Virtual Seminar on Climate Economics

Federal Reserve Bank of San Francisco

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The Food Problem and the Aggregate Productivity Consequences of Climate Change

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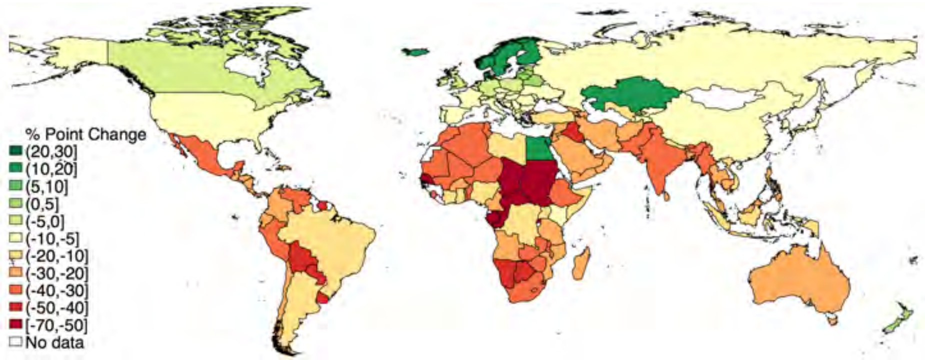
Climate Change Expected to Drive Large Changes in Agricultural Productivity



Source: Cline (2007)

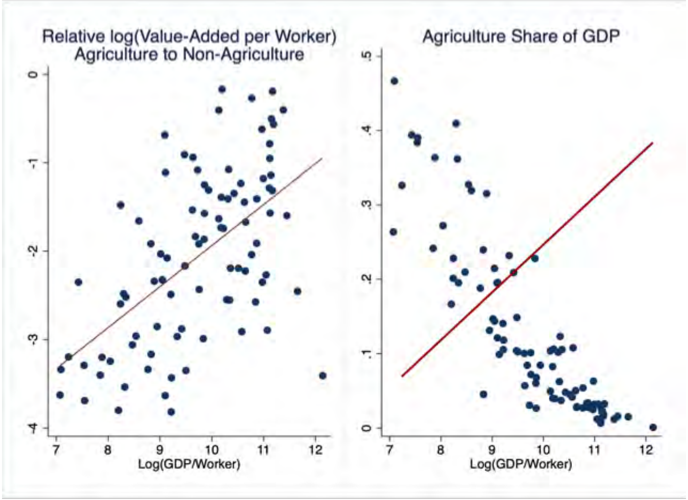
Research Question

- How will climate change affect sectoral reallocation between agriculture and non-agriculture and what are the welfare consequences of these changes?

Conditions for Adaptation by Reallocation

1. Climate change drives changes in *comparative* advantage of agriculture relative to non-agriculture
   - Use globally representative micro-data to estimate the effects of extreme temperatures on manufacturing and services productivity
2. Specialization in agriculture responds to comparative advantage
   - Estimate a global model of sectoral specialization and trade that matches existing patterns
   - Simulate the impact of climate change on sectoral reallocation, trade flows, and welfare in 158 countries

Relative Productivity and Specialization in Agriculture



Source: Tombe (2015) ▸ Employment Shares

The Food Problem

- Why do poor countries specialize in agriculture despite low absolute and relative productivity?
  - Non-homothetic preferences
  - Low substitutability between food and non-food
- Trade barriers tie local consumption to local production
  - Average person in the poorest quartile of the world consumes 91.3% domestically produced food

Sectoral Reallocation in Response to Climate Change

- Model predictions for an agriculture-biased decline in productivity:
  - Exacerbates the "food problem" $\rightarrow$ labor pulled into agriculture
  - Shifts comparative advantage $\rightarrow$ labor pushed out of agriculture
- Climate change driven sectoral reallocation is a horserace between "the food problem" and trade

Results Preview

- Extreme temperatures can substantially reduce manufacturing and services productivity
  - Treatment effects diminish markedly with income and expectations
- The 'food problem' dominates sectoral reallocation
  - Climate change raises ag share of GDP by 2.8 pp for poorest quartile
- WTP to avoid climate change is 1.5-2.7% of global GDP and 6.2-10.0% for poorest quartile
- Trade reduces WTP by only 7.4% relative to autarky
  - In an alternative scenario with increased trade openness, WTP falls by 31% overall and 68% for poorest quartile

Contributions to the Literature

- Contribution: Global empirical micro estimates on the relationship between extreme temperatures and non-agricultural productivity
  - Related literature: Zhang, Deschenes, Meng, & Zhang (2018), Somanathan, Somanathan, Sudarshan, & Tewari (2015), Dell, Jones, & Olken (2012), Burke, Hsiang, & Miguel (2015)
- Contribution: Projecting the impact of climate change on sectoral reallocation and agricultural specialization
  - Related literature - GE effects of climate/weather: Costinot, Donaldson, & Smith (2016); Desmet & Rossi-Hansberg (2015); Dingel, Hsiang, & Meng (2019); Gouel & Laborde (2018); Colmer (2018); Henderson, Storeygard, & Deichmann (2017); Hornbeck (2012); Liu, Shamdasani & Taraz (2020)
  - Related literature - structural transformation: Gollin, Lagakos & Waugh (2013); Lagakos & Waugh (2013); Gollin, Parente, & Rogerson (2007); Vollrath (2009); Alvarez-Cuadrado & Poschke (2011); Bustos, Caprettini, & Ponticelli (2016); Duarte & Restuccia (2009); Matsuyama (1991); Samaniego & Sun (2016); Comin, Lashkari, & Mestieri (2020); Hicks, Kleemans, Li, & Miguel (2018); Gollin, Hansen, & Wingender (2018); Matsuyama (1992); Tombe (2015); Uy, Yi, & Zhang (2013); Teigner (2018); Fiszbein & Johnson (2020);
- Contribution: Embedding credible micro estimates of temperature effects into quantitative macro model to analyze policy and welfare
  - Related literature - empirical estimates: Deschenes & Greenstone (2007, 2011), Lobell & Burke (2010), Schlenker & Roberts (2009), Barreca, Clay, Deschenes, Greenstone, & Shapiro (2016), Heutel, Miller, & Molitor (2017), Graff Zivin & Neidell (2014), Auffhammer (2015), Carleton et al. (2020), & many others
  - Related literature - quantitative climate-economy models: Nordhaus (2008), Hope (2006), Tol (2002), Anthoff, Hepburn, & Tol (2009), Golosov, Hassler, Krusell & Tsyvinski (2014), Acemoglu, Akcigit, Hanley & Kerr (2016), Acemoglu, Aghion, Bursztyn, & Hemous (2012)

Outline

1 Introduction

2 Empirical Estimates
- Data
- Empirical Strategy
- Empirical Results

3 Model Simulations
- Model
- Model Calibration
- Model Counterfactuals

4 Conclusion

Empirical Evidence on Temperature and Non-Agricultural Productivity

Criteria for empirical projections of climate damages (Carleton et al. 2020)

1. Data with global coverage
2. Plausibly causal estimates
3. Account for firm's costs and benefits of adapting to extreme temperatures

