Environment, Development, and Technology

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Paris School of Economics

Outline for Today

- The Causes of High Pollution in Low Income Countries
- Technological Change and the Green Revolution

Environment and Development

Environmental quality is in many ways worse in low-income countries

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IQAir Air Quality Air Monitors Air Purifiers Face Masks For Business News Support Search Dashboard

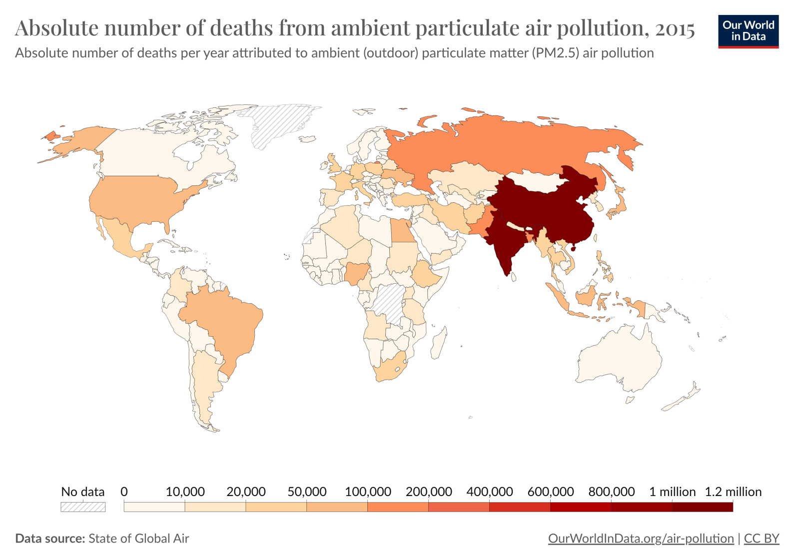
PM2.5 legend

0-5	5.1-10	10.1-15	15.1-25	25.1-35	35.1-50	>50.1
Meets WHO guideline	Exceeds by 1 to 2 times	Exceeds by 2 to 3 times	Exceeds by 3 to 5 times	Exceeds by 5 to 7 times	Exceeds by 7 to 10 times	Exceeds by over 10 times

Rank	City	2022	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	2021	2020	2019	2018	2017
1	Lahore, Pakistan	97.4	133	102.5	85.6	69.3	60.9	52.1	47.8	46.2	64.2	123.2	190.5	192.9	86.5	79.2	89.5	114.9	133.2
2	Hotan, China	94.3	61.7	91.6	132.7	106.2	120.5	69.5	172.5	75	65.1	75	50.3	120	101.5	110.2	110.1	116	91.9
3	Bhiwadi, India	92.7	110.6	98	116.2	149.5	123.8	102.8	38.8	36.5	59.9	85.4	111.4	86.9	106.2	95.5	83.4	125.4	--
4	Delhi (NCT), India	92.6	141	100.9	91	98	73.2	56.2	34.3	31.1	38.3	99.7	176.8	171.9	96.4	84.1	98.6	113.5	108.2
5	Peshawar, Pakistan	91.8	110.2	103.5	78.3	68.5	53.5	56.3	51.8	57.8	79	100	132	212.1	89.6	--	63.9	--	--
6	Darbhanga, India	90.3	127	77.9	83.1	64.9	46.3	39.1	21	25.4	32.1	86.8	179.9	248	175.9	--	--	--	--
7	Asopur, India	90.2	110.3	89	104.6	124.4	73.4	52.3	44.1	34.9	37.1	74.1	139.7	201.2	--	--	--	--	--
8	N'Djamena, Chad	89.7	162.3	163.7	245.6	103.7	74.2	36.6	21.2	21.8	22.1	49.7	59.9	132.4	77.6	--	--	--	--
9	New Delhi, India	89.1	133.7	95.2	86.4	93.7	72.5	54.9	33.6	30.5	37.7	94.9	170.1	166.8	--	--	--	--	--
10	Patna, India	88.9	128	99.8	105.1	98.1	58	53.8	37.5	35.8	37.5	65.3	141.9	209.2	78.2	68.4	82.1	119.7	118.5
11	Ghaziabad, India	88.6	135.5	104.4	95.5	87	67.1	54.9	32.1	29.5	38.5	103.1	157.3	159.2	102	106.6	110.2	135.2	144.6
12	Dharuhera, India	87.8	104.3	74.4	87.1	101.8	89.5	70.6	39.7	36.8	56.4	103.4	148.3	129.6	76.9	72.5	--	--	--
13	Baghdad, Iraq	86.7	70.6	53.3	76.8	99.2	128.3	130.9	85.7	103.3	59.2	73.1	78.1	88.7	49.7	--	39.6	--	--

Rich countries have cleaned up

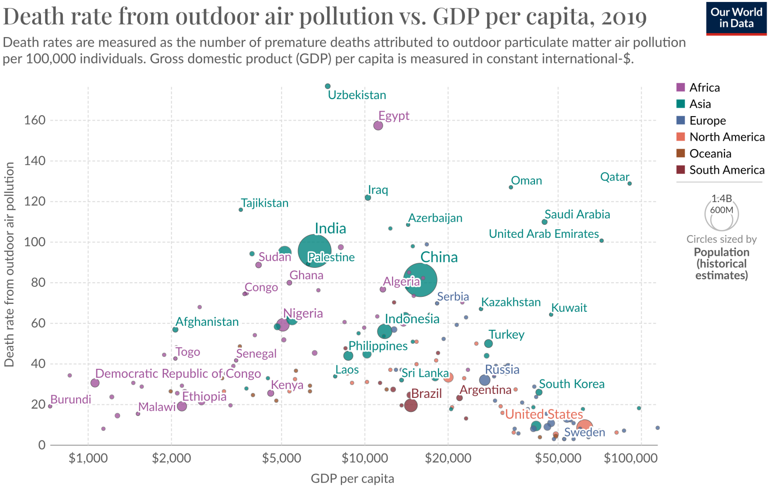
Air Pollution



Air Pollution

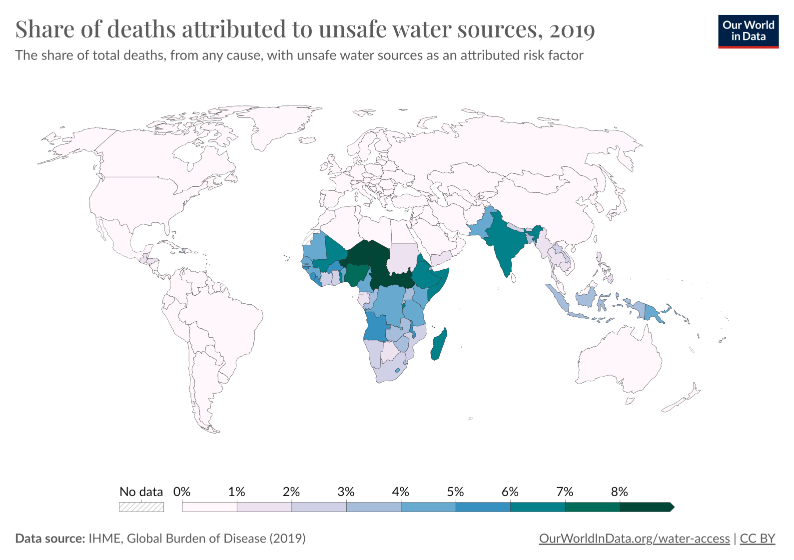
Death rate from outdoor air pollution vs. GDP per capita, 2019

Death rates are measured as the number of premature deaths attributed to outdoor particulate matter air pollution per 100,000 individuals. Gross domestic product (GDP) per capita is measured in constant international-$.



