Climate Change and Migration: the case of Africa

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Motivation

- Implications of climate change (CΔ): at the center of the policy debate
- Drastic (potential) consequences for Sub-Saharan Africa (SSA):
  - High dependence on agriculture
  - Low usage of modern inputs
  - Rapid population growth

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  - High dependence on agriculture
  - Low usage of modern inputs
  - Rapid population growth
- Great Climate Migration (Lustgarten, 2020):
  - High vulnerability of SSA (in terms of migration responses to CΔ)
  - Rigaud et al. (2018): intranational climate migration $\sim$ millions by 2050

Research Questions and Outline

1. How can CΔ lead to migration flows in SSA (within/across countries)?
2. How economic mechanisms and potential policies interact with CΔ effects?

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This project: Data + Model = long-run GE effects of climate change

1. Climate change: agricultural productivity shock
   - FAO-GAEZ data: variation at location-crop level
2. Embed it in a multi-sector spatial GE model to quantify:
   - CΔ migration by the end of the 21st century
   - Role of migration and trade policies on CΔ effects

Main Results and Takeaways

1. Aggregate CΔ effects:
   - Migration flows (22 million) and real GDP pc losses (-2%)
   - Magnitude of results: determined by spatial frictions
2. Distributional effects:
   - Heterogeneous migration responses across space [-280K, 270K]
   - Country-level welfare effects: [-14%, 3%]
   - Production adaptation across sectors + trade: mitigate CΔ effects
3. SSA as the European Union (↓ trade and migration barriers):
   - EU's migration and trade policies: aggregate vs. distributional trade-offs
   - Main channel: CΔ-induced structural change

Contribution more

1. Introduce CΔ migration into the structural change/development literature:
   - Climate shocks: push-factors of migration (past and future)
     (Henderson et al., 2017; Rigaud et al., 2018; Benveniste et al., 2020; Burzyński et al., 2022)
   - Mobility barriers: obstacle for migration, structural change, and development
     (Gollin et al., 2014; Bryan et al., 2014; Bustos et al., 2016; Lagakos et al., 2018; Bryan and Morten, 2019; Pellegrina and Sotelo, 2021; Imbert et al., 2022; Henderson and Turner, 2020)

2. Contribution to the spatial climate change literature:
   (Desmet et al., 2021; Balboni, 2021; Conte et al., 2024; Cruz and Rossi-Hansberg, 2024)
   - Crop-level CΔ (Costinot et al., 2016) and migration
   - CΔ, structural change (the "food problem"), and migration
     (Gollin et al., 2007; Nath, 2022; Conte et al., 2021; Cruz, 2024)
   - Carefully quantified real-world policies and their interaction with CΔ effects

Road Map

1. Data:
   - Main data sources
   - Motivating evidence
2. Theory:
   - Theoretical model
   - Model quantification
3. Counterfactuals for Climate Migration:
   - Main counterfactuals
   - Policy experiment: SSA as the EU
   - Additional experiments and robustness
4. Final remarks and further work

Data

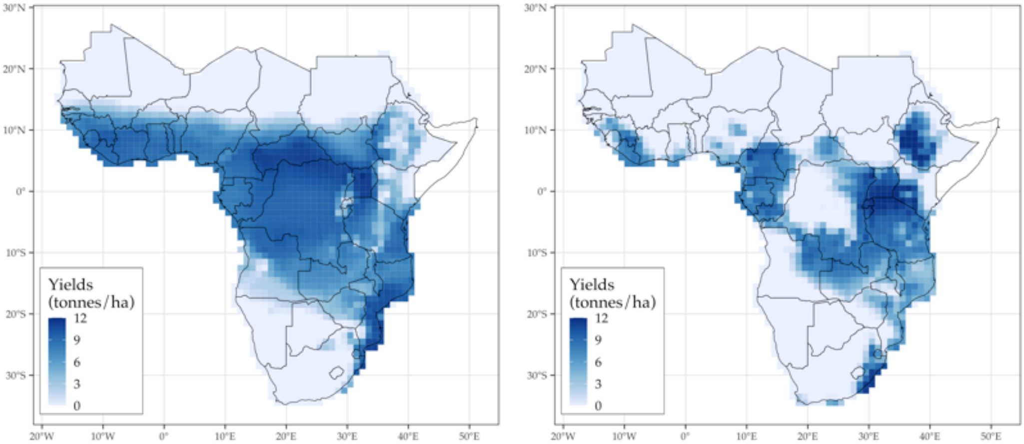
Spatial Data: $1^\circ \times 1^\circ$ grid cells ($\sim$ 2000 cells) more

