The Impact of The Pico Y Placa Policy On Fine Particulate Matter In Lima, Peru

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Abstract

Lima has been ranked among the top most polluted cities in the Americas. Vehicular emissions are the dominant source of pollution in the city. In order to reduce congestion and pollution levels during the XVIII Pan- and Parapan-American Games, Lima government officials enacted the *pico y placa* policy to restrict the number of vehicles on certain heavily trafficked roads in the city at rush hours between Monday to Thursday based on the last digit of their license plates. This policy was retained after the Games. In this paper we evaluate the impact of this policy on fine particulate matter concentration levels (PM$_{2.5}$) at a background site in the city using a difference-in-difference approach. We find that the policy resulted in increases on PM$_{2.5}$ levels on Monday-Thursday compared to Friday-Sunday levels after the policy was enacted, compared to previous years. However, such an increase was not significant. These results suggest the need for additional policies to reduce pollution due to traffic in Lima. It also suggests the need to track the response to this policy over time to evaluate its efficacy.

Introduction

Lima is one of the most highly polluted cities in the Americas (WHO (World Health Organization), 2016). Silva et al., (2017) reported that between 2010 and 2015, the average annual concentrations of particulate matter with diameter < 10 µm (PM$_{10}$) and < 2.5 µm (PM$_{2.5}$) were 84 and 26 µg/m$^3$, respectively. They found that PM$_{2.5}$ concentrations at six of the ten regulatory monitors in Lima exceeded the World Health Organization (WHO) daily guideline on 77% of the days between 2014 and 2015. PM$_{2.5}$ concentrations in Lima show seasonal trends, with the highest levels observed in the summer (Romero et al., 2020b).

Epidemiologic evidence has found that air pollution was responsible for 2,300 premature deaths due to cardiorespiratory disease in Lima adults every year between 2001–2011 (Gonzales and Steenland, 2014). Tapia et al., (2020) found that between 2000 and 2016, an interquartile range increase in PM$_{2.5}$ was associated with a 4% increase in respiratory emergency room (ER) visits. There is thus an urgent need to reduce pollution levels in Lima.

Vehicular emissions are the dominant source of pollution in the city (Arias Velásquez et al., 2019; Silva et al., 2017). The diurnal peaks of PM$_{2.5}$ during rush hours (Romero et al., 2020b; Sánchez Ccoyllo et al., 2011), as well as the association between proximity to roads and the concentrations of PM$_{2.5}$ and Black Carbon (BC) is evidence of this (Underhill et al., 2015). The government has attempted to mitigate vehicular pollution by phasing out lead from gasoline, reducing the sulfur content in diesel and reducing the permissible age of vehicles. However, despite these efforts, the number of vehicles in the city is rapidly increasing. Between 2000 and 2014, emissions from registered vehicles in the Lima Metropolitan Area (LMA) increased by almost 65%. In 2019, Lima had a fleet of more than 2.7 million motor vehicles, that has been projected to grow at 7% per year (C. Posada, 2018). The average age of Lima’s vehicular fleet exceeds 15 years for private vehicles and 22 years for public transport vehicles (BBVA, 2010), and
thus the emissions from an average vehicle is much higher than a typical vehicle in the developed world. It is exceedingly important to develop effective transportation policies to reduce vehicular emissions.

To this end, research has been undertaken to understand the spatially disaggregated impact of vehicular emissions (Romero et al., 2020a, c). Such analyses can inspire the development and implementation of targeted policies to reduce emissions. Other crucial research has examined the impact of traffic regulations on certain main avenues in Lima on air pollution (Morales-Ancajima et al., 2019). More work is needed to evaluate existing transportation policies on air pollution, so that they can be fine-tuned.

In 2019, Lima hosted the XVIII Pan- and Parapan- American Games (Games) (July 26-September 1). A major concern before and during this event were the traffic and high levels of pollution that could potentially affect the athletes. Therefore, the Peruvian government, in collaboration with regional authorities, adopted a variety of traffic control actions just before and during the Games. Most of these policies were discontinued after the end of the Games except for the pico y placa policy, which continued until mid-2020, when it was temporarily halted due to the COVID-19 emergency in the city. In this article, we evaluate the impact of the pico y placa policy on PM$_{2.5}$ concentrations in Lima using a difference-in-difference methodology.

