RESEARCH ARTICLE

Pollution and Mobility in the Mexico City Metropolitan Area in Times of COVID-19

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ABSTRACT

This paper analyzes the relation between COVID-19, air pollution emissions, and mobility in the Mexico City Metropolitan Area. We test if the restrictions to economic activity introduced to mitigate the spread of COVID-19 are associated with a structural change in air pollution levels and mobility. Our results show that mobility in public transportation was significantly reduced following the government's recommendations. Nonetheless, the reduction in mobility was not accompanied by a reduction in air pollution. Moreover, Granger-causality tests show that the precedence relation between mobility and air pollution disappeared as a product of the restrictions. Thus, our results show that air pollution in the MCMA seems primarily driven by industrial activity. In this regard, governments should redouble their efforts to develop policies aimed at reducing industrial pollution.

KEYWORDS

COVID-19; structural change; pollution; mobility; public transport.

JEL Classification: I18, C12, C22.

1. Introduction

The COVID-19 pandemic is one of the most serious health crisis in recent memory. The official death toll around the World surpassed 1 million as of September 29, 2020. Considering reporting problems in some countries and that the pandemic is still not under control, the true death toll may not be known for several years.

To slow the rate of infection, countries around the world imposed restrictions on economic activity. Most of the restrictions can be motivated by the early results from the rate of infection in Wuhan, China; see Kraemer et al. (2020), Prem et al. (2020). The restrictions on economic activity resulted in mass unemployment and reductions to GDP across the World. If the current pandemic follows similar dynamics as previous events, the economic effects may be felt even in the long-run, see Rodríguez-Caballero and Vera-Valdés (2020). In this context, assessing the effect of economic restrictions on mobility and pollution emissions is of great importance.

We add to the literature by testing if the economic restrictions introduced a structural change in mobility in the Mexico City Metropolitan Area (MCMA, hereinafter). In particular, we test if the number of passengers in the MCMA public transit system suffers a statistically significant change due to the economic restrictions due to COVID-19. The MCMA is an interesting case due to its high population density and the high number of workers in the informal sector. We find a statistically significant reduction in the number of passengers in both the subway system (Metro, hereinafter) and the bus rapid transit system (Metrobus, hereinafter). Moreover, our results show that the number of cyclists at several stations across the MCMA suffered a significant decrease. Thus, our results suggest that a large share of the inhabitants of the MCMA stopped using public transit during this period signaling a decrease in mobility. These results are in line with the ones from Badr et al. (2020), and Cartenì, Di Francesco, and Martino (2020) for the US and Italy.

In connection with the structural change in mobility, this paper tests if the restrictions resulted in lower air pollution in the MCMA. The evidence of the effect that restrictions have on pollution levels across the world is mixed. Significant reductions in Nitrogen Dioxide (NO2, hereinafter) are encountered in, among others, Brazil, India, and Spain; see Baldasano (2020), Shehzad, Sarfraz, and Shah (2020), and Nakada and Urban (2020). However, Adams (2020) finds that Particle Matter 2.5 (PM 2.5, hereinafter) levels did not change in response to a region-wide state of emergency in Ontario, Canada. Meanwhile, Berman and Ebisu (2020) found some small declines in PM 2.5 levels in the US, but the results differ significantly between urban and non-urban counties. The authors argue that the different effects of economic restrictions between NO2 and PM 2.5 may be explained by the fact that multiple non-transportation sources, including emissions from food industries and biomass burning, contribute to PM 2.5 levels. In this regard, they argue for more research on the impacts of the COVID-19 pandemic on industrial sourced pollutants. Moreover, Wang et al. (2020) find that severe air pollution events still occurred in most areas in the North China Plain even after all avoidable activities in China were prohibited on January 23, 2020.

Thus, this paper tests the effects that the economic restrictions had on air pollution in the MCMA. We measure air pollution in terms of PM 10 (fine inhalable particles with diameters of 10 micrometers and smaller), PM 2.5 (inhalable particles with diameters of 2.5 micrometers and smaller), and SO2 (sulfur dioxide). Our results show an overall decreasing trend in pollution levels in the MCMA throughout the years. Nonetheless, no statistically significant change is detected due to the economic restrictions imposed due to COVID-19. Moreover, Granger-causality tests show that the precedence of mobility on air pollution almost vanished during the period of economic restrictions.

The results from this analysis could help in designing policies aimed to reduce pollution levels in the MCMA. In particular, structural changes in mobility in the public system do not seem to be associated with changes in air pollution levels. In this regard, our results suggest that tackling air pollution requires policies specifically aimed at reducing pollution in the industrial sector.

