# Mortality Impact of Transboundary Air Pollution: Evidence from East Asia

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We would like to thank Keisuke Ito for their exceptional research assistance.

# China is building more than half of the world's new coal power plants

Some 176 gigawatts of coal capacity was under construction in 2021, and more than half of that was being built in China

ENVIRONMENT 26 April 2022

By Adam Vaughan

A coal-fired power plant in Datong, Shanxi province, China

Imaginechina Limited/Alamy Stock Photo

# At the same time, China has implemented agrresive environmental policies

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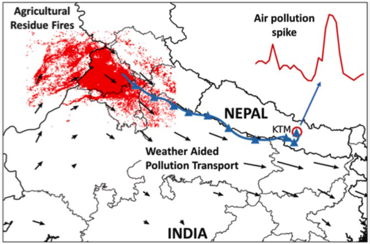
By Jeff Kearns, Hannah Dormido and Alyssa McDonald

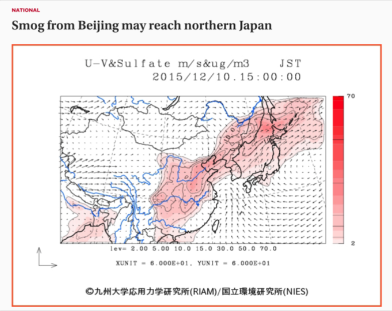
March 9, 2018

China is cracking down on pollution like never before, with new green policies so hard-hitting and extensive they can be felt across the world, transforming everything from electric vehicle demand to commodities markets.

# International spillover effects are becoming important





# However, economic analysis usually does not incorporate it

- Analyses of environmental policies typically focus on domestic benefits
  - Evaluations of environmental regulations in the United States
  - Recent environmental policies in China "War against pollution"
- However, a country's pollution reductions may create spillover benefits
  - e.g. China's environmental policy could benefit surrounding countries
  - In this case, conventional approaches may understate a policy's benefits

# In this paper, we study this international spillover effect

1. Integrate atmospheric science modeling with econometric estimation
   - Previous studies use indirect measures of transboundary air pollution
   - We use the HYSPLIT model to obtain direct measures at hour-city level
   - Bring these data to an econometric framework

2. Use the universe of individual-level mortality data in South Korea
   - We observe date, location, age, cause of death etc.
   - Estimate the mortality impact of transboundary air pollution

3. Quantify a hidden benefit of recent air quality improvements in China

# Road map of the talk

1. Data and Descriptive Evidence
2. Empirical Analysis and Results
3. Policy Implications

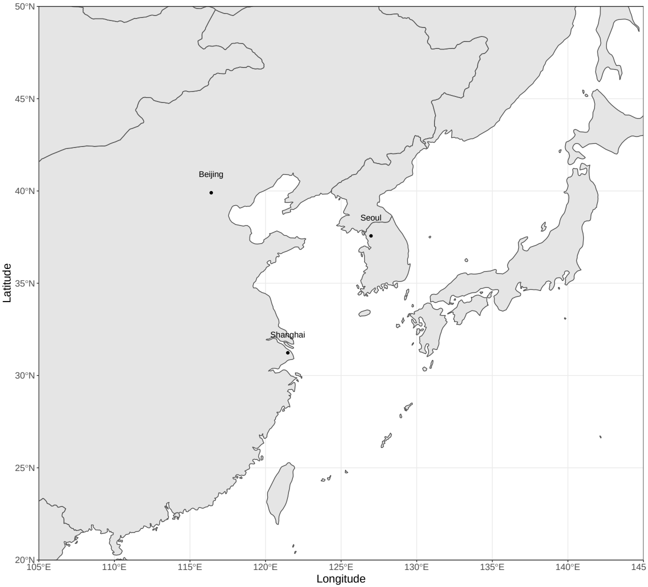
# Data and Descriptive Evidence

# Data 1) $PM_{2.5}$ and weather data in China and South Korea

- Hourly $PM_{2.5}$ at the monitor level in China and South Korea
  - January 2015 to Decmber 2019
  - Sources: Korea Environment Corporation and Berkeley Earth

