

# Inappropriate Technology: Evidence from Global Agriculture

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## Global R&D is highly concentrated in the rich world

25% of total R&D in the US vs. 3.6% in Africa and South Asia combined (US NSF, 2020)

Two opposing interpretations:

- 1 Ideas are broadly applicable and spread around the world from innovating countries
- 2 Technology is context specific and **inappropriate** in places dissimilar from frontier countries

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**This paper:** investigates the inappropriate technology hypothesis in global agriculture





European Maize Borer  
Dominant threat: **US, Europe**  
Effective GM Variety ✓



Maize Rootworm  
Dominant threat: **US**  
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Maize Stalk Borer  
Dominant threat: **sub-Saharan Africa**  
Effective GM Variety ✗



# This Paper: Inappropriate Technology in Global Agriculture

**Measurement:** potential inappropriateness from **dissimilarity of pest/pathogen environment**

- Comprehensive pest/pathogen-level distribution and host plant data from CABI
- Variation at crop-by-location-pair level

combined with global data on plant variety development and transfer + agricultural production

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**Main Results:** frontier technology's inappropriateness, driven by pest/pathogen dissimilarity,

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**Quantification:** estimates, interpreted via model, suggest that

- Inappropriateness explains 10-15% of global productivity disparities
- Mediates impacts of ongoing trends: rise of new R&D leaders, climate change

## Related Literature

- **Appropriate technology.** Atkinson and Stiglitz (1969); Salter (1969); David (1975); Stewart (1978); Basu and Weil (1999); Acemoglu and Zilibotti (2001), Caselli and Wilson (2004); Caselli and Coleman II (2006); Jerzmanowski (2007)
- **Technology diffusion.** Griliches (1957); Diamond (1997); Comin and Hobijn (2010); Comin and Mestieri (2018); Keller (2004); Kerr (2008); Costinot, Donaldson, Kyle, and Williams (2019); Kerr (2008); Conley and Udry (2010); Suri (2011); Atkin, Khandelwal, and Osman (2017)
- **Environmental conditions and development.** Montesquieu (1748); Kamarck (1976); Diamond (1997); Sachs and Warner (1997); Bloom and Sachs (1998); Gallup, Sachs, and Mellinger (1999); Sokoloff and Engermann (2000)
- **Disparities in agricultural productivity.** *General:* Caselli (2005); Adamopoulos and Restuccia (2011); Lagakos and Waugh (2013). *Technology focus:* Foster and Rosenzweig (1995, 1996, 2004, 2010); Evenson and Gollin (2003 a,b); Lansing (2009)
- **Neglected tropical (human) diseases.** Hotez et al. (2007, 2009, 2010); Hotez and Kamath (2009); Kremer (2002); Kremer and Glennerster (2004)

# Outline

- ① Measurement
- ② Results: Technology Transfer
- ③ Results: Agricultural Production
- ④ Quantification and Applications

# Pest and Pathogen Data: CABI Crop Pest Compendium

- Crop pest and pathogen (CPP) level information sheets compiled from extensive and collaborative research library (CABI, WB, FAO, USDA, CGIAR)
- Gold-standard for CPP measurement in ecological sciences e.g., Bebber et al. (2013, 2014)

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- Global distribution of **4,951 CPPs** (viruses, bacteria, insects, fungi, weeds, and protists)

African Maize Stalk Borer  
*Busseola fusca*



Affected crops: Maize; Sorghum; Rice;  
Sugarcane

Western Corn Rootworm  
*Diabrotica virgifera virgifera*



Affected crops: Maize; Millet; Pumpkins;  
Sunflower; Soybeans

Rice Blast Disease  
*Magnaporthe oryzae*



Affected crops: Barley; Rice; Wheat

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- Global distribution of **4,951 CPPs** (viruses, bacteria, insects, fungi, weeds, and protists)
- CPP-specific host plant lists: **132 host crops**
- **Key information:** identity of all CPPs in country  $\ell$  that damage crop  $k$  CPP-Level Innovation

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# Measuring CPP Mismatch

- Our measure of potential inappropriateness (crop-by-country-pair):

$$\text{CPPMismatch}_{k,\ell,\ell'} = 1 - \frac{\text{Number of Common CPPs}_{k,\ell,\ell'}}{\left(\text{Number of CPPs}_{k,\ell} \times \text{Number of CPPs}_{k,\ell'}\right)^{1/2}}$$

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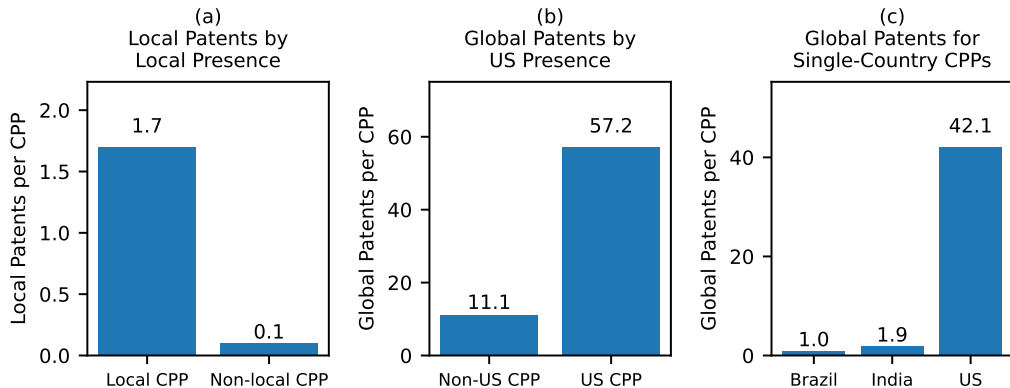
- Part of a standard class of divergence (one-minus-similarity) measures, satisfying standard properties including *replication invariance* (Jost et al., 2011) Alternate Metric: Jaccard (1900, 1901)
- Alternative measures, discussed in paper, based on...
  - Excluding “potentially invasive” CPPs as categorized by CABI
  - Measuring agro-climatic differences (e.g., temperature)

## Validation of Premise: Disparities in CPP Innovation

- Text analysis matching all global patents (*Patsnap*) to CPPs and inventor countries
- Measure *patents per CPP* for all CPPs and inventor countries

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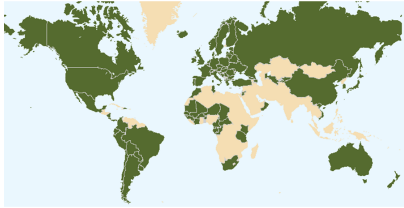
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# Outline

- ① Measurement
- ② Results: Technology Transfer
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## Global Innovation: UPOV Plant Variety Database



Map: UPOV Member Countries

- Seed certificates from all countries with variety protection
- Collected by the Union for the Protection of New Varieties of Plants (UPOV)
- Proprietary data obtained after UPOV council approval



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**Key feature:** unique crop variety identifiers across countries [Details](#)

**Outcome:**  $V_{k,\ell',\ell}$  = varieties of  $k$  developed for  $\ell'$  transferred to  $\ell$  since 2000

# Empirical Model: Technology Transfer

Crop-by-origin-by-destination estimating equation:

$$V_{k,\ell',\ell} = \beta \cdot \text{CPPMismatch}_{k,\ell,\ell'} + \chi_{\ell,\ell'} + \chi_{k,\ell} + \chi_{k,\ell'} + \epsilon_{k,\ell,\ell'} \quad (1)$$

- $V_{k,\ell',\ell}$  = transferred  $k$ -varieties from  $\ell'$  to  $\ell$
- Fixed effects: Crop-by-origin, crop-by-destination, origin-by-destination
- *Model interpretation* in paper: absorb market size (origin, destination), bilateral trade cost

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**Main hypothesis:**  $\beta < 0$ , local focus and context specificity depresses technology diffusion

$\beta = 0$  if the context-specific component of technology

# Inappropriateness Impedes Technology Transfer

Sensitivity

Invasive

Africa

Agro-climatic

	(1)	(2)	(3)
Dependent Variable:	Biotech Transfer (asinh)	Any Biotech Transfer (0/1)	log Biotech Transfer
CPP Mismatch (0-1)	-0.0624** (0.0235)	-0.0275** (0.0106)	-1.202*** (0.386)
Crop-by-Origin Fixed Effects	Yes	Yes	Yes
Crop-by-Destination Fixed Effects	Yes	Yes	Yes
Origin-by-Destination Fixed Effects	Yes	Yes	Yes
Observations	204,287	204,287	5,791
R-squared	0.439	0.383	0.797

*Notes:* The unit of observation is a crop-origin-destination. All possible two-way fixed effects are included in all specifications. The dependent variable is listed at the top of each column. Standard errors are double-clustered by origin and destination and \*, \*\*, and \*\*\* indicate significance at the 10%, 5%, and 1% levels.

# Does Mismatch with Frontier Matter More?

## Defining the Frontier, $L_{k,\ell'}$ :

- Identify a set of crop-specific leaders  $T_N(k)$  using the UPOV data, comprised of  $N$  countries with most variety development ( $L_{k,\ell'} = \mathbb{I}\{\ell' \in T_N(k)\}$ )

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## Augmented estimating equation:

$$y_{k,\ell,\ell'} = \beta_1 \cdot \text{CPPMismatch}_{k,\ell,\ell'} + \beta_2 \cdot L_{k,\ell'} \times \text{CPPMismatch}_{k,\ell,\ell'} + \chi_{\ell,\ell'} + \chi_{k,\ell} + \chi_{k,\ell'} + \epsilon_{k,\ell,\ell'} \quad (2)$$

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**Interpretation:**  $\beta_2 < 0$  means effects driven by dissimilarity to technological leaders

# Does Mismatch with Frontier Matter More? Yes

	(1)	(2)	(3)
	Dependent Variable is (asinh) Biotech Transfers		
Frontier defined as:	Top Variety Developer	Top 2 Variety Developers	Top 3 Variety Developers
CPP Mismatch (0-1)	-0.0229** (0.00986)	-0.0181* (0.00917)	-0.0136 (0.00884)
CPP Mismatch (0-1) x Frontier (0/1)	-0.332*** (0.0699)	-0.343*** (0.0623)	-0.322*** (0.0535)
Crop-by-Origin Fixed Effects	Yes	Yes	Yes
Crop-by-Destination Fixed Effects	Yes	Yes	Yes
Country Pair Fixed Effects	Yes	Yes	Yes
Observations	204,287	204,287	204,287
R-squared	0.384	0.385	0.385

*Notes:* The unit of observation is a crop-origin-destination. The definition of a leader in each specification is noted at the top of each column and the dependent variable is noted in the panel heading. Standard errors are double-clustered by origin and destination and \*, \*\*, and \*\*\* indicate significance at the 10%, 5%, and 1% levels.