This article proceeds as follows. The next section presents the data used in this study. Section 3 analyzes if the restrictions introduced due to COVID-19 resulted in structural changes in air pollution levels and mobility in the Mexico City Metropolitan Area, while Section 4 presents results from Granger-causality tests between mobility and air pollution in times of COVID-19. Section 5 concludes.

2. Data

The data comes from Mexico City's data repository available online at datos.cdmx.gob.mx. We gathered data on air pollution (PM 10, PM 2.5, and SO2) levels at all stations and the number of passengers at all Metro and Metrobus stations. Moreover, we gathered data on the number of cyclists at several data collection stations. The data is updated to July 31, 2020, and it covers several years.

The data presents several missing observations and some outliers that we clean first.

Outliers were detected in a few observations of the Metro lines and the number of cyclists. A few observations (no more than 10 in total) show a thousand-fold increase compared to the rest. We attribute these differences to errors at capturing the data. We remove the outliers and impute them using observations in close proximity. It is worth pointing out that the small proportion of imputed outliers do not qualitatively alter the results.

Missing data are reported for some of the air pollution measuring stations. The missing values seem to have randomly occurred for some days. Given the vast amount of information, we construct daily indexes for the air pollution measured in the MCMA. The construction of the index is motivated by the strong correlation that exists across air pollution-measuring stations; see Figure A2 in Appendix A. In this regard, missing observations are smoothed out by the construction of the index.

Moreover, the number of cyclists at all stations is not reported from October of 2019 to February of 2020. We attribute these missing observations to an administrative error. Thus, the missing observations for the number of cyclists cannot be considered to be completely at random. Given the number of missing observations for the number of cyclists and the non-random nature of them, we decided to merge the two subsamples and use this data only as a robustness exercise.

Furthermore, we remove weekends and holidays given the strong seasonal effect in the number of passengers in the public transit system and the number of cyclists.

The complete datasets are available in the corresponding author's GitHub repository at: github.com/everval.

3. Structural Changes Due to COVID-19

This section uses the time series defined in Section 2 to test if restrictions imposed to mitigate the spread of COVID-19 affected pollution and mobility levels in the MCMA.

The Mexican Government established "La Jornada Nacional de Sana Distancia" (JNSD, hereinafter) on March 23, 2020; see Secretaría de Salud (2020). The plan established four measures to mitigate the effects of COVID-19 on the general population. The actions considered were:

(1) Personal hygiene recommendations.
(2) Suspension of activities deemed non-essential.
(3) Postponement of mass gathering events (more than 5,000 participants).
(4) Guidelines for care of the elderly.

The goal of the plan was to impose social distancing measures and slow the spread of the virus. The preventive measures ended on May 30, 2020. This section uses JNSD as a natural experiment to test if the restrictions introduced structural changes in pollution and mobility.

As a first step, we test the series for a unit root using the standard test by Dickey and Fuller (1979). All specifications of the Dickey-Fuller tests regarding drift and trend reject the null of a unit root in the data. Moreover, given that the construction of the indexes involved aggregation, we estimate the fractional difference parameter for the series; see Granger (1980); Haldrup and Vera-Valdés (2017). To avoid the effect of the specification of the mean to affect the results, we use semiparametric estimators in the frequency domain; see Geweke and Porter-Hudak (1983), and Andrews and Guggenberger (2003). All tests find the data to be stationary. Note that to avoid spurious results due to the possible structural change, all stationarity tests considered only the 2017 to 2019 subperiod; see Martínez-Rivera, Ventosa-Santaulària, and Vera-Valdés (2012). Detailed results from the unit root and fractional integration tests are available upon request.

Once we have guaranteed that our data is stationary, we consider the following specification to test for a structural change:

$$y_t = \alpha_0 + \beta_0 t + \alpha_1 DU_t + \beta_1 DT_t + \epsilon_t, \tag{1}$$

where y_t is the pollution or mobility measure, and $t = [1, 2, \cdots, T]'$, with T the sample size. Furthermore, DU and DT are dummy variables that model the possible structural change due to JNSD. That is, $DU = [0, \cdots, 0, 1, \cdots, 1]'$, and $DT = [0, \cdots, 0, 1, 2, \cdots, T_1]'$, where the non-zero elements start in March 23, 2020, and T_1 is the size of the subsample after that date. We test for a change in level if $\alpha_1 \neq 0$, and for a change in both level and trend if $\alpha_1 \neq 0$ and $\beta_1 \neq 0$.