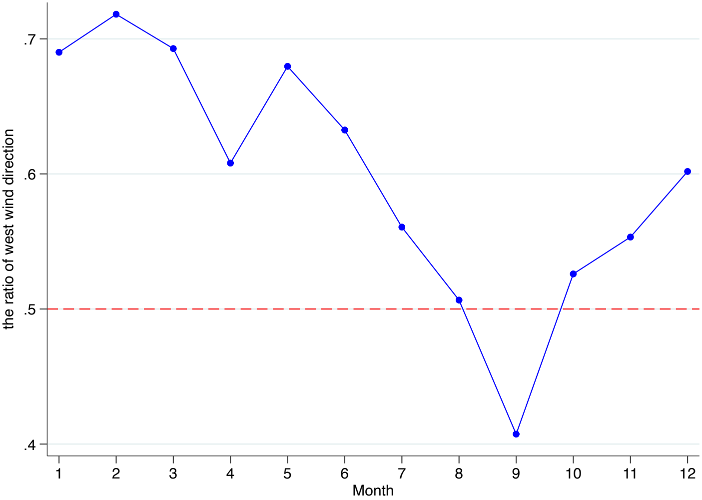
- Monitor-level weather data in South Korea
  - Source: Korea Meteorological Administration

# Westerlies create strong wind from China to South Korea

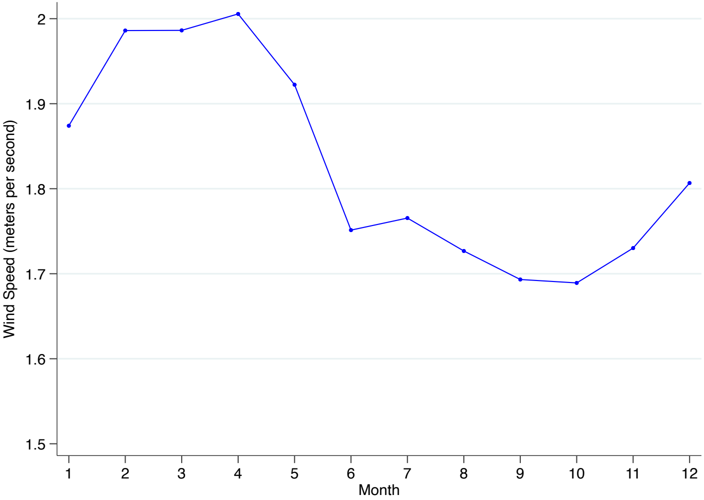


# Winter and spring: Particularly prevailing west wind

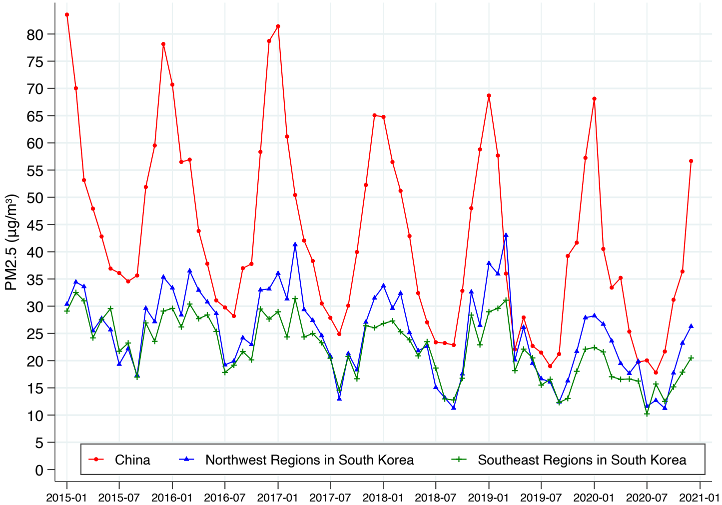
- The ratio of west wind in Seoul = west wind / (west + east wind)