Data source: IHME, Global Burden of Disease (2019); Data compiled from multiple sources by World Bank
OurWorldInData.org/outdoor-air-pollution | CC BY

Water Pollution

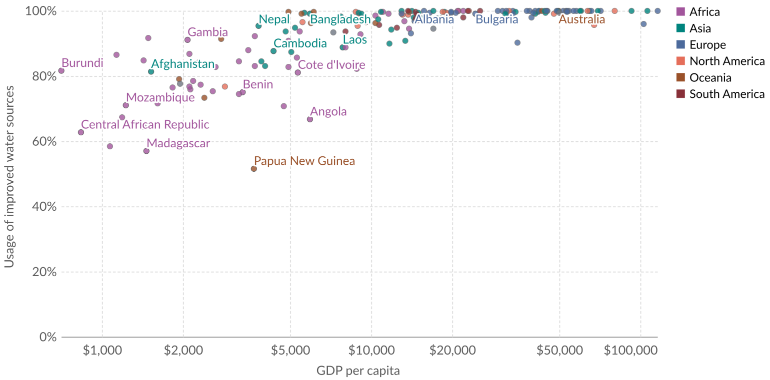


Water Pollution

Improved water sources vs. GDP per capita, 2021

Our World in Data

An improved drinking water source includes piped water on premises and other sources (public taps or standpipes, tube wells or boreholes, protected dug wells, protected springs, and rainwater collection). GDP per capita is measured in constant international-$.



Data source: WHO/UNICEF Joint Monitoring Programme (JMP) for Water Supply and Sanitation; Data compiled from multiple sources by World Bank

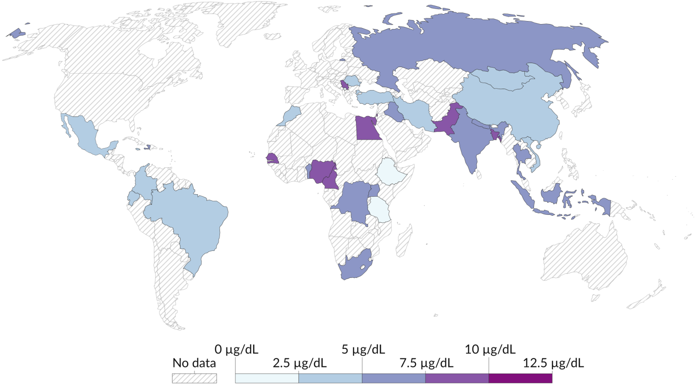
OurWorldInData.org/water-access |

Toxicity

Mean lead concentrations in the blood of children

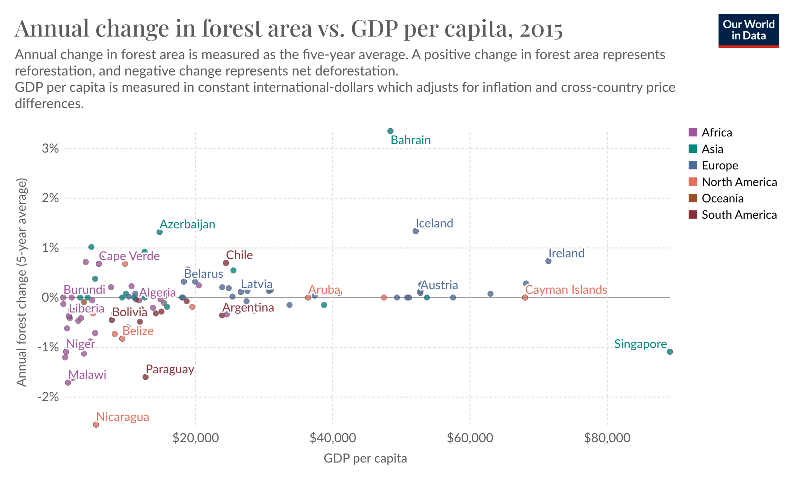
Our World in Data

Mean lead concentrations in the blood of children aged 0 to 14 years old between 2010 and 2019. There is no defined 'safe' level for lead blood concentrations. The WHO adopts a threshold of 5 µg/dL as an achievable maximum level in children.



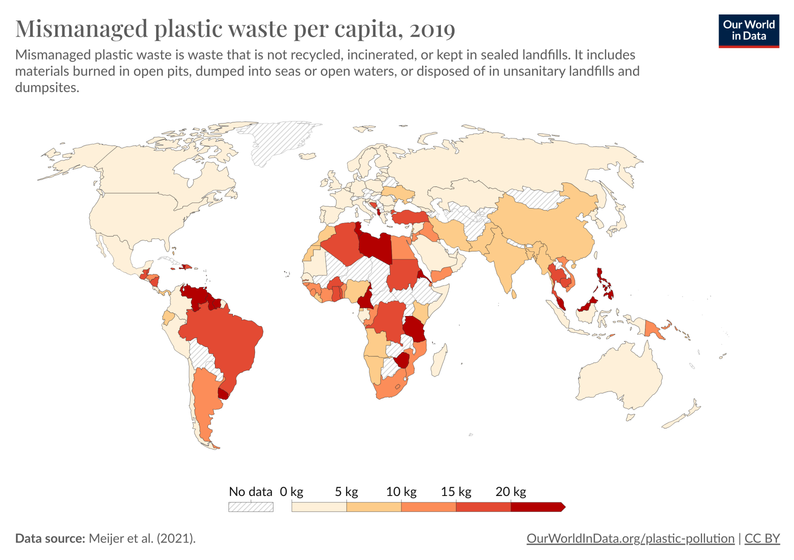
Data source: Ericson et al. (2021). Blood lead levels in low-income and middle-income countries: a systematic review. The Lancet Planetary Health.

Deforestation



Data source: Food and Agriculture Organization of the United Nations, Data compiled from multiple sources by World Bank
Note: The UN FAO publish forest data as the annual average on 10- or 5-year timescales. The following year allocation applies: "1990" is the annual average from 1990 to 2000; "2000" for 2000 to 2010; "2010" for 2010 to 2015; and "2015" for 2015 to 2020.

