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

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Lecture 4

How does the environment affect economic development?

Housekeeping

- State things that are due.

Today

- **Guiding question:** how does the environment affect economic development?

- 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**
- 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

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: exploain 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 $f(\cdot)$, and q_{it} traded at price P_t
  - Agent endowed with labor a_{it}, sold at wage ω_t
  - Labor can be affected by weather (z_{it})

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

- **Financial Constraints**: Savings (x_{it}) and borrowing are limited by:
  - Minimum savings: $x_{it} \geq -b_i(r_t)$
  - Maximum savings: $x_{it} \leq b_i(r_t)$

- **Budget Constraint**: Income is used for consumption and health investments:

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

Setup

- **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, or proximity to water (where pathogens thrive in hot weather), denoted by agent-specific function $h_i(\cdot)$
- **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 correlation 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:
  - increases responsiveness of $a_i(z_{it})$ to z_{it}^T.
  - raises prices for health goods P_t above that of urban
  - lower 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

What is the effect on weather on health?

- What is the ideal experiment?
- What variation in environmental quality can approximate the experiment?
  - How would you measure environmental quality?
  - What might this measure miss?
  - What variation isolates a causal relationship?
  - What does that variation miss?

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
  - New method: long differences (Burke and Emerick, 2016)

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 ↑ mortality, 2) driven by rural populations, 3) credit access mitigates effect by facilitating consumption smoothing

Empirical Implications

- Remember permanent income hypothesis?
  - Income shocks in $t = 0$ caused by weather shock only affects contemporaneous survival via extent to which income shock reduces NPV lifetime income
- From model: if two agents face same shock at $t = 0$, and one has income stream that depends on weather
  - Then impact of shock on his death is stronger
- What if income shocks are at high frequency?
  - Will weather shock be enough to affect remaining lifetime income (and survival)?
  - This is why studying climate vs. weather is important

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?

- Impact governed by daily mean alone
- Impact of days' mean temperature on annual mortality is constant within 3° intervals
    - This is reasonable
- By using number of days in each bin, assume that the sequence of hot and cold days is irrelevant.
- Annual deviation from district average is random
- Anything else? Reverse causality?

Secondary Approach

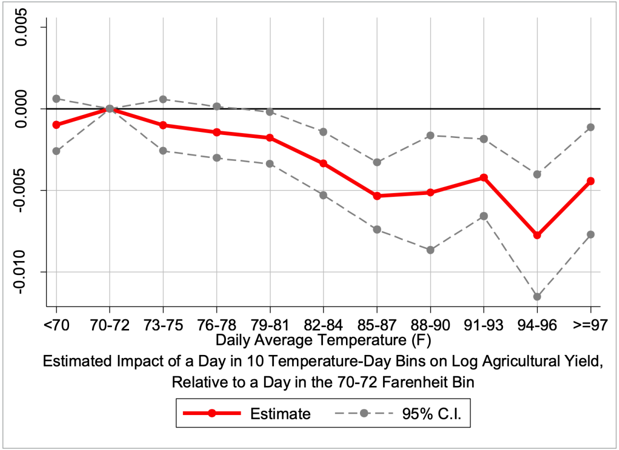
- consolidates same information
- workhorse model nowadays because more parsimonious

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

- where CDD80 is cumulative degree days in district that exceeded 80°.
- 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

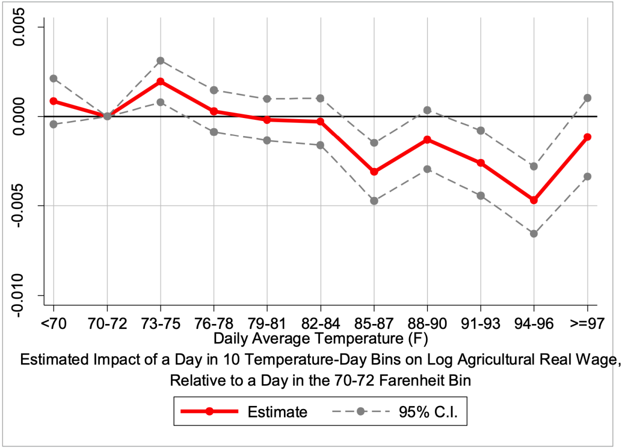
Figure 3: The Effect of Daily Average Temperatures on Log Agricultural Yields.