1. GDP and Population:
   - 2000: both values from (G-Econ, Nordhaus et al., 2006)
   - 1975: population from (GHSP, Florczyk et al., 2019)
   - 2080: population estimates (UN's Population Prospects, at the country level)
2. Transportation network: African extract from gROADS and transportation friction surface from Weiss et al. (2018)
3. Agriculture: GAEZ agro-climatic potential yields (IIASA and FAO, 2012):
   - Unit: tons/ha, subsistence (rainfed) technology
   - Crops: cassava, maize, millet, rice, sorghum, wheat
   - Time periods: 1975, 2000 and 2080 (RCP 8.5)

CΔ and Agricultural Productivity

spatial–crop heter.

Figure 1: CΔ effects on potential yields of cassava for 2000 (left) and 2080 (right).



Model

Model Outlook

- Static, multi-sector spatial GE model

- Ingredients from quantitative spatial economics (Allen and Arkolakis, 2014; Redding and Rossi-Hansberg, 2017):
  - Love for varieties (consumers) **+**
  - Trade frictions (production and trade) **+**
  - Congestion forces (location choice) **=**
  - Spatial allocation of economic activity

- Main outcomes: sectoral production in the most productive regions

- Sectoral specialization: disciplined by barriers to structural change (agricultural goods $\equiv$ subsistence)

Environment

- N locations $i, j \in S = \{1, ..., N\} \in$ country $c \in C$ countries, $K - 1$ crops (agriculture), $K \equiv$ non-agric. sector:
  - Sector-specific productivity $A_i^k \in \mathcal{A} = \{A_1^1, ..., A_N^K\}$ and land stock $H_i \in \mathcal{H}$
  - Amenity value $u_i \in \mathcal{U}$

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- Initial population $\mathcal{L} = \{L_i^0\}_{i \in S}$, inelastic supply labor and earn v_j:
  - Heterogeneous w.r.t. location choice $\sim G(\theta, u_j (L_j / H_j)^{-\alpha})$
  - Migration barriers $\bar{m}_{ij} = \text{dist}\,(i,j)^{\phi} \times m_{c(j)} \geq 1 \in \mathcal{M}$
  - Mobility on S: subj. to congestion forces $\left(\theta, \alpha, \phi, \{m_c\}_{c=1}^{C}\right)$

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Main Features

- Technology: Cobb-Douglas (labor + land) with Hicks-neutral $\boldsymbol{b_i^k A_i^k} \equiv \text{TFP}_i^k$ ($A_i^k \equiv$ fundamental productivity, $b_i^k \equiv$ efficiency shifter)
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- Consumption choice: Multi–level CES demand over location–sector varieties q_{ij}^k and CES aggregates C_j^k
  - $\eta_k, \gamma_a, \sigma \equiv$ lower, middle, and upper level CES, $\xi_k \equiv k$'s trade elasticity
  - Bilateral expend. shares: $\lambda_{ij}^k \propto \left(p_{ij}^k / P_j^k\right)^{-\xi_k} \equiv g\left(\boldsymbol{w}, \boldsymbol{r}, \boldsymbol{b^k}, \boldsymbol{A^k}, \mathcal{T}; \xi_k\right) \; \forall i, j, k$

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- Non-/Agricultural expenditures: shares μ_j^k, $k = a, K$
    - Non–homothetic upper-tier (Comin et al., 2021):

$$\mu_j^k = \Omega_k \times \underbrace{\left(P_j^k / P_j\right)^{1-\sigma}}_{\text{substitution effect}} \times \underbrace{\left(w_j / P_j\right)^{\varepsilon_k - (1-\sigma)}}_{\text{income effect}}$$

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From Theory to Data: Calibration and Validation

