Environmental and Development Economics
Module 3 - How does the environment affect development?

Raahil Madhok
UMN Applied Economics

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Lecture 4

How does the environment affect economic development?

Housekeeping

- Consider pitching your research idea to me during office hours
- Next week, you have TWO options for the presentation paper
- Your class presentation grade is an average of each one
- Question about revealed preference WTP lecture (Sept 19)

Today

- **Guiding question:** how does the environment affect economic development?
- Start identifying envirodevonomics parameters
- Today's focus: health effects
- Next time: productivity and direct income effects

Recall our model of environment and development

$$MWTP_e = \frac{\lambda_e}{\lambda_y} = \frac{1}{\lambda_y}\left(\frac{\partial u}{\partial e} + \frac{\partial u}{\partial h}\frac{\partial h}{\partial e}\right) + \frac{\partial \Delta y}{\partial e} + \frac{\partial \Delta y}{\partial h}\frac{\partial h}{\partial e}$$

- Most research in environment/development economics seeks to identify $\frac{\partial h}{\partial e}$
  - At this point, $\frac{\partial h}{\partial e} > 0$ is unambiguous
  - Focus is on **magnitudes**
  - Less work on mechanisms and moderators
- What about indirect effects via productivity and health ($\frac{\partial \Delta y}{\partial h}\frac{\partial h}{\partial e}$)?
  - This is the research frontier
  - Next lecture

Existing Work to Date

- Largely from developing countries (see Janet Currie papers)
  - Review paper: "What Do We Know About Short- and Long-Term Effects of Early-Life Exposure to Pollution?' '(Currie et al. 2014)
- Less in developing countries
  - Most benchmark magnitudes: Bharadwaj and Eberhard (2008); Jayachandran (2009); Chen et al. (2013); Greenstone and Hanna (2014); Arceo et al. (2016); Cesur et al. (2016); He et al. (2016); Barwick et al. (2018); Heft-Neal et al. (2018); Chang et al. (2019); Heft-Neal et al. (2019); Pullabhotla (2019); Bombardini and Li (2020); Fan et al. (2020); He et al. (2020); Adhvaryu et al. (Forthcoming); Madhok et al. (2024, Working Paper)
- Less work on non-health effects
  - See Aguilar-Gomez et al. (2022) for review
- Empirical innovations: new quasi-experiments for identifying pollution impacts
  - Thermal inversion, wind direction IV (see Oliva & Deryugina)
  - Newest technique: HYSPLIT dispersion model (NOAA)

Existing Work to Date

- Consensus that there are large negative effects in developing countries
  - Little evidence on why
- Open questions:
  - Are marginal damages higher or lower in LMICs? (Colmer et al.,2021)
  - Are differences in marginal damages because of non-linear dose-response
  - Are differences in marginal damages because of weak institutions/development?
  - Long term effects of exposure?
- Conceptual frameworks needed

Lets formalize our intuition

- Weather can harm health directly (physiological stress)
  - Or indirectly, e.g. by lowering incomes of those in weather-dependent (outdoor) jobs
- There is a market for defensive goods (e.g. medicine, AC, etc.) which $\uparrow$ P(survival)
- But in developing countries, credit constraints restrict consumption smoothing
- Lets incorporate this into a model and study the comparative statics
  - Goal: explain how weather affects health, considering financial constraints
  - Health is endogenously determined by consumption and health investments

Setup

- **Agents:** value consumption c_{it} and health h_{it}.
- **Objective:** Maximize lifetime utility

$$\mathbb{E}_0\left[\sum_{t=0}^{\infty}\beta^t u_i(c_{it}, h_{it})\right]$$

- **Health Status**: Determined by health investments (q_{it}) + exogenous weather (z_{it})

$$h_{it} = h_i(\underbrace{q_{it}}_{(+)}, \underbrace{z_{it}}_{(-)})$$

Setup

Production

- c_{it} produced by $f(\cdot)$, which requires capital + labor
- Assume defensive good q_{it} traded at price P_t (numeraire)