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# Empirical Model: Agricultural Output

Crop-by-country estimating equation:

$$\log \text{Output}_{k,\ell} = \beta \cdot \text{CPPMismatchFrontier}_{k,\ell} + \chi_k + \chi_\ell + \Omega'_{k\ell} \Gamma + \epsilon_{k,\ell} \quad (3)$$

where  $\text{CPPMismatchFrontier}_{k,\ell}$  is (technology weighted) CPP mismatch with the frontier set:

$$\text{CPPMismatchFrontier}_{k,\ell} = \sum_{\ell' \in T_N(k)} \left( \text{Share Varieties}_{k,\ell'}^{\text{UPOV}} \right) \times \left( \text{CPPMismatch}_{k,\ell,\ell'} \right)$$

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Controls, derived from model, are

- **Absorbed effects:** Aggregate differences across crops ( $\chi_k$ ) and countries ( $\chi_\ell$ )
- **Measures of innate suitability** ( $\Omega'_{k\ell}$ ):
  - 1 Predicted output from agronomic models (FAO GAEZ)
  - 2 Flexible controls for geography and CPP presence selected by post-double LASSO

# Inappropriateness $\Rightarrow$ Lower Output

Mismatch Metrics

Agro-climatic

Areas

Mismatch with US

Invasive

	(1)	(2)	(3)	(4)
Dependent Variable is log Output				
CPP Mismatch (0-1)	-7.136*** (0.959)	-5.721*** (0.663)	-7.202*** (0.461)	-6.288*** (0.501)
log(FAO-GAEZ-Predicted Output)		0.353*** (0.0499)		
<i>Included in LASSO Pool:</i>				
Top CPP Fixed Effects	-	-	Yes	Yes
Ecological Features x Crop Fixed Effects	-	-	No	Yes
Controls in LASSO Pool			335	3935
Crop Fixed Effects	Yes	Yes	Yes	Yes
Country Fixed Effects	Yes	Yes	Yes	Yes
Observations	6,704	2,353	6,707	5,903
R-squared	0.600	0.609		

*Notes:* The unit of observation is a country-crop pair. Columns 1-2 report OLS estimates and columns 3-4 report post double LASSO estimates. The set of ecological features includes: temperature, precipitation, elevation, ruggedness, growing season days, soil acidity, soil clay content, soil silt content, soil coarse fragment volume, and soil water capacity. Standard errors are double-clustered by crop and country and \*, \*\*, and \*\*\* indicate significance at the 10%, 5%, and 1% levels.

# Inappropriateness and Output: Sensitivity and Additional Results [Adoption](#)

## Sensitivity Analysis:

- **Falsification tests** using CPP mismatch non-technology leader countries [Link](#)
- Additional controls and robustness [FE](#) [Controls](#)

## Additional Results:

- Within-country estimates from Brazil and India [Link](#)
- Additional outcomes, including exports (↓) and price volatility (↑) [Link](#)
- Effects on technology adoption using farm-level micro-data from eight African countries sub-Saharan Africa [Link](#)

## Effect of Changes in Technological Leadership:

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# The Effects of Inappropriateness: Present and Future

**Results so far:** effects of inappropriateness in current equilibrium

**Natural question:** what about other scenarios? e.g.,

- “No inappropriateness,” to highlight magnitudes at stake
- Different technological leaders or global ecology, to model ongoing changes to the world

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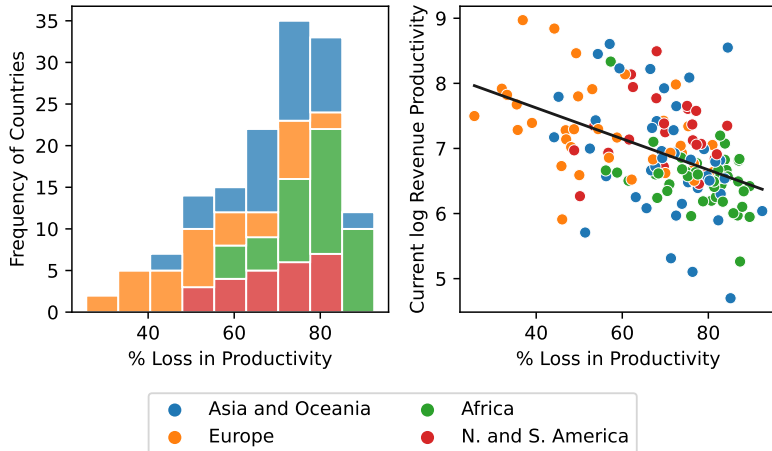
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Non-CPP Mismatch

Level Effect: **57.9%**

Units: % Reduction



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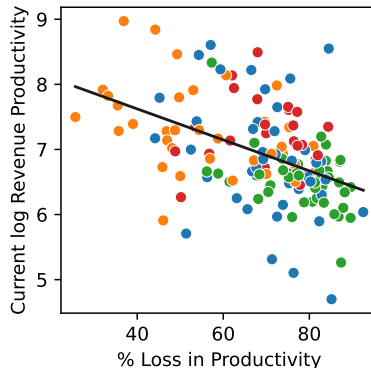
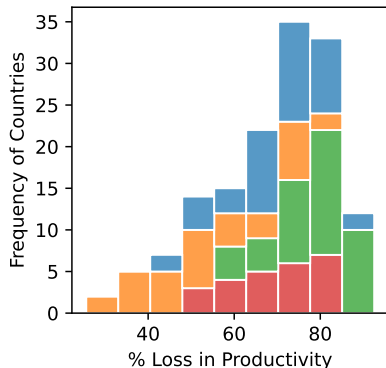
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Units: % Reduction

Disparity Effect: **14.4%**

Units: % Increase in IQR of log productivity



● Asia and Oceania

● Europe

● Africa

● N. and S. America

# Applications and “Real-World” Counterfactuals

- 1 **Where should research optimally be targeted to maximize global output?** [Link](#)

*Crop-level estimates of “best” countries suggest targeting China, India and parts of Africa*



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*Crop-level estimates of “best” countries suggest targeting China, India and parts of Africa*
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*Findings suggest ↗ ecological similarity and hence ↗ appropriateness of frontier technology*

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- 2 How will climate-induced CPP range shifts affect innovation, productivity? [Link](#)  
*Findings suggest ↗ ecological similarity and hence ↗ appropriateness of frontier technology*
- 3 **How would the emergence of BRIC (Brazil, Russia, India, and China) as ag-tech leaders reshape world productivity?** [Link](#)  
*Rise of BRIC increases productivity on average, especially in Africa and Asia*

# Conclusion

We studied effects of inappropriate technology in agriculture, focusing on mismatch of ecology and plant-specific pests and pathogens

We found empirically that inappropriateness shapes. . .

- 1 The global transfer of agricultural technology
- 2 Global agricultural specialization and output

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Future work:

- How could **policy** address gaps in access to appropriate technology?
- How does **climate change** affect the appropriateness of agricultural technology and how “globally appropriate” is modern climate-resilient technology?
- How do the lessons from this paper apply to **other sectors**?

# Producers and Technology Demand

Details

- Crops  $k \in \{1, \dots, K\}$ , with global prices  $(p(k))_{k=1}^K$
- Locations  $\ell \in \{1, \dots, L\}$ , each with farmers  $i \in [\ell - 1, \ell)$  and where  $L$  is “Leader”

Tractable model of (agricultural) specialization  
as in Eaton and Kortum, 2002; Costinot, et al., 2016

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- Farmer  $i \in [\ell - 1, \ell)$ , growing  $k$ , has productivity

$$\psi_{k,i} = \left( \underbrace{X_{k,i}}_{\text{Technology}} \right)^{1-\gamma} \left( \underbrace{\omega_{k,\ell}}_{\text{Suitability}} \times \underbrace{\theta_{k,\ell}}_{\text{Technology Quality}} \times \underbrace{\epsilon_{k,i}}_{\text{Fréchet shock } (\eta)} \right)^{\gamma}$$

and chooses  $k$  and quantity of frontier technology  $X_{k,i}$  to maximize profits

Tractable model of (agricultural) specialization  
as in Eaton and Kortum, 2002; Costinot, et al., 2016

# Producers and Technology Demand Details

- Crops  $k \in \{1, \dots, K\}$ , with global prices  $(p(k))_{k=1}^K$
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New: endogenous and locally-tuned technologies

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- Technology, developed in  $L$ , has following productivity

$$\theta(k, \ell) = \exp \left( \underbrace{\alpha \log A_k}_{\text{General}} + \underbrace{\frac{1-\alpha}{T} \sum_{t \in \mathcal{T}(k, \ell)} \log B(t, k, \ell)}_{\text{Context-specific (“Bugs”)}} \right)$$

where  $\alpha \in (0, 1)$  and  $\mathcal{T}(k, \ell) \subset \mathbb{N}$  are sets of pests and pathogens, normalized to  $T > 0$



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# Innovators and Technology Supply [Back](#)

A representative, profit-maximizing innovator in  $L$ , develops technologies [Back](#)

- Benefits = revenue from seed sales, net of bilateral frictions  $\exp(-\rho_{\ell,L})$
- Costs = convex “research costs” with **local knowledge spillovers**
  - *Knowledge gaps*: more “scientific inputs” for pest/pathogen threats in  $L$  [Evidence](#)  
Abstractions: Romer (1986). Realities: breeding practices, germplasm, ...

# Innovators and Technology Supply [Back](#)

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## Definition: Equilibrium

An equilibrium is a vector of production  $(Y_{k,\ell})$ , total input demands  $(X_{k,\ell',\ell})$ , prices  $(p_k)$ , and CPP technology development  $(B_{t,k,\ell',\ell})$  such that

- 1 Farmers optimize, given correct conjectures of prices, and aggregate production and input demand is consistent with a LLN over realized idiosyncratic shocks.
- 2 Innovators optimize, given correct conjectures of prices and revenue productivities
- 3 Markets clear for each crop, or  $(p_k)_{k=1}^K = d((Y_k)_{k=1}^K)$  where  $Y_k = \sum_{\ell=1}^L Y_{k,\ell}$ .

## Result: Environmental Mismatch and Technology Transfer [Back](#)

*Mismatch:* Let  $\delta_{k,\ell,L}$  denote the share of  $(k,\ell)$  pest and pathogen threats *not* present in  $L$

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### Proposition: Technology Transfer

Technology diffusion from the leader  $L$  to any country  $\ell$  can be written as

$$\log X_{k,L,\ell} = \beta_{k,L} \cdot \delta_{k,L,\ell} + \chi_{k,L} + \chi_{k,\ell} + \chi_{\ell,L}$$

where the  $\chi$  are additive fixed effects and  $\beta_{k,L} \leq 0$ , with equality if all technology is context-neutral or there is no knowledge spillover.

### Proposition: Production and Specialization

Production of crop  $k$  in country  $\ell$  can be written as

$$\log Y_{k,\ell} = \pi_{k,L} \cdot \delta_{k,L,\ell} + \eta \cdot \log \omega_{k,\ell} + \chi_\ell + \chi_k$$

where the  $\chi$  are additive fixed effects,  $\omega_{k,\ell}$  is innate suitability, and  $\pi_{k,L} \leq 0$ , with equality if all technology is context-neutral or there is no knowledge spillover.