Data And Methods

1.1. Pico y Placa

Pico y placa policy, established by Ordinance N2164 by the Metropolitan Municipality of Lima, restricted the number of vehicles on the road in Lima from Monday to Thursday from 6:30 am to 10:00 am and from 5:00 pm to 9:00 pm based on their license plate number. Specifically, vehicles with a license plate ending in an even digit or zero, could not circulate on certain roads (displayed in Fig. 1) between Monday and Wednesday during those hours, while those with license plates ending with an odd digit could not be on the roads between Tuesday and Thursdays during the same hours (https://www.gob.pe/institucion/munilima/normas-legales/285775-2164, Metropolitan Municipality of Lima (In Spanish)). No restrictions were applied on holidays and non-working days.

The pilot period of this policy was between July 22 - August 5, 2019, with a short suspension between July 29 - July 30, 2019 because of national holidays. The second period of this policy, with additional roads, started on August 5, 2019. Because of its success of reducing traffic in main arteries, both phases were extended indefinitely, and was temporarily suspended only recently, in March 16, 2020, due to the COVID-19 emergency in Lima (https://rpp.pe/lima/actualidad/coronavirus-en-peru-covid-19, Metropolitan Municipality of Lima temporarily suspends the Pico y Placa policy (In Spanish)).

1.2. Other Traffic intervention Policies enacted during the Games
The *Lima 2019 Route Plan*, which restricted travel on certain roads in Lima to enable athletes to reach their venues in time, was put in place between July 19 - September 5, 2019. It was executed by the Peruvian National Police (PNP) in coordination with Lima 2019 Organizing Committee (COPAL) (https://www.lima2019.pe/en/road-plan, Lima 2019 Route Plan). This Plan comprised of three different measures (i) permanent *lanes* with 24 hours of restrictions were designated (ii) *temporal lanes* which branch off from the permanent lanes and had temporary restrictions four hours before and two hours after each competition and (iii) *preferential lanes* that enabled official Lima 2019 vehicles, public, and private transportation to circulate at the same time.

Table 1 details the characteristics of all these interventions: the dates of enforcement and the times during the day that the policy came into action. Other than the *pico y placa* program and the Lima Route plan, the other interventions were short-term or temporary controls. Figure 1 displays the location of the different interventions in Lima.
### Table 1
Traffic policies before, during and after the Games

| Reference | Traffic restrictions | Restriction period time |
|-----------|----------------------|-------------------------|
| **Before, during, and after Games** | Lima 2019 Route Plan | July 19 - September 5, 2019 |
| | Pico y placa intervention | July 22, 2019 – March 16, 2020 |
| | - First phase: July 22, 2019 - up to present. | |
| | - Second phase: August 5, 2019 - up to present | |
| | Central road from Chaclacayo to Centro Poblado de Pucará intervention | June 1 - December 31, 2019 |
| **During and after Games** | Independence Day intervention | July 28 - July 29, 2019 |
| | - July 28 (12:00 h) - July 29, 2019 (15:00 h) | |
| | *Suggested alternative roads include Av. Salaverry.* | |
| | National Stadium intervention | |
| | - July 26 (12:00 h) - July 27, 2019 (04:00 h) / August 11 (12:00 h) - August 12, 2019 (04:00 h) / August 23 (12:00 h) - August 24, 2019 (04:00 h) | July 26 – 27, 2019 |
| | | August 11 – 12, 2019 |
| | | August 23 – 24, 2019 |
| | Pan American Marathon and Triathlon Intervention | July 26 – July 29, 2019 |
| | - July 26 (22:00) - July 27, 2019 (22:00 h) / July 28 (7:00 – 13:00 h) / July 28 (22:00 h) - July 29, 2019 (22:00 h) | |
| | Miraflores walking event intervention | |
| | - July 4, 2019 (00:00–15:00 h) / August 11, 2019 (00:00–15:00 h) | July 4, 2019 |
| | Costa Verde cycling event intervention | |
| | - August 6 (9:00–14:00 h) / August 6 (22:00 h) - August 7, 2019 (22:00 h) / August 9 (22:00 h) - August 10 (23:59 h) | August 6 - August 7, 2019 |
| | | August 9 - August 10, 2019 |

