Paper Two

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The investigation into how subway system openings affect urban air pollution, with a focus on particulate concentrations, is presented in this abstract. The study discovered that the opening of a subway system was associated with a 4% decrease in particulates in the area of the city center, which persisted over a four-year time horizon, in cities with higher initial pollution levels. In heavily polluted cities, this reduction was projected to have an annual external mortality benefit of about $1 billion. The findings imply that a significant portion of the cost of building subways may be offset by the reduced mortality caused by less air pollution. The results of this study can be repeated in other cities to learn more about the connection between air pollution and subway openings.

Introduction

The paper investigates the impact of subway systems on air pollution in cities around the world. It uses two main data sources: a description of the world's subway systems and a measure of airborne particulates, Aerosol Optical Depth (AOD), recorded by satellites between February 2000 and December 2017. The analysis uses a comparison of changes in AOD within a city before and after the opening of a subway system to establish its causal effect.

The results show that the average effect of subway openings on AOD is a small decrease that cannot be distinguished from zero, but there is significant heterogeneity across cities. In the case of the 26 cities where AOD fell after the subway opened, the decrease was largest in cities whose initial level of AOD was above the median. The decrease in AOD levels was found to persist for at least 4 years. The results also indicate that subway ridership is a key factor in reducing AOD levels and that subway expansions beyond the initial line have small effects on AOD levels.

The study provides important information for policymakers considering the implementation of subway systems to mitigate air pollution. Based on the results, the authors estimate that a subway opening in an average city initially in the top half of the AOD distribution prevents 22.5 infant deaths and 500 total deaths per year, which is worth about $43m and $1b per year, respectively. The results suggest that subway systems may be cost-effective in reducing air pollution, particularly in cities with high initial levels of AOD. The study also sheds light on transportation behavior in developing countries, finding no evidence of differences between developing and developed world cities in their response to subways.

The study aims to investigate the effect of subways on urban air pollution by using data from a panel of cities. The subways data, used from Gonzalez-Navarro and Turner (2018) and updated to December 2017, define a subway as an electric-powered urban rail system isolated from interactions with vehicle and pedestrian traffic. The latitude, longitude, and date of opening of every subway station in the world were compiled manually between 2012 and 2014. The air pollution data used are based on remotely sensed measures of suspended particulates from Terra and Aqua satellites, providing daily measures of aerosol optical depth of the atmosphere at a 3 km spatial resolution from 2000 to 2017. The study considers the change in aerosol optical depth (AOD) in the period extending from 18 months before to 18 months after a subway opening, using a sample of 58 subway system openings between 2001 and 2016. The study also has ridership data for 42 of the 58 cities, with an average daily ridership of 130,000 people in the 18th month of operation. The study finds that ridership triples over the first three years of operation and begins to slow after three years. The average time construction began was 77 months prior to the opening.

The results of a study on the Aerial Optical Depth (AOD) within 10 km of city centers using satellite imagery from Terra and Aqua satellites. The study aimed to evaluate the relationship between the remotely-sensed AOD and ground-measured particulate matter (pm10 and pm2.5). The results show that AOD is a highly predictive measure of ground-measured particulate matter and the relationship is not sensitive to the exact region used to calculate city average AOD. The study used a monthly average of AOD readings within 10 km of the city center, calculated by averaging over all pixel-days of AOD readings that fall in this region during the month and weighting by the number of pixels observed each day. The results showed that in 2017, the average AOD reading within 10 km of a city center from the Aqua satellite was 0.40 and higher in Asian cities, whereas it was lower in European and North American cities. The second panel of Table 1 presents the AOD averages for 2000 using only the Terra satellite.