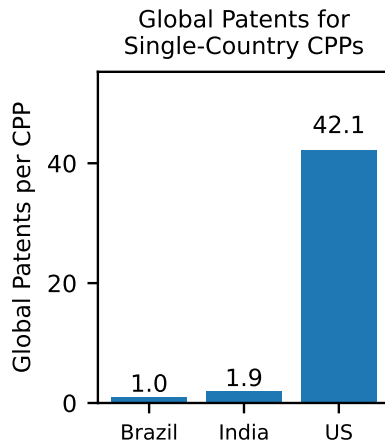
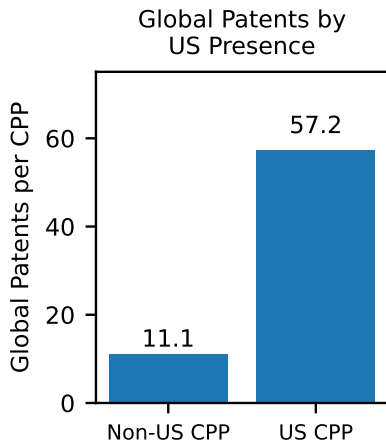
## Validation of Premise: Disparities in CPP Innovation [Back](#)

- Text analysis matching all global patents (*Patsnap*) to CPPs and inventor countries
- Measure *patents per CPP* for all CPPs and inventor countries



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## Alternative Metric: Jaccard (1900,1901)

- Robustness using simplest and most historical measure of divergence (Jaccard, 1900,1901):

$$\text{CPPMismatch}_{k,\ell,\ell'}^J = 1 - \frac{\text{Number of Common CPPs}_{k,\ell,\ell'}}{\text{Number of Unique CPPs}_{k,\ell \cup \ell'}}$$

- **Simple interpretation:** number of common CPPs divided by number of unique CPPs in the country-pair-by-crop triplet

Back

## Intermediate Result: Optimal Planting [Back](#)

Frechet structure generates simple relationship between average productivity (unobserved) and planting and technology choices (observed):

### Lemma

*The measure of farmers planting crop  $k$  is given by*

$$\log x(\ell, k) = -\eta \log \Phi(\ell, k) + \eta \log \omega(\ell, k) + \eta \log p(k) - \eta \log \Xi(\ell) \quad (4)$$

*where  $\Phi(\ell, k)$  and  $\Xi(\ell)$  are productivity indices:*

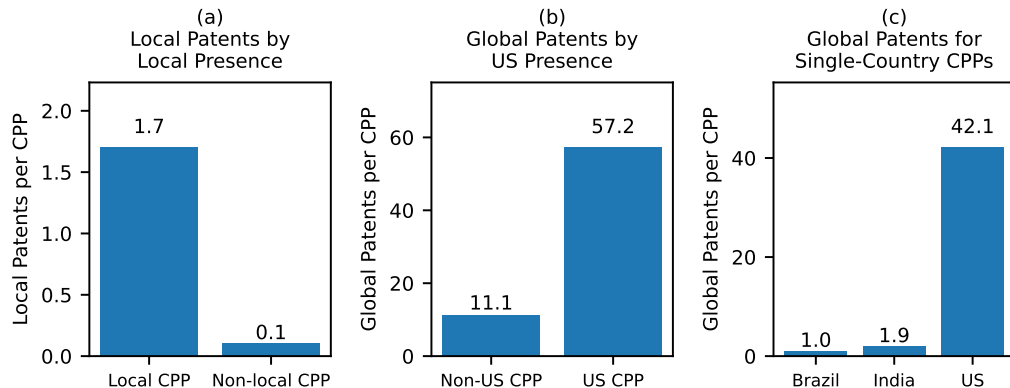
$$\Phi(\ell, k) := \left( \sum_{\ell'} \theta(\ell', k)^\eta \delta(\ell, k, \ell')^{-\eta} \right)^{-\frac{1}{\eta}} \quad \Xi(\ell) := \left( \sum_k p(k)^\eta \omega(\ell, k)^\eta \Phi(\ell, k)^\eta \right)^{\frac{1}{\eta}} \quad (5)$$

*The measure of farmers in  $\ell$  planting crop  $k$  using the technology of  $\ell'$  is given by*

$$\log \pi(\ell, k, \ell') = \log x(\ell, k) - \eta \delta(\ell, k, \ell') + \eta \log \theta(\ell', k) + \eta \log p(k) + \eta \log \Phi(\ell, k) \quad (6)$$

# Global Focus of CPP Innovation [Back](#)

- Text analysis of all global patents (*Patsnap* Database) to patented technologies to CPPs
- 33% of all biological or chemical agricultural patents associated with  $\geq 1$  CPP in our data



# Inappropriateness Impedes Technology Transfer: Sensitivity [Back](#)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Dependent Variable is (asinh) Biotechnology Transfers							
CPP Mismatch (0-1)	-0.0605** (0.0241)	-0.120** (0.0481)	-0.0848*** (0.0258)	-0.0509** (0.0231)	-0.0556** (0.0222)	-0.0434** (0.0189)	-0.0486*** (0.0169)
Jaccard (1900, 1901) Distance Metric		✓					
Broad CPP Presence Classification			✓				
Control for bilateral crop-level trade				✓			
Control for log bilateral distance x Crop FE					✓		
Exclude country pairs <1000km apart						✓	
Exclude country pairs <2000km apart							✓
Mean of CPP Distance Metric	0.423	0.327	0.413	0.423	0.423	0.423	0.423
Crop-by-Origin Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Crop-by-Destination Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country Pair Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	204,287	204,287	204,345	204,287	189,302	185,344	156,007
R-squared	0.439	0.439	0.439	0.442	0.461	0.405	0.372

Notes: The unit of observation is a crop-origin-destination. Specification details are noted at the bottom of each column. Standard errors are double-clustered by origin and destination and \*, \*\*, and \*\*\* indicate significance at the 10%, 5%, and 1% levels.

# Robustness to country-level controls [Back](#)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dependent Variable is log Output								
<i>Panel B: CPP Mismatch with the Estimated Frontier Set</i>								
CPP Mismatch (0-1)	-6.963*** (0.934)	-6.838*** (0.879)	-7.351*** (1.029)	-7.206*** (1.065)	-6.895*** (0.980)	-7.172*** (1.011)	-7.337*** (1.058)	-7.250*** (1.743)
Observations	6,693	6,458	6,227	4,765	6,499	5,838	3,631	2,864
R-squared	0.600	0.632	0.611	0.633	0.613	0.623	0.669	0.781
<i>Panel A: CPP Mismatch with the US</i>								
CPP Mismatch (0-1)	-9.122*** (1.152)	-8.849*** (1.105)	-9.573*** (1.217)	-9.323*** (1.345)	-9.186*** (1.221)	-9.661*** (1.316)	-10.10*** (1.295)	-10.83*** (2.115)
Observations	6,915	6,678	6,433	4,949	6,719	6,032	3,729	2,946
R-squared	0.600	0.632	0.612	0.634	0.614	0.626	0.671	0.786
Crop Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
log Per Capita GDP x Crop FE	No	Yes	No	No	No	No	No	Yes
Trade Share (% GDP) x Crop FE	No	No	Yes	No	No	No	No	Yes
Gini Coefficient x Crop FE	No	No	No	Yes	No	No	No	Yes
Share Arable Land x Crop FE	No	No	No	No	Yes	No	No	Yes
log Agricultural Value Added x Crop FE	No	No	No	No	No	Yes	No	Yes
R&D Share (% GDP) x Crop FE	No	No	No	No	No	No	Yes	Yes

*Notes:* The unit of observation is a crop-country pair. Panel A uses CPP mismatch with the estimated set of technological leader countries and Panel B uses CPP mismatch with the US. Controls included in each specification are noted at the bottom of the column. Standard errors are double-clustered by crop and country and \*, \*\*, and \*\*\* indicate significance at the 10%, 5%, and 1% levels.

## Global Direction of Crop-Specific of Innovation

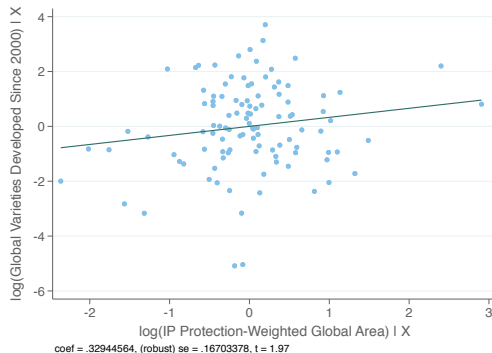
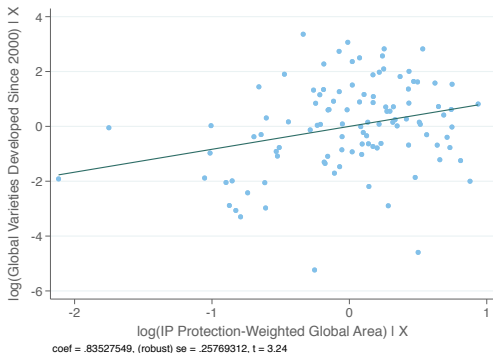
[Back to UPOV](#)

$$\ln(\text{BioTech}_k) = \delta_1 \cdot \ln \text{WrldArea}_k + \delta_2 \cdot \ln \text{GDPArea}_k + \delta_3 \cdot \ln \text{IPArea}_k + \epsilon_k$$

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[Back to UPOV](#)

$$\ln(\text{BioTech}_k) = \delta_1 \cdot \ln \text{WrldArea}_k + \delta_2 \cdot \ln \text{GDPArea}_k + \delta_3 \cdot \ln \text{IPArea}_k + \epsilon_k$$



- **Magnitude:** incremental  $R^2$  on second two regressors: 29% (total  $R^2$ : 48%)
- **Mechanism:** combination of home bias and global focus

[Quantification](#)[Results](#)



# Empirical Model: Home Bias versus Global Focus?

[Back](#)

$$\ln(\text{BioTech}_{k,\ell}) = \delta_0 \cdot \ln \text{Area}_{k,\ell} + \delta_1 \cdot \ln \text{WorldArea}_k + \delta_2 \cdot \ln \text{GDPArea}_k + \delta_3 \cdot \ln \text{IPArea}_k + \chi_\ell + \epsilon_{k,\ell}$$

asinh(Local Area Harvested)	0.227*** (0.0125)	0.213*** (0.00986)	0.209*** (0.0112)	0.204*** (0.00977)	0.204*** (0.00982)	0.155*** (0.00842)
asinh(Global Area Harvested)		0.0565*** (0.0208)	-0.0451 (0.0540)	-0.0155 (0.0310)	-0.0551 (0.0459)	
asinh(Income-Weighted Area Harvested)			0.0925 (0.0606)		0.0512 (0.0620)	
asinh(IP-Protection-Weighted Area Harvested)				0.0814*** (0.0309)	0.0625* (0.0369)	
Country Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Crop Fixed Effects	No	No	No	No	No	Yes
Observations	6,758	6,758	6,758	6,758	6,758	6,758
R-squared	0.495	0.501	0.505	0.506	0.507	0.600

*Notes:* The unit of observation is a crop-by-country pair. The dependent variable is the number of varieties developed in the country for the crop since 2000. Standard errors, clustered by crop, are included in parentheses and \*, \*\*, and \*\*\* indicate significance at the 10%, 5%, and 1% levels.