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Global Panel of Firms

Table: Global Firm-Level Panel Microdata

Country	Data Source	Dataset	Years
Austria	Bureau Van Dijk	Amadeus	1995-2014
Belgium	Bureau Van Dijk	Amadeus	1995-2014
China	National Bureau of Statistics	Chinese Industrial Survey	2003-2012
Colombia	National Administrative Department of Statistics (DANE)	Annual Manufacturing Survey	1977-1991
Finland	Bureau Van Dijk	Amadeus	1995-2014
France	Bureau Van Dijk	Amadeus	1995-2014
Germany	Bureau Van Dijk	Amadeus	1995-2014
Greece	Bureau Van Dijk	Amadeus	1995-2014
India	Central Statistical Office	Annual Survey of Industries	1985-2007
Indonesia	Badan Pusat Statistik	Annual Manufacturing Survey	1975-1995
Italy	Bureau Van Dijk	Amadeus	1995-2014
Norway	Bureau Van Dijk	Amadeus	1995-2014
Spain	Bureau Van Dijk	Amadeus	1995-2014
Sweden	Bureau Van Dijk	Amadeus	1995-2014
Switzerland	Bureau Van Dijk	Amadeus	1995-2014
United Kingdom	Bureau Van Dijk	Amadeus	1995-2014
United States	Census Bureau	Annual Survey of Manufacturers, Census of Manufacturers	1976-2014

Climate Data

- Historical 0.25° by 0.25° reanalysis temperature records from Global Meteorological Forcing Dataset (V3) at Princeton University
- Use daily max temperature following Graff Zivin and Neidell (2014)

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Understanding The Firm's Adaptation Decision

- Firms have a production function with variable labor effort following Burnside, Eichenbaum, and Rebelo (1993) (and many others):

$$Y = AK^{\alpha}(e * L)^{1-\alpha} \text{ with } 0 \leq e \leq 1$$

- Rearranging and taking logs gives:

$$ln\left(\frac{Y}{L}\right) = ln(e) + \left(\frac{1}{1-\alpha}\right) ln(A) + \left(\frac{\alpha}{1-\alpha}\right) ln\left(\frac{K}{Y}\right) \qquad (1)$$

- Effort is a function of exposure to extreme heat and cold and adaptation investments b_h and b_l:

$$e = 1 - CDD * g_h(b_h) - HDD * g_c(b_c) \qquad (2)$$
$$g \geq 0, g' < 0, g'' > 0$$

Understanding The Firm's Adaptation Decision

- The firm maximizes the following profit function:

$$\pi = pAK^{\alpha}(e * L)^{1-\alpha} - wL - rK - c_h b_h - c_c b_c$$

- Taking the FOC for b_h gives the following expression for optimal adaptation investment:

$$-g'(b_h) = \frac{c_h * e}{p * MPL * L * CDD} \tag{3}$$

Derivation

Causal Effect of Temperature

- I treat daily output as a function of daily temperature and aggregate to the annual level for firm i in year t:

$$Y_{it} = \sum_{d=1}^{365} Y_{id} = \sum_{d=1}^{365} f(T_{id}) = F(T)_{it}$$

- Piecewise linear functional form for temperature:

$$f(T) = \begin{cases} \beta_1(5 - T_{max}) & \text{if } T_{max} < 5 \\ 0 & \text{if } 0 \leq T_{max} \leq 30 \\ \beta_2(T_{max} - 30) & \text{if } T_{max} > 30 \end{cases} \tag{4}$$

Causal Effect of Temperature

- I model log revenue per worker at firm i in year t as a function of the vector of temperature effects, $\boldsymbol{\beta}$:

$$ln\left(\frac{Y_{it}}{L_{it}}\right) = \boldsymbol{\beta}F(T)_{it} + \delta_i + \kappa_{rt} + \epsilon_{it} \tag{5}$$

- In the piecewise linear case, this becomes:

$$ln\left(\frac{Y_{it}}{L_{it}}\right) = \beta_1 HDD_{it} + \beta_2 CDD_{it} + \delta_i + \kappa_{rt} + \epsilon_{it}$$

Heterogeneity and Adaptation

- Estimating climate change damages requires projecting temperature-sensitivity

Heterogeneity and Adaptation

- Estimating climate change damages requires projecting temperature-sensitivity
  - In parts of the world with no data
  - In the future
- I test for heterogeneous temperature-sensitivity using the following interacted regression:

$$ln\left(\frac{Y_{it}}{L_{it}}\right) = \beta F(T)_{it} + \gamma_1 ln(GDPpc)_{rt} \times F(T)_{it} + \gamma_2 TMEAN_i \times F(T)_{it} + \delta_i + \kappa_{rt} + \epsilon_{it} \quad (6)$$

Heterogeneity and Adaptation

- The piecewise linear interacted specification is:

$$ln\left(\frac{Y_{it}}{L_{it}}\right) = \beta_{01} HDD_{it} + \beta_{02} CDD_{it}$$
$$+\gamma_{11} ln(GDPpc)_{rt} HDD_{it} + \gamma_{12} ln(GDPpc)_{rt} CDD_{it}$$
$$+\gamma_{21} TMEAN_i HDD_{it} + \gamma_{22} TMEAN_i CDD_{it} + \delta_i + \kappa_{rt} + \epsilon_{it}$$

- This allows me to predict temperature sensitivity anywhere in the world as a function of two readily available variables:

$$\hat{\beta}_2^{Algeria} = \hat{\beta}_{02} + \hat{\gamma}_{12} ln(GDPpc)^{Algeria} + \hat{\gamma}_{22} TMEAN^{Algeria}$$

Identification Assumption

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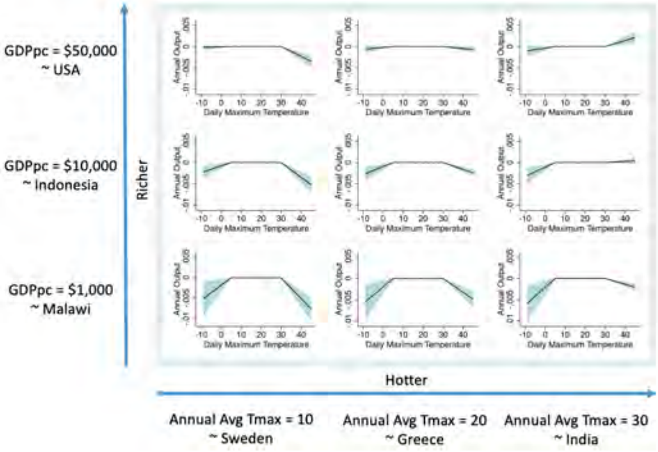
Extreme Temperatures and Output per Worker

Table: Effects of Daily Temperature on Annual Revenue per Worker

	(1) Revenue/Worker	(2) Revenue/Worker	(3) Revenue	(4) Employment	(5) Revenue/Worker
TMax-30	-0.0000311	-0.00119	-0.00250	-0.00131	-0.00100
	(-2.29)	(-4.73)	(-6.80)	(-5.25)	(-4.03)
5-TMax	-0.0000315	-0.000956	-0.00180	-0.000842	-0.000452
	(-2.15)	(-2.15)	(-2.91)	(-1.92)	(-2.07)
(TMax-30) X log(GDPpc)		0.0000715	0.000178	0.000107	0.0000595
		(4.07)	(6.79)	(6.06)	(3.65)
(TMax-30) X $\overline{\text{TMax}}$		0.0000186	0.0000334	0.0000148	0.0000160
		(4.85)	(6.24)	(3.93)	(3.96)
(5-TMax) X log(GDPpc)		0.0000898	0.000167	0.0000769	0.0000416
		(2.14)	(2.85)	(1.85)	(2.02)
(5-TMax) X $\overline{\text{TMax}}$		-0.00000292	0.00000212	0.00000504	0.000000703
		(-1.54)	(0.93)	(2.85)	(0.59)
N	4,125,776	4,125,776	4,125,776	4,125,776	17,938,084
Manufacturing	X	X	X	X	X
Services					X
Firm FE	X	X	X	X	X
Country X Year FE	X	X	X	X	X
Inverse Sample Size Weights	X				
GDP Weights	X				
Countries Included	15	15	15	15	15

