Urgent Drastic Measures Reduce Fine Dust

Jin-Young Choi

University of Frankfurt

Sept. 27, 2018

Motivation

- Air pollution is a main contributor to the burden of disease from environment (Lim et al., 2012), responsible for 7 million premature deaths in 2012, with 3.7 million due to ambient air pollution (WHO, 2014).

- The most harmful pollutants to health related to premature death are fine particulate matter with a diameter of 2.5 microns ($PM_{2.5}$).

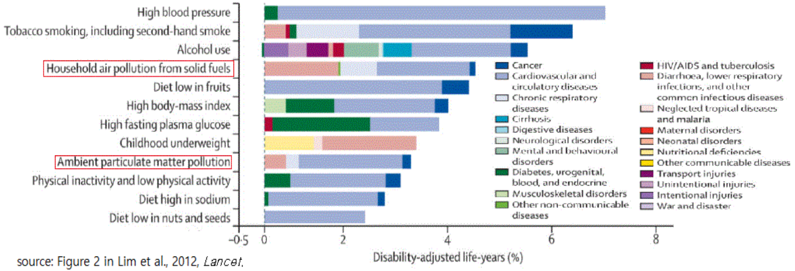


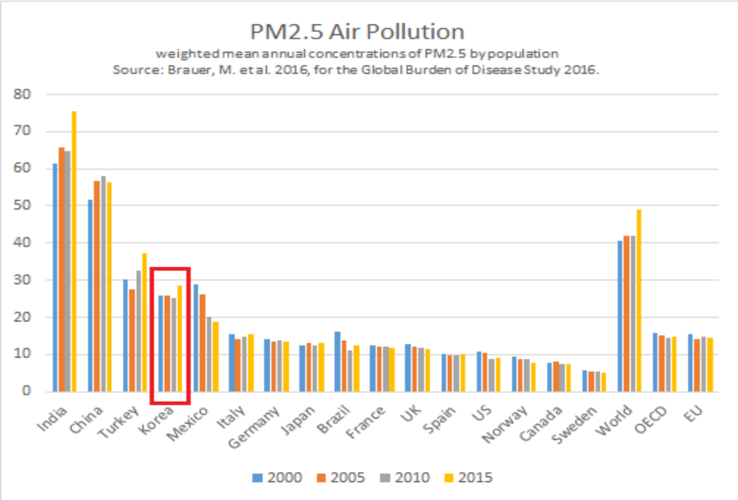
Figure: Burden of disease attributable to 20 leading risk factors in 2010

PM2.5

- $PM_{2.5}$ consists of tiny particles with a diameter less than 2.5 microns.
  - It is measured in micrograms per cubic meter of air ($\mu g / m^3$).
  - There are about 25,000 microns in an inch and million micrograms in a gram.
  - It penetrates deeply into lungs to damage the respiratory system (Xing et al, 2016).
  - hard to avoid, as it easily penetrates indoors (Thatcher & Layton; 1995, Vett et al., 2001)
  - According to International Agency for Research on Cancer (IARC, 2013), PM is a (Group 1) carcinogen .

- $PM_{2.5}$ level in South Korea is the second worst among the OECD countries. National-level policy responses to $PM_{2.5}$ have been implemented since 2015.

PM2.5 Level


PM2.5 Air Pollution
weighted mean annual concentrations of PM2.5 by population
Source: Brauer, M. et al. 2016, for the Global Burden of Disease Study 2016.
80
70
60
50
40
30
20
10
0
India
China
Turkey
Korea
Mexico
Italy
Germany
Japan
Brazil
France
UK
Spain
US
Norway
Canada
Sweden
World
OECD
EU
2000
2005
2010
2015

Emergency Measure

- Given the high level of $PM_{2.5}$, Ministry of Environment implemented "emergency measures" in Seoul metropolitan area (Feb. 15, 2017): when there is serious pollution for two consecutive days, emergency measures (EM) are activated.