Snapshot of the raw data:

UPOV Code	Country	Denomination	Botanical Name	Common Name	App. Date
GOSSY_HIR	AU	Sicot 53	Gossypium hirsutum	Cotton	14-Sep-99
GOSSY_HIR	AU	Sicot 41	Gossypium hirsutum	Cotton	14-Sep-99
GOSSY_HIR	AR	Sicot 41	Gossypium hirsutum L.	Algodonero	13-Aug-01
GOSSY_HIR	AU	Sicot 71	Gossypium hirsutum	Cotton	07-Aug-02
GOSSY_HIR	BR	Sicot 53	Gossypium hirsutum L.	Algodao	11-Nov-03

## Coding:

- SICOT 41: Invented in Australia, transferred to Argentina
- SICOT 53: Invented in Australia, transferred to Brazil
- SICOT 71: Invented in Australia, not transferred

“SICOT”: product line produced by Australian “Cotton Seed Distributors.” *Includes Bollgard Roundup Ready (“Bt”) traits, among other anti-pest traits.*

**Key outcome:**  $V(k, \ell', \ell)$  = varieties of  $k$  developed in  $\ell'$  transferred to  $\ell$  since 2000.

# The US as the Technology Frontier [Back](#)

- 52% global private R&D in North America (Fuglie, 2016)
- 46% of global biological and chemical agricultural patents related to CPPs since 2000 (as we measure them) were assigned to US inventors
- Over 3x as many as the next highest country (Japan)
- 25% of global agricultural science publications in 2000; over 30% after citation-weighting

	(1)	(2)	(3)
	Dependent Variable is (asinh) Biotechnology Transfers		
CPP Mismatch (0-1)	-0.0783** (0.0314)	-0.0737** (0.0309)	-0.0752** (0.0311)
<i>Mismatch in:</i>			
Temperature		-0.0107* (0.00619)	
Precipitation		-0.0141* (0.00807)	
Elevation		-0.00589* (0.00311)	
Ruggedness		-0.000652 (0.00246)	
Soil Clay Content		-0.00596 (0.00568)	
Soil Silt Content		0.00342 (0.00575)	
Soil Coarse Fragment Content		0.000883 (0.00318)	
Soil pH		-0.00825** (0.00355)	
Growing Season Length		-0.00453 (0.00519)	
Available Water Capacity		-0.00561 (0.00466)	
Overall Agro-Climatic Mismatch			-0.0412*** (0.0129)
p-value joint significance	-	0.007	-
Crop-by-Origin Fixed Effects	Yes	Yes	Yes
Crop-by-Destination Fixed Effects	Yes	Yes	Yes
Country Pair Fixed Effects	Yes	Yes	Yes
Observations	153,038	153,026	153,038
R-squared	0.464	0.464	0.464

- Estimate “mismatch” at  $\ell \times k \times \ell'$  level by calculating the value of each agro-climatic characteristic on  $k$ -land from *EarthStat* Database
- For crop  $k$ , and countries  $\ell$  and  $\ell'$ , the agro-climatic index is:

$$d_{k,\ell,\ell'} := \frac{1}{|\mathcal{X}|} \sum_{x \in \mathcal{X}} |\hat{x}_{k,\ell} - \hat{x}_{k,\ell'}|$$

where  $\hat{x}_{k,\ell}$  is measured on the crop- $k$  land of country  $\ell$

# Agro-climatic differences and Output

[Back](#)
[Measurement](#)

	(1)	(2)	(3)
Dependent Variable is log Output			
CPP Mismatch (0-1)	-10.17*** (1.559)	-8.996*** (1.425)	-9.393*** (1.518)
<i>Mismatch in:</i>			
Temperature		-0.582*** (0.155)	
Precipitation		-0.329* (0.186)	
Elevation		0.150 (0.0924)	
Ruggedness		-0.254* (0.135)	
Soil Clay Content		0.0649 (0.0969)	
Soil Silt Content		0.0283 (0.123)	
Soil Coarse Fragment Content		-0.323** (0.134)	
Soil pH		-0.0720 (0.106)	
Growing Season Length		0.0681 (0.124)	
Available Water Capacity		-0.255** (0.116)	
Overall Agro-Climatic Mismatch			-1.319*** (0.285)
Crop Fixed Effects	-	0.000	-
Country Fixed Effects	Yes	Yes	Yes
Observations	Yes	Yes	Yes
R-squared	5,285	5,270	5,285
	0.575	0.591	0.582

- Estimate “mismatch” at  $\ell \times k \times \ell'$  level by calculating the value of each agro-climatic characteristic on  $k$ -land from *EarthStat* Database
- Determine mismatch with *frontier* as in main results
- For  $(k, \ell)$ , the agro-climatic index is:

$$d_{k,\ell,L} := \frac{1}{|\mathcal{X}|} \sum_{x \in \mathcal{X}} |\hat{x}_{k,\ell} - \hat{x}_{k,L}|$$

where  $\hat{x}_{k,\ell}$  is measured on the crop- $k$  land of country  $\ell$

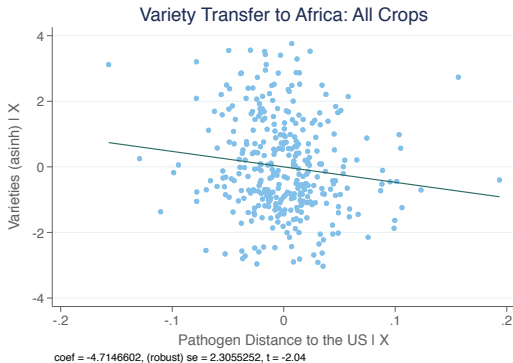
- **Magnitudes:** standardized coefficient for CPP mismatch is **-0.54** and for the agro-climatic index is **-0.15**.

- Most countries in Africa are not UPOV compliant—not in our technology transfer data
- CGIAR's Diffusion and Impact of Improved Varieties in Africa (DIIVA) project collected data on improved crop varieties in Africa south of the Sahara
- For 28 countries and 19 crops provide number of improved varieties introduced since 1960
- Estimating equation for African data:

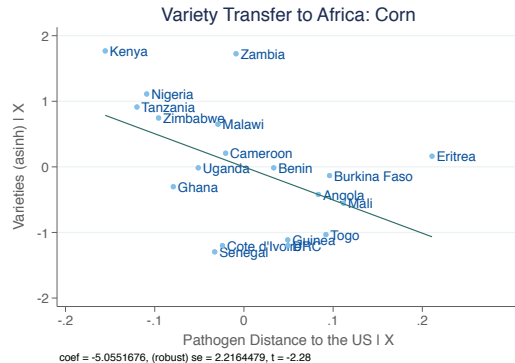
$$y_{k,\ell} = \beta \cdot \text{CPPDistFrontier}_{k,\ell} + \chi_k + \chi_\ell + \epsilon_{k,\ell} \quad (7)$$

- **Absorbed effects:** Aggregate differences across crops ( $\chi_k$ ) and countries ( $\chi_\ell$ )
- **Hypothesis:**  $\beta < 0$ ; in places where tech frontier is “inappropriate,” less tech introduced

# Inappropriateness $\implies$ Less variety introduction in Africa [Back](#)



$$\beta = -4.71 \text{ (2.31)}$$
$$N = 345$$



$$\beta = -5.06 \text{ (2.21)}$$
$$N = 19$$

# Additional Outcomes: Trade and Price Volatility [Back](#)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	<i>Baseline Measure</i>	<i>Trade</i>		<i>Producer Price Volatility</i>			
Dependent Variable:	log Output	log Exports	log Imports	Price SD (Norm. by Global Mean)		log Price SD	
<i>Panel A: CPP Mismatch with the US</i>							
CPP Mismatch (0-1)	-9.285*** (1.199)	-8.768*** (1.200)	1.269 (1.295)	0.523*** (0.126)	0.317*** (0.109)	1.026*** (0.237)	0.671*** (0.224)
Observations	6,926	5,495	5,854	4,580	4,559	4,580	4,559
R-squared	0.599	0.531	0.647	0.244	0.263	0.661	0.667
<i>Panel B: CPP Mismatch with the Estimated Frontier Set</i>							
CPP Mismatch (0-1)	-7.136*** (0.959)	-5.386*** (0.877)	-0.415 (0.871)	0.364*** (0.101)	0.212** (0.0978)	0.628*** (0.177)	0.349** (0.176)
Observations	6,704	5,332	5,687	4,481	4,461	4,481	4,461
R-squared	0.600	0.535	0.649	0.243	0.262	0.662	0.668
Crop Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Control for log Output	No	No	No	No	Yes	No	Yes

*Notes:* The unit of observation is a crop-country pair. The dependent variable is listed at the top of each column and control set listed at the bottom. Standard errors are double-clustered by crop and country and \*, \*\*, and \*\*\* indicate significance at the 10%, 5%, and 1% levels.

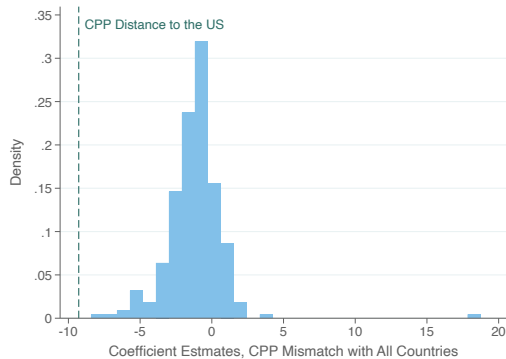


# Inappropriateness $\Rightarrow$ Lower Output: Alternate Mismatch Metrics [Back](#)

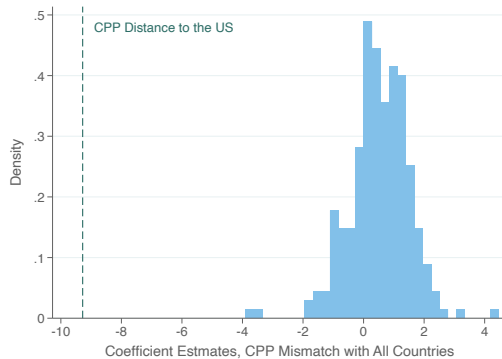
	(1)	(2)	(3)	(4)	(5)	(6)
	Dependent Variable is log Output					
	CPP Distance to US			CPP Distance to Estimated Frontier Set		
CPP Mismatch (0-1)	-9.122*** (1.152)	-9.336*** (1.172)	-8.480*** (0.909)	-6.963*** (0.934)	-7.483*** (1.067)	-6.653*** (0.710)
Baseline	✓			✓		
Broad CPP Presence Classification		✓			✓	
Jaccard (1900, 1901) Distance Metric			✓			✓
Crop Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Country Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	6,915	6,915	6,915	6,693	6,693	6,693
R-squared	0.600	0.601	0.604	0.600	0.601	0.603

*Notes:* The unit of observation is a crop-country pair. The dependent variable is log of crop output and the distance metric used in each specification is noted at the bottom of each column. Columns 1-3 use CPP distance to the US and columns 4-6 use CPP distance to the estimated set of technological leader countries. Standard errors are double-clustered by crop and country and \*, \*\*, and \*\*\* indicate significance at the 10%, 5%, and 1% levels.