Predicted Response Functions

Figure: Predicted Response of Annual Manufacturing Revenue per Worker to Daily Maximum Temperature



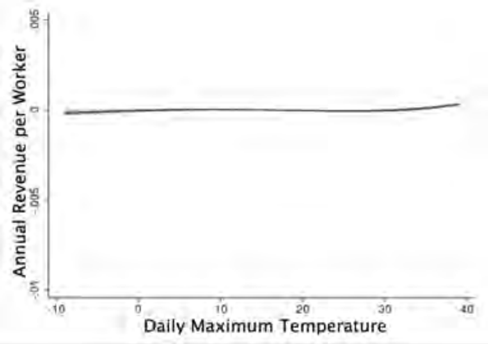
▸ Revenues ▸ Number of Employees ▸ Pooled Manufacturing/Services

Robustness

- 4th Order Polynomial
- Bins
- State X Year FE
- Controlling for Capital
- China Results
- Services Only

U.S. Results

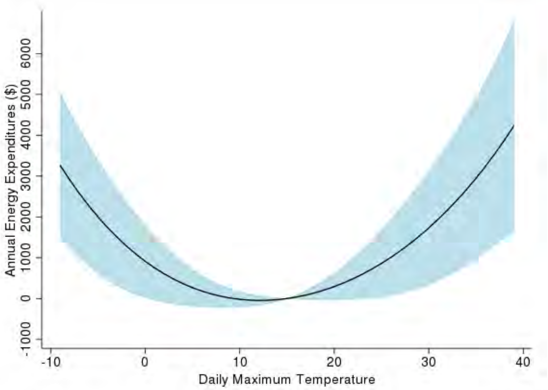
Figure: Estimated Response of Annual U.S. Manufacturing Revenue per Worker to Daily Maximum Temperature



▸ Table ▸ TFPR

U.S. Results - Energy

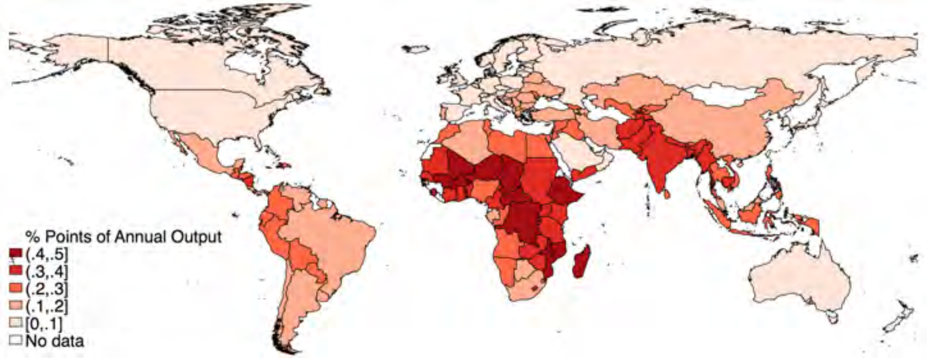
Figure: Estimated Response of Annual U.S. Manufacturing Plant-Level Energy Expenditures to Daily Maximum Temperature



Table

Global Sensitivity to Cold Days

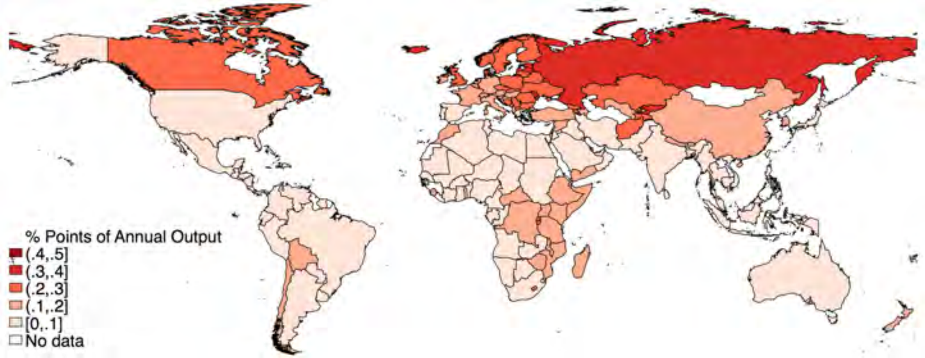
Figure: Predicted Effect of a -5°C Day on Annual Manufacturing Revenue per Worker



Services

Global Sensitivity to Hot Days

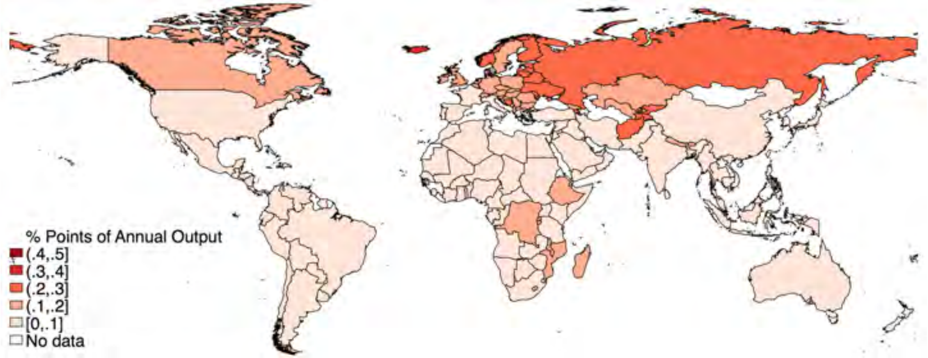
Figure: Predicted Effect of a 40°C Day on Annual Manufacturing Revenue per Worker



▸ Services

Future Global Sensitivity to Hot Days

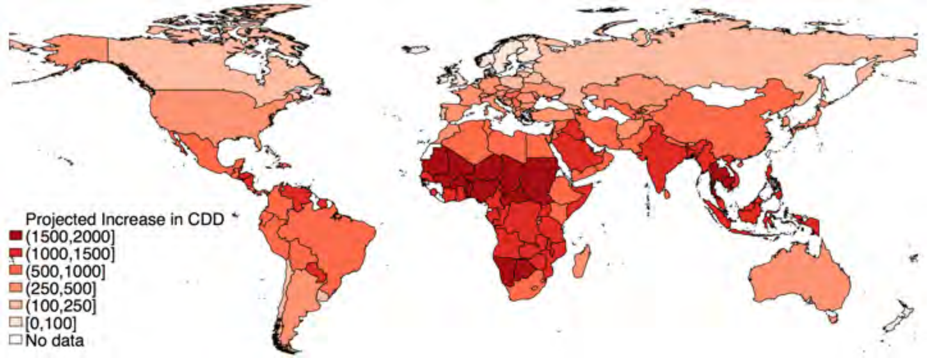
Figure: Predicted Effect of a 40°C Day at 2080 Temperatures on Annual Manufacturing Revenue per Worker