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

Results: Wages

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

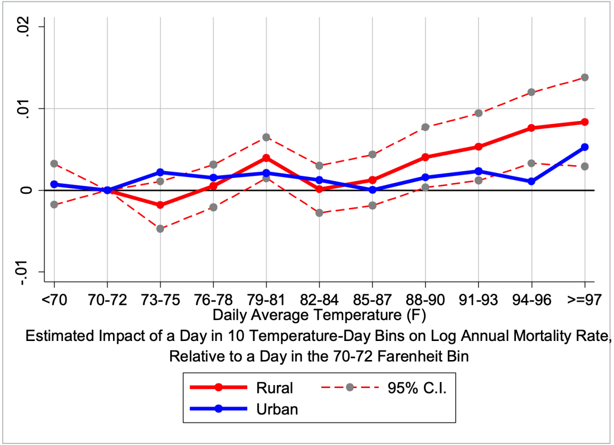
Table 2: Weather and Incomes - Rural-Urban Differences, Exposure by Calendar Year

	Rural		Urban	
	Log (Productivity)	Log (Real Wages)	Log (Productivity)	Log (Real Wages)
Dependent Variable:	(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

What is happening? Direct (agonomical) effect should not vary

Results: Mortality

Figure 6: Mortality Impact of Daily Temperature in Rural and Urban India.



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

Bank Access

- If income → consumption smoothing, then it should mute relationship
  - Mechanism: lifetime utility maximized when $u'(c)$ equated across t (Euler)
- Test: Between 1977-1990, central bank extends banking to the poor
  - Existing banks required to open four branches in unbanked areas
- Method: compare weather-death relationship in banked/unbanked areas
  - Difference in differences
  - Identification problem?
- Instrument: SEE BURGESS AND PANDE (2005)

Equation

- See BURGESS AND PANDE (2005)

Results: Credit Access

- On full sample, one more bank has no effect on weather-death relationship
  - Is single bank opening enough to enable smoothing?
- Make dummy equal to one for 75th pctile of banks, zero for 25th pctile
  - Moving from 25th to 75th pctile of banks eliminates effect of temperature!
- Mitigating effect of banks concentrated within growing season
  - Smoothing by farmers key mechanism
- **Takeaway: credit enables poor to withstand environmental shocks**

Discussion

- aggregated data (district) with satellite temperature makes it hard to distinguish atmospheric/ambient means from experienced exposure
- How can we then measure direct effect through physiological channel
  - Leave it to the epidemiologists…

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 $\rightarrow$ 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)

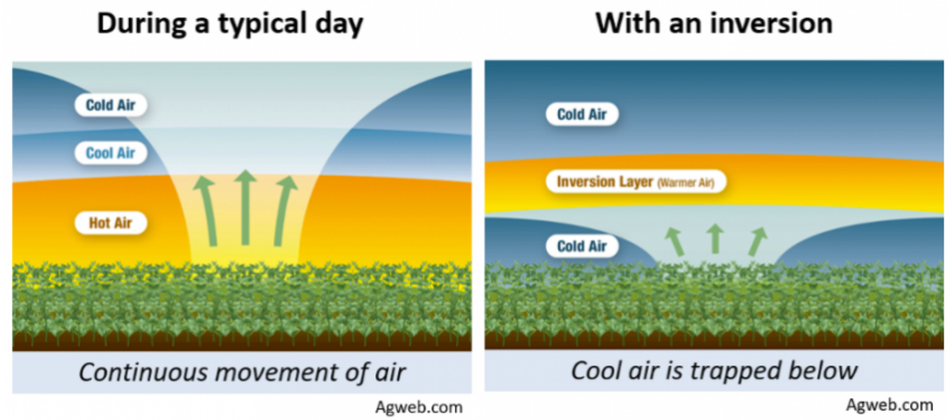
Background

- 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!

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?

- Pros and cons
- Inversions are short lived (last for a few hours)
  - cannot estimate impact of sustained exposure
  - Is mental health affected by rare short term events?
- correlated with weather, which can have direct effect on mental health
  - control for ground level temperature/rain
- If mechanism is through chronic condition, then TI may isolate wrong type of variation
- TI are very localized phenomena. Is this what we want to study?