# Winter and spring: Wind speed is also higher



# $PM_{2.5}$: Suggestive evidence of transboundary air pollution



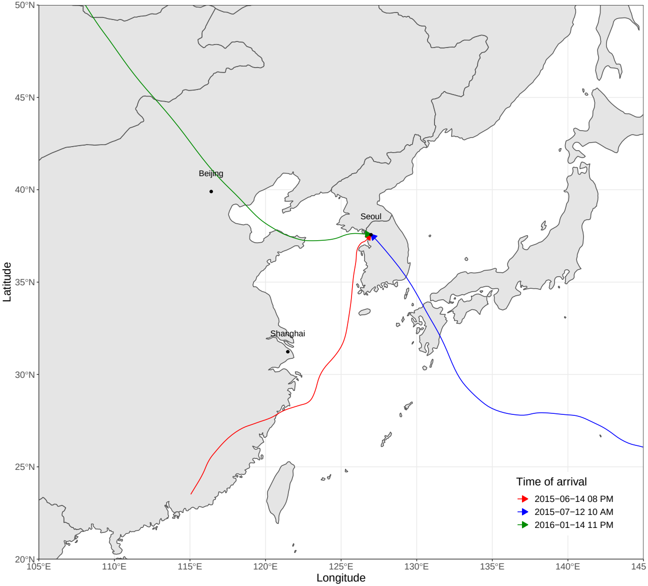

- Summer and fall: $PM_{2.5}$ is similar in NW and SW of South Korea
- Winter and spring: $PM_{2.5}$ is higher in NW than SW of South Korea

# Data 2) Transboundary air pollution data from HYSPLIT

- Previous studies use indirect measures
  - e.g. an interaction between source location's pollution and wind direction

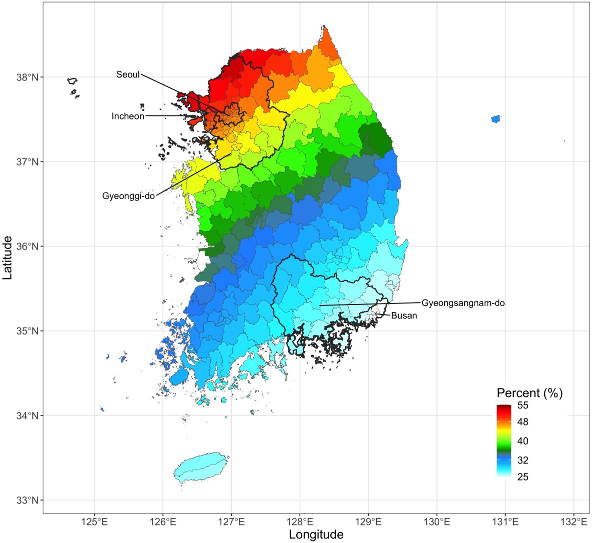
- We use NOAA's HYSPLIT model to obtain a direct measure
  1. Obtain backward particle trajectories for each hour for each city

# Examples of backward trajectories



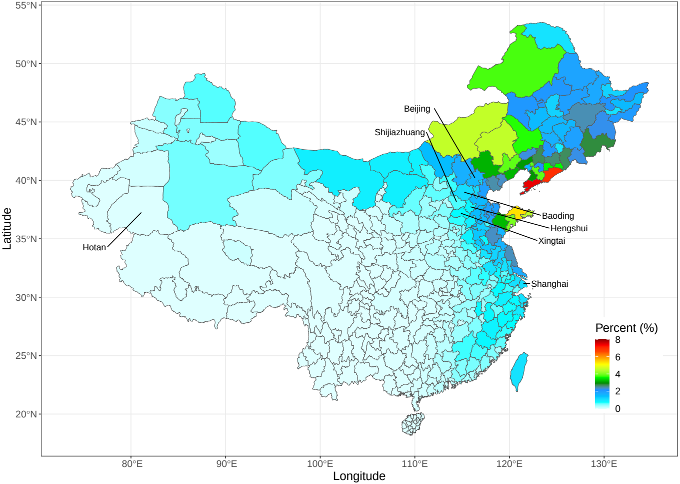
# Frequency of trajectories coming from China