Adaptation Costs

Projected Change in Exposure to Extreme Heat

Figure: Projected Change in CDD Above 30°C
in Daily Maximum Temperature: 2015 to 2080-99

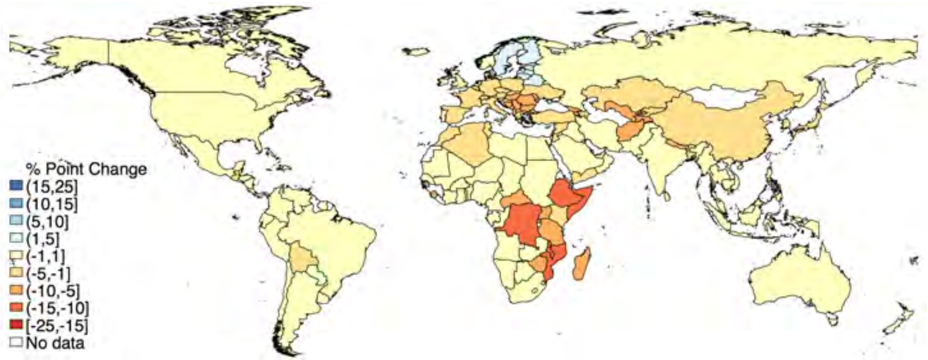


Source: CSIRO-MK-3.6.0 Model Projections - Jeffrey et al. (2013)

Extreme Cold

Global Change in Manufacturing Productivity

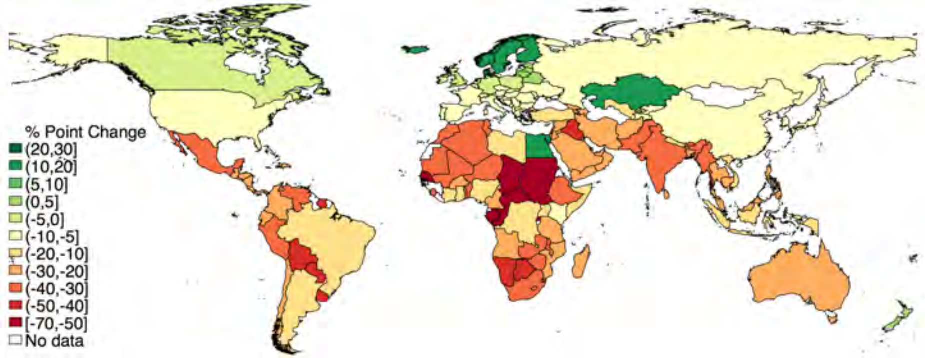
Figure: Projected Impact of Climate Change on 2080-2100 Manufacturing Productivity



Services

Global Change in Agricultural Productivity

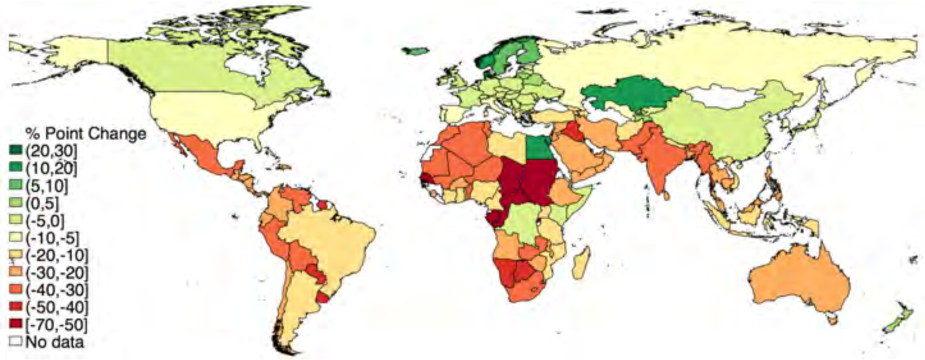
Figure: Projected Impact of Climate Change on 2080-2100 Agricultural Productivity



Source: Cline(2007)

Global Change in Relative Agricultural Productivity

Figure: Projected Impact of Climate Change on 2080-2100 Relative Agricultural Productivity



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Model Ingredients

- Consumers have non-homothetic CES preferences over three sectoral final goods: agriculture, manufacturing, and services Equations
- Intermediate goods producers draw productivity from sector-country specific Fréchet distributions: Equations

$$Z_{jk} = f(\mu_{jk}, T_k, E(T_k))$$

- Agriculture and manufacturing traded, services nontraded Equations
  - Iceberg trade costs vary at the importer-exporter-sector level
- Wages adjust to aggregate productivity so trade balances

Aggregate Productivity & Welfare

- I calculate willingness-to-pay as equivalent variation for each shock:

$$WTP_k = -EV_k = -\left[E(U_k^1; P_{ak}^0, P_{mk}^0, P_{sk}^0) - w_k^0\right] \tag{7}$$

- I calculate GDP by deflating nominal income by a Tornqvist price index using sectoral expenditure shares to weight prices:

$$P_k^T = \prod P_{jk}^{(x_{jk0}+x_{jk1})/2} \tag{8}$$

$$GDP_k = \frac{wL}{P_k^T}$$

Labor Market Equilibrium

- Labor market clearing condition:

$$L_k = L_{ak} + L_{mk} + L_{sk}$$

- In autarky, labor shares equal expenditure shares: $p_j c_j = wL_j$

- With trade, labor shares equal income shares accounting for net exports:

$$l_{jk} = \pi_{jkk} X_{jk} + \sum_{n \neq k}^{N} \pi_{jkn} X_{jn} \frac{w_n L_n}{w_k L_k} \tag{9}$$

Labor Reallocation in Response to Climate Change

- Consider an agriculture-biased negative productivity shock:
  - $\frac{p_{ak}}{P_k} \uparrow$, $\frac{w_k}{P_k} \downarrow$
- Agriculture expenditure share:

$$X_{ak} = \Omega_a \left(\frac{p_{ak}}{P_k}\right)^{1-\sigma} \left(\frac{w_k}{P_k}\right)^{\epsilon_a-(1-\sigma)}$$

in logs:

$$log X_{ak} = log(\Omega_a) + \underbrace{(1-\sigma) log\left(\frac{p_{ak}}{P_k}\right)}_{\text{Substitution Effect}} + \underbrace{(\epsilon_a - (1-\sigma)) log\left(\frac{w_k}{P_k}\right)}_{\text{Income Effect}}$$

Labor Reallocation in Response to Climate Change

- "The Food Problem"
- Agricultural productivity falls $\rightarrow \frac{p_{ak}}{P_k} \uparrow$, $\frac{w_k}{P_k} \downarrow$

$$logX_{ak} = log(\Omega_a) + \underbrace{(1-\sigma)log\left(\frac{p_{ak}}{P_k}\right)}_{\text{Substitution Effect}} + \underbrace{(\epsilon_a - (1-\sigma))log\left(\frac{w_k}{P_k}\right)}_{\text{Income Effect}}$$

- $\sigma = 0.27 \rightarrow$ substitution effect raises X_{ak}
- $\epsilon_a = 0.29 \rightarrow$ income effect raises X_{ak}

Labor Reallocation in Response to Climate Change

- Agriculture labor share:

$$l_{ak} = \underbrace{\pi_{akk}}_{\downarrow} \underbrace{X_{ak}}_{\uparrow} + \underbrace{\sum_{n \in N} \pi_{akn} X_{an} \frac{w_n L_n}{w_k L_k}}_{\downarrow}$$