# Falsification: Effect of CPP Mismatch with All Countries

[Back](#)

(a) Unconditional



(b) Conditional on CPP Mismatch with the US

# Inappropriateness $\Rightarrow$ Lower Output: Crop $\times$ Continent FE [Back](#)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Dependent Variable is log Output							
	CPP Mismatch with the Estimated Frontier				CPP Mismatch with the US			
CPP Mismatch (0-1)	-8.780***	-8.198***	-6.999***	-6.385***	-8.809***	-9.831***	-8.780***	-8.198***
	(0.769)	(0.742)	(0.595)	(0.614)	(1.124)	(2.608)	(0.769)	(0.742)
log(FAO-GAEZ-Predicted Output)		0.273***				0.239***		
		(0.0770)				(0.0704)		
<i>Included in LASSO Pool:</i>								
Top CPP Fixed Effects	-	-	Yes	Yes	-	-	Yes	Yes
Ecological Features x Crop Fixed Effects	-	-	No	Yes	-	-	No	Yes
Crop x Continent Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	6,631	2,334	6,696	5,903	6,844	2,334	6,920	6,069
R-squared	0.679	0.689			0.680	0.694		

*Notes:* The unit of observation is a country-crop pair. Columns 1-4 use CPP mismatch with the estimated set of technological leader countries and columns 5-8 use CPP mismatch with the US. Columns 1-2 and 5-6 report OLS estimates and columns 3-4 and 7-8 report post double LASSO estimates. Country and crop-by-continent fixed effects are included in all specifications, and included in the amelioration set in the post-double LASSO specifications. The Top CPPs are defined as the top 200 CPPs defined by (i) the number of countries in which they are present and (ii) the number of host crops that they infect. Since the two sets overlap, the total number is 335. The set of ecological features includes: temperature, precipitation, elevation, ruggedness, growing season days, soil acidity, soil clay content, soil silt content, soil coarse fragment volume, and soil water capacity. Standard errors are double-clustered by crop and country and \*, \*\*, and \*\*\* indicate significance at the 10%, 5%, and 1% levels.

# Inappropriateness $\Rightarrow$ Lower Output: Additional Controls [Back](#)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dependent Variable is log Output								
<i>Panel B: CPP Mismatch with the Estimated Frontier Set</i>								
CPP Mismatch (0-1)	-6.963*** (0.934)	-6.838*** (0.879)	-7.351*** (1.029)	-7.206*** (1.065)	-6.895*** (0.980)	-7.172*** (1.011)	-7.337*** (1.058)	-7.250*** (1.743)
Observations	6,693	6,458	6,227	4,765	6,499	5,838	3,631	2,864
R-squared	0.600	0.632	0.611	0.633	0.613	0.623	0.669	0.781
<i>Panel A: CPP Mismatch with the US</i>								
CPP Mismatch (0-1)	-9.122*** (1.152)	-8.849*** (1.105)	-9.573*** (1.217)	-9.323*** (1.345)	-9.186*** (1.221)	-9.661*** (1.316)	-10.10*** (1.295)	-10.83*** (2.115)
Observations	6,915	6,678	6,433	4,949	6,719	6,032	3,729	2,946
R-squared	0.600	0.632	0.612	0.634	0.614	0.626	0.671	0.786
Crop Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
log Per Capita GDP x Crop FE	No	Yes	No	No	No	No	No	Yes
Trade Share (% GDP) x Crop FE	No	No	Yes	No	No	No	No	Yes
Gini Coefficient x Crop FE	No	No	No	Yes	No	No	No	Yes
Share Arable Land x Crop FE	No	No	No	No	Yes	No	No	Yes
log Agricultural Value Added x Crop FE	No	No	No	No	No	Yes	No	Yes
R&D Share (% GDP) x Crop FE	No	No	No	No	No	No	Yes	Yes

*Notes:* The unit of observation is a crop-country pair. Panel A uses CPP mismatch with the estimated set of technological leader countries and Panel B uses CPP mismatch with the US. Controls included in each specification are noted at the bottom of the column. Standard errors are double-clustered by crop and country and \*, \*\*, and \*\*\* indicate significance at the 10%, 5%, and 1% levels.

# Inappropriateness $\Rightarrow$ Lower Area [Back](#)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Dependent Variable is log Area Harvested							
	CPP Mismatch with the Estimated Frontier				CPP Mismatch with the US			
CPP Mismatch (0-1)	-7.139*** (0.941)	-7.020*** (0.725)	-7.200*** (0.437)	-5.837*** (0.496)	-9.517*** (1.212)	-12.08*** (2.892)	-9.541*** (0.595)	-7.855*** (0.635)
log(FAO-GAEZ-Predicted Output)		0.363*** (0.0487)				0.303*** (0.0768)		
<i>Included in LASSO Pool:</i>								
Top CPP Fixed Effects	-	-	Yes	Yes	-	-	Yes	Yes
Ecological Features x Crop Fixed Effects	-	-	No	Yes	-	p	No	Yes
Controls in LASSO Pool			335	3935	-	-	335	3935
Crop Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	6,469	2,268	6,474	5,748	6,675	2,268	6,683	5,908
R-squared	0.609	0.603			0.612	0.612		

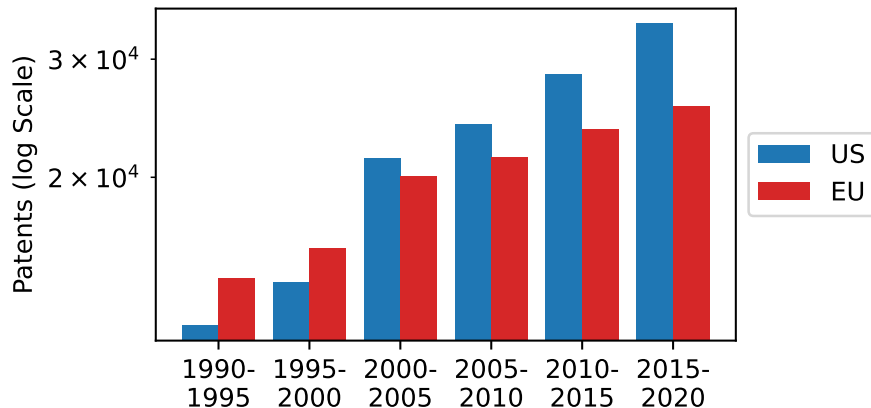
*Notes:* The unit of observation is a country-crop pair. Columns 1-4 use CPP mismatch with the estimated set of technological leader countries and columns 5-8 use CPP mismatch with the US. Columns 1-2 and 5-6 report OLS estimates and columns 3-4 and 7-8 report post double LASSO estimates. Country and crop fixed effects are included in all specifications, and included in the amelioration set in the post-double LASSO specifications. The Top CPPs are defined as the top 200 CPPs defined by (i) the number of countries in which they are present and (ii) the number of host crops that they infect. Since the two sets overlap, the total number is 335. The set of ecological features includes: temperature, precipitation, elevation, ruggedness, growing season days, soil acidity, soil clay content, soil silt content, soil coarse fragment volume, and soil water capacity. Standard errors are double-clustered by crop and state and \*, \*\*, and \*\*\* indicate significance at the 10%, 5%, and 1% levels.

# Inappropriateness of US $\Rightarrow$ Lower Output [Back](#)

	(1)	(2)	(3)	(4)
	Dependent Variable is log Output			
CPP Mismatch (0-1)	-9.285*** (1.199)	-10.60*** (3.024)	-9.325*** (0.617)	-8.454*** (0.652)
log(FAO-GAEZ-Predicted Output)		0.298*** (0.0814)		
<i>Included in LASSO Pool:</i>				
Top CPP Fixed Effects	-	-	Yes	Yes
Ecological Features x Crop Fixed Effects	-	-	No	Yes
Controls in LASSO Pool	-	-	335	3935
Crop Fixed Effects	Yes	Yes	Yes	Yes
Country Fixed Effects	Yes	Yes	Yes	Yes
Observations	6,915	2,353	6,920	6,069
R-squared	0.600	0.617		

*Notes:* The unit of observation is a country-crop pair. Columns 1-2 report OLS estimates and columns 3-4 report post double LASSO estimates. The set of ecological features includes: temperature, precipitation, elevation, ruggedness, growing season days, soil acidity, soil clay content, soil silt content, soil coarse fragment volume, and soil water capacity. Standard errors are double-clustered by crop and country and \*, \*\*, and \*\*\* indicate significance at the 10%, 5%, and 1% levels.

## Rise of the US and *Changes* in Output [Back](#)



$$\Delta \log y_{k,\ell}^{90-10} = \beta_1 \cdot \text{CPPMismatch}_{k,\ell}^{US} + \beta_2 \cdot \text{CPPMismatch}_{k,\ell}^{EU} + \gamma \cdot \log y_{k,\ell}^{1990} + \chi_\ell + \chi_k + \epsilon_{k,\ell}$$

# Rise of the US and *Changes* in Output [Back](#)

	(1)	(2)	(3)	(4)
	$\Delta \log \text{Output}$		$\Delta \log \text{Area Harvested}$	
CPP Mismatch with the US	-0.999*	-0.974*	-1.004**	-1.044*
	(0.520)	(0.572)	(0.502)	(0.533)
CPP Mismatch with the EU	0.644	0.251	0.352	0.222
	(0.512)	(0.531)	(0.529)	(0.534)
Crop Fixed Effects	Yes	-	Yes	-
Country Fixed Effects	Yes	Yes	Yes	Yes
Crop x Continent Fixed Effects	-	Yes	-	Yes
<i>p-value</i> , Dist US - Dist EU	0.097	0.249	0.172	0.216
Observations	6,414	6,338	6,183	6,107
R-squared	0.281	0.366	0.262	0.353

*Notes:* The unit of observation is a country-crop pair. In columns 1-2, the dependent variable is the change in log output from the 1990s to 2010s and in columns 3-4 it is the change in log area harvested from the 1990s to 2010s. Standard errors are double-clustered by country and crop and \*, \*\*, and \*\*\* indicate significance at the 10%, 5%, and 1% levels.



- Potentially important mechanism, but also potentially correlated with omitted factors and important to make sure they alone do not drive the result
- Use CABI Invasive Species Compendium (ISC), a list of global invasive species and species with high invasion potential
- The ISC identifies 748 CPPs as invasive, or 15% of the sample
- Estimate all versions of CPP mismatch after restricting to non-invasive species

# The Role of Invasive Species

[Back \(Output\)](#)
[Back \(Diffusion\)](#)

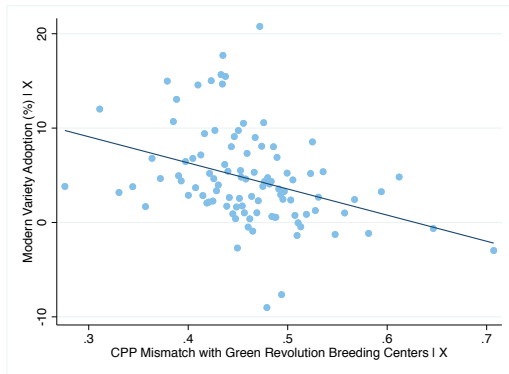
	(1)	(2)	(3)	(4)	(5)
	Technology Transfer			Technology Adoption	Output
Dependent Variable:	asinh Biotech Transfer	Any Biotech Transfer	log Biotech Transfer	Improved Seed (=1)	log Output
CPP Mismatch Without Invasive Species	-0.0712*** (0.0241)	-0.0304*** (0.0096)	-0.5451 (0.34)		
CPP Mismatch with the Frontier Without Invasive Species				-0.248*** -0.0743	-6.335*** (0.948)
Crop-by-Origin Fixed Effects	Yes	Yes	Yes	-	-
Crop-by-Destination Fixed Effects	Yes	Yes	Yes	-	-
Country Pair Fixed Effects	Yes	Yes	Yes	-	-
Country Fixed Effects	-	-	-	Yes	Yes
Crop Fixed Effects	-	-	-	Yes	Yes
Observations	202,154	202,154	5,752	115397	6,858
R-squared	0.4397	0.3831	0.7965	0.213	0.584

*Notes:* The unit of observation is a crop-origin-destination in columns 1-3, a farm-crop pair in column 4, and a crop-country pair in column 5. Standard errors are double-clustered by origin and destination in columns 1-3, clustered by crop-country in column 4, and double clustered by crop and country in column 5. In all cases, the independent variable is constructed after excluding invasive CPPs. The fixed effects included in each specification are noted at the bottom of each column. \*, \*\*, and \*\*\* indicate significance at the 10%, 5%, and 1% levels.