- For each city, we calculate % of hours that had trajectories from China



# Where did these trajectories come from?

- For each city in China, we calculate % of hours that had trajectories to Korea



# Data 2) Transboundary air pollution data from HYSPLIT

1. Obtain backward particle trajectories for each hour for each city
    - Need to obtain 6.57 million trajectories (24 hourly trajectories/day $\times$ 365 days/year $\times$ 5 years $\times$ 228 cities in South Korea)
2. For each trajectory, identify time and location when it hits China
    - We use 1 km height in China and check robustness with other heights
3. Identify $PM_{2.5}$ at this location (in China) and time
    - We call this $PM_{2.5}$ by "Transboundary $PM_{2.5}$"
    - i.e., Transboundary $PM_{2.5}$ is the level of $PM_{2.5}$ at the source location

# Data 3) Mortality and ER visits

- The universe of mortality data in South Korea (1997-2019)
  - Date, hour, city, and cause of death. Age and gender.
  - Source: Statistics Korea

- Emergency hospital admissions in South Korea (2013-2017)
  - City-by-day data by symptoms
  - Source: National Health Insurance Service

# Road map of the talk

1. Data and Descriptive Evidence
2. Empirical Analysis and Results
3. Policy Implications

# Empirical Analysis and Results

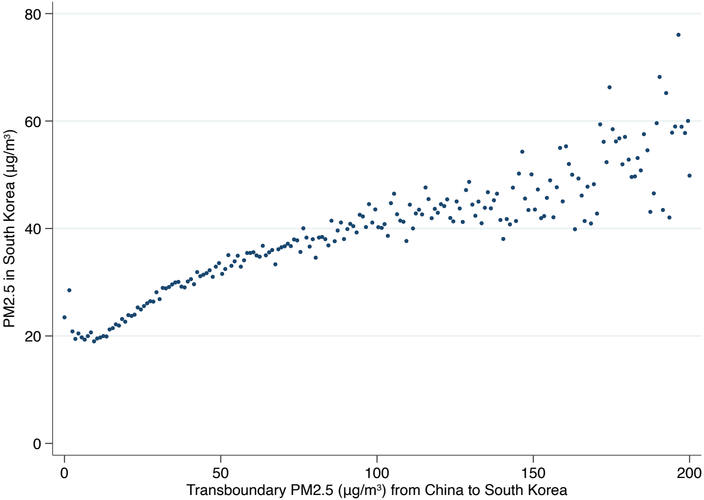
# 1st stage: Transboundary $PM_{2.5}$ & $PM_{2.5}$ in South Korea

$$\text{PM}_{ct} = \alpha_1 \text{TransboundaryPM}_{ct} + \alpha_2 X_{ct} + \theta_{ymc} + u_{ct}, \tag{1}$$

- Variables:
  - $\text{PM}_{ct}$: Hourly $PM_{2.5}$ in South Korean city $c$ in hour $t$
  - $\text{TransboundaryPM}_{ct}$: Hourly transboundary $PM_{2.5}$ from China that reached South Korean city $c$ in hour $t$
  - $X_{ct}$: A vector of control variables (weather etc.)
  - $\theta_{ymc}$: Fixed effects (e.g., year-by-month-by-city FE)
  - We cluster standard errors at the city level