[1] https://elcomercio.pe/lima/transporte/pico-placa-sera-aplicado-dias-29-30-julio-noticia-nndc-659586-noticia/?ref=ecr
[2] https://www.gob.pe/institucion/mtc/noticias/45580-mtc-restringira-circulacion-de-vehiculos-pesados-en-la-carretera-central-durante-el-feriado-largo-por-fiestas-patrias
1.3. PM\textsubscript{2.5} data

Lima has a limited number of reference air quality monitors. Only one station monitored PM\textsubscript{2.5} data both before and after the \textit{pico y placa} policy came into force, at the US Embassy (Latitude: -12.099398, Longitude: -76.96888).

The location of this monitoring site vis a vis the streets impacted by the traffic policies can be seen in Fig. 1. The US monitor is located away from localized sources. It thus is well placed to capture overall changes in PM\textsubscript{2.5} levels in Lima from the \textit{pico y placa} intervention. As can be seen there are a few missing measurements in early 2016, and in late 2017 (Figure S1 in Supplementary Information).

We plot the average hourly, daily, monthly PM\textsubscript{2.5} levels for the months July to December (while the \textit{pico y placa} policy was in place) for 2019, and for years prior to 2019, to visualize the impact of the policy on temporal patterns of PM\textsubscript{2.5} levels.

1.4. Methods

In order to evaluate the impact of the many traffic policies on PM\textsubscript{2.5} levels in the city, in an ideal experiment, we would compare PM\textsubscript{2.5} concentrations in the absence of these policies, with concentrations after the policies were enacted. Unfortunately, such a counterfactual scenario does not exist in reality. Thus, in this study a Difference in Difference approach (DiD) is applied in order to estimate the effects of such interventions during our study period, by exploiting the fact that the \textit{pico y placa} policy was in force on Monday-Thursday, but not Friday-Sunday.

Briefly, we estimate the difference in the difference in PM\textsubscript{2.5} levels after the restriction for Monday-Thursday (treatment group) compared to PM\textsubscript{2.5} concentrations on Friday-Sunday (control group) after the \textit{pico y placa} intervention (July-December, 2019) compared with levels in previous years.

We restrict our analysis to July 31-December 31 (the months in 2019 for which the \textit{pico y placa} was in force) for all years for which we have data to account for the seasonal changes in PM\textsubscript{2.5} concentrations.

Our strategy is encapsulated in regression Eq. 1.

\[
Y_t = \beta_0 + \beta_1(P_1) \times Y_{2019} + \beta_2(P_1) + \beta_3(P_2) + \beta_4.x_t + u_t \quad \text{...............(1)}
\]

\(Y_t\) denotes average hourly PM\textsubscript{2.5} from the US Embassy monitor: on the \textit{pico y placa} policy intervention for \textit{July 31-December 31} across multiple years.
$P_1$ is a dummy variable that is 1 for data between Monday and Thursday and 0 otherwise, indicating the treatment group for which the *pico y placa* policy was in place.

$Y_{2019}$ is a dummy variable indicating the intervention has occurred. It is 1 for 2019 and 0 otherwise, indicating the intervention took place.

$P_2$ is a dummy variable corresponding to the other policy interventions, to separate out the impacts of the different interventions from that of the *pico y placa* policy. From Table S1, several policy interventions were enacted before and during the Games. The *Lima 2019 Route Plan* is the longest running intervention, with others in force for only a short time concurrently. We assign $P_2 = 1$, when the *Lima 2019 Route Plan* is enforced: July 19 - September 5, 2019, and 0 otherwise.