Plot

```r
library(here)
```

```
here() starts at /Users/lucas/Documents/paper2
```

```r
library(dplyr)
```

```
Attaching package: 'dplyr'


The following objects are masked from 'package:stats':

    filter, lag


The following objects are masked from 'package:base':

    intersect, setdiff, setequal, union
```

```r
subway_data <- read.csv(file = '/Users/lucas/Documents/paper2/Subway_Ridership_V4.csv')
head(subway_data)
```

```
  Country  Urbanname Year Quarter Month  Ridership ReferencePeriod X X.1 X.2
1   Chile Valparaiso 2005                1,718,222          Yearly
2   Chile Valparaiso 2006                7,947,049          Yearly
3   Chile Valparaiso 2007               11,350,000          Yearly
4   Chile Valparaiso 2008               12,590,000          Yearly
5   Chile Valparaiso 2009               13,710,000          Yearly
6   Chile Valparaiso 2010               14,030,000          Yearly
  X.3 X.4 X.5 X.6 X.7 X.8
1  NA  NA  NA  NA  NA  NA
2  NA  NA  NA  NA  NA  NA
3  NA  NA  NA  NA  NA  NA
4  NA  NA  NA  NA  NA  NA
5  NA  NA  NA  NA  NA  NA
6  NA  NA  NA  NA  NA  NA
```

```r
subway_data<- subway_data %>%
  mutate(Ridership = ifelse(Month == ' ' , NA, Ridership))
```

```r
class(subway_data$Year)
```

```
[1] "integer"
```

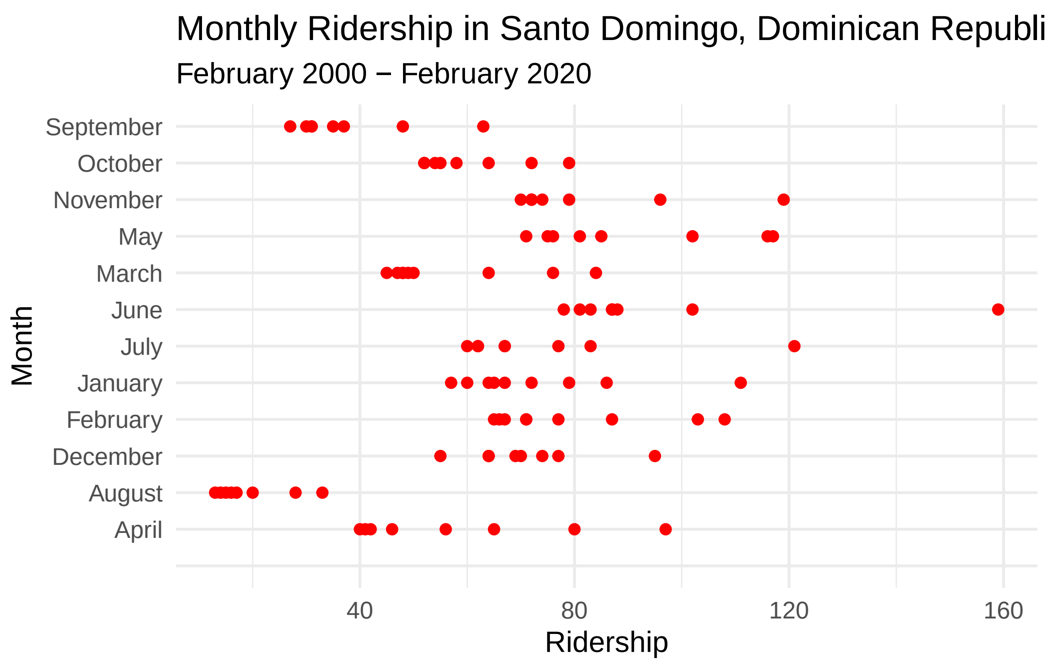

Figure 1: Monthly Ridership in Santo Domingo, Dominican Republic

```r
library(dplyr)
library(ggplot2)
library(ggplot2)


subway_data <- subway_data |>
  filter (Year == '2005')

subway_data
```

```
        Country  Urbanname Year Quarter     Month  Ridership ReferencePeriod
1         Chile Valparaiso 2005          November    201,165         Monthly
2         Chile Valparaiso 2005          December    620,245         Monthly
3       Okinawa       Naha 2005           January    984,100         Monthly
4       Okinawa       Naha 2005          February    937,100         Monthly
5       Okinawa       Naha 2005             March  1,173,000         Monthly
6       Okinawa       Naha 2005             April  1,047,000         Monthly
7       Okinawa       Naha 2005               May  1,056,000         Monthly
8       Okinawa       Naha 2005              June  1,015,000         Monthly
9       Okinawa       Naha 2005              July  1,099,000         Monthly
```