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

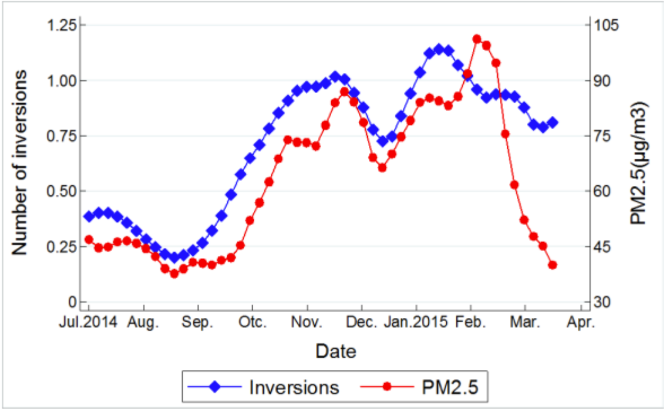


Figure 1. Time Trend of $PM_{2.5}$ and Thermal Inversion

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

Main Results: Persistence

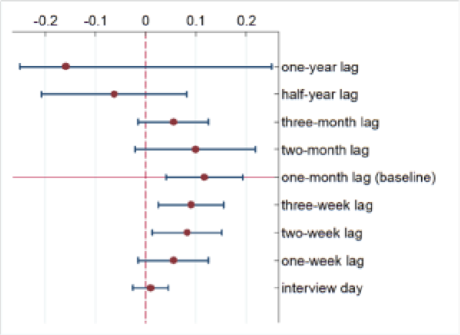


Figure A.1: Impact of PM2.5 on the K6 score

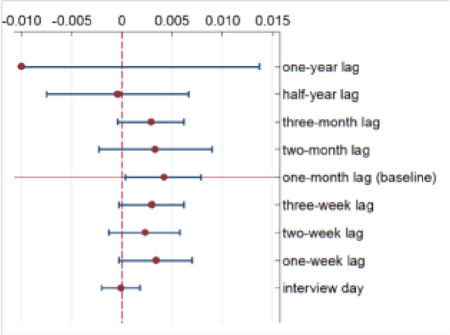


Figure A.2: Impact of PM2.5 on K6$\geq$12

- 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

- small sample
- few counties
- Small time window
  - cannot include year FEs or control for annual macro trends
- exploit short term variation (daily)
- mechanism unclear

Lecture 5

How does the environment affect economic development?

Housekeeping

- State things that are due

Today

- **Guiding question:** how does the environment affect economic development?

- Today's focus: productivity and income
  - worker productivity
  - absenteeism

Pollution and Productivity

- We know temperature is neg. associated w/ output (Dell, Jones, and Olken 2012)
- We also know high temperatures are associated with lower crop yields
  - Mendelsohn and Dinar (1999), Auffhammer et al. (2006), Schlenker and Roberts (2009), Lobell et al. (2011), and Gupta et al. (2017)
- What are the mechanims?
  - heat stress, mortality, conflict
- Open and policy-relevant research area
  - If we know importance of each mechanism, we know where to target policy

Somanathan et al. (2021): Temperature, Productivity, and Labor

- **Research question:** What is the effect of temperature on output?
    - How does heat stress mediate the temperature-output relationship
- **Setting:** India's manufacturing sector (cloth weaving, sewing, steel)
- **Data:** High-frequency (15 year panel, daily)
    - Worker-level, sewing line level, team level, plant-year, district-year
- **Design:** panel fixed effects
- **Result:** 1) heat $\downarrow$ plant-level annual output, 2) driven by output elasticity of labor, not capital 3) AC used in labor-intensive tasks (pareto efficient)

Background

- Workers should respond quickly when working in uncomfy temperatures
  - Heat impacts on labor can be identified from daily or aggregated data
  - Distinguishes heat stress from alternative mechanisms which materialized over long time scales (i.e. conflict)
- Two channels through which temperatures affect workers
  - Produce less (productivity)
  - Absenteeism
- Can we expect lumpy investments in climate control in developing countries?
  - Depends on value-added per worker
  - If too low, then electricity cost not worth it

Data: Worker + Cloth Weaving

- Worker data
  - Surveyed output and attendance from cloth-weaving, garment sewing, and steel firms
  - Three cloth-weaving factories in Surat,
  - Eight garment plants (Delhi, Hyderabad, Chhindwara)
  - Steel plant (one large plant in Central India)

- Cloth data (2012): 147 workers
  - Daily meters woven (for each worker)
  - Worker pay slips each day (output + attendance)

Data: Garment Sewing

- Garment sewing (2012-2013): Line level
  - Lines of 10-20 workers
  - Productivity: hourly output relative to target
  - Daily production from 103 sewing lines

- Climate control
  - Phased rollout of cooling equipment
  - 84 of 103 sewing lines in Delhi, of which 74 had cooling