- "The Food Problem" - agricultural productivity falls $\rightarrow X_{ak}$ rises
- Comparative advantage shifts
  - Import more food (π_{akk} falls)
  - Export less food (π_{akn} falls)

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Simulated Method of Moments

Table: Model Parameters and Target Moments

Parameters	Data Moment	Data Source
σ	Sectoral GDP Shares	World Bank
Ω_a, Ω_m, Ω_s	Sectoral GDP Shares	World Bank
ϵ_a, ϵ_m, ϵ_s	Sectoral GDP Shares	World Bank
θ_a, θ_m	Calibrated from Tombe (2015)	
τ_{jkn}	Trade Flows	UN Comtrade
Z_{jk}	Sectoral Value-Added per Worker	World Bank
L_k	Population	World Bank

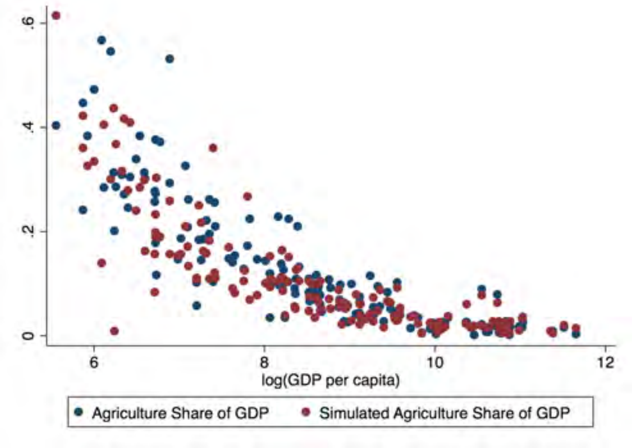
Parameter Estimates

Table: Consumption Parameter Estimates

Parameter	Description	Estimate
σ	Cross-Sector Elasticity of Substitution	0.27
		(0.21)
ϵ_a	Agriculture Utility Elasticity	0.29
		(0.39)
ϵ_m	Manufacturing Utility Elasticity	1.00
		(0.27)
ϵ_s	Services Utility Elasticity	1.15
		(0.41)
Ω_a	Agriculture Taste Parameter	11.7
		(0.51)
Ω_m	Manufacturing Taste Parameter	3.70
		(0.35)
Ω_s	Services Taste Parameter	10
		(-)

Model Fit - Agriculture Share of GDP

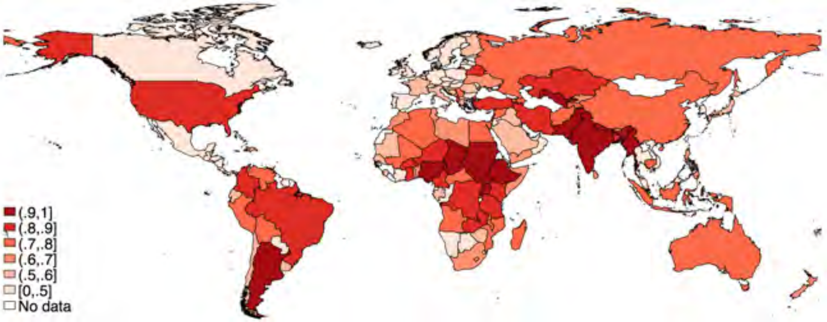
Figure: Agriculture Share of GDP - Data vs. Simulation



▸ Manufacturing ▸ Services ▸ Alternative View ▸ Stone-Geary ▸ GDP Per Capita ▸ Relative Price of Food

Simulated Domestic Share of Ag Expenditures

Figure: Simulated Domestic Production Share of Agriculture Expenditures



Model Fit

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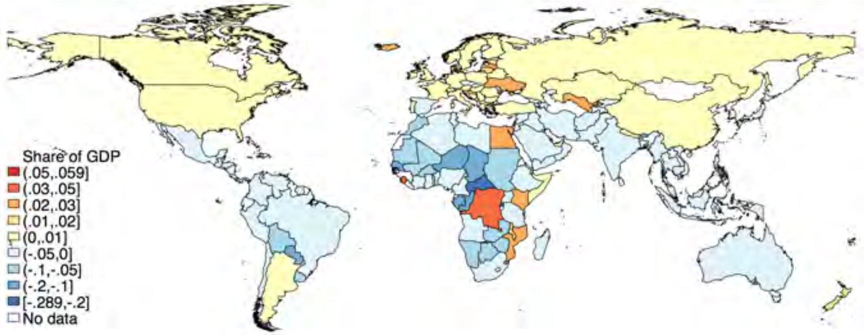
Model Simulations

- Adjust Z_{jk} for all 3 sectors in all 158 countries using empirically estimated climate change productivity losses
- Re-estimate equilibrium and calculate effects of climate change

Climate Change Effect on Agriculture Net Exports

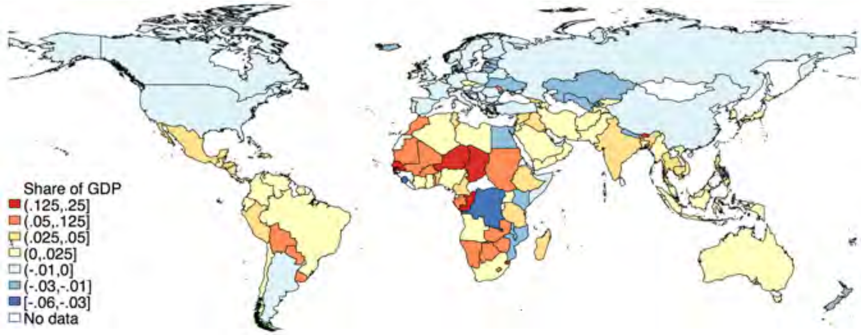
Figure: Climate Change Driven Change in Agriculture Net Exports (Share of GDP)



Domestic Production Share of Consumption

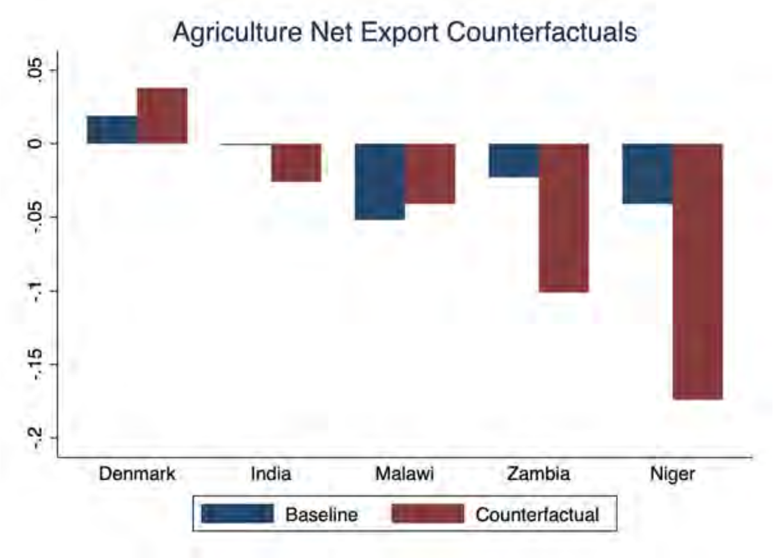
Climate Change Effect on Manufacturing Net Exports

Figure: Climate Change Driven Change in Manufacturing Net Exports (Share of GDP)