Labor

- Agent endowed with labor a_{it} (random), sold at wage ω_t
- Labor can be affected by weather (z_{it})

$$a_{it} = a_i(z_{it})$$

Financial Market

- Agent can (partially) save/borrow to (partially) smooth consumption over t
- **Financial Constraints**: Savings (x_{it}) and borrowing are limited by:
  - Borrowing constraint (mininum savings): $x_{it} \geq -b_i(r_t)$
  - Saving constraint (maximum savings): $x_{it} \leq b_i(r_t)$
  - $b(\cdot)$ unrestricted s.t. agent can be unconstrained
- **Budget Constraint**: income is used for consumption and health investments:

$$x_{i,t+1} \leq r_t x_{it} + w_t a_i(z_{it}) - P_t q_{it} - c_{it}$$

Equilibrium

- All markets must clear each t, which endogenously determines prices (r_t, w_t)
  - Note P_t is exogenously set in world market

- Returns to capital/labor are functions of their aggregate
  - Capital demand: from production function $f(\cdot)$
  - Capital supply: savings transformed into capital for production

- **Market Equilibrium**: set optimal demand for labor/capital = aggregate supply
  - where $K_t = \int x_{it} di$
  - wages w_t and interest rates r_t are determined in equilibrium as:

$$w_t = w(K_t), \quad r_t = r(K_t)$$

Mechanisms relating weather to health

- **Direct health effect:** random shock z_{it} enters health directly: $h_{it} = h_i(q_{it}, z_{it})$
  - Physiological channel: extreme temperature stresses cadiovascular/respiratory system
  - Impact can depend on region, $h_i(\cdot)$
- **Indirect health effect:** through productivity $a_i(z_{it})$
  - Likely in rural areas, where ag workers are outside
- **Mitigation:** agent minimizes neg. utility shock from z_{it} by purchasing q_{it}.
  - This could also be opp cost of working inside (at lower w_{it}) to avoid outdoors
  - Effect of mitigation limited by $\frac{\partial h_i(q_{it}, z_{it})}{\partial q_{it}}$
- **Smoothing:** agent can also mitigate by reallocating resources b/w periods
  - Agents with near-binding borrowing constraints experience worse shocks

Comparative Statics

- **Object of interest**: aggregate covariance b/w health h_{it} and weather z_{it}:

$$H_t = \left| \frac{\int h_{it} z_{it}^{(T)} di}{\int h_{it} di} \right|$$

- **Rural Areas**: Consider a set of changes that:
  - $\uparrow$ responsiveness of $a_i(z_{it})$ to z_{it}^T (more exposed to weather extremes).
  - $\uparrow$ prices for health goods P_t above that of urban (lower market access)
  - $\downarrow$ incomes by reducing $a_i(z_{it})$ for any z_{it}
  - Any one of these leads to increase in H_t

Prediction: rural areas will have stronger correlation b/w weather and health

Effect of Bank Access

- **Relaxing financial constraints** increases either or both of $(-b_i(r_t), b_i(r_t))$
  - Partial credit modeled as increase in $b_i(r_t)$ only (i.e. can save more)
  - Allows agents to smooth consumption; draw down savings to mitigate weather shock
  - Reduces the correlation between weather shocks z_{it} and health outcomes h_{it}.

- **Prediction**: Prediction: $H_t \downarrow$ as $b_i(r_t) \uparrow$
  - Areas with better financial access have smaller effect of z_{it} on health

Aside: Climate change versus weather

- Climate change is long term, weather is short term
- Studying impacts of weather is easier:
  - Usually use high dimensional fixed effects
  - E.g. with district and state-year FEs, exploit monthly deviations from average
- Studying impacts of climate is harder:
  - There is no good counterfactual for climate change

Deschenes et al. (2013): Weather and Death in India

- **Research question:** how do temperature shocks affect mortality?
  - How does that different between urban/rural areas?
  - What is the role of income as an intermediary?
- **Setting:** Indian districts from 1957-2000
- **Data:** daily gridded weather + annual infant mortality
- **Design:** panel fixed effects
  - Difference-in-differences with rural bank expansion
- **Result:** 1) heat $\uparrow$ mortality, 2) driven by rural populations, 3) credit access mitigates effect by facilitating consumption smoothing

Data

Rural

- Yields: annual, district level output/cultivated area (27 crops) (World Bank)
- Ag price index: mean crop price weighted by value in district (World Bank)
- Ag wages: daily wage rate (World Bank)

Urban

- Manufacturing productivity: output per worker (ASI)
- Urban CPI: NSS survey
- Manufacturing wages: ASI (nominal wage / CPI)