$x_t$ is a vector of covariates that includes a cubic polynomial to account for meteorological variables: temperature, humidity, wind speeds, as well as interactions of these variables with day-of-year and day-of-week. It also includes fixed effects corresponding to year, month of year, hour of day, and interactions between hour of day and $P_1$ to account for temporal trends in PM$_{2.5}$ concentrations.

The error is $u_t$. We clustered errors by month.

In Eq. 1, $\beta_0$ can be interpreted as the baseline average levels of PM$_{2.5}$, $\beta_2$ can be interpreted as the average difference between the treatment (PM$_{2.5}$ levels on Mon-Thurs) and control groups (PM$_{2.5}$ levels on Friday - Sunday) between July 31- December 31 in years prior to 2019. The coefficient of chief interest, $\beta_1$ can be interpreted as the difference in PM$_{2.5}$ levels between the treatment and control groups after the intervention.

We control for other short-term policy interventions in 2019 using $P_2$. In order to further avoid the confounding impacts of other policies: $P_2$, we repeat the regression only considering *September 6 - December 31, 2019*, and *October - December 31* (well after the Pan- and Parapan-American games).

The identification assumption of the DiD model is that unobserved factors that could affect PM$_{2.5}$ values are not correlated with the treatment, conditional on the covariations ($x_t$) and that these unobserved factors do not affect PM$_{2.5}$ concentrations in a manner that is nonlinear in time and not captured by the current independent variables in the model. Therefore, we also present supplementary analyses, where we limit the years in the treatment group to 2018 to ensure that other time-varying factors do not affect our results.

### 1.5. Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

**Results**
Figure 2 displays the average hourly, daily, monthly PM$_{2.5}$ levels for the months July to December (while the *pico y placa* policy was in place) for 2019, and for years prior to 2019, to explore the impact of the policy on temporal patterns of PM$_{2.5}$ levels.

It can be seen that PM$_{2.5}$ concentrations peaked in September, 2019 compared to previous years, and then decreased for the months of October - December 2019 (lowest monthly levels compared with others months before and during 2019) as shown in Fig. 2. No significant change was identified in July 2019 compared with previous years. Average hourly variation shows increases in the diurnal peaks likely corresponding to the morning rush-hour traffic in Lima at around 9:00 am and 11 pm in 2019 of PM$_{2.5}$, in comparison to previous years. Such increases in peak levels of PM$_{2.5}$ appear to be particularly pronounced on Wednesdays and Thursdays (during the *pico y placa* policy) in 2019, although we observe such increases on the weekend as well when the *pico y placa* policy was not in force.

The peaks of PM$_{2.5}$ measured, however do not appear to have been temporally displaced after the intervention occurred, indicating that the intervention has likely not resulted in changes in traffic patterns.

Figure 3 presents plots of the residuals of a regression of hourly PM$_{2.5}$ concentrations on the weather, temporal variable: $x_t$. These residuals are averaged across months within each year and offer insight into the estimates of the DiD model.

It appears that the residuals for previous years for the monitor at the US Embassy track each other closely. However, likely due to the introduction of interventions related to the Pan- and Parapan-American games, the unexplained mean hourly PM$_{2.5}$ concentrations are high in July, August and September, 2019. There is a notable decrease in the residual for months of November and December, 2019.

Such an exercise in plotting the residuals provides some information on if there are other factors affecting PM$_{2.5}$ conditional on factoring in the various daily, weekly, monthly and seasonal trends of PM$_{2.5}$, which as mentioned previously is a key assumption in the DiD approach. The similarity of the residual before the impacts of the interventions indicates that this assumption holds in our analysis.