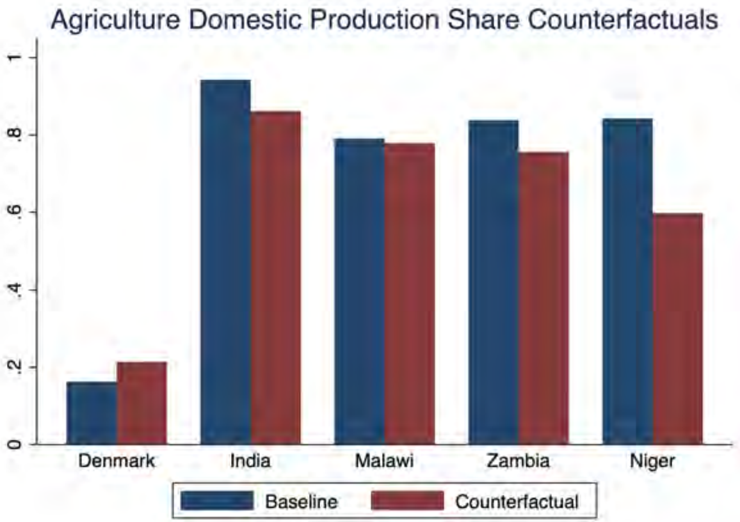


▸ Domestic Production Share of Consumption

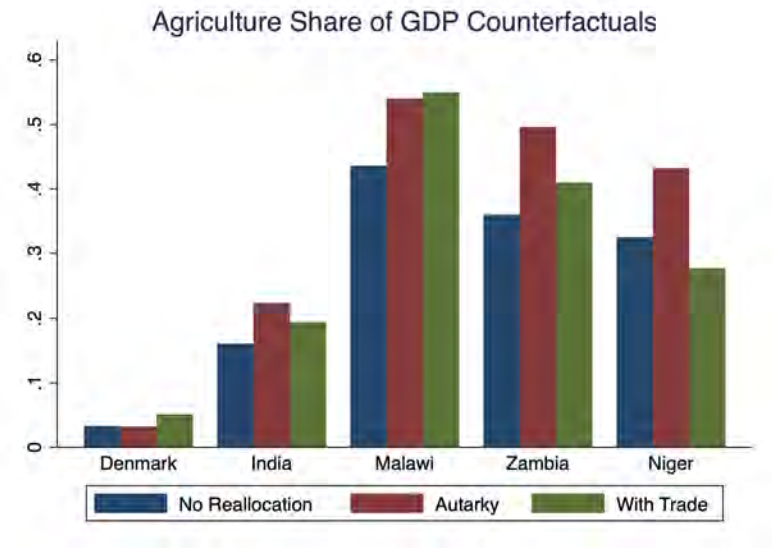
Climate Change Effect on Agriculture Net Exports



Climate Change Effect on Agriculture Domestic Production Shares



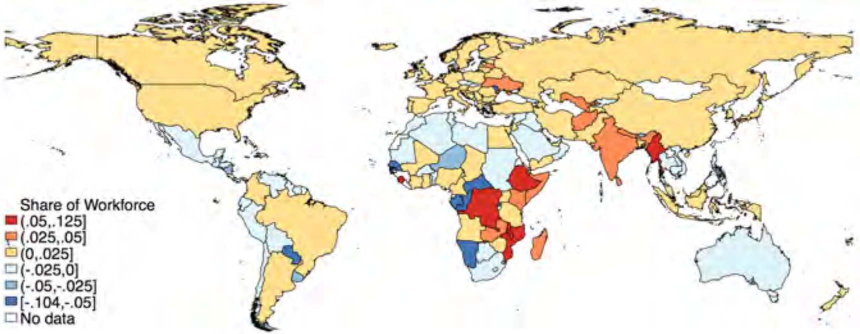
Climate Change Effect on Agriculture Share of GDP



SSA ME ASIA SA NA EU PAC

Climate Change Effect on Agriculture Share of GDP

Figure: Climate Change Driven Change in Agricultural Share of Labor

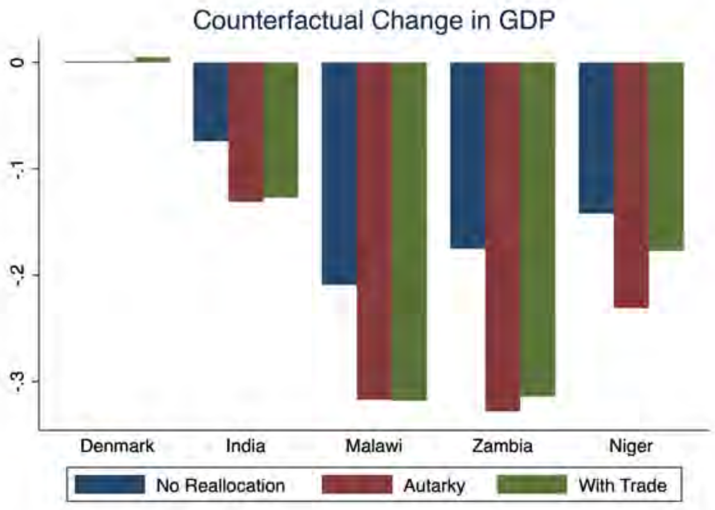


Agriculture Reallocation Summary

Table: Counterfactual Agriculture Share of GDP

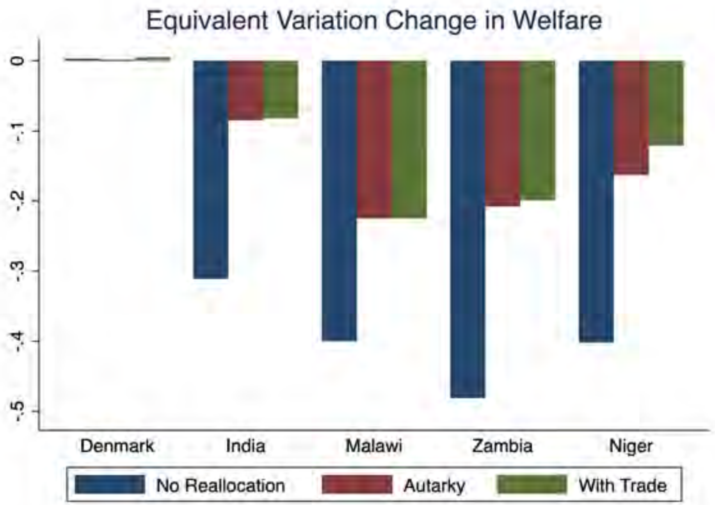
	No Reallocation	Autarky	With Trade
Poorest Quartile	.199	.256	.227
World	.038	.044	.043

Climate Change Effect on GDP



▸ SSA ▸ ME ▸ ASIA ▸ SA ▸ NA ▸ EU ▸ PAC

Willingness-to-Pay



Summary of Climate Change Impacts

Table: Percent Change in GDP

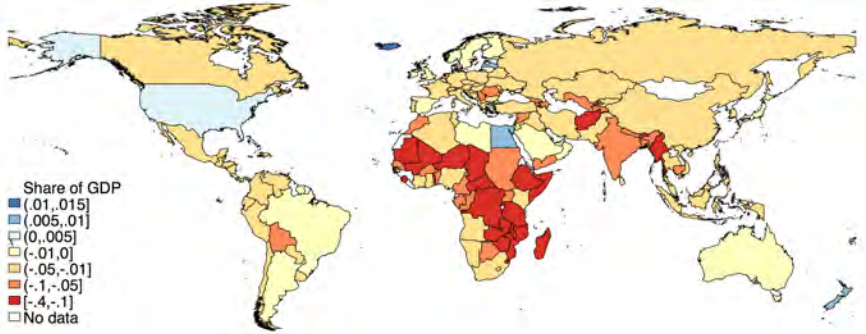
	No Reallocation	Autarky	With Trade
Poorest Quartile	-.083	-.132	-.126
World	-.019	-.023	-.021