The test for structural change proceeds as follows:

- Estimate the unrestricted model, Equation (1), and recover the residual sum of squares, $URSS$.
- Estimate the restricted model, Equation (1) with $\alpha_1 = 0$ and $\beta_1 = 0$, or $\beta_1 = 0$, and recover the residual sum of squares, $RRSS$.
- Compute the test statistic for the null hypothesis of no structural change by

$$F = \frac{(RRSS - URSS)/r}{URSS/(T - k)},$$

  where T is the sample size, k is the number of parameters in the unrestricted model, and r is the number of restrictions.
- The test statistic follows a F distribution with r and $T - k$ degrees of freedom.

In the following, we test for a structural change in mobility via public transport systems and air pollution levels in the MCMA.

3.1. *Mobility Data*

Figure 1 presents the mobility indexes for Metro, Metrobus, and Cyclists. The data ranges from 2017 to July 31, 2020. The shaded region contains the period considered in JNSD. Also plotted are the estimates from the linear model in Equation (1). We allow for both a change in level and a change in level and trend at the start of the JNSD. As can be seen from the figure, the mobility indexes' dynamics change significantly due to JNSD. Nonetheless, note the large number of missing values for the index on the number of cyclists. In this regard, the results from the Cyclists index should be taken as a robustness exercise.

Table 2 presents the estimates from Equation (1), allowing for a change in level and a change in level and trend, and the results form the structural change test. The table presents some interesting findings.

First, note the different results regarding the trend coefficient, β_0. There is no significant trend in the number of Metro users, while a significant but small positive trend in Metrobus users over the last 3 years. The Cyclists index shows a significant small increasing trend, but the large number of missing values should be considered before any statistical certainty can

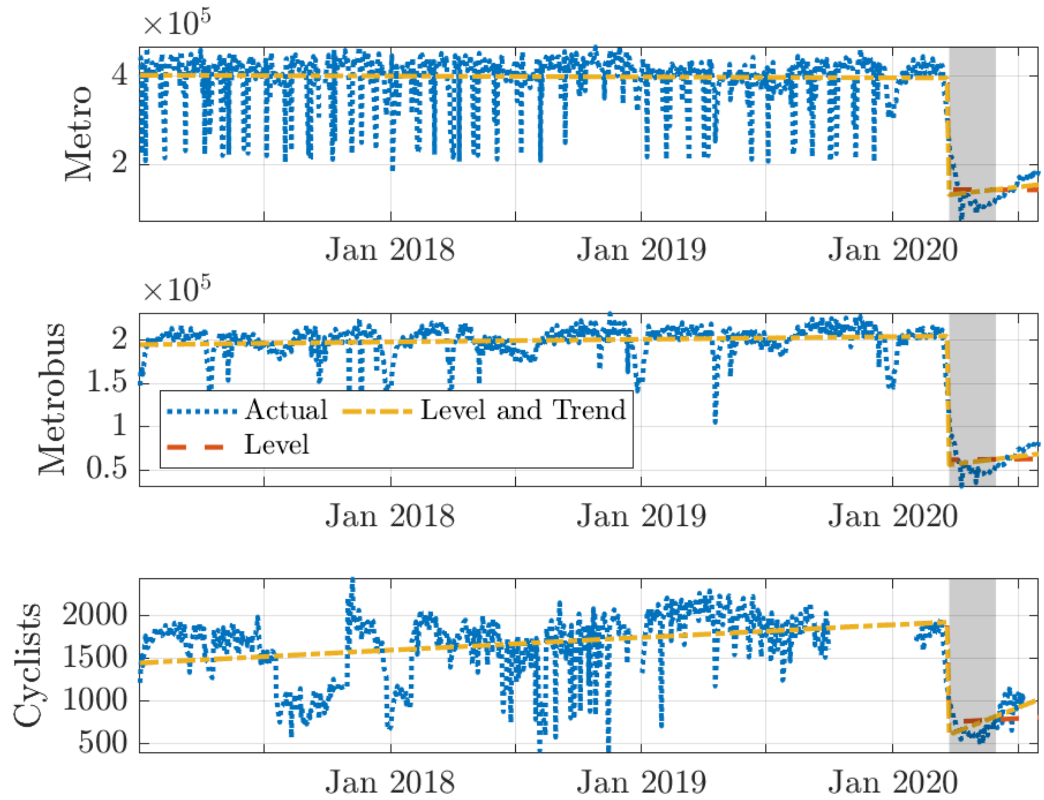

Figure 1. Mobility indices in the Mexico City Metropolitan Area. The figure shows actual values (dotted blue) along with fitted values from the linear models with a change in level (dashed orange) and change in level and trend (dashed-dotted yellow). JNSD is shown in the shaded area.