Table 2 presents the DiD estimation results. We see that the *pico y placa* policy is associated with a small increase in PM$_{2.5}$ concentration at the US embassy, of $\sim 3$ µg/m$^3$ (Analysis 1 in Table 2) which is not significant. When we controlled for other policy interventions, this did not change.
Table 2
DiD results for the US embassy monitor for July 31 - December 31. Time was controlled for by including fixed effects corresponding to: year, month, a dummy variable signifying: Monday-Thursday/Friday-Sunday and interactions of the variable with hour of day. Weather was controlled for by including third degree polynomials of temperature, humidity, wind speed and interactions between each meteorological parameter and day of year and day of week.

| Analysis | Years 2016, 2017, 2018 and 2019 were considered | Only September 6- December 31 were considered for years 2016–2019 | October 1- December 31 were considered for the years 2018 and 2019 | Years 2018 and 2019 were considered |
|----------|-----------------------------------------------|---------------------------------------------------------------|---------------------------------------------------------------|-----------------------------------------------|
| Estimate: $\beta_1$ ($\mu g/m^3$) | 3.681 (standard error: 3.062) (p > 0.1) | 3.836 (standard error: 3.222) (p > 0.1) | 6.113 (standard error: 3.968) | 2.536 (standard error: 2.540) |
| Impact of other policies | Treatment (Monday-Thursday) x $Y_{2019}$ | No other policies during this time period | No other policies during this time period | No other policies during this time period | No other policies during this time period |
| N | 10,157 | 10,157 | 7,907 | 4,136 | 6,513 |
| R squared | 0.25 | 0.26 | 0.29 | 0.20 | 0.31 |

No other policies during this time period

| N | 10,157 | 10,157 | 7,907 | 4,136 | 6,513 |
| R squared | 0.25 | 0.26 | 0.29 | 0.20 | 0.31 | 0.33 |
Table 3
Summary of findings of the impact of the *pico y placa* policy in other countries

| Location | Findings |
|----------|----------|
| Santiago, Chile starting in 1986 originally only applied to vehicles lacking catalytic converters that were subject to a license plate restriction. From 2008 onwards, this restriction was extended to all vehicles on emergency days | Frésard (1998) found the policy had a disproportionate impact on low-income families that could not afford clean cars. In addition, a large number of families bought a second car, which in many cases, was more polluting than the first car. This research found that the effect of this restriction on traffic capacities was limited (5% reduction in traffic) |
| Mexico city introduced, ‘Hoy No Circula’ in 1989 | Davis (2008) found that the Hoy No Circula policy had no impact on air pollution in Mexico city. This study found evidence that this policy led to the total increase in vehicular sales, instead of nudging residents to using non motorized transport |
| Bogota, Colombia in 1998 | Cantillo and Ortúzar (2014) report that such a policy resulted in a decrease in trips by cars in the short term. However, in the long term, trips by cars returned to original levels. Similarly PM$_{10}$ levels decreased in the short-term, but also rebounded as vehicle trips went up. |
| Rio de Janeiro, Brazil during the 2014 World Soccer Cup and the 2016 Summer Olympics and Paralympic Games | Research found that PM$_{10}$ and PM$_{2.5}$ had increased compared with previous years during the Olympic Games, despite the driving restrictions mainly due to construction activities to prepare the city (Ventura et al., 2019). |
| Quito, Ecuador in May 2020 | A significant 9–11% reduction in CO concentration during peak hours was observed after the implementation of the *pico y placa* program in the period Jan 2008 - Dec 2012 (Carrillo et al., 2016). The research reports that it is likely the policy worked here because many residents were too poor to be able to purchase additional cars. |
| Beijing and Tianjin during the 2008 Olympic Games | Cai and Xie (2011) report that the policy was able to significantly alleviate pollution during the Olympic Games and was an effective temporary solution to reduce pollution. |
| New Delhi, India during 2016 | (Chowdhury et al., 2017) found no clear reduction in PM$_{2.5}$ during the period of the odd-even policy enactment. They said this was likely because of unfavorable meteorological conditions, and the dominance of other sources of pollution during this period. |

This result did not change when

1. We restricted the days considered to September 6 - December 31 when the other interventions had ended (Analysis 2). Here we can see that the difference between the concentrations increases to $\sim 6 \ \mu g/m^3$ but is still not significant
2. From Fig. 3, it appears that there could be other unusual events occurring in September, possibly related to the Pan- and Parapan-American games that our model had not accounted for. We
therefore, also rerun our analysis considering days in October - December (Analysis 3). Here the estimate decreases to 3.3 µg/m³ but is not significant.