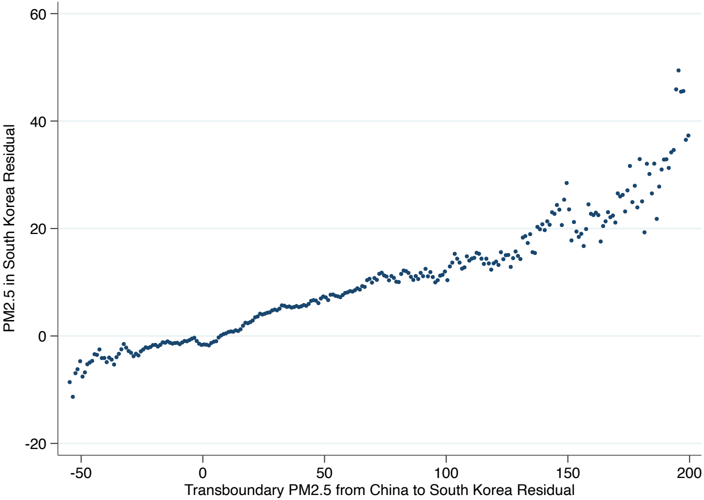
# 1st stage: Transboundary $PM_{2.5}$ & $PM_{2.5}$ in South Korea

- Raw data (hourly $PM_{2.5}$) with no control, with bin size = 1 unit of $PM_{2.5}$



# 1st stage: Transboundary $PM_{2.5}$ & $PM_{2.5}$ in South Korea

- Resisualized with fixed effects and controls used in last column of next table



# 1st stage: Transboundary $PM_{2.5}$ & $PM_{2.5}$ in South Korea

Dependent variable: Hourly $PM_{2.5}$ in South Korean cities

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| Hourly Transboundary $PM_{2.5}$ | 0.170 | 0.129 | 0.129 | 0.129 | 0.122 |
| | (0.003) | (0.002) | (0.002) | (0.002) | (0.002) |
| Constant | 22.776 | | | | |
| | (0.221) | | | | |
| Observations | 9160118 | 9107025 | 9107025 | 9107025 | 9107025 |
| KP F-stat | 3885 | 5730 | 5819 | 5774 | 5812 |
| Year-Month-City FE | No | No | Yes | Yes | Yes |
| Year-Month FE | No | Yes | No | No | No |
| Month-City FE | No | Yes | No | No | No |
| Month-Province FE | No | No | No | No | No |
| City FE | No | No | No | No | No |
| Day of week-City FE | No | Yes | Yes | Yes | Yes |
| Rainfall quartile-City FE | No | Yes | No | Yes | No |
| Temperature quartile-City FE | No | Yes | No | Yes | No |
| Rainfall decile-City FE | No | No | No | No | Yes |
| Temperature decile-City FE | No | No | No | No | Yes |
| Rainfall quartile FE | No | No | Yes | No | No |
| Temperature quartile FE | No | No | Yes | No | No |

- 1 unit increase in transboundary $PM_{2.5}$ $\rightarrow$ 0.12 increase in $PM_{2.5}$ in Korea

# Impacts on Mortality

# Reduced-form: Transboundary $PM_{2.5}$ & Mortality

$$\text{Mortality}_{ct} = \sum_{j=0}^{J} \beta_j \text{TransboundaryPM}_{c,t-j} + \delta X_{ct} + \theta_{ymc} + u_{ct}, \qquad (2)$$

- Variables:
  - $\text{Mortality}_{ct}$: Hourly mortality in South Korean city $c$ in hour $t$
  - $\text{TransboundaryPM}_{c,t-j}$: Hourly transboundary $PM_{2.5}$ from China that reached South Korean city $c$ in hour $t-j$
  - $X_{ct}$: A vector of control variables (weather etc.)
  - $\theta_{ymc}$: Fixed effects (e.g., year-by-month-by-city FE)
  - We cluster standard errors at the city level

# Reduced-form: Transboundary $PM_{2.5}$ & Mortality

Dependent variable: Mortality at hour-city level (death per billion people)