Table: Equivalent Variation Change in Welfare (Share of GDP)

	No Reallocation	Autarky	With Trade
Poorest Quartile	-.277	-.092	-.088
World	-.04	-.018	-.017

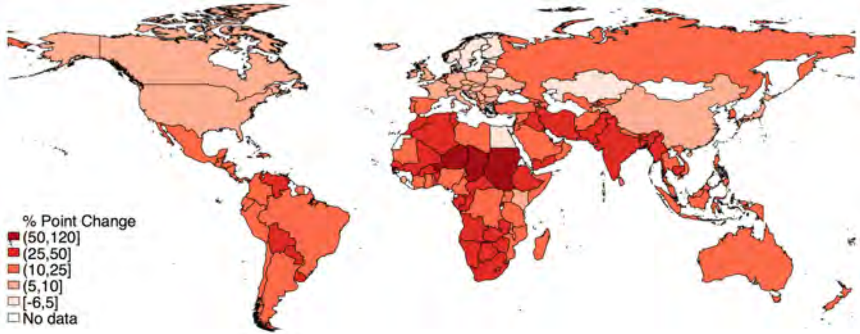
Willingness-to-Pay

Figure: Equivalent Variation Change in Welfare (Share of GDP)



Food Prices

Figure: Climate Change Driven Change in Food Prices



Results Summary

Table: Climate Change Counterfactual Summary

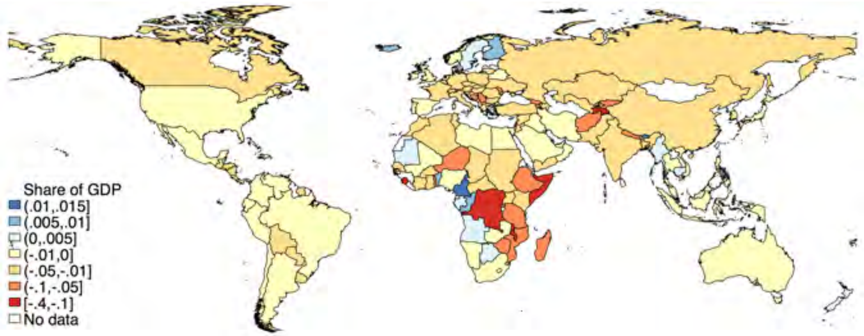
Country	Δ Ag Labor Share	Δ GDP	EV	Δ Food Prices
Poorest Quartile	.028	-.126	-.088	.377
World	.005	-.021	-.017	.223

Low Trade Cost Counterfactual

- Replace all τ_{jkn} with standard small value
- Rescale all Z_{jk} to match initial levels of income
- Repeat climate change counterfactuals

Low Trade Cost Counterfactual

Figure: Equivalent Variation Change in Welfare
Low Trade Cost Counterfactual



Agriculture Net Exports Agriculture Share of GDP Food Prices GDP

Low Trade Cost Case Results Summary

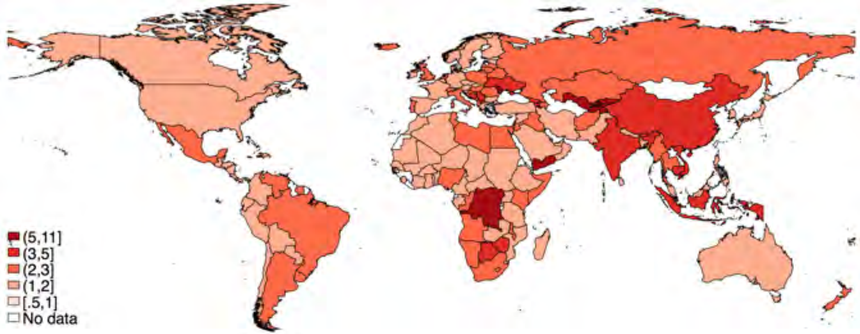
Table: Climate Change Counterfactual Summary
Alternative Trade Cost Cases

	Δ Ag Labor Share	Δ GDP	EV	Δ Food Prices
Estimated Trade Cost Case				
World	.005	-.021	-.017	.223
Poorest Quartile	.028	-.126	-.088	.377
Low Trade Cost Case				
World	.002	-.015	-.013	.1
Poorest Quartile	-.012	-.034	-.029	.109

Example Countries

Predicted Economic Growth

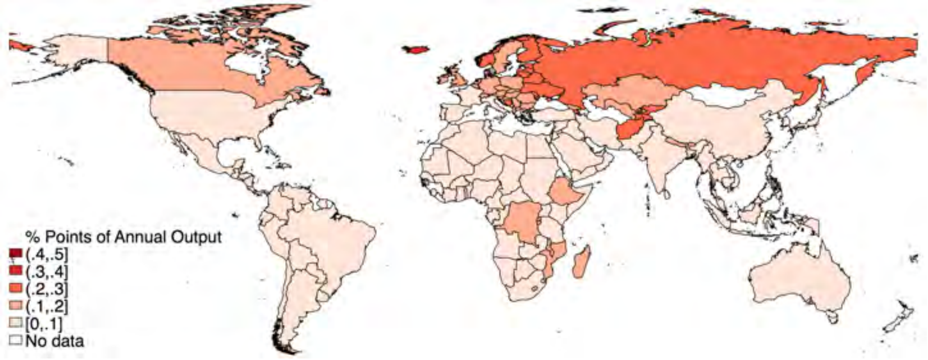
Figure: Projected Per Capita Income - 2080 Relative to Present



Source: Shared Socioeconomic Pathway 3 - IIASA Energy Program

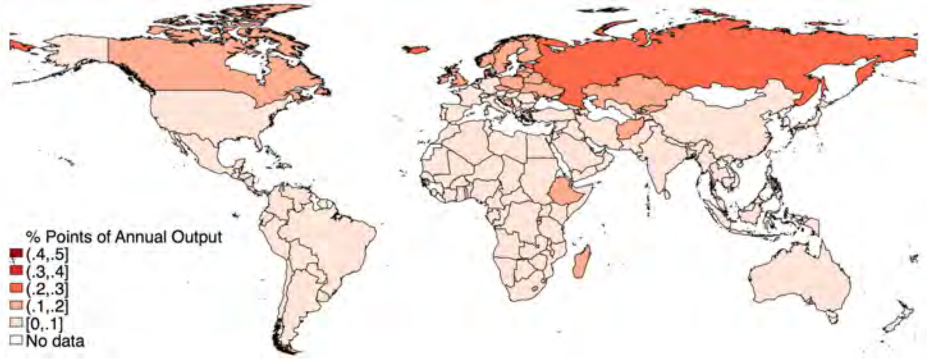
Global Non-Agricultural Sensitivity to Hot Days - Current Incomes

Figure: Predicted Effect of a 40°C Day at 2020 Incomes on Annual Manufacturing Revenue per Worker



