Pollution Rides on the Wind: The Effects of Transboundary Air Pollution from China on Ambient Air Quality in South Korea

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INTRODUCTION

- In the last decade, South Korea has suffered from increased levels of air pollution.
- For policy, an important question is: to what degree are the pollution problems experienced in South Korea due to domestic versus Chinese sources?
- In 2013, a report commissioned by the South Korean government estimated that prevailing westerly winds transport substantial amounts of air pollution from China into South Korea.
- Importantly, the report estimated that 30-50% of ambient $PM_{2.5}$ pollution levels in South Korea originated from Chinese deserts and cities.

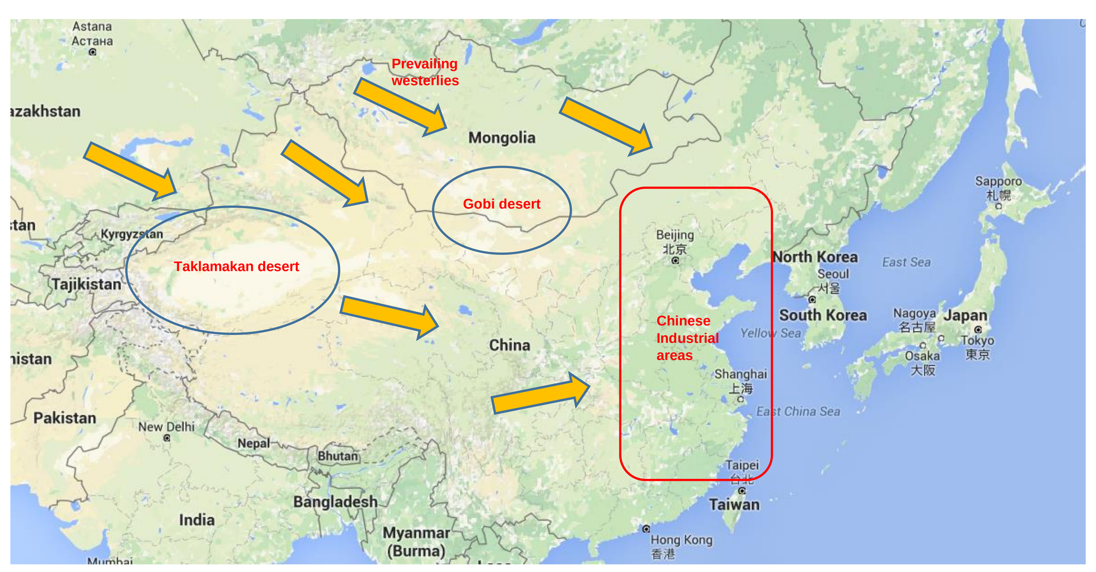

Figure 1. Prevailing westerly winds transport dust from deserts in west China and Inner Mongolia (i.e., Taklamakan, Gobi) and pollution from industrial cities (Beijing, Shanghai) to South Korea.

OBJECTIVES

- Using random fluctuations in wind direction, I econometrically estimate the average effect of dust and industrial pollution emissions from China on ambient pollution levels in South Korea.
- As a first step, I estimate which wind direction is associated with the highest level of pollution levels in South Korea.
- To differentiate pollution from Chinese deserts (primarily during spring) and cities (primarily during winter), I examine the wind direction / ambient pollution level relationship across seasons.

DATA

- Two sets of panel data are used:

1) Daily average concentrations of PM_{10} are downloaded from the Korea Environment Corporation (KECO) website.

2) Daily weather monitoring data (precipitation, temperature, wind speed, wind direction) are gathered from the Korean National Climate Data Service System (NCDSS) website.

- The data cover all seven metropolitan areas and nine provinces in South Korea.
- Data collection period:
  January 1, 2006 – December 31, 2014

METHODS

- Figure 2 plots the bivariate relationship between PM_{10} concentrations and wind direction.