Plastic Waste

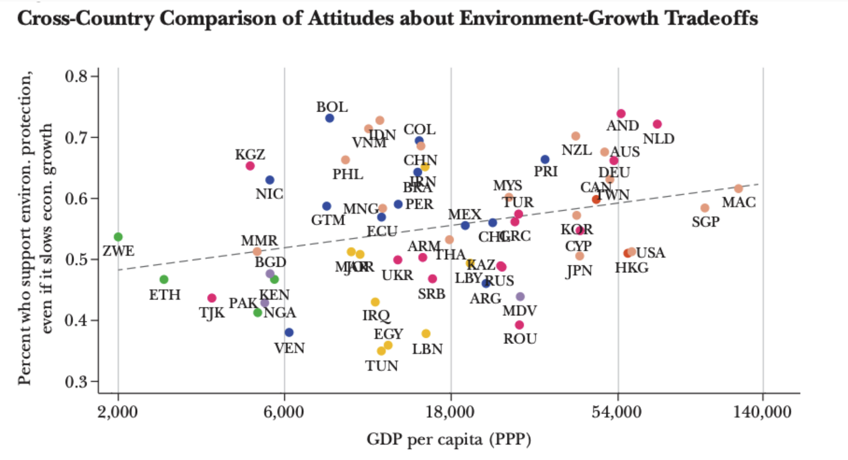


Willingness to Pay for Environmental Quality

Greenstone and Jack (2015): Envirodevonomics

- Why is marginal WTP for environmental quality so low in low-income countries?
- Provocative framing, but what does marginal willingness to pay mean? (Hint: it is not necessarily how much you 'care' about the environment
- Is it true?
  - Kremer et al (2011) analyze an RCT that improves water quality at some springs in Kenya. Households choose between water sources at different distances.
    - Find reduction in diarrhea and child mortality, but limited HH behavior change: $0.89 wtp to avoid diarrhea and implied $769 VSL
  - Cohen and Dupas (2010) find 60% of HHs in Kenya not willing to pay $0.60 for mosquito nets that significantly reduce malaria risk - 20% effect on child mortality?
  - Mobarak et al (2012) finds negligible adoption of cookstoves that reduce indoor smoke and environmental impact, even at large discounts, despite awareness of benefits.

Willingness to Pay for Environmental Quality



Glennerster and Jayachandran (2023)

Willingness to Pay for Environmental Quality

Model from Greenstone and Jack (2015): Utility from environment, health, and consumption:

$$u(e, h(s, e), c) \text{ s.t. } y \geq c_e(e) + c_s(s) + c \tag{1}$$
$$y = y_0 + \Delta y(e, h(s, e)) \tag{2}$$
$$e = e_0 + \Delta e + a(c, s) \tag{3}$$

Health effects and environmental quality can be mitigated by spending on self-protection

Willingness to Pay

WTP for Environmental Quality:

$$MWTP_e = \frac{\frac{du}{de}}{\frac{du}{dy}} = \frac{dc_e}{de} \tag{4}$$

$$\frac{dc_e}{de} = \frac{\frac{\delta u}{\delta e}}{\frac{du}{dy}} + \frac{\frac{\delta u}{\delta h}\frac{\delta h}{\delta e}}{\frac{du}{dy}} + \frac{\delta \Delta y}{\delta e} + \frac{\delta \Delta y}{\delta h}\frac{\delta h}{\delta e} \tag{5}$$

WTP for Self Protection:

$$MWTP_s = \frac{\frac{du}{ds}}{\frac{du}{dy}} = \frac{dc_s}{ds} \tag{6}$$

$$\frac{dc_s}{ds} = \frac{\frac{\delta u}{\delta e}\frac{da}{ds}}{\frac{du}{dy}} + \frac{\frac{\delta u}{\delta h}(\frac{\delta h}{\delta s} + \frac{\delta h}{\delta e}\frac{\delta e}{\delta s})}{\frac{du}{dy}} + \frac{\delta \Delta y}{\delta e}\frac{\delta a}{\delta s} + \frac{\delta \Delta y}{\delta h}(\frac{\delta h}{\delta s} + \frac{\delta h}{\delta e}\frac{\delta a}{\delta s}) \tag{7}$$

Willingness to Pay for Environment

$$\frac{dc_e}{de} = \frac{\frac{\delta u}{\delta e}}{\frac{du}{dy}} + \frac{\frac{\delta u}{\delta h}\frac{\delta h}{\delta e}}{\frac{du}{dy}} + \frac{\delta \Delta y}{\delta e} + \frac{\delta \Delta y}{\delta h}\frac{\delta h}{\delta e} \tag{8}$$

Several possibilities:

- Low benefits (direct values for e and indirect through health) or low information about benefits

Willingness to Pay for Environment

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- Time and state mismatch: credit and insurance market failures

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- High costs of increasing e
- Time and state mismatch: credit and insurance market failures
- Interpersonal mismatch between benefits and costs: Classic externalities (with high transaction costs)

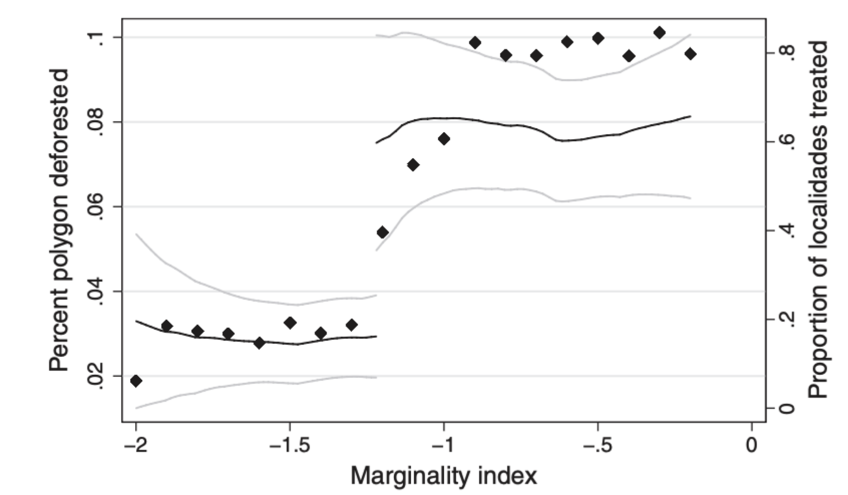
High Marginal Utility of Income

If true, increases in income should increase demand for environmental quality

Alix-Garcia et al (2013): The Ecological Footprint of Poverty Alleviation

- Opportunidades: large cash transfers to households in Mexico based on household level and village level 'marginality' thresholds

The Ecological Footprint of Poverty Alleviation



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- Opportunidades: large cash transfers to households in Mexico based on household level and village level 'marginality' thresholds
- Large increases in household spending on beef and milk
- Heterogeneity in impacts: More deforestation in more isolated communities with worse road infrastructure
  - Consistent with an environmental kuznets curve type story?
- Sharp tradeoffs between poverty and environmental goals

High costs of increasing environmental quality?