Data: Rail and Steel Plant

- Supplies rectangular blocks of steel to Indian Railways
- Three shifts per day
- Workers assigned to one of three teams, which rotate across shifts
- Data:
  - Team and number of blocks for each shift during 1999-2008
  - 9,172 shifts over 3,337 working days
  - Team-level absences over 857 days for 2000-2003

Garment factory and cloth weaving

Rail/Steel Mill

Data: Panel

- Annual Survey of Industries (1999-2013)
  - Census of large manufacturing plants (> 100 workers)
  - Random sample of small plants
  - Output, fixed assets, input expenses, employment
  - Unbalanced panel of 58,377 plants
- District Manufacturing GDP (1998-2009)
  - Planning Commission of India
  - ASI plants + unregistered plants
- Weather: public weather stations + gridded data (IMD)
  - Daily maximum at closest station to factory
  - Gridded data for panel data

Data: Diamond Firms

- Survey 150 diamond cutting plants in Surat
  - Random sample from 500 registered units
- Five operations: 1) grading 2) marking, 3) rounding, 4) cutting, 5) polish
- Ask about number of workers and use of AC in each operation
- Ask to rate on 1-5 scale importance of each operation to quality of final output
  - Why?

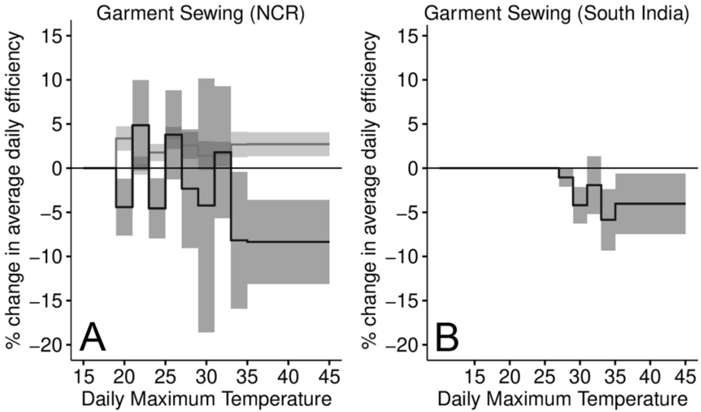
Empirical Strategy

Temperature-output estimated with weekly data as follows:

$$y_{iw} = \alpha_i + \gamma_M + \gamma_t + \sum_{j=2}^{J} \beta_j T_{iw}^{j} + \theta R_{iw} + \lambda X_{iw} + \epsilon_{iw}$$

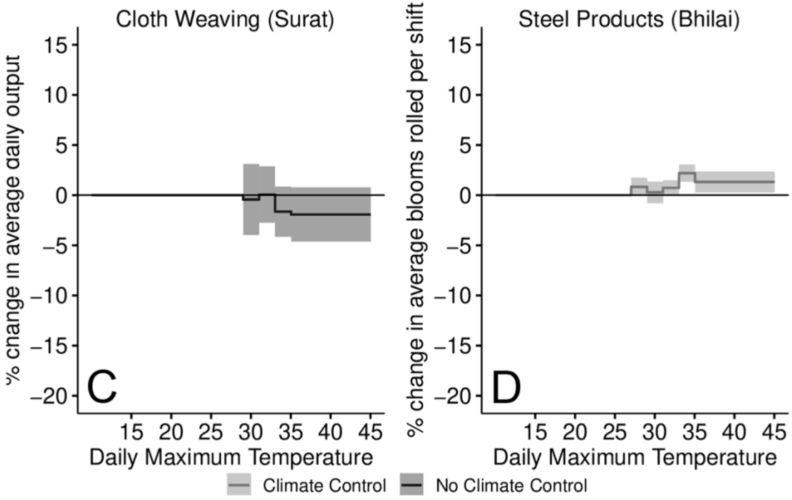
- y_{iw} is physical output by worker i in week w
- If absent, output=0 for that day before aggregating to week
- α_i is individual FE (what does it account for?)
- $\gamma_{M/t}$ are month/year FEs (what does it account for?)
- T_j counts days falling into temperature bin j (captures nonlinearities)

Results: Garment Sewing



- output is lower in hotter weeks **without climate control**
- Moving from lowest to highest temperature bin ↓ productivity by 8%
- Note: these are 90% CI's!