Empirical Strategy

Flexible specification to model effect of daily temperature:

$$Y_{dt} = \sum_{j=1}^{11} \theta_j TMEAN_{dtj} + \sum_k \delta_k 1\{RAIN_{dt} \text{ in tercile k}\} + \alpha_d + \gamma_t + \lambda_r^1 t + \lambda_r^2 t^2 + \epsilon_{dt}$$

- r is a climatic region
- $TMEAN$ is days in year t where:
  - daily mean temp $< 70°$, $\geq 97°$, or in the nine 3° bins in between
- θ_j's capture non-linearities, despite having annual unit of analysis
- $RAIN$ accounts for correlation b/w temperature and rainfall

Identifying Assumptions?

Secondary Approach

- Consolidates same information
- Workhorse model nowadays because more parsimonious

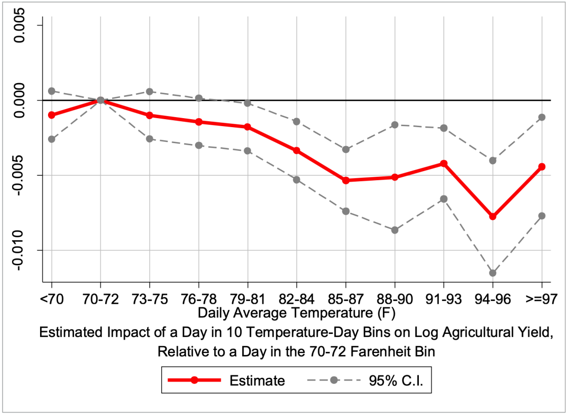
$$Y_{dt} = \beta CDD80_{dt} + \sum_{k=1}^{3} \delta_k 1\{RAIN_{dt} \text{ in tercile k}\} + \alpha_d + \gamma_t + \lambda_r^1 t + \lambda_r^2 t^2 + \epsilon_{dt}$$

- where CDD80 is cumulative degree days in district that exceeded 80°. e.g. if two days over 80, one at 82 and other at 84, then CDD=2+4=6
- All bins $j < 80°$ are zero
  - The three above 80° restricted to be linearly increasing in average temp
- Assumption: days when mean daily temp below 80 irrelevant for determining Y

Results: Yields

Test of indirect channel through labor productivity, $a_i(z_{it})$

Figure 3: The Effect of Daily Average Temperatures on Log Agricultural Yields.

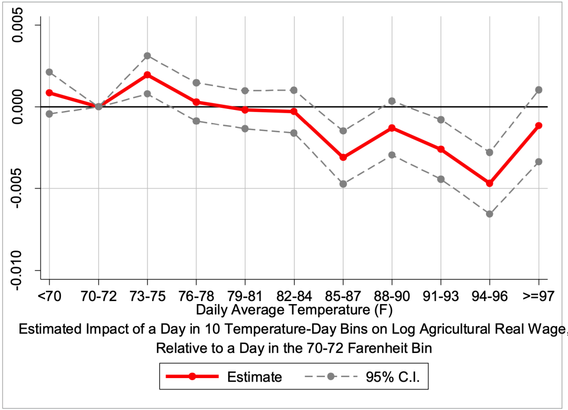


A single day with temperature over 85° reduces yields by 0.5%

Results: Wages

Test of indirect channel through $a_i(z_{it})$

Figure 4: The Effect of Daily Average Temperatures on Log Real Agricultural Wages.



A single day with temperature over 85° reduces ag wages by 0.25-0.5%

Results: Urban vs. Rural

Table 2: Weather and Incomes - Rural-Urban Differences, Exposure by Calendar Year

	Rural		Urban	
Dependent Variable:	Log (Productivity)	Log (Real Wages)	Log (Productivity)	Log (Real Wages)
	(1)	(2)	(3)	(4)
A. Temperature (degree-days over 90F)/10	-0.0023*	-0.0023***	0.0003	0.0012
(std error)	(0.0009)	(0.0006)	(0.0033)	(0.0036)
[Effect of 1 std dev in CDD90]	[-0.023]	[-0.022]	[0.002]	[0.009]
B. Temperature (degree-days over 80F)/10	-0.0034***	-0.0026***	-0.0006	0.0006
(std error)	(0.0006)	(0.0004)	(0.0013)	(0.0013)
[Effect of 1 std dev in CDD80]	[-0.126]	[-0.098]	[-0.021]	[0.021]
C. Temperature (degree-days over 70F)/10	-0.0023***	-0.0018***	-0.0010	0.0005
(std error)	(0.0004)	(0.0003)	(0.0008)	(0.0008)
[Effect of 1 std dev in CDD70]	[-0.132]	[-0.101]	[-0.053]	[0.023]
Observations	8,304	8,304	512	592