Mobility	Change in level				Change in level and trend				
	α_0	β_0	α_1	F	α_0	β_0	α_1	β_1	F
Metro	$4(10^5)$	-7.488	$-3(10^5)$	1384	$4(10^5)$	-7.904	$-3(10^5)$	255	693
p-values	0	0.353	0	0	0	0.327	0	0.201	0
Metrobus	$2(10^5)$	12.260	$-1(10^5)$	4975	$2(10^5)$	12.061	$-1(10^5)$	123	2496
p-values	0	0	0	0	0	0	0	0.039	0
Cyclists	1448	0.593	-1171	552	1450	0.589	-1322	3.826	280
p-values	0	0	0	0	0	0	0	0.024	0

Table 1. Unrestricted equation estimation and structural change test.

be discussed. Nonetheless, the results suggest that more people use public transit systems in the MCMA in the last years.

Second, note the statistically significant change in the level associated with JNSD for all indexes. These results are in line with the ones from Badr et al. (2020), and Cartenì, Di Francesco, and Martino (2020) for the US and Italy. For the MCMA, the structural change is quite large. All indexes more than halved during JNSD. That is, most users seem to have followed the Government's recommendations during JNSD and avoided the public transport system. Given the lack of data on the number of private cars and the number of passengers in them, we cannot directly extrapolate this result to state that people remained at home during JNSD. Nonetheless, the change in level is so large that there seems to be some suggestion that this was indeed the case to a certain degree. Furthermore, as a robustness exercise, Table A1 in Appendix A reports the results from the structural change test for all Metro and Metrobus lines individually and for the number of cyclists reported at several points in the MCMA. The results from the robustness exercise are in line with the ones for the indexes.

Finally, note the positive and statistically significant trend coefficient after JNSD for the Metrobus and Cyclists indexes. The estimators point to an increasing number of public transport users during JNSD and the period directly after. The increasing trend is particularly apparent for the Cyclists index. This may relate to the notion of cycling being a less risky option of transport than the closed space offered by the Metro and Metrobus systems. This line of inquiry is left open for future research.

3.2. *Pollution Data*

Figure 2 presents the air pollution indexes. The figure shows PM 10, PM 2.5, and SO2 levels from 2017 until July 31, 2020. The shaded region contains the period considered in JNSD. Also plotted are the estimates from the linear model in Equation (1). We allow for both a change in level and a change in level and trend at the start of the JNSD. As shown in the figure, the air pollution levels' dynamics do not seem to significantly change due to JNSD.

Furthermore, Table 2 presents the estimates from Equation (1), allowing for a change in level and a change in level and trend, and the results form the structural change test. The table presents some interesting findings.

Pollutant	Change in level				Change in level and trend				
	α_0	β_0	α_1	F	α_0	β_0	α_1	β_1	F
PM 10	4.412	-0.007	-1.322	1.102	4.429	-0.007	-2.681	0.021	0.849
p-values	0	0	0.294	0.294	0	0	0.215	0.440	0.428
PM 2.5	1.806	-0.003	-1.431	3.151	1.805	-0.003	-1.384	-0.001	1.574
p-values	0	0	0.076	0.076	0	0	0.318	0.967	0.208
SO2	1.027	-0.002	-0.028	0.006	1.029	-0.002	-0.157	0.002	0.039
p-values	0	0	0.936	0.936	0	0	0.792	0.789	0.962

Table 2. Unrestricted equation estimation and structural change test.

First, the estimates show a significant decreasing trend for all pollutants across the period considered. Nonetheless, the estimates from the trend parameter are quite small. That