Results: Cloth and Steel



Lagged Effects

- Previously, β_j combined productivity and absenteeism channel
- Now we use daily data

$$y_{id} = \alpha_i + \gamma_M + \gamma_t + \sum_j \beta_j T^j_{id} + \sum_j \omega_j L^j_{id} + \theta R_{id} + \lambda X_{id} + \epsilon_{id}$$

- where T^j is now an indicator for day d falling into temperature bin j
- X_{id} includes day-of-week FE
- L^j_{id} counts number of days in bin j during six preceding days

Discussion

- Is lag specification plausible?
  - Is six days a plausible window to detect cumulative exposure?
- What are the identification assumptions?
- What are the threats?

Lagged Effects: Productivity

TABLE 2
Effect of Hot Days on Worker Output

	Climate Control		No Climate Control		
	Garments (Log Efficiency)	Steel (Log Blooms Rolled)	Weaving (IHS Meters)	Garments (Log Efficiency)	
	(1)	(2)	(3)	(4)	(5)
T (33°–35°C)	.025**	.028*	−.040**	−.129***	−.007
	(.010)	(.017)	(.019)	(.042)	(.037)
T (above 35°C)	.035***	.020**	.011	−.154***	.008
	(.014)	(.009)	(.022)	(.041)	(.046)
L (33°–35°C)	−.004	.005	−.033***	−.009	.004
	(.005)	(.004)	(.011)	(.012)	(.010)
L (above 35°C)	−.011**	−.002	−.027***	−.019	.015
	(.005)	(.005)	(.009)	(.027)	(.018)
Climate control	Yes	Yes	No	No	No
Number of units	74 lines	9 teams	147 workers	10 lines	19 lines
Time span (days)	730	3,337	365	730	730

- Lower output on hot days in sites w/o climate control
- Weavers: additional day $> 35°$ in past week $\downarrow$ daily output by 3%

Lagged Effects: Absenteeism

TABLE 3
EFFECT OF HOT DAYS ON WORKER ABSENTEEISM

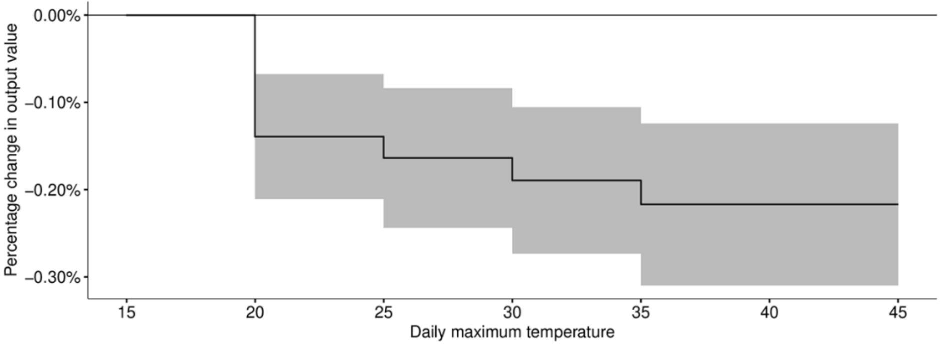
	Climate Control			No Climate Control		
	Garments		Steel	Weaving	Garments	
	Paid (1)	Unpaid (2)	(All) (3)	(All) (4)	Paid (5)	Unpaid (6)
T (33°–35°C)	.082***	−.083	−.011	.003	−.001	.796
	(.022)	(.065)	(.048)	(.004)	(.128)	(.678)
T (above 35°C)	.115***	.031	.051	−.004	−.034	1.001
	(.027)	(.049)	(.068)	(.004)	(.117)	(.862)
L (33°–35°C)	−.018	−.047	.044***	.006***	.017	.772
	(.011)	(.032)	(.014)	(.002)	(.077)	(.686)
L (above 35°C)	.021**	−.001	.045**	.005***	.078	.567
	(.010)	(.022)	(.020)	(.002)	(.083)	(.426)
Number of units	224 lines		9 teams	147 workers	42 lines	
Time span (days)	730		3,337	365	730	

- How do you interpret these results?