From Theory to Data: Matching SSA in 2000

Parameters	Description	Source
Panel A: Demand parameters		
$\eta_k = 5.4$	Lower-tier CES ($k \neq K$, crops)	Costinot et al. (2016)
$\eta_K = 4$	Lower-tier CES (non-agriculture)	Desmet et al. (2018)
$\gamma_a = 2.5$	Mid-tier CES (across crops)	Sotelo (2020)
$\sigma = 0.26$	Upper-tier CES	Comin et al. (2021)
$\epsilon_a = 0.2$	Non-homothetic CES (agriculture)	Comin et al. (2021)
$\epsilon_K = 1$	Non-homothetic CES (non-agriculture)	Comin et al. (2021)
Panel B: Supply parameters		
$\xi_k = 5.66$	Sectoral trade elasticity ($k \neq K$, crops)	Pellegrina (2022)
$\xi_K = 6.63$	Sectoral trade elasticity (non-agriculture)	Pellegrina (2022)
$\alpha^k = 0.39$	Crop labor share ($k \neq K$)	Fajgelbaum and Redding (2022)
$\alpha^K = 0.58$	Non-agricultural labor share	Fajgelbaum and Redding (2022)
Panel C: Location choice parameters		
$\theta = 3$	Migration elasticity $\in [2, 4]$	Morten and Oliveira (2024)
$\beta = 0.32$	Congestion to population density	Desmet et al. (2018)

From Theory to Data: Matching SSA in 2000

	Subset	Description	Data source / Moment matched
$\mathcal{L}$	–	SSA's initial population	Population data in 2000 and 1990
$\{b_i^k, \Omega_k\}_{i,k}$	–	Production and consumption shifters	Spatial-sectoral output/expenditures
$\mathcal{H}$	–	Land endowments	Grid cell land areas
$\mathcal{A}$	$\{A_i^k\}_{i \in S, k \neq K}$	Agricultural productivities	FAO-GAEZ data go
	$\{A_i^K\}_{i \in S}$	Non–agricultural productivities	Spatial distribution of GDP
$\mathcal{U}$	–	Amenities	Spatial distribution of population
$\mathcal{T}$	dist(i,j)	Bilateral travel distances	Transportation data
	$\delta = 0.17(0.01)$	Distance elasticity of τ	Spatial dispersion of prices go
	$\tau^F = 6.75(0.38)$	Tariffs	Aggregate bilateral trade flows
$\mathcal{M}$	dist(i,j)	Bilateral travel distances	Transportation data
	$\phi = 0.41(0.02)$	Distance elasticity of m_{ij}	Internal migr. flows (from census) go
	$\{m_c\}_{c=1}^C$	Country migration barriers	Country-level bilateral migration flows

results: outer loops | results: trade network | results: fundamentals | model validation

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Climate Change and Migration: Counterfactuals and Policy Experiments

Main Counterfactual

- Solve for 2080's equilibrium with $\mathcal{G}(S)$ but using:
  - $\mathcal{L}$ for 2080 **+**

1. $\{A_i^k\}_{k \neq K}$ with CΔ **-**
2. $\{A_i^k\}_{k \neq K}$ (no CΔ)

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- Results: CΔ migration ($\sim$ 22 million), welfare losses (real GDP pc $\downarrow$ 1.7%), non-agricultural employment ($\downarrow$ 0.82%) CΔ migration empl. results welfare results

		Location Level			Country Level			
	Aggregate	Bottom decile	Median	Top decile	Angola	Senegal	Nigeria	Tanzania
Δ Population (K)	22,315.27	-108.05	-0.63	94.59	-1,686.26	-347.16	133.24	2,760.20
Δ Non–agric.	-0.82	-10.89	-1.40	16.16	4.92	2.78	-0.31	-2.53
Δ Real GDP pc	-1.76	-22.86	-3.76	4.56	-16.60	-32.81	-1.11	2.50

Policy Experiment: SSA as frictionless as the European Union

A. Trade, Migration, and Sectoral Specialization: mitigating role

- Trade: attenuates "the food problem" (Gollin et al., 2007; Nath, 2022)
- Trade and migration: subsitutes as adaptation (Conte et al., 2021)
- Migration: key adaptation (Cruz and Rossi-Hansberg, 2024)