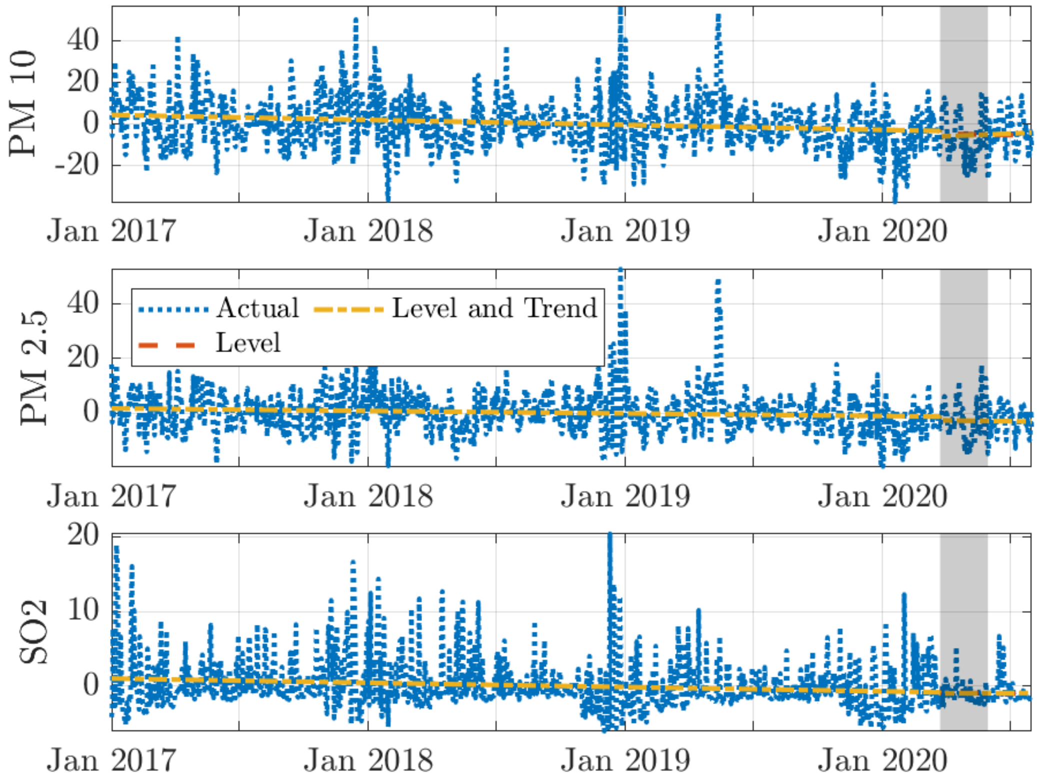

Figure 2. Pollution indices in the Mexico City Metropolitan Area. The figure shows actual values (dotted blue) along fitted values from linear model with a change in level (dashed orange) and change in level and trend (dashed-dotted yellow). JNSD is shown in the shaded area.

is, pollutant levels have been decreasing through the years, but the decrease seems to be occurring at quite a slow pace.

Second, note that the null of no structural change is not rejected for both tests. That is, the restrictions imposed by JNSD do not seem to be associated with a lower level of air pollution. These results are in line with the ones reported by Adams (2020) for Ontario, Canada. The authors find no significant reduction in PM 2.5 due to restrictions imposed due to COVID-19. Wang et al. (2020) find that severe air pollution events still occurred in most areas in the North China Plain even after all avoidable activities in China were prohibited on January 23, 2020. Moreover, Berman and Ebisu (2020) found some small declines in PM 2.5 levels in the US, but the results differ significantly between urban and non-urban counties.

Third, JNSD can be considered a natural experiment regarding public transport usage on air pollution. The lack of structural change during JNSD, coupled with the significant decrease in the mobility indexes, points to a non-significant effect of the number of users of the public transport system in the MCMA on pollution. As argued before, this may relate to a higher number of private cars during JNSD or to a much more significant effect of industry on air pollution. Thus, these results suggest that tackling air pollution in the MCMA requires specific policies to reduce industry-associated pollution, particularly in light of the positive willingness to pay for clean air by inhabitants of the MCMA; see Rodríguez-Sánchez (2014); Filippini and Martínez-Cruz (2016), and Fontenla, Ben Goodwin, and Gonzalez (2019). To properly assess the relationship between public transport and air pollution, the next section uses the Granger-causality test to assess if there exists a relation of precedence between them. Furthermore, we test if there is a change in this relationship after JNSD.

4. Granger-Causality

In this section, we test the type of relationship that exists between mobility and air pollution indexes. We use the concept of "causality" developed by Granger (1969). Although sometimes misrepresented in the literature, the test evaluates if a variable x has explanatory power on the variable y in the sense that x precedes y. We interpret this precedence as changes in variable x being related to changes in variable y. Note that this does not necessarily denote a causal relation given that a third variable could be driving both x and y. Nonetheless, the literature has settled on denoting this type of test as Granger-causality tests.

The test for Granger causality proceeds as follows:

- Estimate the unrestricted model given by

$$y_t = \alpha_0 + \sum_{i=1}^{k} \alpha_i y_{t-k} + \sum_{i=1}^{m} x_{t-k},$$

  where k, m are the number of lags included in the regression. In applied work, $k = m$ is common. From the estimation, we recover the residual sum of squares, $URSS$.

  In our analysis, we consider specifications including the same number of lags for both variables from he previous week and two weeks before.