15-year plant-level panel results

$$y_{it} = \alpha_i + \gamma_t + \sum_{j=2}^{5} \beta_j T_{it}^{j} + \theta R_{it} + \epsilon_{it}$$

outcome is log value of plant i output in year t



Recap of Results

- Daily worker data: workers are less productive on hot days
- Daily worker data: (kind of) more absenteeism on hot days
- Plant panel: **aggregate** output is lower on hot days
  - This is the object we are interested in
  - Remember $\frac{\partial \Delta y}{\partial h} \frac{\partial h}{\partial e}$
- **How much of the temperature-induced ΔY is due to ΔMP_L?**

Lets make a Cobb-Douglas model

Consider a production function:

$$Y = A \cdot K^{\omega} \cdot L^{\beta}$$

Now modify by letting elasticities be a function of temperature, T

$$Y = A(T) \cdot K^{\omega(T)} \cdot L^{\beta(T)}$$

where:

$$A(T) = A_0 + \sum a_j T_j$$
$$\omega(T) = \omega_0 + \sum \omega_j T_j$$
$$\beta(T) = \beta_0 + \sum \beta_j T_j$$

Estimating Equation

- Log-linearizing, we get Equation (7) from the paper:

$$y = \alpha_0 + \sum_{j=2}^{5} \alpha_j T^j + \omega_0 \cdot k + \sum_{j=2}^{5} \omega_j T^j k + \beta_0 \cdot l + \sum_{j=2}^{5} \beta_j T^j l$$

- Data:
  - k: opening value of equipment and machinery at start of financial year
  - l: number of full-time workers
- **Results**
  - temperature effects on output elasticitiy of L is negative and significant
  - temperature effects on output elasticity of K are (weakly) positive
  - Controlling for interactions, residual temperature-output effect is zero
  - Since overall temperature-output relationship is negative, temperature-induced declines in labor productivity drive the effect

Results

TEMPERATURE INTERACTIONS WITH FACTOR INPUTS

	(1)	(2)	(3)	(4)	(5)
T^a					.02324*
					(.01345)
T^2	.00256**	.00008	−.00008		
	(.00097)	(.00211)	(.00162)		
T^3	.00147	−.00205	−.00009		
	(.00103)	(.00229)	(.00165)		
T^4	.00081	−.00094	−.00028		
	(.00108)	(.00237)	(.00170)		
T^5	.00003	−.00499*	−.00171		
	(.00118)	(.00259)	(.00185)		
l	.8612***		.91426***	.36520***	
	(.0957)		(.09660)	(.05910)	
k		.20433**	.06629		
		(.05674)	(.04114)		
$l \times T^2$	−.00098***		−.00134***	−.00056**	
	(.00027)		(.00034)	(.00022)	
$l \times T^3$	−.00067**		−.00104***	−.00038**	
	(.00027)		(.00027)	(.00017)	
$l \times T^4$	−.00052*		−.00077***	−.00030*	
	(.00027)		(.00027)	(.00017)	
$l \times T^5$	−.00036		−.00075***	−.00039**	
	(.00029)		(.00029)	(.00018)	
$k \times T^2$		−.00009	.00028*		
		(.00015)	(.00015)		
$k \times T^3$		.00005	.00022*		
		(.00016)	(.00012)		
$k \times T^4$		−.00003	.00016		
		(.00016)	(.00011)		
$k \times T^5$		.00022	.00024**		
		(.00018)	(.00012)		

Discussion

- What do you think about the paper
- Critique
- How can they improve the identification?
- This data is as good as it gets: did they do everything they could?
  - What about long term effects/adaptation?
- Alternative explanations

Back to the model

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

- 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**

- What about indirect effects via productivity $(\frac{\partial \Delta y}{\partial h}\frac{\partial h}{\partial e})$?
  - This is the research frontier

- Next: what about $\frac{\partial \Delta y}{\partial e}$, the direct effect of environment on incomes
  - Almost no research on this

How might the environment **directly** affect incomes?

- Assume landholders vary in distance to a central market
- Each chooses land and labor to maximize farm profits
- New PA imposed that overlaps existing productive land and restricts land use
- Assuming initially efficient allocation, what happens to net welfare?
- What if land rents increase outside the PA?

Background: Conservation and Development

- On other hand, PAs may generate tourism income and other positive spillovers
- Surprisingly little evidence on income channel
- Main challenge: non-random placement of PAs

Sims (2010): Conservation and Development: Evidence from Thailand

Research Question: How does PA policy affect local poverty outcomes? - What are the mechanisms?