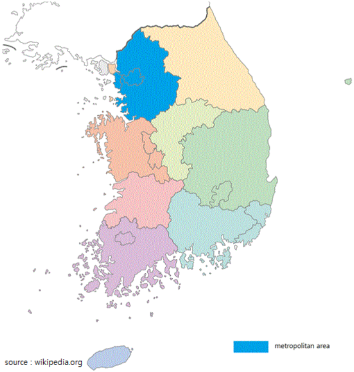
- EM to reduce air pollution has been introduced in other countries as well.
  - Paris has been implementing EM from 1997, Beijing from 2015, and Delhi from 2017.
  - Requirements for EM to be activated are different across cities.
  - They are mostly triggered by a high PM level.
  - EM restricts traffic drastically and heavily cuts down on the capacity utilization of factories causing air pollution.

Literature Review

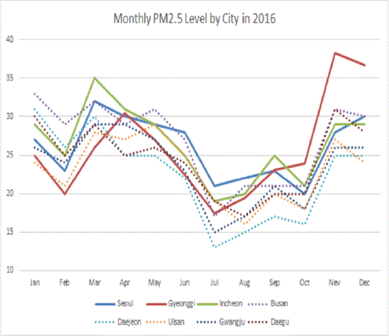
- EM has positive effects on air pollution levels:
  - According to Environmental Protection Agency of China (2015), EM reduced the $PM_{2.5}$ in Beijing by 17∼25%.
  - Traffic jams in Paris reduced by up to 40% as result of EM.
- No academic literature on the effect of EM, but many papers analyzing effects of environmental policies for air quality (Davis 2008, Currie & Walker 2011, Viard & Fu 2015, Gehrsiz 2017, Lee et al. 2018 & references therein).
- EM is different from other typical environmental policies, as EM is targeted for certain polluted days, not being a preventative measure for any long run improvement.
- This paper investigates the effect of EM on air quality, measured by $PM_{2.5}$, in the short run.

Emergency Measure in South Korea 1

- EM imposed only in Seoul and its surrounding areas (Incheon and Gyeounggi).
  - One half of the population live here (Statistics Korea, 2018).
  - The $PM_{2.5}$ level is much higher in these areas.



source : wikipedia.org



source : Air Quality Annual Regort (2016), National Institute of Environmental Research(NIER)

Emergency Measure in South Korea 2

- The EM is implemented tomorrow if all of the following conditions are met today:
  1. Regional average $PM_{2.5}$ level during midnight∼4pm is higher than 50_{mg}.
  2. Regional forecast of $PM_{2.5}$ for the next day is "bad" (higher than 50_{mg}).
  3. 1) and 2) hold in all of Seoul, Incheon and Gyeounggi.

- The EM is announced at 17:30 to be implemented next day 6:00∼21:00.

- The EM was first activated in January 15,17,18 of 2018, and 6 times in total since its beginning in 2017.

Emergency Measure in South Korea 3

- The EM in South Korea consists of
  1. Cars in the public sector are barred on alternate days according to car plate numbers.
  2. 80 air pollutant emission facilities in the public sector reduce operation capacity.
     - e.g. combined heat & power (CHP) plants (max. 17.6% ↓), waste disposal facilities (max. 50% ↓), sewage treatment plants (max. 44% ↓) in Seoul.
  3. 514 construction sites in the public sector implement fine dust reduction measures.
     - e.g. using sprinkler trucks and dustproof devices.
- In addition to these, Seoul takes extra measures:
  1. 360 public parking lots are closed.
  2. Public transportation in Seoul is free from 6:00∼9:00 and 18:00∼21:00.

Emergency Measure in South Korea 4

- Note that there two different EMs: EM imposed only in Seoul and EM imposed in all Seoul metropolitan areas.
  - The first is activated in Seoul if condition 1 and 2 hold only in Seoul.
  - The second is activated in all Seoul metropolitan areas if these conditions hold in all areas.
  - EM for Seoul includes additional actions.
- However, in the actual data, EM for Seoul never be activated alone.
- Thus, we focus the second EM with a different treatment for Seoul.