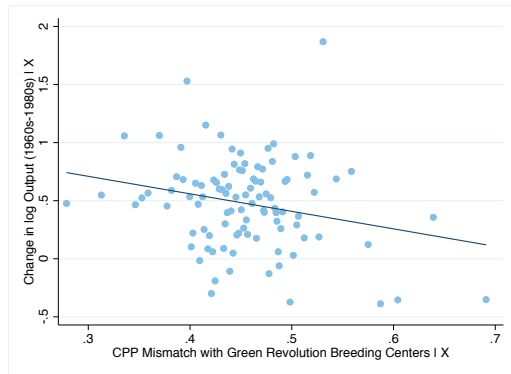
- A coordinated international effort to develop high-yielding varieties (HYVs) of staple crops for countries with high risk of famine
- But effects differed drastically across locations (Evenson, 2005) potentially due to ecological differences between the international agricultural research centers where varieties were developed and large parts of the world (Pingali, 2012; Lansing, 2009)
- Measure CPP mismatch with Green Revolution breeding centers by identifying the country where breeding took place for each crop:

$$\text{CPPDistGR}_{k,\ell} = \sum_{\ell'} \text{CPPMismatch}_{k,\ell,\ell'} \times \mathbb{I}\{\text{IARC for } k \text{ is in } \ell\}$$

# CPP Mismatch ↘ Adoption of GR Technology and Output Growth [Back](#)



(c) Modern Variety Adoption



(d)  $\Delta \log$  Output (1960-1980)

*Notes:* Binned partial correlation plots, after absorbing country and crop-by-continent fixed effects, in which the independent variable is  $\text{CPPDistGR}_{k,\ell}$  and the dependent variable is listed at the top of each sub-figure. In (a), the dependent variable is the share of production using modern varieties in 1980 ( $p = 0.006$ ) and in (b), it is the change in log output between the 1960s and the 1980s ( $p = 0.017$ ).

- Zoom in further for Brazil and India, two of the worlds' largest agricultural economies
  - Production data from most recent, nationally representative Census of Agriculture
  - CPP data at state ( $s$ ) level from CABI
- State-by-crop empirical model:

$$\log(\text{Output}_{k,s}) = \beta \cdot \text{CPPDistFrontier}_{k,s} + \chi_{k,\ell(s)} + \chi_s + \Omega'_{ks} \Gamma + \epsilon_{k,s} \quad (8)$$

- **Absorbed effects:** state ( $\chi_s$ ) and crop  $\times$  country ( $\chi_{k,\ell(s)}$ ) fixed effects  $\Rightarrow$  measuring a different effect (e.g., holding fixed crop-specific research, trade, CPPs, etc.)
- **Capturing local suitability ( $\Omega$ ):** Identical strategy, now measured at state-by-crop level
- **Hypothesis:**  $\beta < 0$ : inappropriateness  $\rightarrow$  lower output for specific crops within states

# Inappropriateness $\Rightarrow$ Lower Output Within Countries

[Separate Countries](#)
[Back to Main](#)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Dependent Variable is log Output							
	CPP Mismatch with the US				CPP Mismatch with the Estimated Frontier			
CPP Mismatch (0-1)	-9.285*** (1.199)	-10.60*** (3.024)	-9.325*** (0.617)	-8.454*** (0.652)	-7.136*** (0.959)	-5.721*** (0.663)	-7.202*** (0.461)	-6.288*** (0.501)
log(FAO-GAEZ-Predicted Output)		0.298*** (0.0814)				0.353*** (0.0499)		
<i>Included in LASSO Pool:</i>								
Top CPP Fixed Effects	-	-	Yes	Yes	-	-	Yes	Yes
Ecological Features x Crop Fixed Effects	-	-	No	Yes	-	-	No	Yes
Controls in LASSO Pool	-	-	335	3935			335	3935
Crop Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	6,926	2,353	6,931	6,069	6,704	2,353	6,707	5,903
R-squared	0.599	0.617			0.600	0.609		

*Notes:* The unit of observation is a country-crop pair. Columns 1-4 use CPP mismatch with the US and columns 5-8 use CPP mismatch with the estimated set of technological leader countries. Columns 1-2 and 5-6 report OLS estimates and columns 3-4 and 7-8 report post double LASSO estimates. Standard errors are double-clustered by crop and country and \*, \*\*, and \*\*\* indicate significance at the 10%, 5%, and 1% levels.

# Ecological Mismatch I: Geographic Attributes

AgroClim Table (Technology)

AgroClim Table (Output)

Counterfactual Estimates

	Item	Unit	Description	Source
1	<b>Temperature</b>	deg C	Annual mean from 1981 to 2010	Willmott and Matsuura University of Delaware dataset
2	<b>Precipitation</b>	mm	Annual mean from 1981 to 2010	Willmott and Matsuura University of Delaware dataset
3	<b>Elevation</b>	m	Dist. above sea level	GTOPO30 Digital Elevation Model
4	<b>Ruggedness</b>	m <sup>2</sup>	Rel. elevation to neighboring grid cells	Metric of by Riley, DeGloria, and Elliot (1999) as constructed by Nunn & Puga (2012)
5	<b>Growing season</b>	days	Sufficiently warm and moist days <sup>1</sup>	FAO GAEZ
6	<b>Soil acidity</b>	pH	in water to 250m	SoilGrids and WoSIS
7	<b>Clay content</b> <sup>2</sup>	% mass	to 250m	SoilGrids and WoSIS
8	<b>Silt content</b>	% mass	to 250m	SoilGrids and WoSIS
9	<b>Coarse fragments</b>	% volume	to 250m	SoilGrids and WoSIS
10	<b>Water capacity</b>	% volume	to 250m	SoilGrids and WoSIS

<sup>1</sup>Temperature > 5 C and (Precipitation + Soil Moisture) > 0.5 × Potential Evapotranspiration

<sup>2</sup>Soil types defined by particle diameter. Clay = 0 to 2 μm; Silt = 2 to 50 μm; Coarse fragments = over 2mm.

# Ecological Mismatch II: Global Cropland Distributions

AgroClim Table

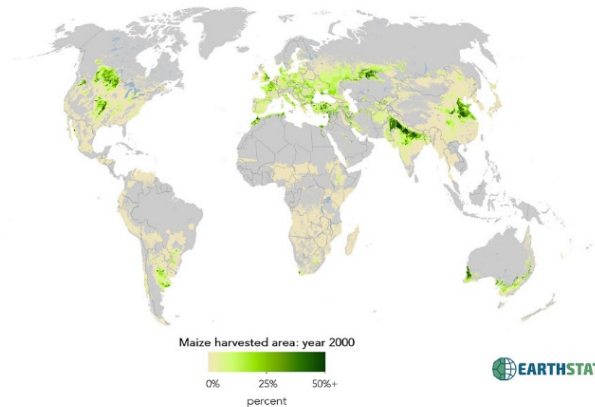
AgroClim Table (Output)

Counterfactual Estimates

Harvested area cross-section  
from EarthStat

<http://www.earthstat.org/>

*Created by combining national, state, and county level census statistics with a recently updated global data set of croplands on a 5 minute by 5 minute (~10 km by 10 km) latitude/longitude grid. The resulting land use data sets depict **circa the year 2000** the area (harvested) and yield of **175 distinct crops of the world**.*





# Ecological Mismatch III: Constructing Agroclimatic Mismatch

AgroClim Table (Technology)

AgroClim Table (Output)

Counterfactual Estimates

**Crop-level geographic distance.** For crop  $k$ , between country  $\ell$  and  $\ell'$ :

$$d_{k,\ell,\ell'} := \frac{1}{|\mathcal{X}|} \sum_{x \in \mathcal{X}} |\hat{x}_{k,\ell} - \hat{x}_{k,\ell'}| \quad (9)$$

where  $\hat{x}_{k,\ell}$  is measured on the crop- $k$  land of country  $\ell$

*Assumption:* exactly where crops are planted does not (entirely) reflect selection into low geographic mismatch from peers

*Interpretation of functional form:*

- Normalized characteristics, a crop-and-country specific average re-centered by global mean and normalized by global dispersion [details](#)
- Absolute value metric (like in Bazzi et al., 2016). Appealing simplicity: easy to separate out contribution of each component.

# Constructing AgroClimatic Mismatch

AgroClim Table (Technology)

AgroClim Table (Output)

Counterfactual Estimates

$x$  = attribute;  $\ell \in \{1, \dots, L\}$  = country;  $g$  = grid cell;  $k$  = crop

- 1 Calculate cropland average per attribute.

$$x_{\ell} := \sum_{g \in \ell} \frac{\text{AnyCropArea}_g}{\sum_{g \in \ell} \text{AnyCropArea}_g} \cdot x_g \quad \text{e.g., avg. pH of soil in Brazilian farmland}$$

- 2 Calculate global mean and standard deviation. For normalization.

$$\mu(x) := \frac{1}{L} \sum_{\ell} x_{\ell} \quad \sigma(x) := \frac{1}{L^{1/2}} \left( \sum_{\ell} (x_{\ell} - \mu(x))^2 \right)^{1/2} \quad \text{e.g., global distribution of pH}$$

- 3 Calculate crop-level attributes.

$$x_{k,\ell} := \sum_{g \in \ell} \frac{\text{CropArea}_{k,g}}{\sum_{g \in \ell} \text{CropArea}_{k,g}} \cdot x_g \quad \text{e.g., avg. pH of soil in Brazilian soybean land}$$

- 4 Calculate normalized (unitless) attributes.