We have seen some examples of RCT payments for ecosystem services that were very cost-effective

- Cash for Carbon: Payments to conserve forest in Uganda cut deforestation
- Money (Not) to Burn: Paying farmers not to burn crops saves life for $4,000

High costs of increasing environmental quality?

We also discussed some reasons why scale up is difficult: Spillovers, adverse selection, moral hazard

Calel et al (2021) Do Carbon Offsets Offset Carbon?

- Clean development mechanism (CDM) under the Paris Agreement gives carbon credits to firms that subsidize wind farms in India
- Ideally you want to subsidize marginal projects: projects that would not have happened without a subsidy
- BLatantly Infra-marginal Projects (BLIMPS): Subsidized projects that have $>>$ profitability than non-subsidized projects
  - Authors find at least half of CDM wind farms are BLIMPS

High costs of increasing environmental quality?

Another reason: Political Economy and Corruption

- Corruption both increases costs of enforcing environmental regulations and lowers effectiveness

Duflo et al (2013): Truth-telling by Third-party Auditors and the Response of Polluting Firms: Experimental Evidence from India

- Strict command and control regulations in India on firm pollution levels
- Regulations are enforced by third party auditors that are chosen and paid by the firms
- Treatment group: auditors paid out of a centralized pool
- Researchers go back and check actual pollution levels for both groups

High costs of increasing environmental quality?

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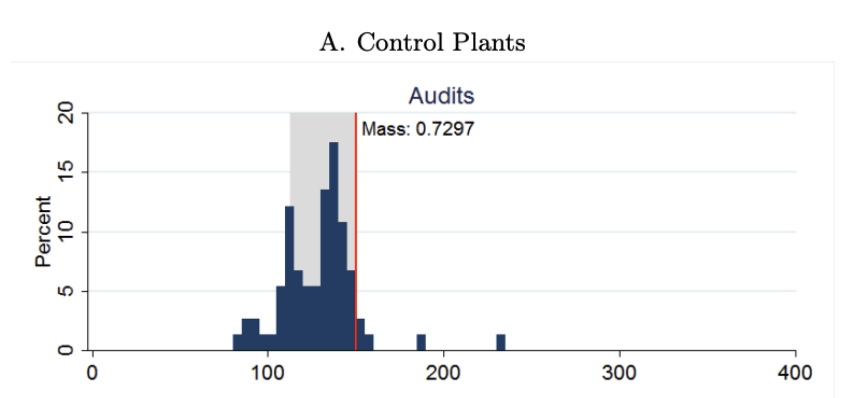

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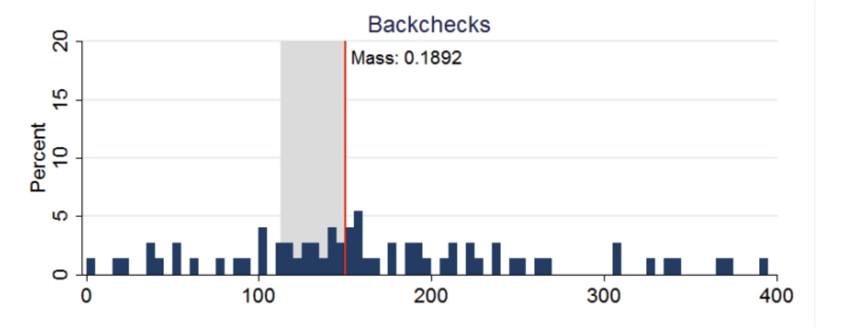

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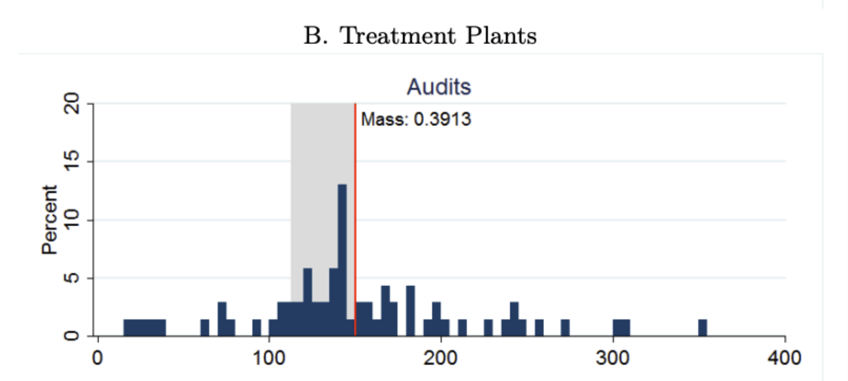

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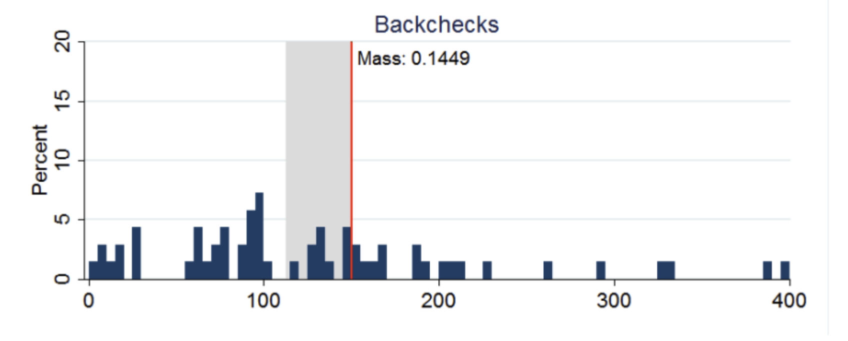

Credit and Insurance Market Failures

What if benefits of environment occur in a different time period?

- E.g. Child health affects education affects earnings in adulthood
- If markets are perfect, I take a loan to pay for it
- Widespread credit market failures in low-income countries

Berkouwer and Dean (2022): Credit, Attention, and Externalities in the Adoption of Energy Efficient Technologies by Low-Income Households

- RCT on 1,000 HHs in Nairobi offering energy efficient charcoal cookstoves
- Reduces spending on charcoal 39% annually - save \$237 over two years. Market price of stove is \$40 (243% return!)
- How much are HHs willing to pay for these savings?

Credit and Insurance Market Failures: Berkouwer and Dean (2022)

How can we estimate household willingness to pay?

- Ask them? Subject to stated preference caveats

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    - Only gives a bound on WTP

Credit and Insurance Market Failures: Berkouwer and Dean (2022)

How can we estimate household willingness to pay?