3. We restricted our time period to 2018 and 2019 to avoid having to account for other time varying trends in pollution (Analysis 4)

**Discussion And Conclusions**

Our results indicate that the difference in PM$_{2.5}$ concentrations on Monday-Thursday for the months July to December, 2019 in comparison to PM$_{2.5}$ concentrations on Friday-Sunday for the same months, relative to the difference for the same months in previous years is small and positive (~ 3 µg/m³), and not significant (Table 1).

This could be for several reasons. We hypothesize that:

1. Although the *pico y placa* policy may have resulted in reduced PM$_{2.5}$ concentrations on specific roads, vehicular volume may have increased on others, resulting in little change in overall PM$_{2.5}$ concentrations. More work is required to continue to track the impact of the policy on vehicular volume in Lima.

2. From Fig. 2, it appears that PM$_{2.5}$ concentrations are higher on Monday and Wednesday, but we also see that the peaks on the weekends also increased post July, 2019 compared to concentrations in previous years. This could mean that *pico y placa* has changed overall traffic flow patterns over every day of the week. Alternatively, 2019 could have also been an outlier year for Lima, with more visitors in the city due to the Games. This possibility warrants the need for continued monitoring to keep tracking the impact of the *pico y placa* policy.

3. From Fig. 3, it appears that an unusual event is occurring between July-September, 2019. It is unclear what causes this peak. When we restricted our experiment to only considering the months of October-December, the increase in PM$_{2.5}$ concentrations on Monday-Thursday compared to Friday-Sunday dwindled. This could mean that residents of Lima had adjusted to the policy, traffic patterns had reduced on Monday-Thursday, resulting in a much smaller difference between levels of PM$_{2.5}$. This suggests that the response to the policy is still adapting and needs to be tracked over time. Alternatively, another event occurred in Lima that caused increased levels of PM$_{2.5}$ concentrations on Monday-Thursday compared to Friday-Sunday. For example, as mentioned earlier, there could have been an influx of visitors in the city. Our model does not capture such an event. Again, this result suggests the need to continue tracking the effects of this policy.

4. The impacts of the policy are localized/affect certain parts of the city. In this experiment we have only used measurements from one monitor. There is a need to expand monitoring in Lima to evaluate the overall impact of the *pico y placa* policy in different parts of the city.

The *pico y placa* has been enacted in other locations. Past research in other cities has shown that such a policy only has limited short-term effects on traffic and like our research, has shown to have limited
impact on air pollution.

Despite the fact that most studies (including ours) have shown that the *pico y placa* policy does not typically result in lowering air pollution levels in the long term, many governments have adopted it as a strategy to reduce pollution. It is important to track the impact of such policies to make a case for additional regulation to decrease pollution.

**Declarations**

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**Declarations of interest**

The authors declare no conflict of interest and no competing financial interests.

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**Supplementary Table**

Supplementary Table S1 is not available with this version.
Figure 1

Map showing the locations of an air quality monitor at the US Embassy (US embassy) overlaid on the map of Lima with the (a) Lima 2019 Route Plan. Permanent lanes referred to those with restrictions laid for 24 hours, temporary lanes referred to those with restrictions imposed 4 hours before and 2 hours after each game, and preferential lanes prioritized accredited buses. (b) Pico y placa policy. Continuous lines referred to the alternative ways that drivers can use at the pico y placa period. Discontinuous lines referred to the main permanent roads under the pico y placa measures. (c) Independence Day intervention
Figure 2
Trends in PM2.5 from July onwards at the monitor at the US embassy before 2019, and during 2019 (when the pico y placa policy came into effect).

Figure 3

Residuals of a regression of hourly PM2.5 concentrations from the US Embassy monitor on the weather, and the diurnal/weekly/monthly variables (xt). These residuals are averaged across months within each year.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SuplementaryMaterial.docx