Estimation Strategy 1

- The goal is finding the effect of EM (D_t) on the level of $PM_{2.5}$ (Y_t). Some difficulties in finding the treatment effect: EM (D_t) is activated today if yesterday $PM_{2.5}$ (Y_{t-1}) and the forecasted $PM_{2.5}$ for today ($E_{t-1}(Y_t)$) were high.
- The least restrictive way to find the effect is regression discontinuity (RD), but the EM was activated only 6 days, there is no T group around the cutoff of Y_{t-1}, and $E_{t-1}(Y_t)$ is categorical ("Good", "Normal", "Bad").
- Also, among those 6 days, only 3 days (January 15,17,18 in 2018) can be used, because 1 day falls on a weekend (Dec. 30, 2017) and 2 days are after a reform of the EM (March 26 & 27, 2018).
- Instead of RD, multiple conditions of the EM are utilized in difference in differences (DD) framework.

Estimation Strategy 2

- Specifically, EM is activated ($D_{d,r,y} = 1$for $r = Seo, Gye, Inc$, $d > Feb.15$, $y \geq 2017$) if the following conditions hold, where d indicates day, r region, $y$year, and $\overline{Y}$ is the regional average of $PM_{2.5}$ during 00~4pm:

Cond1) $\overline{Y}_{d-1,Seo}$, $\overline{Y}_{d-1,Gye}$, and $\overline{Y}_{d-1,Inc}$ are higher than 50.

Cond2) forecast$_{d-1}$ of $\overline{Y}_{d,Seo}$, $\overline{Y}_{d,Gye}$, and $\overline{Y}_{d,Inc}$ are "Bad".

- Using daily variation, regional variation, and yearly variation, we will find a counterfactual of Y ($\equiv Y^0$).

Notations

- $Y_{i,d,r,y}$: daily average $PM_{2.5}$ at observatory i, day d, region r, and year y.
- $S^1_{d,r,y} \equiv \overline{Y}_{d-1,r,y}$: regional average of $Y_{i,d-1,r,y}$ during 00∼4pm on day $d-1$, region r, and year y.
- $S^2_{d,r,y} \equiv E_{d-1}(\overline{Y}_{d,r,y}) \in \{Good, Normal, Bad\}$: forecast for the regional average of $Y_{d,r,y}$ made one day ago.
- $D_{d,r,y} = 1$ for $r = Seo, Gye, Inc, \;\; d > Feb.15, \;\; y \geq 2017$ if $C^1_{d,r,y} \times C^2_{d,r,y}$=1 where
  - $C^1_{d,r,y} \equiv 1[S^1_{d,Seo,y} \geq 50] \times 1[S^1_{d,Gye,y} \geq 50] \times 1[S^1_{d,Inc,y} \geq 50]$
  - $C^2_{d,r,y} \equiv 1[S^2_{d,Seo,y} = \text{Bad}] \times 1[S^2_{d,Gye,y} = \text{Bad}] \times 1[S^2_{d,Inc,y} = \text{Bad}]$
- $W_{i,d,r,y}$: weather conditions (wind direction & speed, temperature, humidity, precipitation).

Triple DD 1

Consider a treatment effect model:

$$\begin{aligned} Y_{i,d,r,y} &= Y^0_{i,d,r,y} + (Y^1_{i,d,r,y} - Y^0_{i,d,r,y}) D_{d,r,y} \\ &= Y^0_{i,d,r,y} + \beta_{D,i,d,r,y} D_{d,r,y}. \end{aligned} \tag{M}$$

First-difference in days by group & year:

$$\begin{aligned} \Delta Y_{i,d,r=g,18} &= \Delta Y^0_{i,d,r=g,18} + \beta_{D,i,d,r=g,18} \Delta D_{d,r,y}, \\ \Delta Y_{i,d,r=g,17} &= \Delta Y^0_{i,d,r=g,17}, \\ \Delta Y_{i,d,r\neq g,18} &= \Delta Y^0_{i,d,r\neq g,18}, \\ \Delta Y_{i,d,r\neq g,17} &= \Delta Y^0_{i,d,r\neq g,17} \end{aligned}$$

where $\Delta X_{i,d,r,y} \equiv X_{i,d,r,y} - X_{i,d-1,r,y}$ and $g \equiv \{Seoul, Gyeonggi, Incheon\}$.