Setting: Thailand in 2000

Data: Household consumption surveys + PA locations

Empirical Strategy: Instrument PA location with priority watershed status

Results: PAs increase consumption and lower poverty - Higher tourism is the main mechanism

Data

- Wildlife sanctuaries (N=31) and national parks (N=57)
  - Source: World Database on Protected Areas
  - Includes year of establishment

- Poverty Mapping
  - Model household income in 2000 Thai Economic Survey as a function of household characteristics and assets
  - Use coefficient to predict household income in census households

- Poverty Measure

$$FGT(\alpha) = \frac{1}{n} \sum_{y_i < p} \left(\frac{p - y_i}{p} \right)^{\alpha}$$

where p is poverty line and y_i is income

Empirical Strategy: Ordinary Least Squares

$$y_{ij} = \beta_1 PA_{ij} + \beta_2 G_{ij} + \beta_3 X_{ij} + \alpha_j + \epsilon_j$$

- y_{ij} is socioeconomic outcome for locality i in district j
- PA_{ij} is share of locality land designated as PA prior to 2000
- G_{ij} are fixed geographic controls (slope, elevation, water, etc.)
- X_{ij} is a measure of pre-treatment (historic forest cover, distance to major roads)
- α_i are district fixed effects

What variation is exploited?

What are the identification assumptions?

What are potential omitted characteristics?

OLS Results

	Outcomes			
	(1)	(2)	(3)	(4)
	Log consumption (Baht/month)	Poverty headcount ratio	Poverty gap	Squared poverty gap
Share protected	0.135***	−0.066***	−0.017***	−0.006**
	(0.033)	(0.017)	(0.006)	(0.002)
R^2	0.593	0.702	0.627	0.563
N localities	4113	4113	4113	4113

- Median land share protect is $1/3$
- Expected $\uparrow$ in consumption is about 4.5% (divide by coeff. by 3)

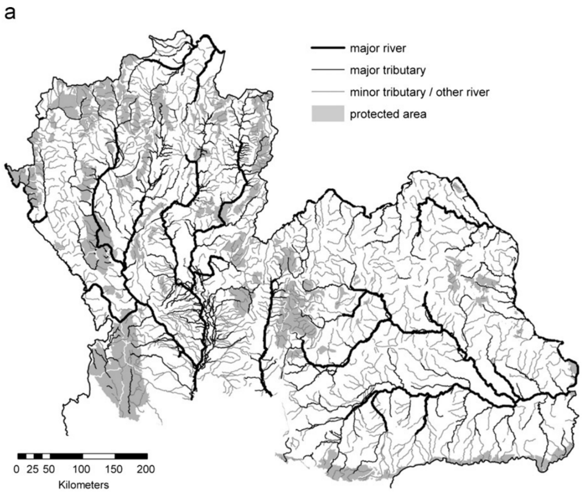
Instrumental Variables Solution

- Instrument PA placement with **priority watershed status**
- Upper watersheds (headwaters) protected to improve **downstream** water quality
  - Watershed protected not driven by local (headwater) economic needs
- First Stage:

$$PA_{ij} = \pi_1 Z_{ij} + \pi_2 G_{ij} + \pi_3 X_{ij} + \pi_4 W_{ij} + \delta_j + u_{ij}$$

- Z_{ij} includes a) i overlaps major tributary, b) distance to nearest major tributary .
- π_1 picks up variation in PA driven by differences in downstream characteristics

Watershed Instrument



Discussion

Is the IV plausible? Why or why not?

IV Results

	Outcomes			
	(1) Log consumption (Baht/month)	(2) Poverty headcount ratio	(3) Poverty gap	(4) Squared poverty gap
IV estimates				
A. Intersects with tributary				
Share protected	0.372**	−0.183**	−0.063*	−0.030*
	(0.184)	(0.092)	(0.034)	(0.017)
B. Distance to major tributary				
Share protected	0.358**	−0.187**	−0.069**	−0.033*
	(0.172)	(0.093)	(0.035)	(0.017)
C. Both instruments				
Share protected	0.365**	−0.185**	−0.066**	−0.031*
	(0.170)	(0.088)	(0.033)	(0.016)

- Signs agree with OLS, but magnitudes are more than 2x as large
- Consistent with idea that OLS negatively biased

Mechanisms: Is tourism responsible?

- PAs restricts land use, so why does income increase?
- Test 1: Test whether impacts in national parks > in wildlife sanctuaries
  - Idea: NP's encourage tourism whereas sanctuaries only permit ecotourism/research
- Test 2: Back-of envelope calculation
  - if we know costs/benefits of tourism, is it enough to explain net $\uparrow$ in consumption?
- Test 3: Are benefits higher where tourism is higher
  - Park statistics show that visitation is highest near major cities

Test 1: National parks vs. Wildlife Sanctuaries

Socioeconomic outcomes and share protected by IUCN category.