- Estimate the restricted model given by

$$y_t = \alpha_0 + \sum_{i=1}^{k} \alpha_i y_{t-k},$$

and recover the residual sum of squares, $RRSS$.

- Compute the test statistic for the null hypothesis of no structural change by

$$F = \frac{(RRSS - URSS)/m}{URSS/(T - k - m - 1)},$$

where T is the sample size, k is the number of parameters in the unrestricted model, and r is the number of restrictions.

- The test statistic follows a F distribution with m and $T - k - m - 1$ degrees of freedom.

Some papers have shown that Granger-causality can produce spurious results when the data follow a stationary processes with structural breaks or unit root processes; see Ventosa-Santaulària and Vera-Valdés (2008) and Rodríguez-Caballero and Ventosa-Santaulària (2014) for more details. Thus, our methodology relies on testing for Granger-causality in the period before JNSD and contrasts the results against estimation in the period after JNSD.

Results from the Granger-causality test for the period before JNSD are presented in Table 3. The table shows that Metrobus Granger-causes air pollution in terms of emissions of SO2. Thus, there is statistical evidence that Metrobus usage changes are associated with SO2 air pollution changes. Nonetheless, recall that we cannot conclude that Metrobus usages cause SO2 pollution to increase in the typical sense given that a third common factor for both could be the main driver behind both dynamics. In this context, more Metrobus users could be associated with more economic activity and more cars on the road.

Furthermore, we find some evidence that Metro usage also Granger-causes SO2 air pollution, particularly in the one-week specification. This again points to some link between increased activity in the MCMA and increased air pollution. Nonetheless, note that both variables do not Granger-cause PM 10 nor PM 2.5. Thus, there seem to be some other dominant drivers behind PM 10 and PM 2.5 pollution.

Period	PM 10		PM 2.5		SO2	
1/1/2017-1/2/2020	GC(1)	GC(2)	GC(1)	GC(2)	GC(1)	GC(2)
Metro	1.112	1.120	1.188	1.154	2.197	1.448
p-value	0.353	0.344	0.313	0.319	0.053	0.155
Metrobus	1.326	1.530	0.741	0.975	3.419	2.070
p-value	0.251	0.124	0.593	0.464	0.005	0.025

Table 3. Test for public transport Granger-causes air pollution in the period before JNSD. The tests consider specifications including lags from the previous week, $GC(1)$, and two weeks before, $GC(2)$.

To evaluate the effect that JNSD had on the precedence relation between mobility and air pollution, Table 4 presents the results from the Granger-causality test for the post-JNSD period. The table shows that the relation of Granger-causality between mobility variables and SO2 disappeared during JNSD.

Period	PM 10		PM 2.5		SO2	
JNSD-9/7/2020	GC(5)	GC(10)	GC(5)	GC(10)	GC(5)	GC(10)
Metro	0.530	0.536	0.487	0.650	1.828	1.370
p-value	0.753	0.855	0.784	0.763	0.122	0.226
Metrobus	0.709	0.659	0.610	0.641	1.634	1.182
p-value	0.619	0.755	0.692	0.771	0.166	0.329

Table 4. Test for public transport Granger-causes air pollution in the period following JNSD. The tests consider specifications including lags from the previous week, $GC(1)$, and two weeks before, $GC(2)$.

Overall, the results from Tables 3 and 4 support the notion that the link between public transport users and air pollution was temporarily broken during JNSD. That is, the reduction in public transport users during JNSD was not accompanied by a reduction in air pollution.

5. Conclusions

This paper analyzes the relation between COVID-19, air pollution exposure, and mobility in the MCMA.

We test if the Mexican Government's economic and social restrictions to mitigate the spread of the virus produced a structural change in air pollution and mobility in the MCMA. This paper shows that mobility in public transportation was significantly reduced following the government's recommendations. We find that mobility in public transit systems in the MCMA decreased by more than 65%. Moreover, our results show that the number of cyclists at several stations across the MCMA also suffered a significant decrease. Thus, our results suggest that a large share of the inhabitants of the MCMA stopped using public transit during this period signaling a decrease in mobility.

In connection with the structural change in mobility, we analyzed if the restrictions resulted in lower air pollution in the MCMA. Our results show an overall decreasing trend in pollution levels in the MCMA throughout the years. Nonetheless, no statistically significant change is detected due to the economic restrictions imposed due to COVID-19. Furthermore, Granger-causality tests show that the precedence relation between mobility and air pollution disappeared as a product of the restrictions.

The results from this analysis could help in designing policies aimed to reduce pollution levels in the MCMA. In particular, structural changes in mobility in the public system do not seem to be associated with changes in air pollution levels. In this regard, our results suggest that tackling air pollution may require policies specifically aimed at reducing pollution in the industrial sector.