B. Policy Experiment: SSA as the European Union (trade/migration policies)

		SSA as frictionless as the EU		
	Baseline	Migration Policy	Trade Policy	Both
Δ Pop. (M)	22.32	34	9.18	20.46
Δ Non–agric. (%)	-0.82	-0.54	-0.84	-0.76
Δ GDP pc (%)	-1.76	-1.01	-1.31	-1.41
[bottom, top]	[-14.62; 3.27]	[-11.32; 4.69]	[-6.32; 3.69]	[-5.64; 3.35]

EU vs SSA spatial frictions Alternative welfare measures Level CΔ effects

Additional Experiments, Extensions, and Robustness Checks

1. One-crop vs. multi-crop: larger welfare losses
2. Homothetic preferences: major welfare gains
   - Economy substitutes out agricultural consumption for non-agriculture
3. Endogenous fertility: reduces population growth in damaged locations
   - Less climate migration
4. Rest of the World: larger migration flows and welfare losses
   - Attenuated if reducing migration and trade barriers with ROW
5. Productivity growth: attenuates welfare losses; ambiguous migration effects
6. Alternative climate damages: (amenities, non-agric.) mildly magnifies effects
7. CΔ assumptions: weaker effects with RCP 4.5 (less severe)

Final Remarks

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- Study and quantify climate migration in SSA by combining:
  - Rich spatial data for SSA
  - Tractable, transparent spatial GE model
- Main results: CΔ effects on migration, welfare, and structural change
  - Sector adaptation and trade: key adaptation mechanisms
  - Trade and migration policies: powerful mitigation tools (EU as benchmark)

Thank you!

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Appendix

Contribution to the Literature: Details back

- Weather shocks and migration: empirical literature (Baez et al., 2017; Cai et al., 2016; Gröger and Zylberberg, 2016; Henderson et al., 2017)
- Spatial structural change (Desmet and Rossi-Hansberg, 2014; Eckert and Peters, 2018; Fan et al., 2021; Fajgelbaum and Redding, 2022; Takeda, 2022)
- Migration (barriers) and development (Bryan and Morten, 2019; Caliendo et al., 2021; Morten and Oliveira, 2024; Lagakos et al., 2018)
- Market integration and development (Asturias et al., 2019; Donaldson, 2018; Nagy, 2023; Ducruet et al., 2020; Sotelo, 2020; Atkin and Donaldson, 2015; Donaldson and Hornbeck, 2016; Atkin et al., 2021)

Additional Data Sources

back

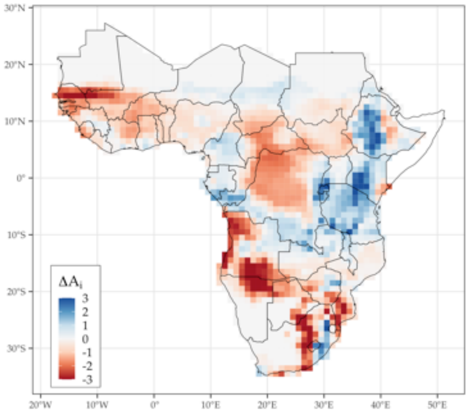
- Sectoral production data (2000 circa):
  - Crop-cell-level production (tons, FAO-GAEZ)
  - Crop-country-level production (US$, FAOSTAT)
  - Country-level sectoral VA (WBDI)

- Trade data: country-pair-sector tradeflows (1990-2005) from the International Trade and Production Database (ITPD-E, Borchert et al., 2021)

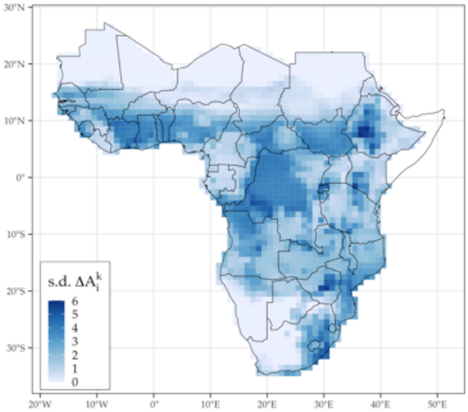
- Migration data: country-pair flows (1990-2005, from Abel and Cohen, 2019)

