cases are statistically no significant. The variable used to measure fuel consumption is the monthly volume of sales in cubic meters in both cases. The estimates in Table 6 were repeated including a lag for gasoline and diesel. Both fuels with and without lag remained non-significant.

These results are not surprising because the set of programs analyzed here does not encourage the population to reduce gasoline consumption and since fuel consumption has remained stationary during the study period, ozone generation has not increased but it has not decreased either. The policy to regulate the pollution of ozone produced by motor vehicles in Mexico City at no time determines or identifies the social cost generated by the users of vehicles with internal combustion engines, therefore, at no time proposes a mechanism that encourages the agents who generate pollution to pay the social cost of their actions. (To internalize the externality they generate). This policy has as its only instrument to limit the circulation of internal combustion vehicles regardless of the volume of emissions they generate. But the results suggest that the policy has only encouraged the increase in the City's vehicle fleet, an increase that has been tested by Eskeland, G., and Feyzioglu (1997), Davis (2008) and Gallego et al. (2013).

Therefore, it is possible to conclude that the policy to regulate the pollution of ozone produced by motor vehicles in Mexico City is ineffective to achieve the objectives of preventing, minimizing, and controlling the emission of ozone.

6. Final Remarks

The institutional structure of the policy to regulate and reduce the ozone pollution generated by motor vehicles in Mexico City, as well as the empirical evidence, do not allow to affirm that the following objectives are being fulfilled: Prevent and control the emission of air pollutants (ozone in particular) and reduce adverse effects on population health. Monitor the environmental performance of vehicles. Prevent, minimize, and control the emission of pollutants (ozone in particular) from mobile sources in circulation.

The policy does not seek to determine the social cost of pollution generated by each vehicle, only seeks to reduce the circulation of some of them and takes as a criterion the rate at which various pollutants are emitted but at no time determines, with any of its programs, the volume of pollutants emitted by each vehicle. The policy also does not define a concept of "health" and therefore cannot quantify the effects of pollutant emissions on health. In the study period, which covers eight years, there is no increase, but neither a reduction in the maximum levels of ozone nor a rise in the long-term sales volumes of gasoline and diesel. On the other hand, the number of registered motor vehicles increases significantly. To establish effective policy measures in solving the problem of environmental pollution in the City, it is necessary to incorporate the root causes in the analysis. The causes of air pollution in Mexico City are deeper than those indicated in the programs analyzed here. The number of motor vehicles in circulation is only an effect of more complex situations.

Mexico City (but not all its conurbation area) enjoys the highest levels of life quality in the country. It has the largest concentration of educational institutions, basic and higher level, the largest and most modern hospitals, concentrates the main financial institutions. Public transportation is the largest and cheapest in the country. For a long time, the federal and city governments have granted multiple subsidies to a large part of the population in the consumption of goods and services such as water, transportation, real estate deeds, support to the elderly, as well as students of basic education, among others. All these benefits generate an important attraction to settlers of other federative entities that migrate to the City looking to enjoy its advantages and services. The problem is that population density and high standard of living have resulted in a significant increase in land and housing prices, which means that many of the inhabitants of the City have to establish themselves in the conurbation municipalities of neighbors states (mainly the State of Mexico) where the prices of the house are more accessible, creating a strong demand for basic services, especially transportation. Although most of the population of the Metropolitan Area of Mexico City lives in the surrounding municipalities of the State of Mexico, it has very limited means of transportation compared to the inhabitants of the city; for example, of the 195 stations of the System of Collective Transportation (Metro), 184 are in the city (with a population around 9 million people) and 11 stations in the surrounding municipalities of State of Mexico (with a population around 13 million people).

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