Abbreviations

The following abbreviations are used in this manuscript:

MCMA	Mexico City Metropolitan Area
PM 10	Particle Matter with diameters of 10 micrometers and smaller
PM 2.5	Particle Matter with diameters of 2.5 micrometers and smaller
SO2	Sulfur Dioxide
GC	Granger-causality
JNSD	*Jornada Nacional de Santa Distancia.*

Disclosure Statement

The authors declare no conflict of interest.

Data Availability Statement

The data that support the findings of this study were derived from resources freely available in the public domain at datos.cdmx.gob.mx. The data is publicly available in the corresponding author's GitHub repository at github.com/everval.

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Appendix A. Additional Tables and Figures

A.1. *Structural Change Tests for Individual Public Transport Lines*

Table A1. Structural change test for individual Metro and Metrobús lines, and number of cyclists at several reporting stations.

Mobility	F_{level}	$p-value$	F_{trend}	$p-value$
Metro Line 1	1839	0	930	0
Metro Line 2	1729	0	865	0
Metro Line 3	1030	0	515	0
Metro Line 4	1382	0	691	0
Metro Line 5	934	0	467	0
Metro Line 6	945	0	471	0
Metro Line 7	953	0	476	0
Metro Line 8	1523	0	762	0
Metro Line 9	760	0	380	0
Metro Line A	559	0	280	0
Metro Line B	1878	0	940	0
Metro Line 12	1134	0	566	0
Metrobus Line 1	5429	0	2716	0
Metrobus Line 2	2947	0	1471	0
Metrobus Line 3	5646	0	2824	0
Metrobus Line 4	4993	0	2616	0
Metrobus Line 5	4469	0	2232	0
Metrobus Line 6	3446	0	1720	0
Metrobus Line 7	4369	0	2229	0
Ciclovía Reforma	160	0	80	0
Ciclovía Revolución	77	0	51	0
Ciclovía Patriotismo	257	0	128	0