- Ask them? Subject to stated preference caveats
- Make an offer at price p and see if they accept
  - Only gives a bound on WTP
- Becker-DeGroot-Marschak method:
  - Ask subject how much they are willing to pay
  - Draw a random price p
  - If WTP $\geq$ p, subject pays p and receives item

Credit and Insurance Market Failures: Berkouwer and Dean (2022)

Recall savings are \$237 over two years. Household WTP in the control group is ....

Credit and Insurance Market Failures: Berkouwer and Dean (2022)

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2 treatment arms to test possible explanations:

- Inattention: text message reminders asking about charcoal savings. Complete an accounting exercise to calculate their annual savings immediately before BDM.

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    - No change in WTP
- Credit constraints: Offer a 3 month loan at low interest rates
    - Doubles WTP – completely closing gap with savings *over that 3 month period*

Externalities

What if the benefits of environmental good aren't aligned with who pays for it?

- Classic externalities: not unique to low-income countries
- Yet higher transaction costs, social norms, or other market failures can exacerbate these issues

Miller and Mobarak (2013): Gender Differences in Preferences, Intra-Household Externalities, and Low Demand for Improved Cookstoves

- RCT on cookstoves in Bangladesh
- Women cook more, and thus benefit more (reduced indoor pollution), but men control household budgets

Social Norms and Externalities

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- 2 price treatments: Free and highly subsidized
- 2 offer treatments: Husband and wife

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Cluster	Group	Households	Ordered Stove*	Purchased Stove*
Free Stove (I/II)	I - Stove offered to men	197	94% (81%)	69% (75%)
	II - Stove offered to women	202	100% (87%)	70% (83%)
Subsidized Stove (III/IV)	III - Stove offered to men	197	72% (81%)	26% (75%)
	IV - Stove offered to women	203	69% (79%)	29% (73%)
	Total	799	84% (82%)	49% (78%)

*Numbers in parenthesis give percentages, by group, of those who chose the chimney stove, conditional on having ordered any stove at all. So, for example, 94% of group I ordered a stove, and of these, 81% order the chimney stove (so 19% ordered the efficiency stove).

Discussion

An NGO in a low-income country wants to improve sanitation in informal settlements, a context where open defecation is common. They are considering two options:

- Building public toilets and charging a small user fee to cover maintenance.
- Offering subsidized toilets to individual households.

Identify some possible costs and benefits associated with both options.

What about trade?

"the economic logic behind dumping a load of toxic waste in the lowest wage country is impeccable" – Larry Summers, 1991

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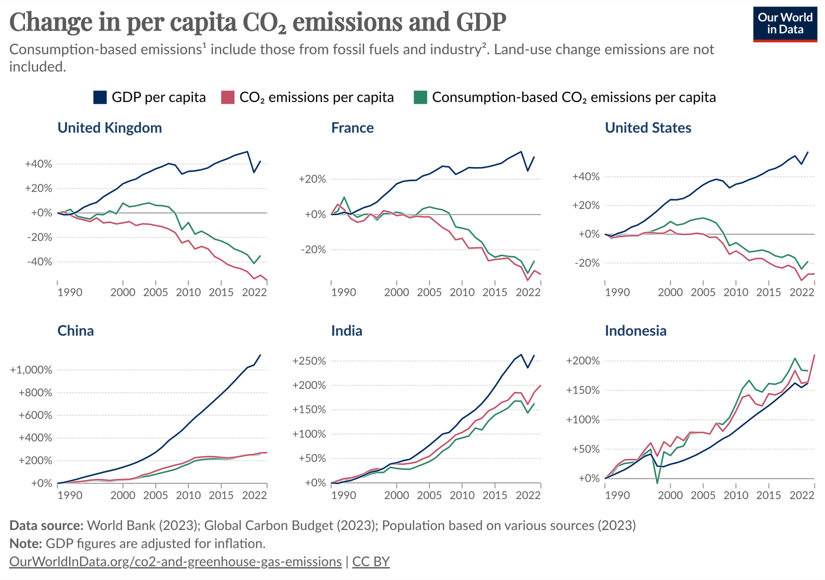
How much is the fault of rich countries? Did rich countries clean up simply through offshoring? Do environmental regulations disadvantage domestic industry? Are they less effective than expected due to leakage?

- Central to current dates about Carbon Border Adjustment Mechanism in the EU.

Pollution Havens Hypothesis: Chichilnisky (1994)

- 2 countries: differ only in their 'institutions' – pollution migrates to country with weaker institutions, trade reduces total welfare

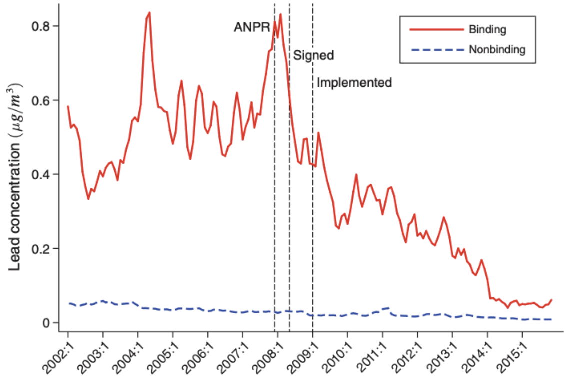
Consumption Adjusted Emissions: Carbon ‘Footprint’



Pollution Havens Hypothesis

Tanaka et al (2022): North-South Displacement Effects of Environmental Regulation: The Case of Battery Recycling

- In 2009 US tightened air quality regulations on lead by a factor of 10



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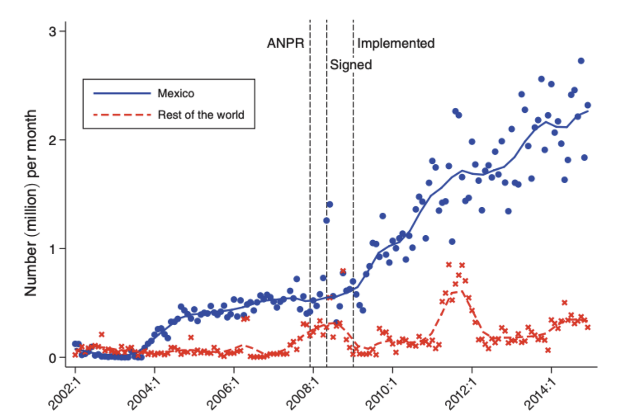

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TABLE 2—EFFECTS ON BIRTHWEIGHT IN MEXICO

	Ministry of Health (MH) hospitals			
	(1)	(2)	(3)	(4)
Panel A. Hospital discharge records				
1. Outcome: 1(*Birthweight* < 2.5 *kg*)				
Near × Post	0.022	0.043	0.049	0.048
	(0.0081)	(0.011)	(0.012)	(0.011)
Pre-reform mean (Near=1)	0.128	0.128	0.128	0.128
2. Outcome: Birthweight (*grams*)				
Near × Post	−35.0	−32.3	−40.4	−38.5
	(10.2)	(16.0)	(16.2)	(16.3)
Pre-reform mean (Near=1)	3,006.6	3,006.6	3,006.6	3,006.6
Observations	319,165	319,165	319,165	319,165
Locality effects	Yes	Yes	Yes	Yes
Municipality-year effects	Yes	Yes	Yes	Yes
Locality characteristics × Post	No	Yes	Yes	Yes
Hospital effects	No	No	Yes	No
Hospital-year effects	No	No	No	Yes

Takeaways

Why do we see low WTP for e in low-income countries?