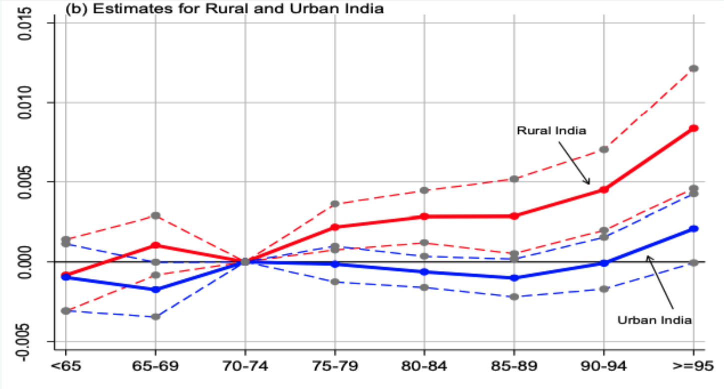
- This corroborates Prediction 1 from model!

Results: by Growing Season

Table 2: Impact of Daily Temperature on All-Age Mortality in Rural and Urban India.

	Rural Temperature		Urban Temperature	
	75-89°F (1a)	**>90°F** (1b)	**75-89°F** (2a)	**>90°F** (2b)
A. Exposure over Calendar Year				
Impact of Temperature	0.0021**	0.0047***	0.0001	0.0012
(std error)	(0.0007)	(0.0010)	(0.0005)	(0.0008)
B. Exposure over Agricultural Calendar				
Impact of Growing Season Temperature	0.0028***	0.0067***	0.0005	0.0016
(std error)	(0.0008)	(0.0016)	(0.0006)	(0.0013)
Impact of Non-Growing Season Temperature	-0.0047*	-0.0024	-0.0032	-0.0020
(std error)	(0.0023)	(0.0023)	(0.0017)	(0.0016)
Test of equality across agricultural seasons	0.002	0.001	0.058	0.060

- This is also consistent with Prediction 1 from model!



Rural: years with more days with exceeding 87° have 0.5% higher mortality

Bank Access

- Prediction 2: bank access enables consumption smoothing
  - Relaxing borrowing/saving constraints should mute relationship
- Test: Between 1977-1990, central bank extends banking to the poor
  - Existing banked (urban) areas must open 4 branches in unbanked (rural) areas
- Method: difference in differences
  - Compare mortality in hot and cold places before and after bank access

Results: Credit Access

	Panel Estimates, Rural		2SLS, Rural		2SLS, Urban	
	Temperature		Temperature			
	75-89 °F	>90 °F	75-89 °F	>90 °F	75-89 °F	>90 °F
	(1a)	(1b)	(2a)	(2b)	(3a)	(3b)
Dependent Variable is Log Annual Mortality Rate						
Main Effect of Temperature	0.0024***	0.0067***	0.0026***	0.0121***	0.0000	0.0017
(std error)	(0.0009)	(0.0012)	(0.0010)	(0.0019)	(0.0007)	(0.0021)
Main Effect of Number of Bank Branches			1.0633		0.1262	
(std error)			(0.7407)		(0.1143)	
Temperature x Bank Branches			-0.0041*	-0.0216***	-0.0010	-0.0013
(std error)			(0.0021)	(0.0055)	(0.0006)	(0.0014)

- Effect of moderate and hot days on mortality is moderated by bank access
- Bank branches more than offset weather-death relationship

Takeaway: credit enables poor to withstand environmental shocks

Discussion

- Aggregate data entangles ambient means and experienced exposure
- What exactly makes rural areas more vulnerable?
- How much of the weather-death effect is direct vs. indirect?
  - Empirically, we did not identify model parameters separately
- Will weather shock be enough to affect remaining lifetime income?