Triple DD 2

Take difference in years for $r = g$ and $r \neq g$:

$$\Delta Y_{i,d,r=g,18} - \Delta Y_{i,d,r=g,17}$$
$$= \Delta Y^0_{i,d,r=g,18} - \Delta Y^0_{i,d,r=g,17} + \beta_{D,i,d,r=g,18} \Delta D_{d,r=g,18},$$
$$\Delta Y_{i,d,r\neq g,18} - \Delta Y_{i,d,r\neq g,17} = \Delta Y^0_{i,d,r\neq g,18} - \Delta Y^0_{i,d,r\neq g,17}.$$

Let χ denote (observed) confounder and now assume a simple model for Y^0:

$$Y^0_{i,d,r,y} = g(\chi_{i,d,r,y}) + \delta_i + \delta_d + \delta_r + \delta_y \tag{M$_0$}$$
$$+ \delta_{d,r} + \delta_{d,y} + \delta_{r,y} + U_{i,d,r,y},$$
$$\Longrightarrow \ \Delta Y^0_{i,d,r,y} = \Delta g + \Delta\delta_{d,r} + \Delta\delta_{d,y} + \Delta U_{i,d,r,y};$$

for a (known) flexible function g of $\chi_{i,d,r,y}$ and unobserved fixed effects δ.
$\Delta\delta_{d,r}$ does not appear in the differences $\Delta Y_{i,d,r=g,18} - \Delta Y_{i,d,r=g,17}$ and $\Delta Y_{i,d,r\neq g,18} - \Delta Y_{i,d,r\neq g,17}$.

Triple DD 3

Let $\widetilde{\beta}_D$ denote $\widetilde{\beta}_D \equiv E(\beta_{D,i,d,r=g,18}|\chi = x, r = g, y = 18)$ and for simplicity, drop $\chi = x$ for a while.

Take $E(\cdot|r = g, y = 18)$ on $\Delta Y_{i,d,r=g,18} - \Delta Y_{i,d,r=g,17}$ and $\Delta Y_{i,d,r\neq g,18} - \Delta Y_{i,d,r\neq g,17}$:

$$
\begin{aligned}
&E(\Delta Y_{i,d,r=g,18}|r = g, y = 18) - E(\Delta Y_{i,d,r=g,17}|r = g, y = 17) \\
&= \widetilde{\beta}_D \Delta D_{d,r=g,18} + \Delta\delta_{d,18} - \Delta\delta_{d,17} \\
&+ E(\Delta U_{i,d,r=g,18}|r = g, y = 18) - E(\Delta U_{i,d,r=g,17}|r = g, y = 17)
\end{aligned}
$$

$$
\begin{aligned}
&E(\Delta Y_{i,d,r\neq g,18}|r \neq g, y = 18) - E(\Delta Y_{i,d,r\neq g,17}|r \neq g, y = 17) \\
&= \Delta\delta_{d,18} - \Delta\delta_{d,17} \\
&+ E(\Delta U_{i,d,r\neq g,18}|r \neq g, y = 18) - E(\Delta U_{i,d,r\neq g,17}|r \neq g, y = 17).
\end{aligned}
$$

Triple DD 4

The triple DD defined by (writing '$y = \#$' as '$\#$')

$$\begin{aligned}&\{E(\Delta Y_{i,d,r=g,18}|r=g,\ 18) - E(\Delta Y_{i,d,r=g,17}|r=g,\ 17)\} \\ &-\{E(\Delta Y_{i,d,r\neq g,18}|r\neq g,\ 18) - E(\Delta Y_{i,d,r\neq g,17}|r\neq g,\ 17)\} \\ &= \widetilde{\beta}_D \Delta D_{d,r=g,18}\end{aligned} \tag{trDD}$$

equals the treatment effect if $\Delta D_{d,r=g,18} = 1$ and

$$\begin{aligned}&E(\Delta U_{i,d,r=g,18}|r=g,\ 18) - E(\Delta U_{i,d,r=g,17}|r=g,\ 17) \\ &= E(\Delta U_{i,d,r\neq g,18}|r\neq g,\ 18) - E(\Delta U_{i,d,r\neq g,17}|r\neq g,\ 17)\end{aligned} \tag{ID$_t$rDD}$$

$$\iff$$

$$\begin{aligned}&E(\Delta U_{i,d,r=g,18}|r=g,\ 18) - E(\Delta U_{i,d,r\neq g,18}|r\neq g,\ 18) \\ &= E(\Delta U_{i,d,r=g,17}|r=g,\ 17) - E(\Delta U_{i,d,r\neq g,17}|r\neq g,\ 17)\end{aligned} \tag{ID$_t$rDD$'$}$$