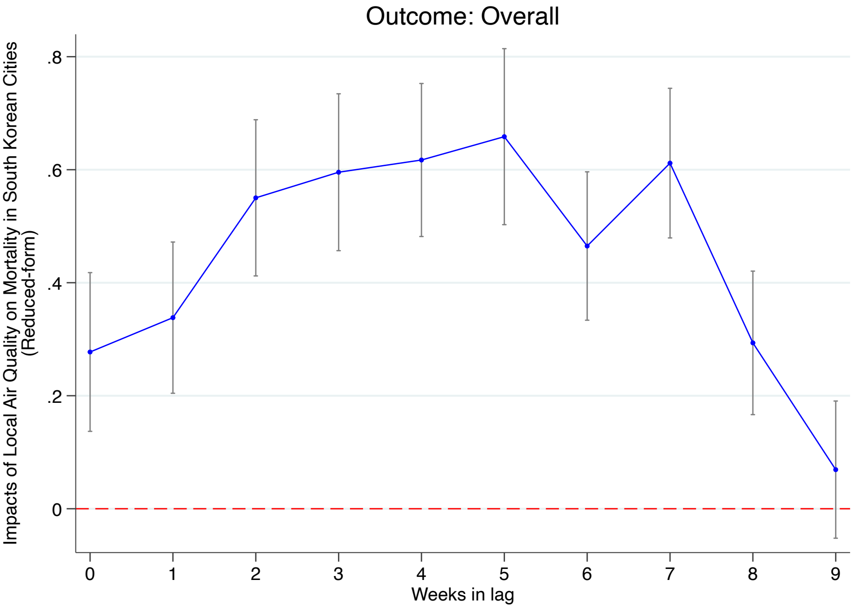
| | Respiratory/ cardiovascular | Elderly | Infant | Overall |
|---|---|---|---|---|
| Hourly Transboundary PM $_{2.5}$ | 1.66 | 19.00 | 6.67 | 3.56 |
| (past 0-70 days) | (0.17) | (2.17) | (3.33) | (0.34) |
| Observations | 9555368 | 9555368 | 9555368 | 9555368 |
| Mean of dependent variable | 148 | 3259 | 314 | 618 |
| Percent change relative to the mean | 1.12 | 0.58 | 2.12 | 0.58 |

- 1 $\mu g/m^3$ increase in transboundary $PM_{2.5}$ from China in the past 70 days $\rightarrow$ an increase in hourly mortality in South Korea by 3.56 per billion people
- This is a 0.6% increase relative to mean hourly mortality (618/billion people)

# Reduced-form: Weekly lagged effects

| | Respiratory/ cardiovascular | Elderly | Infant | Overall |
|---|---|---|---|---|
| Hourly Transboundary $PM_{2.5}$ (past 0-7 day) | 0.14 (0.04) | 1.35 (0.48) | 0.90 (0.58) | 0.28 (0.07) |
| Hourly Transboundary $PM_{2.5}$ (past 7-14 day) | 0.21 (0.03) | 1.93 (0.47) | 0.37 (0.64) | 0.34 (0.07) |
| Hourly Transboundary $PM_{2.5}$ (past 14-21 day) | 0.25 (0.04) | 3.16 (0.45) | 2.02 (0.64) | 0.55 (0.07) |
| Hourly Transboundary $PM_{2.5}$ (past 21-28 day) | 0.25 (0.03) | 3.59 (0.46) | -0.36 (0.59) | 0.60 (0.07) |
| Hourly Transboundary $PM_{2.5}$ (past 28-35 day) | 0.23 (0.04) | 3.61 (0.49) | 1.18 (0.70) | 0.62 (0.07) |
| Hourly Transboundary $PM_{2.5}$ (past 35-42 day) | 0.27 (0.04) | 3.81 (0.51) | 0.10 (0.69) | 0.66 (0.08) |
| Hourly Transboundary $PM_{2.5}$ (past 42-49 day) | 0.14 (0.03) | 2.41 (0.44) | 1.21 (0.75) | 0.46 (0.07) |
| Hourly Transboundary $PM_{2.5}$ (past 49-56 day) | 0.22 (0.03) | 3.50 (0.45) | 0.87 (0.70) | 0.61 (0.07) |
| Hourly Transboundary $PM_{2.5}$ (past 56-63 day) | 0.12 (0.03) | 1.74 (0.40) | 0.42 (0.57) | 0.29 (0.06) |
| Hourly Transboundary $PM_{2.5}$ (past 63-70 day) | 0.09 (0.03) | -0.09 (0.42) | 0.67 (0.64) | 0.07 (0.06) |
| Observations | 9555318 | 9555318 | 9555318 | 9555318 |
| Mean of dependent variable | 148 | 3259 | 314 | 618 |