Heterogeneous Effects of CΔ back

A: Change in average suitability to agriculture (ton/ha)

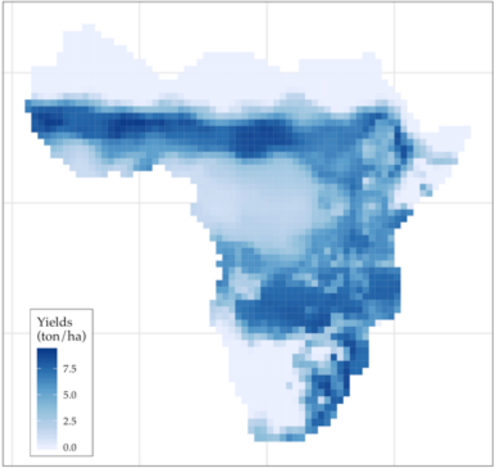


B: Standard deviation of changes in crop suitabilities at the location level

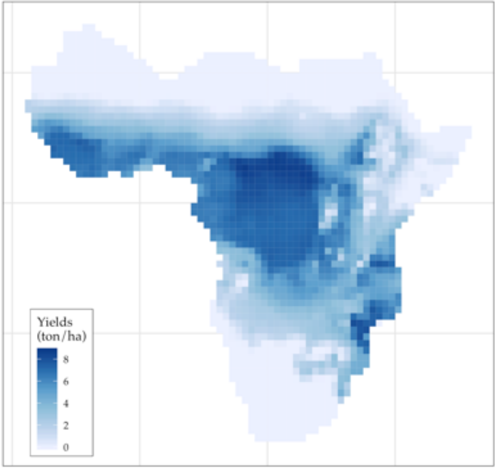


Drawing $\{A_i^k\}$ from FAO-GAEZ back

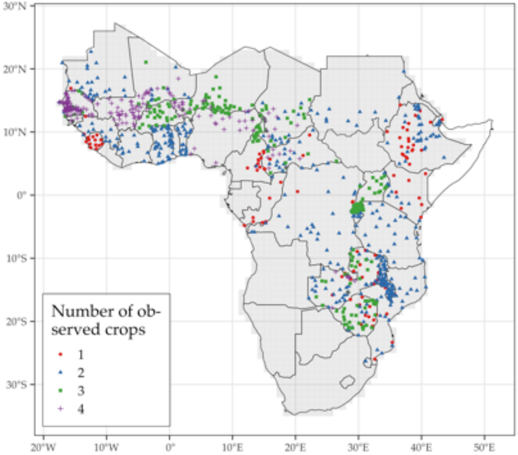
A: Sorghum potential yields (2000)



B: Rice potential yields (2000)



Newly Collected Price Data back



Crop price data from WFP-VAM project (FAO):

- $\sim$ 40 countries and 900 markets (coordinates)
- 4 crops: maize, millet, sorghum, rice
- Covers 2000–2018