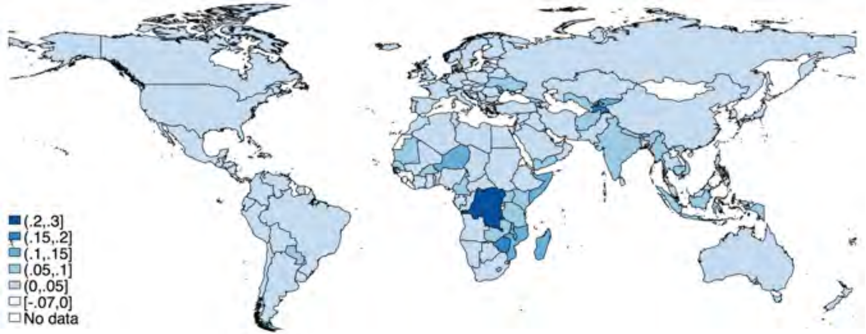
Global Non-Agricultural Sensitivity to Hot Days - Future Incomes

Figure: Predicted Effect of a 40°C Day at 2080 Incomes on Annual Manufacturing Revenue per Worker



Change in Simulated Agriculture Share of GDP - Current vs. Future Incomes

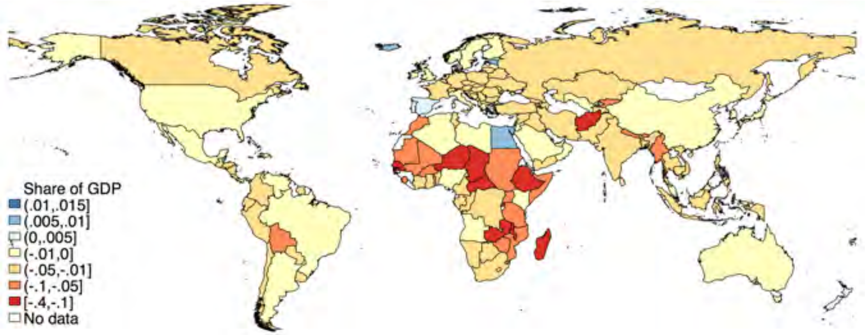
Figure: Projected Reduction in Agriculture Share of GDP - Present to 2080



Present Future

Willingness-to-Pay At Future Incomes

Figure: Equivalent Variation Change in Welfare from 2080 Incomes (Share of GDP)



Agriculture Net Exports | Agriculture Share of GDP | Food Prices | GDP

Adaptation Costs & Benefits Summary

Table: Climate Change Counterfactual Summary

	Equivalent Variation Change in Welfare
Current Income Baseline	
World	-.017
Poorest Quartile	-.088
Current Income Baseline Plus Adaptation Costs	
World	-.027
Poorest Quartile	-.100
Future Income Baseline Plus Adaptation Costs	
World	-.015
Poorest Quartile	-.062

Example Countries

Robustness

Table: Climate Change Counterfactual Summary
Alternative Model Assumptions

Country	Δ Ag Labor Share	Δ GDP	EV	Δ Food Prices
Baseline				
World	.005	-.021	-.017	.223
Poorest Quartile	.028	-.126	-.088	.377
Lognormal Productivity				
World	.005	-.023	-.018	.209
Poorest Quartile	.022	-.131	-.09	.338
Stone-Geary Preferences				
World	.003	-.018	-.015	.219
Poorest Quartile	.028	-.107	-.07	.371

Heterogeneous Workers | Stone-Geary Consumer Preferenes | Lognormal Productivity Distributions | Shadow Value of Migration

Supporting Evidence on Reallocation

- Gollin, Hansen, & Wingender (2018), Bustos, Caprettini, & Ponticelli (2016) - agricultural productivity $\uparrow$, agricultural labor share $\downarrow$ across countries and within Brazil
  - Fiszbein & Johnson (2020) - heterogeneous effects on reallocation depending on trade openness
- Colmer (2020) & Liu, Shamdasani, & Taraz (2020) - weather shocks and agricultural labor share in Indian districts
- I add my own country level regressions to this body of evidence

Country-Level Panel Regressions

Table: Country-Level Panel Regression

	(1) log(GDP)	(2) Food Share of Imports	(3) Ag Share of GDP	(4) Ag Labor Share
KDD X 100	-0.121	0.00258	0.00875	0.00991
	(-2.31)	(0.64)	(1.08)	(1.55)
GDD X 100	0.0505	-0.00429	-0.00140	-0.00138
	(1.64)	(-2.45)	(-1.54)	(-0.38)
Observations	3602	2916	3171	3715
Country FE	X	X	X	X
Year FE	X	X	X	X
Ag Labor Weights	X	X	X	X

Unweighted Specification | Outcome Data | Climate Data | Regression Equation

Outline

1 Introduction

2 Empirical Estimates
- Data
- Empirical Strategy
- Empirical Results

3 Model Simulations
- Model
- Model Calibration
- Model Counterfactuals

4 Conclusion

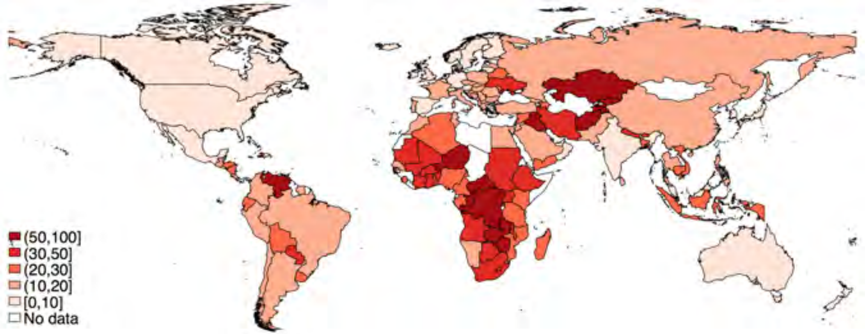
Policy Implications

- Benefits of climate change mitigation
- Optimal investments in climate change adaptation
- Importance of trade openness for climate change adaptation

▸ Caveats

Barriers to Trade

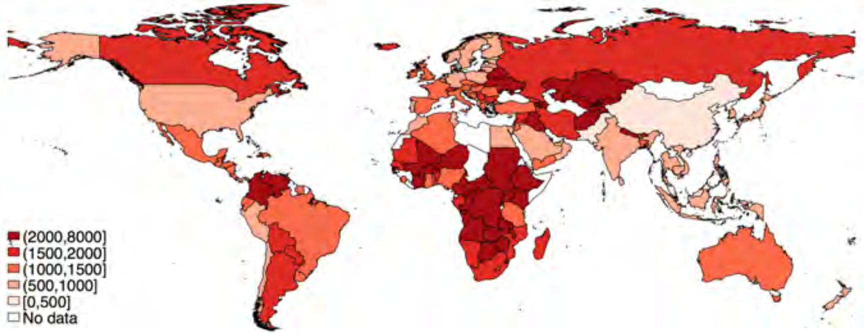
Figure: Days to Import a 20-Foot Container



Source: World Bank Ease of Doing Business Index

Barriers to Trade

Figure: Non-Tariff Costs to Import a 20-Foot Container (USD)



Source: World Bank Ease of Doing Business Index

Summary & Conclusion

- Extreme temperatures harm non-agricultural productivity, but limited effects in rich countries and to expected shocks
- Climate change likely to exacerbate 'the food problem' and raise agricultural share of production hot, poor countries
- Trade does little for climate change adaptation under current policy but freer trade could dramatically reduce damages in poor countries