10	Okinawa	Naha	2005	August	1,183,000	Monthly
11	Okinawa	Naha	2005	September	1,113,000	Monthly
12	Okinawa	Naha	2005	October	1,203,000	Monthly
13	Okinawa	Naha	2005	November	1,075,000	Monthly
14	Okinawa	Naha	2005	December	1,097,000	Monthly
15	India	Delhi	2005	January	8,040,000	Monthly
16	India	Delhi	2005	February	8,580,000	Monthly
17	India	Delhi	2005	March	9,120,000	Monthly
18	India	Delhi	2005	April	9,660,000	Monthly
19	India	Delhi	2005	May	10,200,000	Monthly
20	India	Delhi	2005	June	10,740,000	Monthly
21	India	Delhi	2005	July	11,280,000	Monthly
22	India	Delhi	2005	August	11,820,000	Monthly
23	India	Delhi	2005	September	12,360,000	Monthly
24	India	Delhi	2005	October	12,900,000	Monthly
25	India	Delhi	2005	November	13,440,000	Monthly
26	India	Delhi	2005	December	13,980,000	Monthly
27	Iran	Tehran	2005	January	17,229,166	Monthly
28	Iran	Tehran	2005	February	17,416,666	Monthly
29	Iran	Tehran	2005	March	17,604,166	Monthly
30	Iran	Tehran	2005	April	17,791,666	Monthly
31	Iran	Tehran	2005	May	17,979,166	Monthly
32	Iran	Tehran	2005	June	18,166,666	Monthly
33	Iran	Tehran	2005	July	18,486,110	Monthly
34	Iran	Tehran	2005	August	18,805,554	Monthly
35	Iran	Tehran	2005	September	19,124,998	Monthly
36	Iran	Tehran	2005	October	19,444,442	Monthly
37	Iran	Tehran	2005	November	19,763,886	Monthly
38	Iran	Tehran	2005	December	20,083,330	Monthly
39	Portugal	Porto	2005	January	1,014,000	Monthly
40	Portugal	Porto	2005	February	942,000	Monthly
41	Portugal	Porto	2005	March	1,094,000	Monthly
42	Portugal	Porto	2005	April	1,169,000	Monthly
43	Portugal	Porto	2005	May	1,360,000	Monthly
44	Portugal	Porto	2005	June	1,215,000	Monthly
45	Portugal	Porto	2005	July	1,223,000	Monthly
46	Portugal	Porto	2005	August	1,181,000	Monthly
47	Portugal	Porto	2005	September	1,738,000	Monthly
48	Portugal	Porto	2005	October	2,490,000	Monthly
49	Portugal	Porto	2005	November	2,519,000	Monthly
50	Portugal	Porto	2005	December	2,536,000	Monthly
51	Puerto Rico	San Juan	2005	June	720,000	Monthly
52	Puerto Rico	San Juan	2005	July	720,000	Monthly