# Reduced-form: Weekly lagged effects



# 2nd stage: $PM_{2.5}$ in South Korea & Mortality

$$\text{Mortality}_{ct} = \sum_{j=0}^{J} \beta_j \text{PM}_{c,t-j} + \delta X_{ct} + \theta_{ymc} + u_{ct}, \tag{3}$$

- Variables:
  - $\text{Mortality}_{ct}$: Hourly mortality in South Korean city $c$ in hour $t$
  - $\text{PM}_{c,t-j}$: Hourly $PM_{2.5}$ in South Korean city $c$ in hour $t-j$
  - Instrument = $\text{TransboundaryPM}_{c,t-j}$
  - $X_{ct}$: A vector of control variables (weather etc.)
  - $\theta_{ymc}$: Fixed effects (e.g., year-by-month-by-city FE)
  - We cluster standard errors at the city level

# 2nd stage: $PM_{2.5}$ in South Korea & Mortality

| Dependent variable: Mortality at hour-city level (death per billion people) | | | | |
|---|---|---|---|---|
| | Respiratory/ cardiovascular | Elderly | Infant | Overall |
| Hourly PM $_{2.5}$ (past 0-70 days) | 4.24 (0.47) | 48.60 (5.72) | 17.44 (8.63) | 9.09 (0.94) |
| Observations | 9528960 | 9528960 | 9528960 | 9528960 |
| Mean of dependent variable | 148 | 3258 | 314 | 618 |
| Percent change relative to the mean | 2.86 | 1.49 | 5.55 | 1.47 |
| KP F-stat | 1816 | 1816 | 1816 | 1816 |

- 1 $\mu g/m^3$ increase in local $PM_{2.5}$ in South Korea in the past 70 days $\rightarrow$ an increase in hourly mortality in South Korea by 9.09 per billion people
- This is a 1.47% increase relative to mean hourly mortality (618/billion people)

# Impacts on Emergency Room Visits

# Reduced-form: Transboundary $PM_{2.5}$ & ER visits

Dependent variable: Counts of ER visits at day-city level (visit per billion people)

| | Asthma | Rhinitis | Atopic |
|---|---|---|---|
| Daily Trans. $PM_{2.5}$ | 28.0 | 437.4 | -3.5 |
| (past 0-60 days) | (9.7) | (51.4) | (1.5) |
| Observations | 235388 | 235388 | 235388 |
| Mean of dependent variable | 9228.3 | 14053.4 | 363.5 |
| Percent change relative to the mean | 0.30 | 3.11 | -0.98 |

- We find increases for Asthma and Rhinitis but not for Atopic

# Suggestive Evidence on the Impact of Avoidance Behavior

# Does the "pollution alert" change the damage function?

Dependent variable: Mortality at hour-city level (death per billion people)

| | Respiratory/ cardiovascular | Elderly | Infant | Overall |
|---|---|---|---|---|
| Hourly Transboundary $PM_{2.5}$ (past 0-70day) | 2.04 (0.19) | 25.46 (2.48) | 5.13 (3.62) | 4.47 (0.40) |
| Hourly Alert (past 0-70day) | -73.04 (59.64) | 650.81 (758.45) | 850.75 (1080.57) | 176.44 (129.36) |
| Trans. $PM_{2.5}$ (past 0-70day) $\times$ Alert (past 0-70day) | -3.41 (2.77) | -124.71 (34.71) | -5.18 (45.80) | -20.50 (5.76) |
| Observations | 9555368 | 9555368 | 9555368 | 9555368 |
| Mean of dependent variable | 148 | 3259 | 314 | 618 |