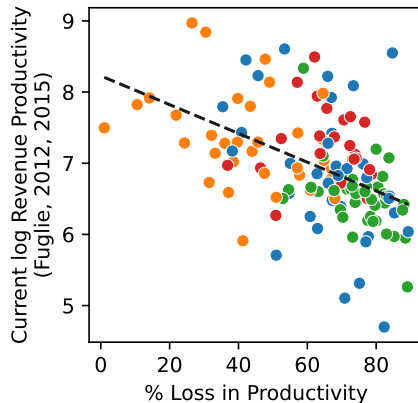
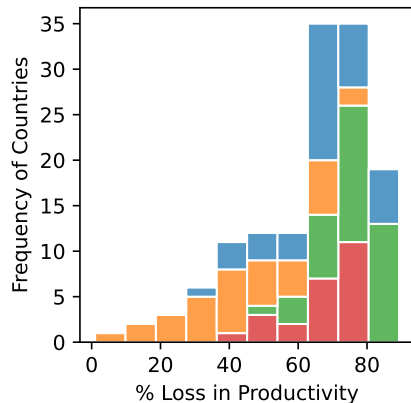
$$\hat{x}_{k,\ell} := \frac{x_{k,\ell} - \mu(x)}{\sigma(x)} \quad \text{e.g., avg. Brazilian soybean pH, relative to global farmland pH}$$

# Total Causal Effects: CPP and non-CPP Mismatch

[Measurement](#)[Back](#)

Level Effect (% Reduction): **52%**

Disparity Effect (% Increase): **16%**



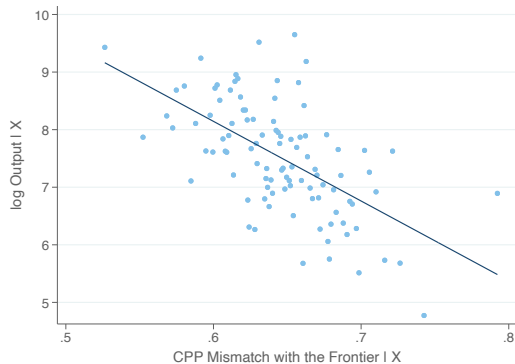
● Asia and Oceania

● Africa

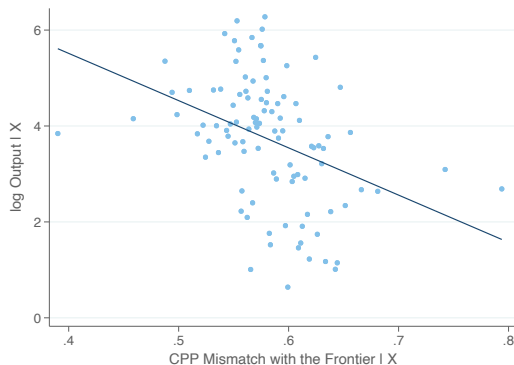
● Europe

● N. and S. America

## Within-Country Estimates: Inappropriateness $\Rightarrow$ Less Production [Back](#)



$$\beta = -8.51 \quad (2.72)$$
$$N = 1,052$$



$$\beta = -9.99 \quad (4.82)$$
$$N = 384$$

# CPPs in the Patent Data

[Back: Background](#)[Back: Theory](#)

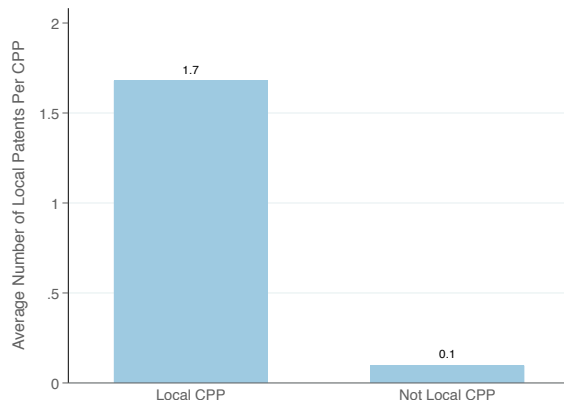
- Identify all global biological or chemical agricultural patents (CPC classes A01H and A01N) related to a CPP in our data via keyword searches of species names (**33% of total**)
- Link each patent to the country of origin of the inventor (*PatSnap* database)
- Construct patent data set at the CPP-by-country level (>400k observations)

# CPPs in the Patent Data

[Back: Background](#)[Back: Theory](#)

- Identify all global biological or chemical agricultural patents (CPC classes A01H and A01N) related to a CPP in our data via keyword searches of species names (**33% of total**)
- Link each patent to the country of origin of the inventor (*PatSnap* database)
- Construct patent data set at the CPP-by-country level (>400k observations)

Innovation focused on local CPPs:



	(1)	(2)	(3)
	CPP-Specific Patents (asinh)	Any CPP- Specific Patent (0/1)	log CPP- Specific Patents
Local CPP	0.0972*** (0.0288)	0.0479*** (0.0106)	0.181*** (0.0635)
Country Fixed Effects	Yes	Yes	Yes
CPP Fixed Effects	Yes	Yes	Yes
Observations	492,422	492,422	8,557
R-squared	0.211	0.202	0.557

*Notes:* The unit of observation is a CPP-by-country pair. The dependent variable is the number of patents registered to inventors in the country and with the CPP's scientific name in the title, abstract, or patent description. Standard errors, clustered by country and CPP, are included in parentheses and \*, \*\*, and \*\*\* indicate significance at the 10%, 5%, and 1% levels.

# Larger Effects in US, Rich Countries

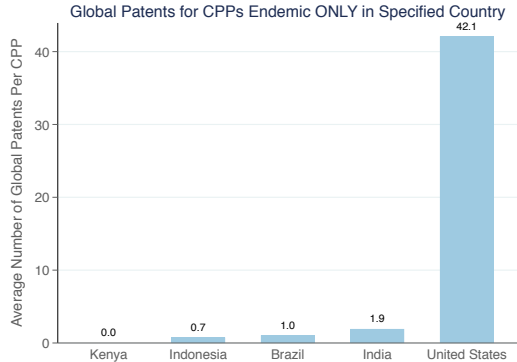
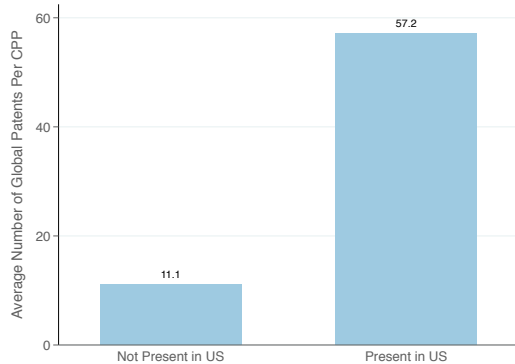
[Back: Background](#)
[Back: Theory](#)

	(1)	(2)	(3)	(4)	(5)	(6)
	CPP-Specific Patents (asinh)	Any CPP- Specific Patent (0/1)	log CPP- Specific Patents	CPP-Specific Patents (asinh)	Any CPP- Specific Patent (0/1)	log CPP- Specific Patents
Local CPP	0.0720*** (0.0242)	0.0395*** (0.00887)	0.142* (0.0711)	0.147*** (0.0418)	0.0679*** (0.0138)	0.172*** (0.0521)
Local CPP x United States (0/1)	1.002*** (0.0274)	0.334*** (0.0108)	0.394*** (0.0825)			
Local CPP x log per-capita GDP (pre-period)				0.0860*** (0.0294)	0.0366*** (0.0101)	0.0492 (0.0593)
Country Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
CPP Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	492,422	492,422	8,557	364,144	364,144	8,478
R-squared	0.233	0.214	0.559	0.240	0.228	0.557

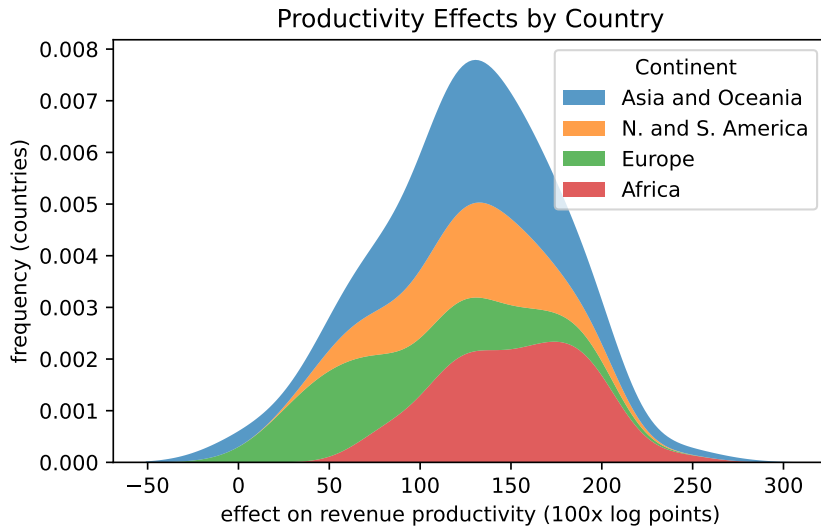
*Notes:* The unit of observation is a CPP-by-country pair. The dependent variable is the number of patents registered to inventors in the country and with the CPP's scientific name in the title, abstract, or patent description. GDP is computed at the country level from 1990-2000 and normalized by the global mean. Standard errors, clustered by country and CPP, are included in parentheses and \*, \*\*, and \*\*\* indicate significance at the 10%, 5%, and 1% levels.



# Inequality Across Countries: Raw Data

[Back: Background](#)[Back: Theory](#)

## Production Moves Toward Africa and Asia [Back](#)



## Innovation locations to maximize productivity [Back](#)

Where would investment in innovation reduce technology mismatch the most?

For each country-crop, estimate productivity if that country became the frontier innovator

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For each country-crop, estimate productivity if that country became the frontier innovator

(1)	(2)	(3)	(4)	(5)
Crop	Sites Chosen to Minimize Global Inappropriateness		Sites Chosen to Minimize Inappropriateness in Countries with Below Median Productivity	
	Best Site	Second Best Site	Best Site	Second Best Site
Wheat	China	India	India	Pakistan
Maize	China	USA	Nigeria	Tanzania
Sorghum	India	Nigeria	Nigeria	India
Millet	Nigeria	India	Nigeria	Zimbabwe
Beans	India	Brazil	India	Tanzania
Potatoes	China	India	India	Russia
Cassava	Nigeria	Ghana	Nigeria	DRC
Rice	China	India	India	Thailand

*Notes:* Column 1 reports the crop name. 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 or output in countries with below median productivity.

# Application: Rapid CPP Migration due to Climate Change [Back](#)

Key looming threat to ecological systems: climate-change induced migration

General: Parmesan et al., 2003, *Nature*. CPPs: Anderson et al., 2004, *Trends Ec. Evo.*; Bebber et al., 2013, *Nat. Clim. Change*

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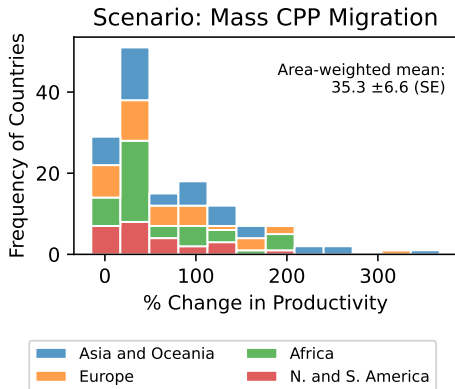
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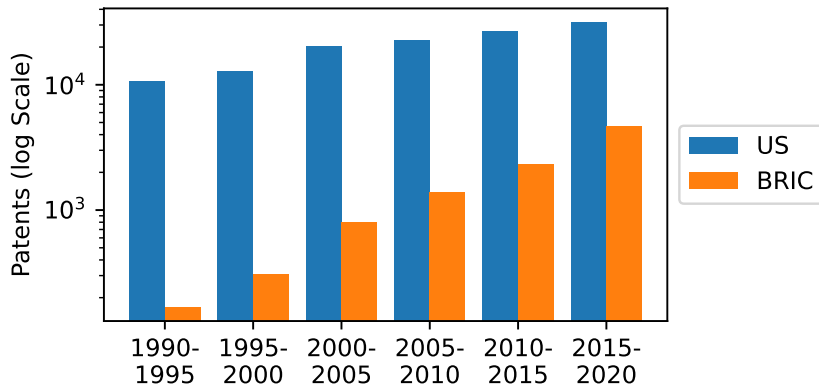
## Application: BRIC Emerge as AgTech Leaders [Back](#)