- Low benefits or low information about benefits: Not really
- High marginal utility of income: Maybe, but not likely to solve environmental issues with redistribution alone.
- High costs of increasing e: Scale up and institutional issues seem very important
- Credit and insurance market failures: Seems very important
- Classic externalities: Exacerbated by interactions with above
- Trade: Important in some cases - more research needed

Technology and the Green Revolution

From Gulliver's Travels

Whoever makes two ears of corn, or two blades of grass, to grow upon a spot of ground where only one grew before, would deserve better of mankind, and do more essential service to his country, than the whole race of politicians put together.

Norman Borlaug

- Born Iowa in 1914
- PhD in plant pathology from University of Minnesota
- 1970 Nobel Peace Prize
- Credited with saving 1 billion lives globally

The Green Revolution

Stem Rust: Possibly responsible for the collapse of the Roman Empire?

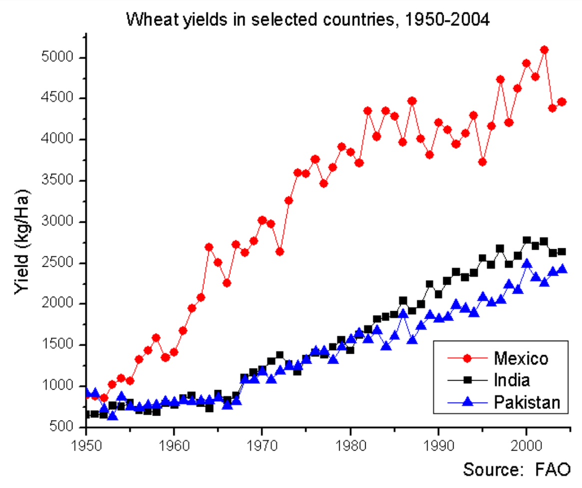
The Green Revolution

High-yield wheat and lodging

The Green Revolution

Dwarf Wheat

The Green Revolution



Rockefeller Foundation promoted technologies widely

Impacts of the Green Revolution

Gollin, Hansen and Wingender (2021): Two Blades of Grass

$$y_{it} = \beta_1 HYV_{it} + \gamma_t + \delta_c + \epsilon_{it} \tag{9}$$

Instrument HYV adoption rates:

$$HYV_{it}^{j} = \sum_{k=1970}^{2000} \alpha_k^j potential_i^j \times year_t^k + \theta_t + \lambda_c + u_{it} \tag{10}$$

Identification assumptions?

Impacts of the Green Revolution

Gollin, Hansen and Wingender (2021): Two Blades of Grass

Table 3: The effect of HYV on population and GDP/capita

	(1)	(2)	(3)	(4)	(5)	(6)
	Dependent Variable (in logs):					
	GDP/capita			*Population*		
Actual HYV adoption	0.987***	1.482***		-0.198***	-0.543***	
	(0.178)	(0.402)		(0.0701)	(0.178)	
Predicted HYV adoption			1.801***			-0.659***
			(0.539)			(0.198)
Observations	420	420	420	420	420	420
Countries	84	84	84	84	84	84
Estimator	OLS	2SLS	OLS	OLS	2SLS	OLS
Kleibergen-Paap	.	25.98	.	.	25.98	.

Notes: The table reports OLS and 2SLS estimates based on estimation equations (1) and (4). Variables are observed decenially over the period 1960–2000. All regressions include country and time fixed effects. The dependent variables are in logs and indicated at the top column. The main explanatory variable are: Actual HYV adoption, which is the actual share planted with HYV crops and Predicted HYV adoption, which is the predicted share of HYV crops according to equation (3). Standard errors (in parentheses) account for arbitrary heteroskedasticity and are clustered at the country level.

*** p<0.01, ** p<0.05, * p<0.1.

Impacts of the Green Revolution

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Table 9: The agricultural sector

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Dependent variable (in logs):						
	Yield/ worker	*Harvest area*	*Fertilizer/ hectare*	*Agri. pop- ulation*	*Agri employ- ment share*	*Pop- ulation*	*GDP/ capita*
Actual HYV adoption	1.919***	-0.538*	2.162**	-1.339***	-0.767***	-0.572***	1.505***
	(0.468)	(0.326)	(0.905)	(0.338)	(0.252)	(0.186)	(0.422)
Observations	405	405	405	405	405	405	405
Countries	81	81	81	81	81	81	81
Estimator	2SLS	2SLS	2SLS	2SLS	2SLS	2SLS	2SLS
Kleibergen-Paap	24.75	24.75	24.75	24.75	24.75	24.75	24.75

Notes: The table reports 2SLS estimates based on estimation equations (1) and (4). Variables are observed decenially over the period 1960–2000. All regressions include country and time fixed effects. The dependent variables are in logs and indicated at the top column. The main explanatory variable is Actual HYV adoption, which is the actual share planted with HYV crops, which is then instrumented with Predicted HYV adoption, which is the predicted share of modern-variety crops according to equation (3). Standard errors (in parentheses) account for arbitrary heteroskedasticity and are clustered at the country level.

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Impacts of the Green Revolution

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Table 10: Demographic effects

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Dependent variable:						
	(in logs)					(in rates)	
	Life Expectancy	*Infant mortality*	*Adult Mortality female*	*Adult Mortality male*	*Fertility rate*	*Rate of natural increase*	*Population growth*
Actual HYV adoption	0.134	-1.958***	-1.689***	-0.996***	-1.524***	-0.270***	-0.274***
	(0.0870)	(0.382)	(0.314)	(0.254)	(0.293)	(0.0636)	(0.0774)
Observations	420	381	420	420	420	420	420
Countries	84	84	84	84	84	84	84
Estimator	2SLS	2SLS	2SLS	2SLS	2SLS	2SLS	YES
Kleibergen-Paap	25.98	23.70	25.98	25.98	25.98	25.98	25.98

Notes: The table reports 2SLS estimates based on estimation equations (1) and (4). Variables are observed decenially over the period 1960–2000. All regressions include country and time fixed effects. The dependent variables are in logs and indicated at the top column. The main explanatory variable is Actual HYV adoption, which is the actual share planted with HYV crops, which is then instrumented with Predicted HYV adoption, which is the predicted share of modern-variety crops according to equation (3). Standard errors (in parentheses) account for arbitrary heteroskedasticity and are clustered at the country level.