Way Forward

- Bank access represents anything that relaxes budget constraint
- Policy could have been subsidies on q_{it}, encouraging seasonal migration, etc.
  - Opean areas for research

Back to the main question

Back to the question

- How does environmental quality affect economic development?
- Most reduced form studies identify $\frac{\partial h}{\partial e}$
- Recall, this is an input into estimating benefits (MTWP) of $\uparrow e$
  - which we need to know in order to set optimal environmental policy
  - optimal in the sense that agents decisions are first-best
- Is physical health the only thing that matters for estimating $\frac{\partial h}{\partial e}$?

Chen et al. (2024): Air Pollution and Mental Health

- **Research question:** What is the impact of air pollution on mental health?
  - Direct mechanism: oxidative stress
  - Indirect mechanism: labor productivity, income, physical activity
- **Setting:** China in 2014-2015
- **Data:** Kessler Physchological Distress Scale
  - PM2.5 from China National Environmental Monitoring Center
- **Design:** instrument pollution with thermal inversions
- **Results:** Pollution $\uparrow$ depression
  - Mechanisms: lower exercise, worse physical health
  - Total cost $=$ \$22.88 billion, similar to mortality costs!

Background

- Why do we care about mental health?
  - Poverty associated with life satisfaction and **stress**
  - These mechanisms affect productivity, which perpetuates poverty
  - See Haushofer and Salicath (2023); Haushofer and Fehr (2014)
- Frontier in development economics: RCTs on income and stress
  - Cash transfers $\uparrow$ subjective well-being (McGuire et al., 2022)
  - Cash transfers $\downarrow$ suicide in Indonesia (Christian et al., 2019)
  - Cash transfers $\downarrow$ depression (Haushofer and Shapiro, 2016)
- Toxicology literature: pollution $\uparrow$ oxidative stress (Calderon-Garciduenas et al., 2003; Sørensen et al., 2003; MohanKumar et al., 2008, Power et al., 2015)

Background

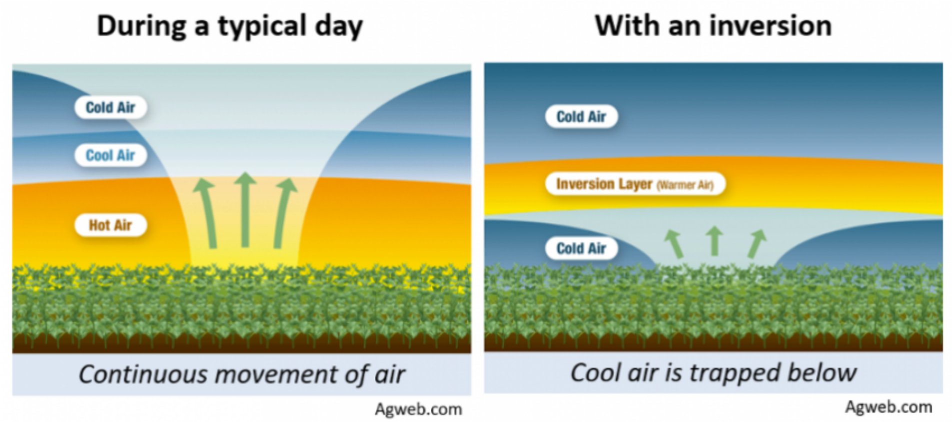
- Theory of change: **pollution** $\rightarrow$ **stress** $\rightarrow$ productivity
  - Poverty correlated with pollution and stress
  - Direct effect of pollution on productivity (Graff Zivin & Niedell, 2012; California)
  - Many parts of the chain are open areas for research!

Air Pollution and Mental Health

What are the empirical challenges?

1. OVB: pollution correlated with economic activity
   - Richer counties more polluted
   - Induces **negative** bias
   - Solution: ?
2. ?
3. ?
4. ?

Instrumental Variable: Thermal Inversion



Instrumental Variable: Thermal Inversion

Instrumental Variable: Thermal Inversion

- Air is warmer near surface, becomes cooler at higher altitudes
- Thermal inversion: temperature-altitude gradient is reversed
  - Rare phenomenon
  - Depends on **random** meteorological factors
- Cool air is denser and does not rise
- Pollution becomes trapped near surface

What do you think?