53	Puerto Rico	San Juan	2005	August	720,000	Monthly
54	Puerto Rico	San Juan	2005	September	720,000	Monthly
55	Puerto Rico	San Juan	2005	October	720,000	Monthly
56	Puerto Rico	San Juan	2005	November	720,000	Monthly
57	Puerto Rico	San Juan	2005	December	720,000	Monthly
58	Russia	Kazan	2005	September	550,000	Monthly
59	Russia	Kazan	2005	October	550,000	Monthly
60	Russia	Kazan	2005	November	550,000	Monthly
61	Russia	Kazan	2005	December	550,000	Monthly
62	South Korea	Gwangju	2005	January	1,015,297	Monthly
63	South Korea	Gwangju	2005	February	1,027,240	Monthly
64	South Korea	Gwangju	2005	March	1,039,183	Monthly
65	South Korea	Gwangju	2005	April	1,051,126	Monthly
66	South Korea	Gwangju	2005	May	1,063,069	Monthly
67	South Korea	Gwangju	2005	June	1,075,016	Monthly
68	South Korea	Gwangju	2005	July	1,082,113	Monthly
69	South Korea	Gwangju	2005	August	1,089,210	Monthly
70	South Korea	Gwangju	2005	September	1,096,307	Monthly
71	South Korea	Gwangju	2005	October	1,103,404	Monthly
72	South Korea	Gwangju	2005	November	1,110,501	Monthly
73	South Korea	Gwangju	2005	December	1,117,598	Monthly
74	Turkey	Istanbul	2005	January	3,785,093	Monthly
75	Turkey	Istanbul	2005	February	3,807,845	Monthly
76	Turkey	Istanbul	2005	March	3,830,597	Monthly
77	Turkey	Istanbul	2005	April	3,853,349	Monthly
78	Turkey	Istanbul	2005	May	3,876,101	Monthly
79	Turkey	Istanbul	2005	June	3,898,864	Monthly
80	Turkey	Istanbul	2005	July	3,939,075	Monthly
81	Turkey	Istanbul	2005	August	3,979,286	Monthly
82	Turkey	Istanbul	2005	September	4,019,497	Monthly
83	Turkey	Istanbul	2005	October	4,059,708	Monthly
84	Turkey	Istanbul	2005	November	4,099,919	Monthly
85	Turkey	Istanbul	2005	December	4,140,130	Monthly
86	United States	Las Vegas	2005	January	691,712	Monthly
87	United States	Las Vegas	2005	February	621,909	Monthly
88	United States	Las Vegas	2005	March	1,002,622	Monthly
89	United States	Las Vegas	2005	April	957,621	Monthly
90	United States	Las Vegas	2005	May	899,685	Monthly
91	United States	Las Vegas	2005	June	872,344	Monthly
92	United States	Las Vegas	2005	July	1,020,796	Monthly
93	United States	Las Vegas	2005	August	934,483	Monthly
94	United States	Las Vegas	2005	September	869,515	Monthly
95	United States	Las Vegas	2005	October	893,424	Monthly

96	United States	Las Vegas	2005	November	773,651	Monthly
97	United States	Las Vegas	2005	December	726,905	Monthly
98	China	Shenzhen	2005	January	3,685,560	Monthly
99	China	Shenzhen	2005	February	3,909,448	Monthly
100	China	Shenzhen	2005	March	4,133,336	Monthly
101	China	Shenzhen	2005	April	4,357,224	Monthly
102	China	Shenzhen	2005	May	4,581,112	Monthly
103	China	Shenzhen	2005	June	4,805,000	Monthly
104	China	Shenzhen	2005	July	5,028,888	Monthly
105	China	Shenzhen	2005	August	5,252,776	Monthly
106	China	Shenzhen	2005	September	5,476,664	Monthly
107	China	Shenzhen	2005	October	5,700,552	Monthly
108	China	Shenzhen	2005	November	5,924,440	Monthly
109	China	Shenzhen	2005	December	6,148,328	Monthly
110	Denmark	Kobenhavn	2005	January	2,928,470	Monthly
111	Denmark	Kobenhavn	2005	February	2,944,442	Monthly
112	Denmark	Kobenhavn	2005	March	2,960,414	Monthly
113	Denmark	Kobenhavn	2005	April	2,976,386	Monthly
114	Denmark	Kobenhavn	2005	May	2,992,358	Monthly
115	Denmark	Kobenhavn	2005	June	3,008,333	Monthly
116	Denmark	Kobenhavn	2005	July	3,024,305	Monthly
117	Denmark	Kobenhavn	2005	August	3,040,277	Monthly
118	Denmark	Kobenhavn	2005	September	3,056,249	Monthly
119	Denmark	Kobenhavn	2005	October	3,072,221	Monthly
120	Denmark	Kobenhavn	2005	November	3,088,193	Monthly
121	Denmark	Kobenhavn	2005	December	3,104,165	Monthly