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Genetically Modified Crops Today

Hansen and Wingender (2023): National and Global Impacts of Genetically Modified Crops

- GM crops today mostly have 2 traits: 'Roundup ready' and Bt production: natural pesticide
- GM versions of cotton, corn, soy, and rapeseed (oil), but nothing for rice, wheat, others
- Widely adopted in Argentina, Australia, Canada, China, Mexico and US, but banned in EU, Russia, much of Africa. Some countries (EU) also ban imports

Triple Difference Estimation:

$$\ln y_{ict} = \delta_i t + \gamma_{ci} + \lambda_{ct} + \sum_{j=-10}^{T} \alpha_j \mathbf{1}[t - E_{ic} = j] \tag{11}$$

Genetically Modified Crops

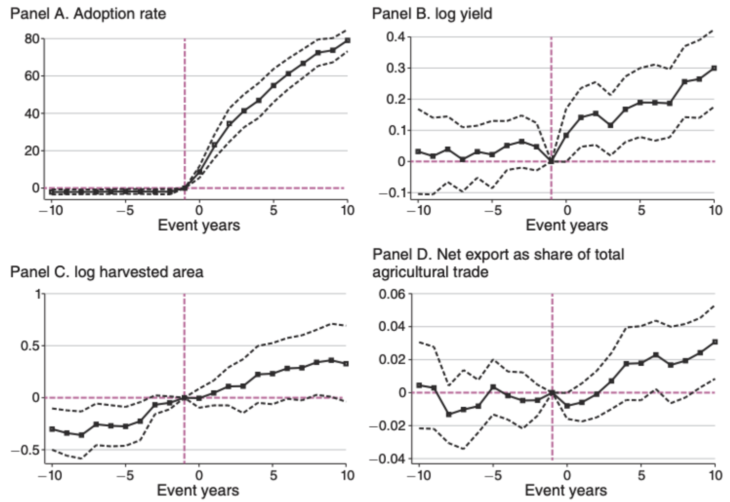


Figure 2. Baseline DDD Event Study Estimates

Genetically Modified Crops

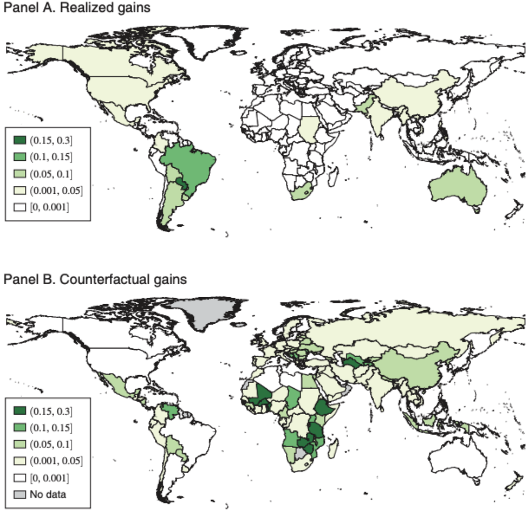


Figure 4. Estimated Realized and Counterfactual Gains Ten Years after GM Adoption

Do we need more innovation in agriculture?

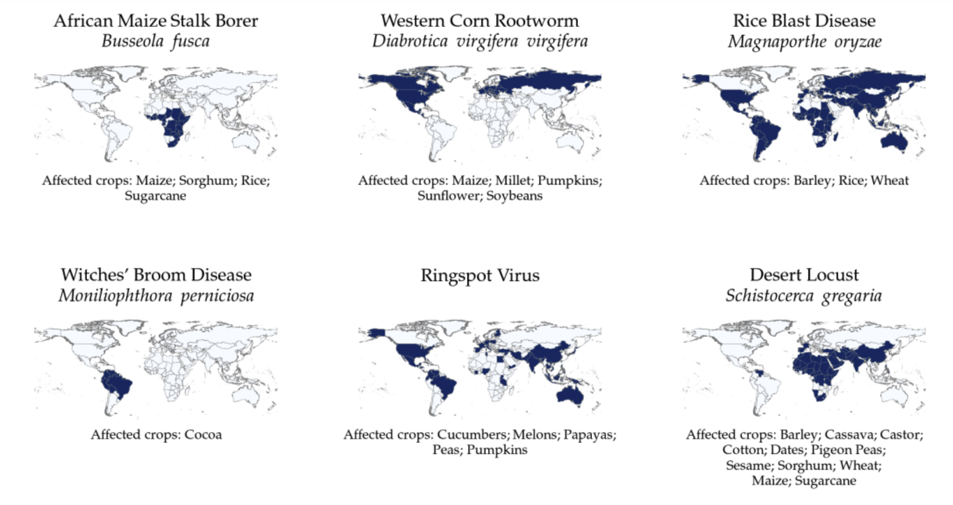
Moscona and Sastry (2022): Inappropriate Technology

- R&D is highly concentrated in a small set of countries. Does it diffuse broadly and easily?

A Billion Dollar Bug: the Corn Rootworm

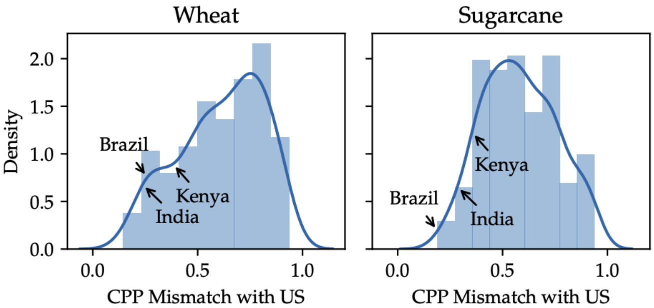
The Maize Stalk Borer: Kills 10% of Kenya Maize Crop Annually

Moscona and Sastry (2022): Inappropriate Technology



Moscona and Sastry (2022): Inappropriate Technology

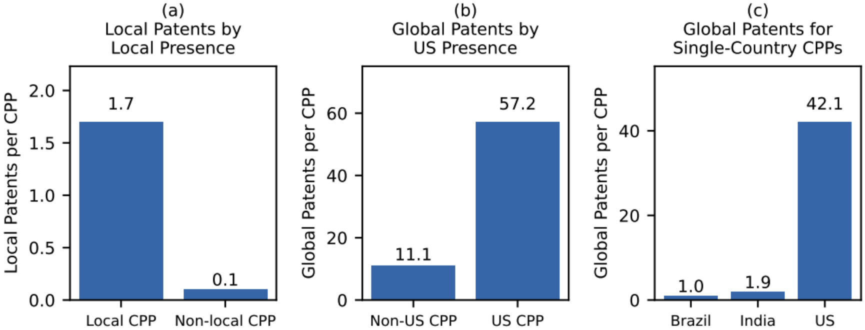
Figure 2: Example of CPP Mismatch Variation



Notes: Histogram (solid bars) and kernel density estimates (lines) for CPP Mismatch$_{\ell,\ell',k}$, where ℓ is the United States and k is the crop indicated in each graph. Values for India, Brazil, and Kenya are labeled.