Data

- Mental health: 2014 China Family Panel Study Survey
  - 16,000 rural and 13,000 urban residents (162 counties out of 1,355)
  - Six questions about mental health on 0-24 Scale
  - Depression, nervousness, restlessness, hopelessness, effort, worthlessness
- Pollution: PM2.5
  - Webscraped
  - Validate with satellite data?
- Thermal inversion (MERRA-2 Air Temperature Layers)
  - Inversion $= 1$ if temperature of first layer (110m) $<$ second layer (320m)
  - IV: number of inversions in month prior to each interview

Inversions and Pollution

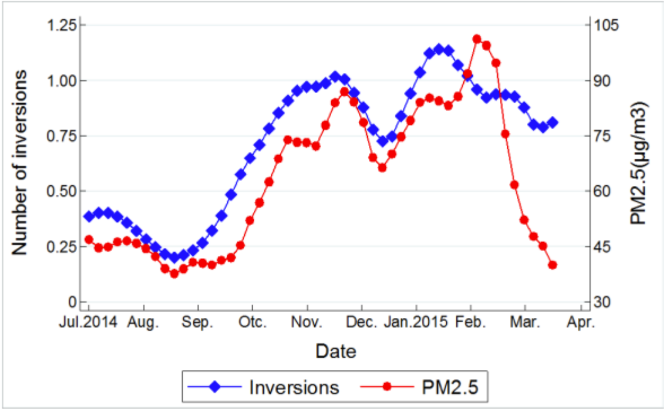


Figure 1. Time Trend of $PM_{2.5}$ and Thermal Inversion

Do thermal inversions seem rare and random?

Empirical Strategy

First Stage:

$$P_{ict} = \alpha_0 + \alpha_1 I_{ict} + f(W_{ict}) + \gamma_c + \sigma_t + \mu_{ict}$$

Second Stage:

$$H_{ict} = \beta_0 + \beta_1 P_{ict} + f(W_{ict}) + \gamma_c + \sigma_t + \epsilon_{ict}$$

- P_{ict} is PM2.5 in month prior to interview
- I_{ict} is instrument, number of thermal inversions in past month
- H_{ict} is total mental illness score (0-24)
- $f(W_{ict})$ are flexible weather controls
- σ_t are year-month FEs (**important**!)

Main Results: Mental Health

TABLE 1—FIRST-STAGE AND IV RESULTS

	First stage		Second-stage estimation			
	$PM_{2.5}$		K6 score		Severe mental illness	
Dep. var.	(1)	(2)	(3)	(4)	(5)	(6)
Thermal inversions	0.2118	0.2638				
	(0.0469)	(0.0357)				
$PM_{2.5}$			0.1229	0.1164	0.0047	0.0042
			(0.0500)	(0.0388)	(0.0025)	(0.0019)
Mean [SD] of dep. var.	47.7132	[18.0450]	2.9556	[3.7598]	0.0438	[0.2047]
Weather controls	No	Yes	No	Yes	No	Yes
KP *F*-statistics	20.36	54.56				

- 1 μ/m^3 PM2.5 $\uparrow$ mental illness by 0.1164 units (4% of mean; 0.4σ)
- 1 μ/m^3 PM2.5 $\uparrow$ prob. of several mental illness by 0.42pp (9.5% of mean)

Main Results: Symptoms

Table 4. Effect of Air Pollution on Mental Health: By Symptom

	About how often do you feel					
	Depression	Nervousness	Restlessness	Hopelessness	Difficulty	Worthlessness
	(1)	(2)	(3)	(4)	(5)	(6)
$PM_{2.5}$	0.0155**	0.0045	0.0134***	0.0150***	0.0183***	0.0123**
	(0.0073)	(0.0062)	(0.0044)	(0.0048)	(0.0055)	(0.0049)
Observations	12,657	12,659	12,660	12,638	12,657	12,649
County *FE*	Yes	Yes	Yes	Yes	Yes	Yes
Year-by-month *FE*	Yes	Yes	Yes	Yes	Yes	Yes
Weather controls	Yes	Yes	Yes	Yes	Yes	Yes
Sample weights	Yes	Yes	Yes	Yes	Yes	Yes
KP *F*-statistic	36.17	36.19	36.20	36.11	36.15	36.09