- The negative coefficient on the interaction term provides suggestive evidence that the marginal damage of pollution is reduced by the alert

# Road map of the talk

1. Data and Descriptive Evidence
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3. Policy Implications

# Policy Implications

# Policy implications (work in progress)

- China had a substantial improvement in air quality from 2015 to 2020
  - There was a decrease in $PM_{2.5}$ by 10 $\mu/m^3$
  - This is partly a result of aggressive environmental policy

- What is the international spillover benefits implied by our estimates?
  - One approach is to monetize our estimates by using the VSL
  - Our current estimate implies that the 10 $\mu/m^3$ reduction in $PM_{2.5}$ in China in 2015-20 provided an international spillover benefit of $8.05 billion per year for South Korea

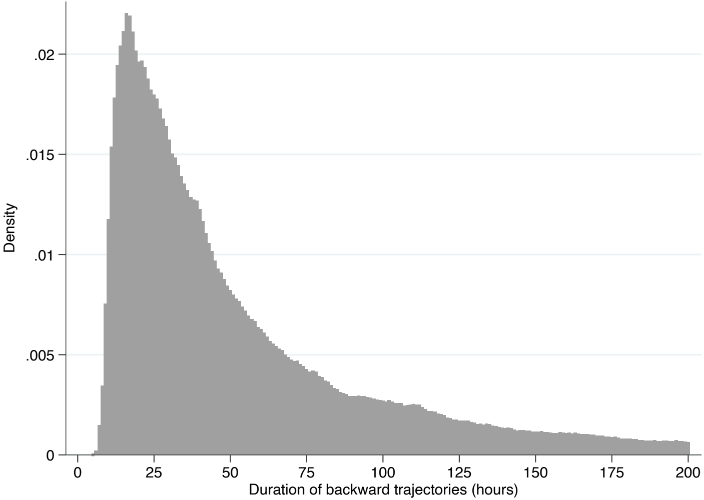
# Conclusion

# In this paper, we study this international spillover effect

1. Integrate atmospheric science modeling with econometric estimation
   - Previous studies use indirect measures of transboundary air pollution
   - We use the HYSPLIT model to obtain direct measures at hour-city level
   - Bring these data to an econometric framework
2. Use the universe of individual-level mortality data in South Korea
   - We observe date, location, age, cause of death etc.
   - Estimate the mortality impact of transboundary air pollution
3. Quantify a hidden benefit of recent air quality improvements in China

# Appendix

# How long does it take for particles to reach South Korea?




- The median is 38 hours

## Table: Summary Statistics

| | Mean | Standard deviation | Min | Max |
|---|---|---|---|---|
| $PM_{2.5}$ ($\mu/$) in Korean cities | 24.99 | 18.06 | 0 | 843 |
| Transboundary $PM_{2.5}$ ($\mu/$) from China to Korean cities | 14.19 | 27.53 | 0 | 695 |
| Transboundary trajectory indicator variable (1 or 0) | 0.39 | 0.49 | 0 | 1 |
| Mortality in Korean cities (hourly deaths per billion) | | | | |
| Overall | 894 | 3,800 | 0 | 200,501 |
| Respiratory/Cardiovascular | 231 | 1,954 | 0 | 117,689 |
| Infant (age $< 1$) | 327 | 27,702 | 0 | 14,084,507 |
| Elderly (age $\geq 65$) | 3,576 | 14,197 | 0 | 928,505 |
| City-level population (in thousands) | | | | |
| Overall | 232 | 240 | 10 | 1,700 |
| Elderly (age $\geq 65$) | 32.16 | 25.27 | 2.10 | 181.83 |
| Infant (age $< 1$) | 1.68 | 1.91 | 0.03 | 12.92 |
| Hourly Temperature ($^\circ C$) | 13.01 | 10.43 | -25.27 | 40.50 |
| Hourly Precipitation (mm) | 0.13 | 1.00 | 0 | 109.50 |