The identified parameter is the average treatment effect on the treated (ATT).

Triple DD 5

- ID'_{trDD} is that the regional difference of ΔU is the same for the two years.
- It is weaker than the usual DD identification assumptions.
  - In "group-wise DD", ΔU should be the same across the regions in 2018.
  - In "time-wise DD", ΔU should be the same across the two years for g.
- To estimate this model, we will use OLS with flexible functions of confounders including lagged Y.
  - D could be endogenous due to its conditions.
  - Since D is product of multiple conditions, each condition can be used as IV.
  - Since each binary condition is based on the running variable S^1 while $S^1$is continuous, the requisite conditions to be a valid IV are plausible if flexible functions of S^1 are included in the regression model.

Air Pollution Data

- The air pollution data are from "airkorea.or.kr" providing real-time (hourly) air pollution levels across South Korea.
- The website is managed by Korea Environment Corporation(K-eco).
- The air pollution information is collected from 323 observatories across 97 regions.
    - 39 in Seoul, 85 in Gyeounggi, 23 in Incheon.
- Potential treated regions and metropolitan cities are considered (219 obs.).

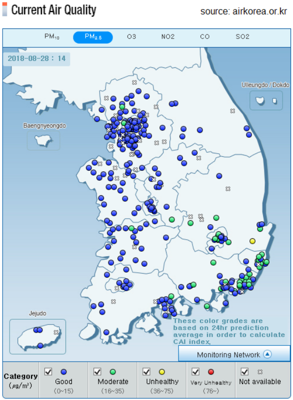


Figure: Map of Observatory in 2018

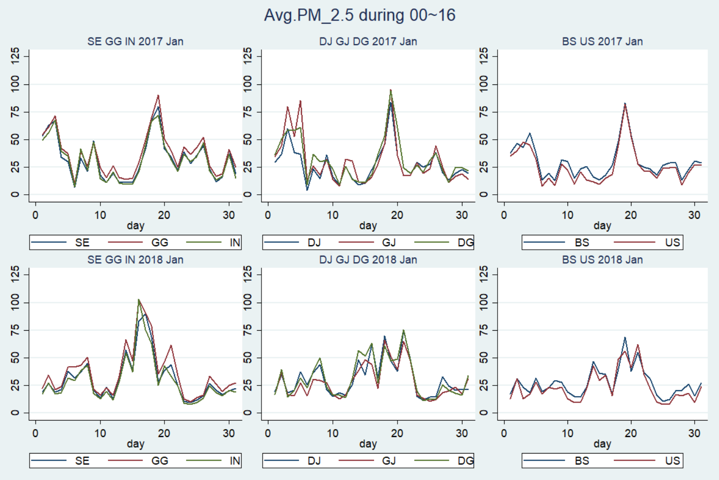
Weather Data

- The concentration of $PM_{2.5}$ in a given location is highly affected by the weather conditions, such as wind direction & speed, temperature, humidity, and precipitation (Harrision et al.; 1997, 2012, Kassomenos et al.; 2014).
- The weather data were obtained from "data.kma.go.kr" providing real-time (hourly) weather information across South Korea.
  - The website is managed by the National Weather Service.
  - The weather information is collected from 494 automatic weather stations (AWS).
- AWS are different from the air pollution observatories.
  - AWS were matched to the observatories based on the distance, and the observatories with its the distance to AWS shorter than 10_{km} were used.
  - As a robustness check, observations with the distance shorter than 5_{km} were also considered.