- Not driven by any one particular symptom

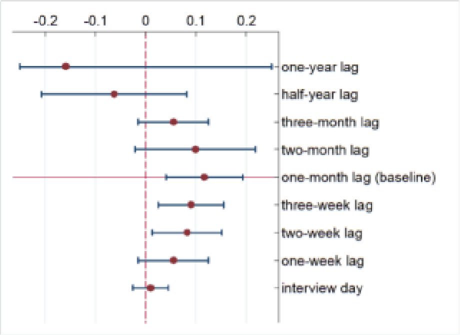


Figure A.1: Impact of PM2.5 on the K6 score

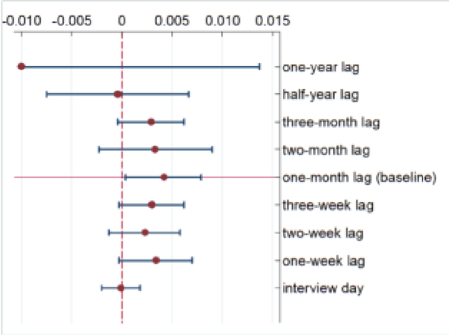


Figure A.2: Impact of PM2.5 on K6$\geq$12

- Effect of pollution exposure on mental health dissipates over time

Mechanisms

- Focus on indirect effects (physical health, productivity, behavior)

Table 6. Mechanism Tests

	Exercise (past 1 week)			Sickness (past 2 weeks)		Self-rated health (past 1 month)
	(1)	(2)	(3)	(4)	(5)	(6)
	1-yes, 0-no	times	hours	1-yes, 0-no	1-not serious, 5-very serious	1-very healthy, 5-very unhealthy
$PM_{2.5}$	-0.0049**	-0.0068*	-0.0448**	0.0020	0.0089*	0.0092*
	(0.0022)	(0.0035)	(0.0209)	(0.0019)	(0.0052)	(0.0056)
Observations	12,664	12,663	12,670	12,670	3,806	12,668
Mean of Dep. Var.	0.4670	2.4008	3.3681	0.2917	3.1140	2.9698
S.D. of Dep. Var.	0.4989	3.1324	6.4268	0.4545	1.4053	1.1816
County *FE*	Yes	Yes	Yes	Yes	Yes	Yes
Year-by-month *FE*	Yes	Yes	Yes	Yes	Yes	Yes
Weather controls	Yes	Yes	Yes	Yes	Yes	Yes
Sample weights	Yes	Yes	Yes	Yes	Yes	Yes
KP *F*-statistic	48.73	48.57	48.72	44.92	59.36	36.30

- Driven by reduction in physical exercise, not other illness
- Very small impact compared to pollution effect (0.002σ vs. 0.4σ)

Heterogeneity

	The K6 Score			
	(1)	(2)	(3)	(4)
	Male	Female	Age 16-60	Age >=60
$PM_{2.5}$	0.0986***	0.0575*	0.0611**	0.1499**
	(0.0268)	(0.0342)	(0.0298)	(0.0599)
Observations	6,093	6,522	9,446	3,169
Mean of Dep. Var.	2.6378	3.2799	2.9504	3.0281
S.D. of Dep. Var.	3.5378	3.9405	3.5819	4.2683
County FE	Yes	Yes	Yes	Yes
Year-by-month FE	Yes	Yes	Yes	Yes
Weather controls	Yes	Yes	Yes	Yes
Sample weights	Yes	Yes	Yes	Yes
KP *F*-statistic	25.14	43.22	32.11	27.20

- Why are effects larger for men?

Economic Cost? Back of the Envelope

- $1\sigma \uparrow$ in PM2.5 leads to $9.5\% \uparrow$ in prob. of severe mental illness
  - About 0.095×1.4 billion $= 13.3$ million additional people
- Annual cost per patient of mental illness in China is $USD 3,665 (Xu et. al 2016)
- Assume 8% of patients with mental illness get treated (Phillips et al., 2009)
- **Economic cost of mental illness:** $13.3 \times 3665 \times 0.008 \times 12 = 46.7$ billion USD
- Mortality cost of 1σ PM2.5 is $USD 30 billion in USA (Deryugina et al., 2016)

Issues with the back of the envelope calculation?

Discussion

Next week

- productivity and direct income effects

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