	Outcomes			
	(1) Log consumption (Baht/mo)	(2) Poverty headcount ratio	(3) Poverty gap	(4) Squared poverty gap
Share WLS (I)	0.054	−0.019	−0.008	−0.004
	(0.050)	(0.032)	(0.013)	(0.006)
Share NP (II)	0.086**	−0.057***	−0.015***	−0.005**
	(0.038)	(0.018)	(0.005)	(0.002)
Share FR (IV)	−0.062***	0.022***	0.005*	0.002
	(0.016)	(0.008)	(0.003)	(0.001)
R^2	0.870	0.596	0.703	0.628
N localities	4113	4113	4113	4113

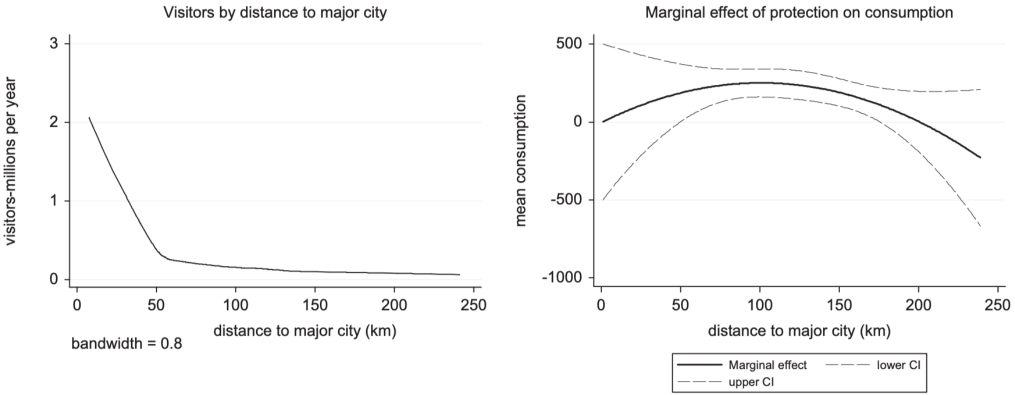
- Effects larger where tourism is allowed (NPs)
- Difference in coefficients not statistically significant

Test 2: Back of the envelope calculation

- Assume income is agricultural and reduced proportionally to land lost
- Assume credit constraints (no savings) $\rightarrow$ income losses $=$ consumption losses
- Consumption cost of PAs is 11% of income (forest cover coeff. - see paper)
- To achieve 5% *net* $\uparrow$ in consumption, tourism must generate 16% consumption
  - Equivalent to 233 Baht per month (0.16 $\times$ mean consumption)
- 10.81 mil. tourists in 2020 and 172,978 hh in PA localities $=$ 61 tourists/hh
- Each tourist would need to contribute: (233*12)/61 $=$ 46 Baht ($USD 1.20) of net income to generate observed increases in consumption

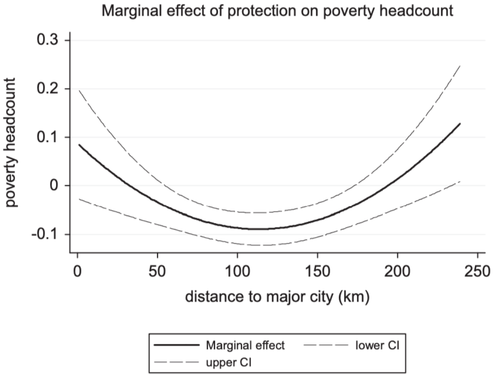
Is this reasonable?

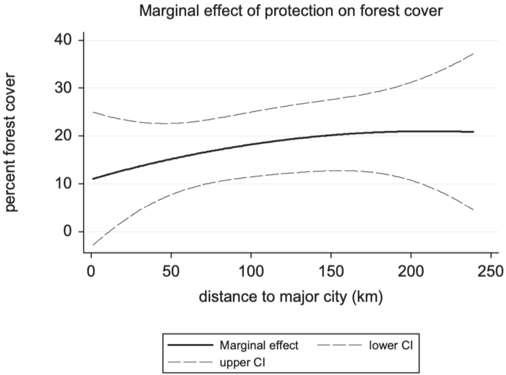
Test 3: Heterogeneity by Distance to City



- Most tourists near city, but effects concentrated at intermediate distance
- Why?

Test 3: Heterogeneity by Distance to City





Discussion

- What do you think of the paper?
- Do you believe the instrument?
- What are some alternative explanations?