Samples 1

- The observation unit is daily average over 6:00∼21:00 at each observatory. The EM is activated only between 6:00∼21:00.
- Samples used in estimation are restricted in several ways:
  - Since air pollution is sensitive to seasonality, only January (in 2017, 2018) data are used (D=1 cases only in January 2018).
  - Observatories in suburbs or islands are excluded.
  - The sample with missing information on important variables (e.g. weather) are dropped.
- The number of observations used in final estimation is 7822.

PM25 in Jan. 2017 and 2018



Data Description

Table 1. Data Description						
	total		D=1		D=0	
Var.	mean	sd	mean	sd	mean	sd
Y	31.95	20.9	67.66	19.2	30.43	19.5
D	0.041					
S_1	33.0	19.9	82.77	16.4	30.83	17.1
S_2	1.986	0.53	1		1.943	0.50
Q	0.635		1		0.619	
Y18	0.586		1		0.568	
Weekend	0.283		0		0.295	
Humid	32.05	28.9	45.25	33.4	31.49	28.6
Rain	0.017	0.09	0.001	0.01	0.018	0.10
Temp	-1.370	5.40	3.353	1.61	-1.571	5.41
Wind_sp	1.860	1.16	1.267	0.55	1.886	1.18
Wind_x	0.003	0.17	0.005	0.14	0.002	0.17
Wind_y	0.145	0.25	0.214	0.26	0.142	0.25

Estimation Model

- The dependent variable : $\Delta Y_{i,d,r,y}$. Some observations are dropped due to missing variables; unbalanced panel.
- The independent variables : all variables in Table 1, except Y.
  - A flexible function of S_r^1 and S_r^2.
  - For $r = g$, we control $S_{r'}^1$ and $S_{r'}^2$ of the neighboring region r' as well as interaction terms with S_r^1 and S_r^2.
  - Weather conditions with region-varying coefficients.
  - Dummy variables for $\Delta\delta_{d,y}$ and $\Delta\delta_{d,r}$.
- The IV's for D : C^1, C^2.

Estimation Results 1

Table 2. Estimation Results in level Y				
	OLS β(tv)		IVE β(tv)	
	(1)	(2)	(3)	(4)
Distance $\leq 10_{km}$				
D	-27.37 (-24.8)	-29.21 (-21.97)	-23.70 (-13.0)	-26.08 (-12.9)
D $\times$ *Seoul*		6.27 (3.70)		8.76 (3.34)
First-stage F-test for IVs			0.000	0.000
Exo. (Score) test P-value			0.009	0.011
Distance $\leq 5_{km}$				
D	-26.57 (-20.9)	-29.14 (-16.9)	-23.36 (-11.2)	-27.50 (-11.1)
D $\times$ *Seoul*		6.20 (3.14)		10.86 (3.62)
First-stage F-test for IVs			0.000	0.000
Exo. (Score) test P-value			0.050	0.014

Estimation Results 2

- The total ATT is -23~-27 of $PM_{2.5}$.
  - -17~-23 for Seoul and -26~-29 for other regions.
- The EM effect is smaller in Seoul.
  - Additional actions are implemented, such as free public transportation during rush-hour.
  - According to the report by the air quality management division in Seoul, traffic volume 1.8%$\downarrow$, subway ridership 2.1% $\uparrow$, bus ridership 0.4% $\uparrow$.

Estimation Results 3

- Concerns for other air pollutant emission facilities.
  - E.g. the number of public waste incineration facilities.
  - 5 in Seoul, 27 in Gyeounggi, 9 in Incheon.
  - The total capacity of those facilities in Gyeounggi is almost twice as high as that of Seoul.
- It is known that a large part of $PM_{2.5}$ comes from the combustion of fossil fuels.
- The effect would be limited, however, because compulsory measures were taken in the public sector.

Conclusions

- The effect of emergency measure (EM) for fine dust reduction in South Korea was examined.
  - EM includes urgent and drastic actions in the public sector.
- It is found that the total ATT is -23~-27 of $PM_{2.5}$.
  - -17~-23 for Seoul and -26~-29 for other regions.
- The effect would be limited, however, because all compulsory actions were implemented only in the public sector.