Moscona and Sastry (2022): Inappropriate Technology

Figure 3: Global Patenting on CPPs



Notes: Graph (a) reports the average number of patented technologies developed in countries ℓ related to CPP threats t if the CPP is present (not present). Graph (b) reports the average number of patented technologies developed about CPPs that are not present in the US and CPPs that are present in the US. Graph (c) reports the number of patented technologies developed about CPPs that are present only in (i.e., endemic to) the countries specified on the x-axis.

Moscona and Sastry (2022): Inappropriate Technology

Findings:

- Diffusion (Biotech transfers) is decreasing in mismatch – especially relative to frontier
- Mismatch with the frontier predicts lower agricultural output
- Use mismatch with green revolution breeding centers and development of US ag-biotech industry relative to Europe as sources of exogenous variation

Embed these estimates in a structural model of innovation, diffusion, and trade

Moscona and Sastry (2022): Inappropriate Technology

Where should we fund the next green revolution?

Table 6: Inappropriateness-Minimizing Centers for Modern Agricultural Innovation

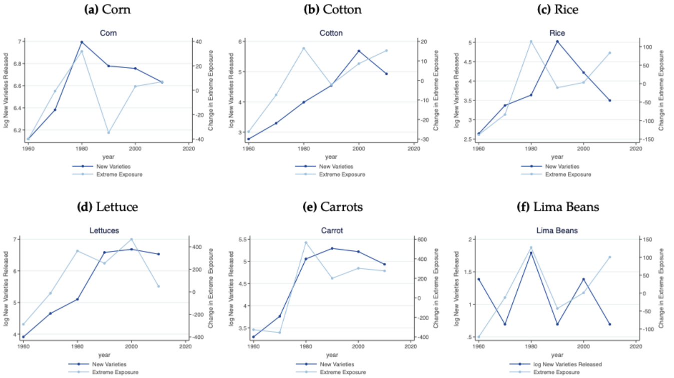
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Crop	Sites Chosen to Minimize Global Inappropriateness				Sites Chosen to Minimize Inappropriateness in Countries with Below Median Productivity			
	Best Site	% Change in Productivity	Second Best Site	% Change in Productivity	Best Site	% Change in Productivity	Second Best Site	% Change in Productivity
Wheat	China	4.87	India	2.75	India	11.17	Pakistan	6.76
Maize	China	13.40	USA	10.24	India	9.08	Tanzania	7.61
Sorghum	India	1.26	Nigeria	1.11	Nigeria	3.39	India	3.08
Millet	Nigeria	1.37	India	1.04	Nigeria	3.43	Zimbabwe	2.02
Beans	India	1.99	Brazil	1.73	India	3.93	China	1.82
Potatoes	China	1.48	India	0.73	India	1.20	China	0.65
Cassava	Nigeria	0.64	Ghana	0.47	Nigeria	1.81	DRC	1.45
Rice	China	10.74	India	9.59	India	16.65	Thailand	10.98

Notes: Column 1 reports the crops included in our analysis of the Green Revolution. Columns 2-5 report the results of our analysis to select the two countries where breeding investment would have the largest positive effect on global output for each crop. Columns 6-9 report the results of our analysis to select the two countries where breeding investment would have the largest positive effect on output in countries with below median overall agricultural productivity. All estimates rely on the full model with non-linear adjustments and price responses.

Technological adaptation to climate change

Moscona and Sastry (2022): Does Directed Innovation Mitigate Climate Damage?

Figure 2: Changes in Extreme Exposure and Variety Releases Across Decades: Examples



Notes: Each graph reports the change in ExtremeExposure$_{k,t}$ (light line, left y-axis) and the change in the (log of the number of) new varieties released (dark line, right y-axis) across decades.

Technological adaptation to climate change

Moscona and Sastry (2022): Does Directed Innovation Mitigate Climate Damage?

Table 3: Innovation and Resilience to Climate Damage

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Dependent Variable is log Land Value per Acre						
	Long Difference Estimates (1950s-2010s)					*Panel Estimates*	
County-Level Extreme Exposure	-0.851***	-1.519***	-0.825***	-0.862***	-0.786***	-0.232**	-0.390***
	(0.211)	(0.240)	(0.203)	(0.238)	(0.226)	(0.107)	(0.132)
	[0.264]	[0.304]	[0.244]	[0.305]	[0.279]	[0.105]	[0.103]
County-Level Extreme Exposure x Innovation Exposure	0.249***	0.425***	0.237***	0.251***	0.230***	0.0912***	0.128***
	(0.0757)	(0.0745)	(0.0728)	(0.0791)	(0.0762)	(0.0315)	(0.0321)
	[0.0945]	[0.0921]	[0.0881]	[0.0995]	[0.0929]	[0.0253]	[0.0243]
County Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State x Decade Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Weighted by Agricultural Land Area	No	Yes	No	No	No	No	Yes
Output Prices and Interactions	No	No	Yes	No	Yes	No	No
Avg. Temp. (°C) and Interactions	No	No	No	Yes	Yes	No	No
Observations	6,000	6,000	5,990	6,000	5,990	20,931	20,931
R-squared	0.989	0.991	0.989	0.989	0.989	0.979	0.984

Notes: The unit of observation is a county-year. Standard errors, double clustered at the county and state-by-decade levels, are reported in parentheses, and standard errors clustered by state are reported in brackets, and *, **, and *** indicate significance at the 10%, 5%, and 1% levels.

Takeaways

- Technology is a (mostly) public good
    - Undersupplied but significant frictions in diffusion
- Low-income countries need more R&D for growth, climate adaptation

Wrapping Up

In this class we briefly covered several key areas of environmental economics and policy:

- Externalities, Public Goods and Voluntary Agreements
- Non-market Valuation: Stated and Revealed Preferences
- Sustainability and Intertemporal Resource Management
- Environment, Development, and Technological Change

What I hope you'll take away: When you see an environmental problem:

- Identify key market failures, externalities
- What would a voluntary agreement look like? Is it possible?
- How can we measure the scale of the damages?
- What would an efficient policy look like? What are some of the distributional implications?

Assessment

- APE students: Policy analysis due April 1
  - I am happy to accommodate extensions if asked at least 1 week in advance.
- Paris 1 students: Contact Mouez Fodha (mouez.fodha@univ-paris1.fr) with questions about your exam

Going Forward

- May 23: European Association of Young Economists Annual Conference at PSE
- June 3: Cities, Infrastructure and the Environment workshop at PSE
- Check out resources on my website: https://sites.google.com/view/mdgordon/teaching
- Take Environmental Economics next year. Tools and models are important: IO, Trade, Machine Learning.
- Email me with research interests if you are interested in PhD