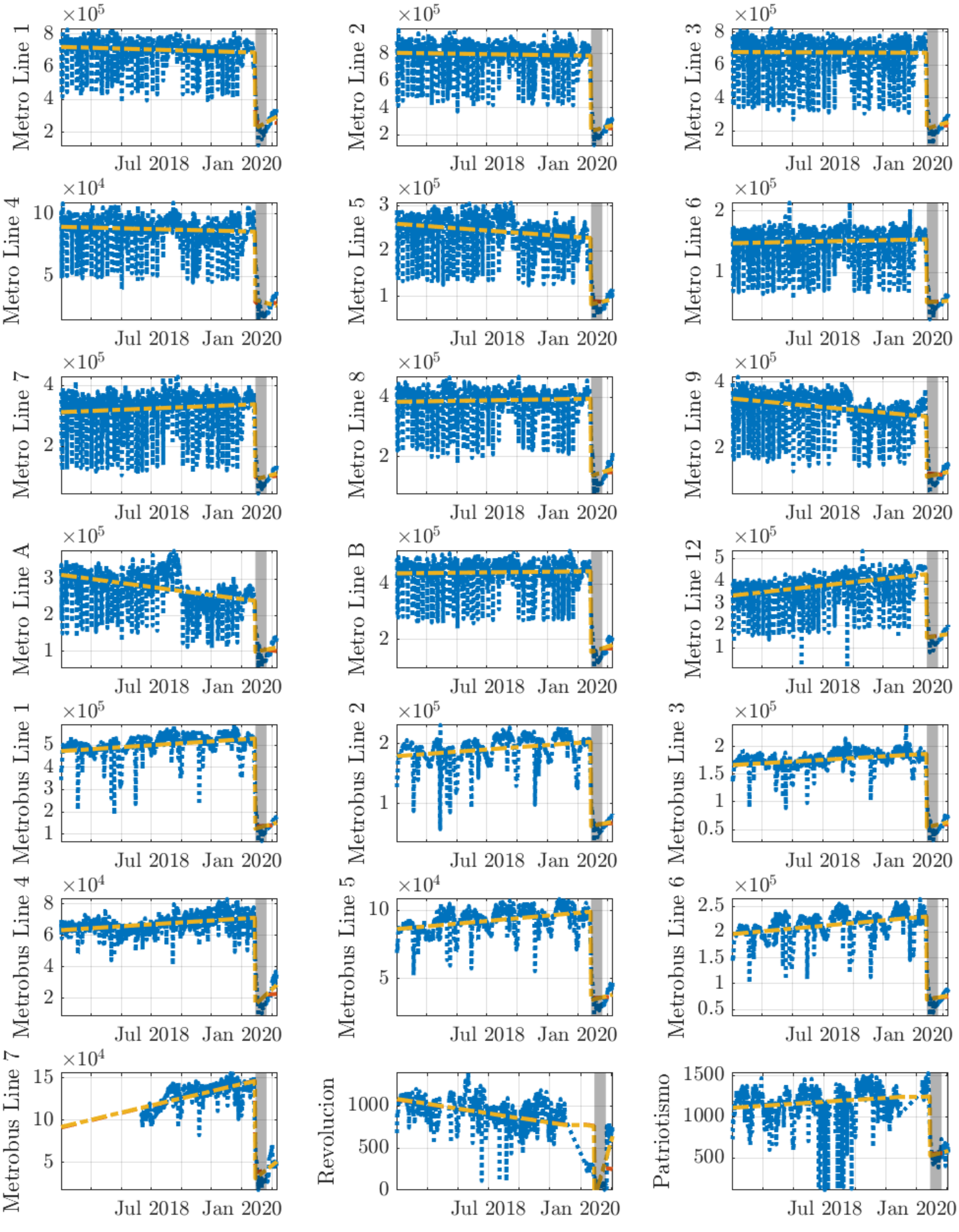

Figure A1. Mobility in the Mexico City Metropolitan Area. The figure shows actual values (dotted blue) along fitted values from linear model with a change in level (dashed orange) and change in level and trend (dashed-dotted yellow). The "Jornada Nacional de Sana Distancia" is shown in the shaded area.

A.2. *Air Pollution Measurements at Individual Stations*

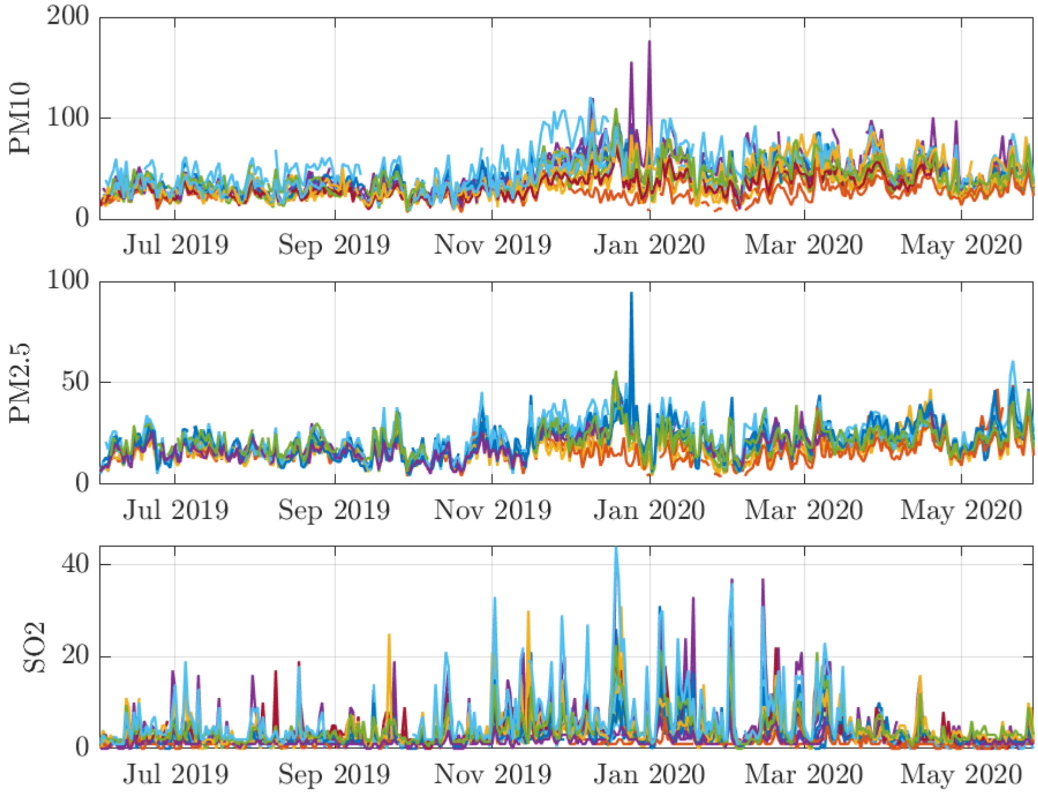

Figure A2. Air pollution measurements in all stations in the Mexico City Metropolitan Area.