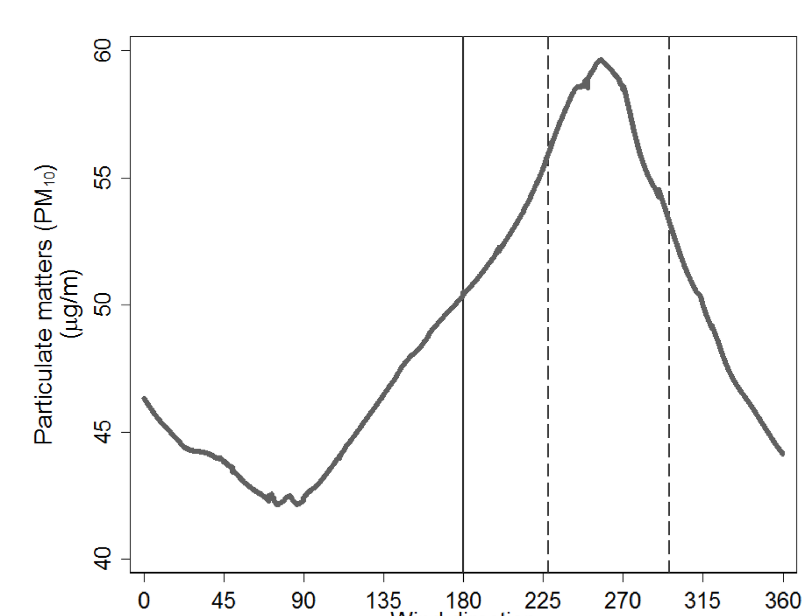

Figure 2. PM_{10} concentrations by wind directions (2006-2014)

Notes: Locally Weighted Scatterplot Smoothing (LOWESS) with bandwidth of 0.2. Left dashed line indicates the direction from Shanghai toward South Korea. Right dashed line indicates the direction from Beijing toward South Korea.

- The following two fixed-effect regression models are estimated:

$$(1)\quad PM_{10_{ct}} = \alpha + \beta_1 Precip_{ct} + \beta_2 Temp_{ct} + \beta_3 W_{S_{ct}} + \beta_4 [W_{S_{ct}} \times 1(W_{D_{ct}})] + \eta_c + \delta_t + \varepsilon_{ct}$$

$$(2)\quad PM_{10_{ct}} = \alpha + \beta_1 Precip_{ct} + \beta_2 Temp_{ct} + \beta_3 W_{S_{ct}} + \beta_4 [W_{S_{ct}} \times \cos(W_{D_{ct}})] + \eta_c + \delta_t + \varepsilon_{ct}$$

where c: city/province, t: time, $Precip$: precipitation, $Temp$: temperature, W_S: wind speed, and W_D: wind direction.

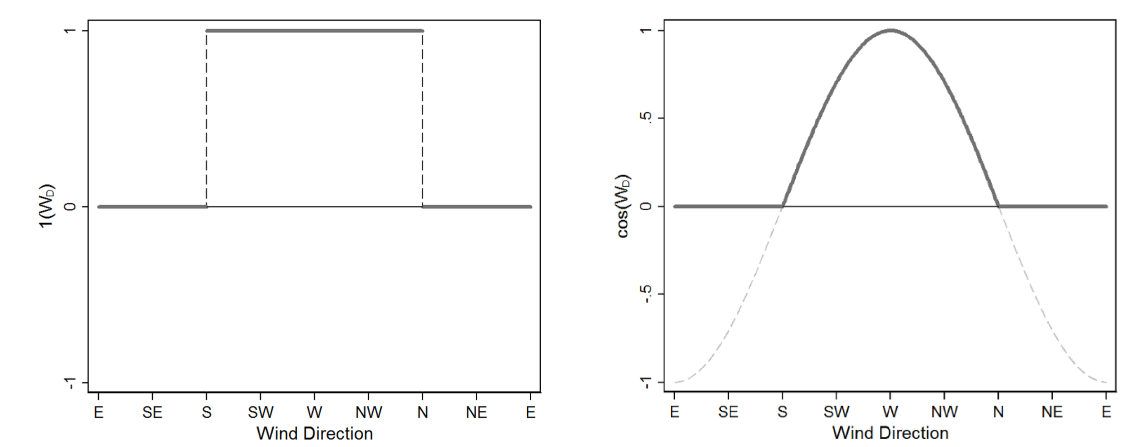

Figure 3. Graphical example of $1(wind\ direction)$ and $\cos(west\ wind)$

Notes: Dummy for westerly wind equals to 1 if the azimuth degrees of wind direction are between 181° and 360°, and 0 otherwise. The trigonometric cosine function is truncated so that directions map them 90° away from the west take a value of 0.