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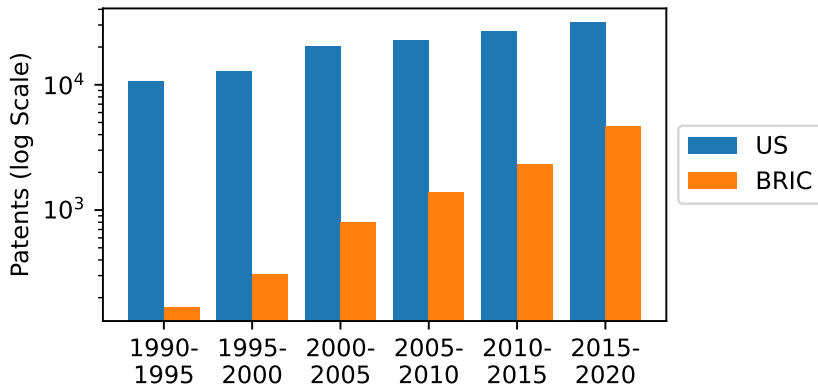
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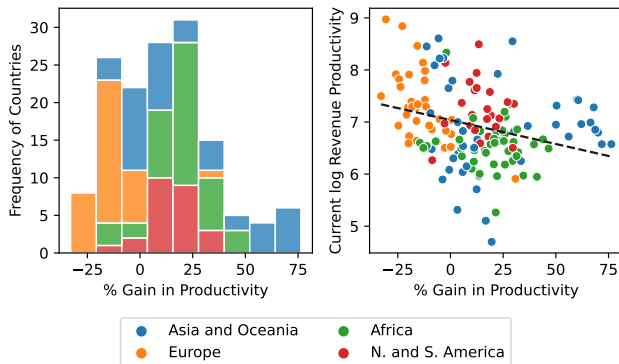
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Finding: **31.2%** increase in global productivity

## Primitives: Innovators and Technology Supply [Back](#)

- The representative innovator in  $L$  develops context-specific attributes of technology for all crops + countries, to maximize profits net of research costs (assume “general” component  $A_k$  fixed)
- **Cost structure:** marginal cost  $(1 - \gamma)^2$  (chosen for convenience) and convex, additively-separable research costs with a knowledge spillover

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- Profit-maximization problem for each  $(k, \ell)$  product can be written as

$$\max_{(B_{t,k,\ell})_{t \in \mathcal{T}_{k,\ell}}} \left\{ \frac{(1 - \gamma)}{\exp(\rho_{L,\ell})} \hat{\Xi}_\ell^{1-\eta} \hat{\rho}_k^{\frac{\eta}{\gamma}} \omega_{k,\ell}^\eta A_k^{\alpha\eta} \prod_{t \in \mathcal{T}_{k,\ell}} B_{t,k,\ell}^{\frac{\eta(1-\alpha)}{T}} - \sum_{t \in \mathcal{T}_{k,\ell}} \exp(-\tau(\hat{B}_{t,k,L})) \frac{B_{t,k,\ell}^{1+\phi}}{T(1+\phi)} \right\}$$

given conjectures  $(\hat{\rho}_k, \hat{\Xi}_\ell)$  for crop prices and endogenous revenue productivity in each country  $\ell$  and conjecture  $(\hat{B}_{t,k,\ell'}, \ell')$  for local research on each pest

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What determines direction and intensity of innovation?

- **Market size effects:** more research for bigger markets (e.g., with high productivity, IP, ...) e.g., Acemoglu and Zilibotti, 2001; Acemoglu, 2002

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- *Knowledge gaps:* more “scientific inputs” for highly-researched pest/pathogen threats  
Abstractions: Romer (1986). Realities: breeding practices, germplasm, ...



# Inappropriateness and the Impacts of the Green Revolution [Back](#)

- A coordinated international effort to develop high-yielding varieties at international agricultural research center (IARCs)
- Adoption of new tech differed drastically across locations (Evenson, 2005) potentially due to ecological mismatch with IARCs (Pingali, 2012; Lansing, 2009)

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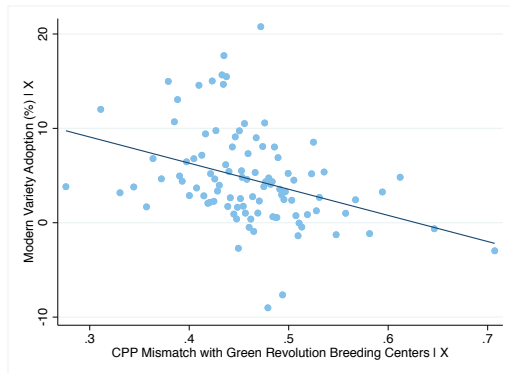
Did **change** in the geography of R&D **shift** the geography of technology use and production?

## CPP Mismatch Reduces Adoption of GR Tech, Output Growth [Back](#)

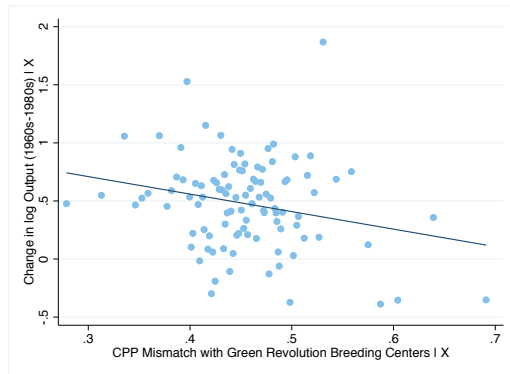
$$y_{k,\ell}^{1980} - y_{k,\ell}^{1960} = \beta \cdot \text{CPPMismatchGR}_{k,\ell} + \chi_{\ell} + \chi_{c(\ell),k} + X'\Gamma + \epsilon_{k,\ell}$$

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(g) Modern Variety Adoption ( $p < 0.01$ )



(h)  $\Delta \log$  Output (1960-1980) ( $p < 0.05$ )

## Input Use by Modern Smallholders in sub-Saharan Africa [Back](#)

- Low penetration of agricultural technology in sub-Saharan Africa despite ostensible benefits (Suri, 2011, Duflo et al., 2011)

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**Does the inappropriateness of technology drive part of the technology adoption gap?**



Estimating equation:

$$y_{z,k} = \beta \cdot \text{CPPMismatchFrontier}_{k,\ell(z)} + \chi_k + \chi_{\ell(z)} + \epsilon_{z,k} \quad (10)$$

where  $z$  indexes plots,  $\ell(z)$  indexes countries, and  $k$  indexes crops.

- **Dependent Variable:** Indicator for improved seed use
- **Absorbed effects:** Aggregate differences across crops ( $\chi_k$ ) and countries/states ( $\chi_{\ell(z)}$ )
- **Prediction:**  $\beta < 0$ ; less use of improved seeds when frontier technology inappropriate

# Inappropriateness $\Rightarrow$ Less Improved Seeds Usage [Back](#)

	(1)	(2)	(3)	(4)	(5)	(6)
	Dependent Variable is Improved Seed Use (=1)					
CPP Mismatch (0-1)	-0.321*** (0.0793)	-0.242*** (0.0805)	-0.237*** (0.0812)	-0.157*** (0.0563)	-0.227*** (0.0793)	-0.237*** (0.0812)
Quadratic Polynomial in Lat and Lon			✓	✓	✓	✓
log Area-Weighted Estimates				✓		
Broad CPP Presence Classification					✓	
Jaccard (1900, 1901) Mismatch Metric						✓
Crop Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Country Fixed Effects	Yes	-	-	-	-	-
State Fixed Effects	No	Yes	Yes	Yes	Yes	Yes
Observations	114,605	114,601	114,601	103,968	114,601	114,601
R-squared	0.213	0.246	0.247	0.235	0.246	0.246

*Notes:* The unit of observation is a plot. The controls included in each specification, as well as the mismatch metric when the baseline measure is not used, are noted at the bottom of each column. Standard errors are clustered by crop-country and \*, \*\*, and \*\*\* indicate significance at the 10%, 5%, and 1% levels.

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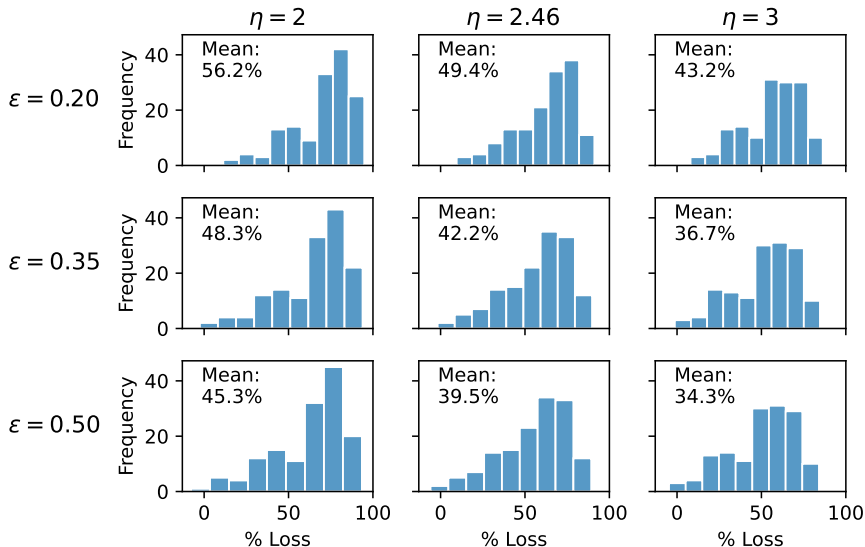
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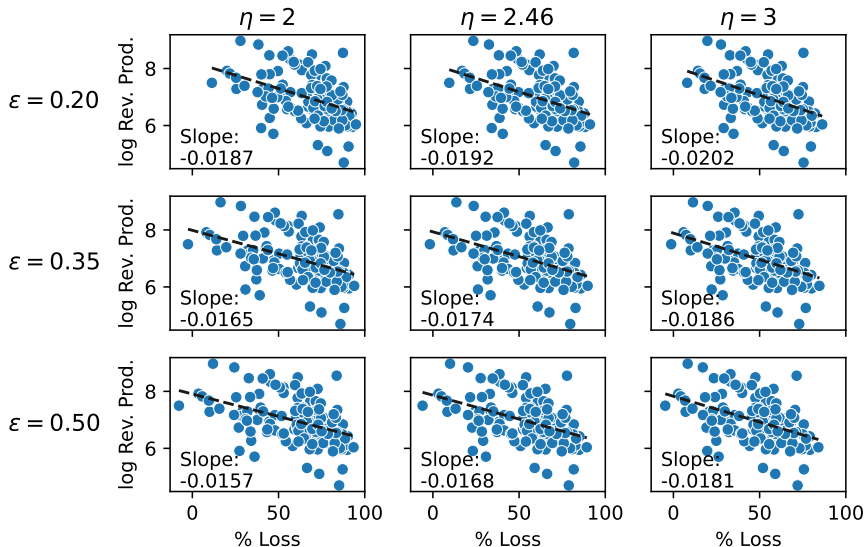
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# Global Productivity Effects: Sensitivity

[Back](#)

# Global Disparities Effects: Sensitivity

[Back](#)

Name	Estimate	Specification/Source	Definition
$\beta$	-7.14	Output Regression	Effect of CPPMismatchFrontier on output
$\eta$	2.46	Costinot et al. (2016)	Elasticity of supply to productivity
$\epsilon$	0.35	Muhammad et al. (2011)	Price elasticity of global food demand
$\pi_{k,\ell}$	—	FAOSTAT Database	Planted area for each crop in each country
$\Xi_\ell$	—	Fuglie (2012, 2015)	Baseline revenue productivity by country