	X	X.1	X.2	X.3	X.4	X.5	X.6	X.7	X.8
1				NA	NA	NA	NA	NA	NA
2				NA	NA	NA	NA	NA	NA
3				NA	NA	NA	NA	NA	NA
4				NA	NA	NA	NA	NA	NA
5				NA	NA	NA	NA	NA	NA
6				NA	NA	NA	NA	NA	NA
7				NA	NA	NA	NA	NA	NA
8				NA	NA	NA	NA	NA	NA
9				NA	NA	NA	NA	NA	NA
10				NA	NA	NA	NA	NA	NA
11				NA	NA	NA	NA	NA	NA
12				NA	NA	NA	NA	NA	NA
13				NA	NA	NA	NA	NA	NA
14				NA	NA	NA	NA	NA	NA
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119	NA	NA	NA	NA	NA	NA
120	NA	NA	NA	NA	NA	NA
121	NA	NA	NA	NA	NA	NA

Conclusion

The paper discussed here is a study to investigate the impact of subway systems on air pollution in cities around the world. The study used two main data sources: satellite-recorded descriptions of the world's subway systems between February 2000 and December 2017 and measurements of the aerosol optical depth (AOD) of particulate matter in the air. The analysis used a comparison of changes in AOD in cities before and after the opening of the subway system to establish its causality.

The results show that the average effect of subway opening on AOD is a small decrease that cannot be distinguished from zero, but there is significant heterogeneity among cities. Among the 26 cities whose AOD decreased after the opening of the subway, the cities with the initial level of AOD higher than the median had the largest decrease. The decline in AOD levels was found to persist for at least 4 years. The results also show that subway ridership is a key factor in reducing AOD levels, and that subway expansion beyond the initial line has little effect on AOD levels.

The findings of this study provide important information for policymakers considering implementing a subway system to mitigate air pollution. The authors estimate that opening subways in an average city originally located in the upper half of the AOD distribution could prevent 22.5 infant deaths and 500 total deaths per year, worth about $43 million and $1 billion per year, respectively. The results suggest that subway systems may be cost-effective in reducing air pollution, especially in cities with high initial levels of AOD.

The study also sheds light on traffic behavior in developing nations, concluding that there are no differences between how developed and developing cities react to subways. This is a significant finding because developing nations may have a greater need for affordable air pollution solutions.

The Terra and Aqua satellites' remote sensing measurements of suspended particulate matter served as the basis for the study's data. Using satellite imagery from the Terra and Aqua satellites, the study evaluated the correlation between remotely sensed AOD and ground-based measurements of particulate matter (pm10 and pm2.5) within 10 km of the city center. The findings demonstrate that AOD is a highly reliable predictor of ground-measured particulate matter and that there is no significant relationship with the precise area used to derive the city-average AOD. The study made use of monthly averages of AOD readings for pixel days that occurred within a 10-kilometer radius of the city center during the month, weighted by the number of pixels observed on each day.

The study's use of changes in AOD levels to gauge the effect of the subway system on air pollution has some limitations. Although AOD is a trustworthy indicator of air pollution, it is only one facet of the intricate issue of urban air pollution. Future studies should look into how the subway system affects other pollutants and the overall quality of the air.

In conclusion, the studies covered in this article offer crucial details on how subway systems affect air pollution in urban areas around the globe. The findings imply that subway systems might reduce air pollution in cities with high initial levels of AOD at a reasonable cost. The findings of this study could be used by policymakers to decide whether to implement subway systems as a way to reduce air pollution. ## Reference