RESULTS

Table 1. Marginal effects of the westerly wind on PM_{10} concentrations

	Year round	Spring	Summer	Fall	Winter
Precipitation (mm)	-0.098***	-0.601***	-0.089***	-0.078*	-0.031
	(0.018)	(0.101)	(0.019)	(0.042)	(0.030)
Temperature (C°)	0.066**	0.169**	0.296***	0.135**	-0.128
	(0.028)	(0.075)	(0.076)	(0.068)	(0.084)
Wind speed (m/s)	-1.820***	-2.098***	-0.987**	-0.930*	-2.819***
	(0.281)	(0.733)	(0.390)	(0.537)	(0.611)
1(Wind direction)× Wind speed	**0.883*** **	**1.737*** **	**1.588*** **	**0.854** **	**2.209*** **
	(0.210)	(0.553)	(0.306)	(0.416)	(0.407)

Table 2. Average effects of westerly winds on PM_{10}

	Year round	Spring	Summer	Fall	Winter
Marginal effect	0.883***	1.737***	1.588***	0.854**	2.209***
	(0.210)	(0.553)	(0.306)	(0.416)	(0.407)
Mean wind speed (m/s)	1.899	2.148	1.794	1.653	2.001
Mean PM_{10} ($\mu g/m^3$)	49.57	62.26	37.72	43.91	54.39
Average effect ($\mu g/m^3$)	1.68	3.73	2.85	1.41	4.42
Percent (%)	**3.38**	**5.99**	**7.55**	**3.21**	**8.13**

Table 3. Marginal effects of each west wind direction on PM_{10} concentrations

	Year round	Spring	Summer	Fall	Winter
$\cos$(wind direction) × wind speed					
NNW	-2.205***	-0.693	1.397***	0.150	1.931***
	(0.255)	(0.691)	(0.524)	(0.535)	(0.577)
NW	-0.802***	1.098	2.892***	0.609	3.019***
	(0.257)	(0.702)	(0.494)	(0.510)	(0.538)
WNW	0.869***	2.164***	**2.616*** **	1.302***	**2.841*** **
	(0.255)	(0.678)	(0.429)	(0.501)	(0.474)
W	2.259***	2.375***	2.337***	1.754***	2.419***
	(0.251)	(0.638)	(0.397)	(0.517)	(0.459)
WSW	3.155***	**2.422*** **	2.195***	**2.048*** **	1.929***
	(0.249)	(0.634)	(0.400)	(0.562)	(0.497)
SW	**3.294*** **	2.033***	1.740***	1.977***	1.053*
	(0.261)	(0.664)	(0.409)	(0.643)	(0.615)
SSW	3.155***	1.409**	0.987**	1.734**	0.204
	(0.284)	(0.704)	(0.403)	(0.776)	(0.814)

Notes: The estimates with the highest R^2 for each season are marked in red.

Table 4. Average effects of winds on PM_{10}

	Year round	Spring	Summer	Fall	Winter
Wind direction	SW	WSW	WNW	WSW	WNW
Marginal effect	3.294***	2.422***	2.616***	2.048***	2.841***
	(0.261)	(0.634)	(0.429)	(0.562)	(0.538)
Mean wind speed (m/s)	1.899	2.148	1.794	1.653	2.001
Mean PM_{10} ($\mu g/m^3$)	49.57	62.26	37.72	43.91	54.39
Average effect ($\mu g/m^3$)	6.26	5.20	4.69	3.39	5.68
Percent (%)	**12.62**	**8.36**	**12.44**	**7.71**	**10.45**

CONCLUSION

- A 1 m/s increase in westerly wind speed is associated with a 2.209 $\mu g/m^3$ increase in daily mean PM_{10} concentrations during winter and a 1.737 $\mu g/m^3$ increase during spring.
- The average westerly wind effect accounts for 3.38% of the annual mean PM_{10} levels, 8.13% in winter, and 5.99 % in spring.
- Specifically, southwest wind (SW) has the greatest year-round effect, accounting for 6.26 $\mu g/m^3$ (12.62%) of total annual mean PM_{10} concentrations.
- West-northwest wind (WNW), blowing from Beijing to South Korea, is associated with the largest average summer and winter seasonal effects, 12.44% and 10.45% respectively.
- West-southwest wind (WSW) has the strongest average impact during spring and fall, 8.36% and 7.71% respectively, corresponding to wind direction from Shanghai to South Korea.
- Results suggest that previous estimates of Chinese contributions to South Korea pollution levels might be overstated.

POLICY IMPLICATIONS

- The South Korean government should work to identify local pollution sources, which may be the largest contributions to PM_{10} in South Korea.
- Increased international collaboration between China, Japan, and South Korea may help to identify ways to decrease emission levels, both domestically and across international borders, benefiting all three countries.