No origin-destination structure: use price dispersion to pin down δ

Quantification Results: Outer Loops back

Figure 2: Results of the outer loops that estimate δ and τ_{ij}^F

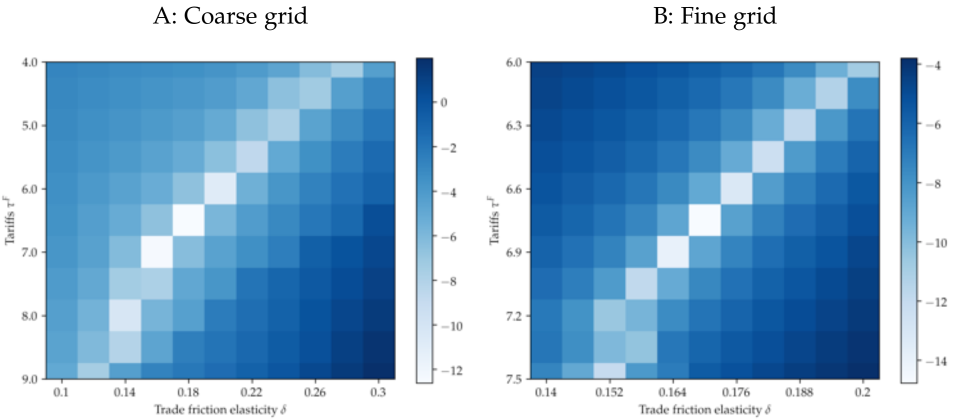
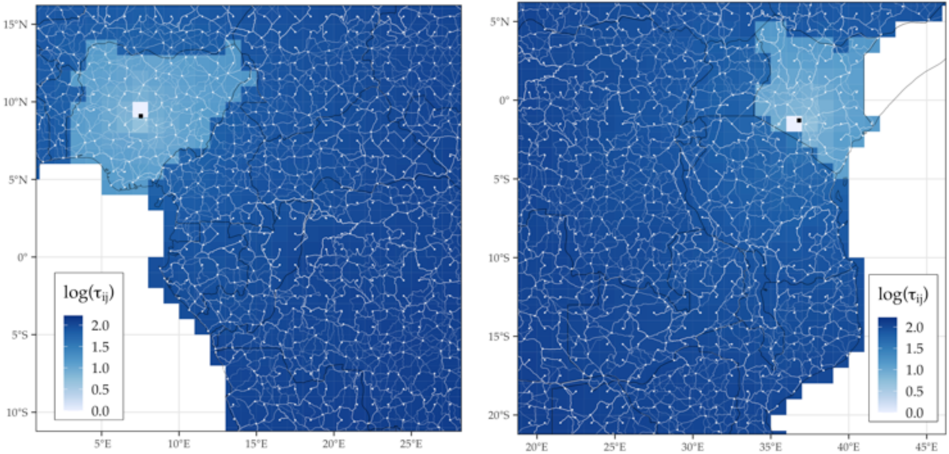
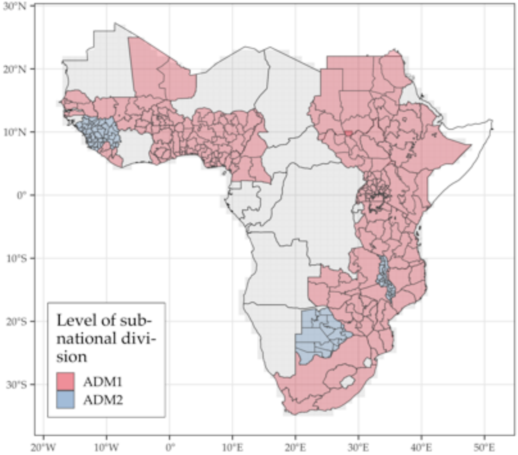


Figure 3: Quantified trade network for two subsamples of SSA. back



Newly Collected Migration Data back



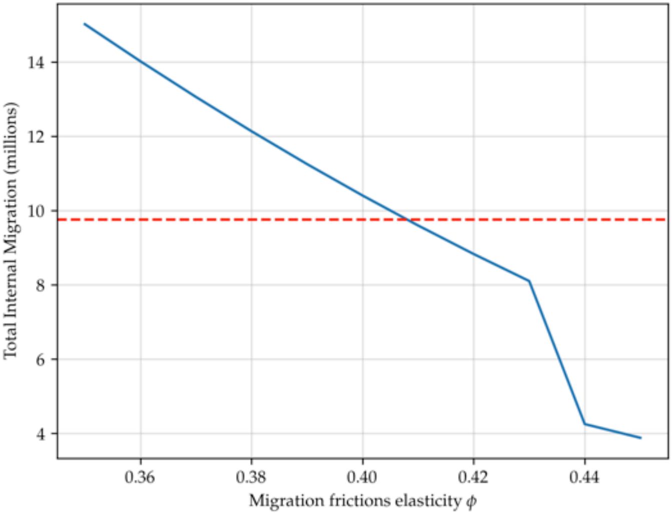
Internal migration data from IPUMS (census):

- $\sim$ 24 countries, 40 years
- Individual-level data ($\sim$ 17 mi obs.)
- Aggregated at admin $\times$ admin level

Identification: total internal migration to pin down ϕ

Quantification Results: Outer Loops back

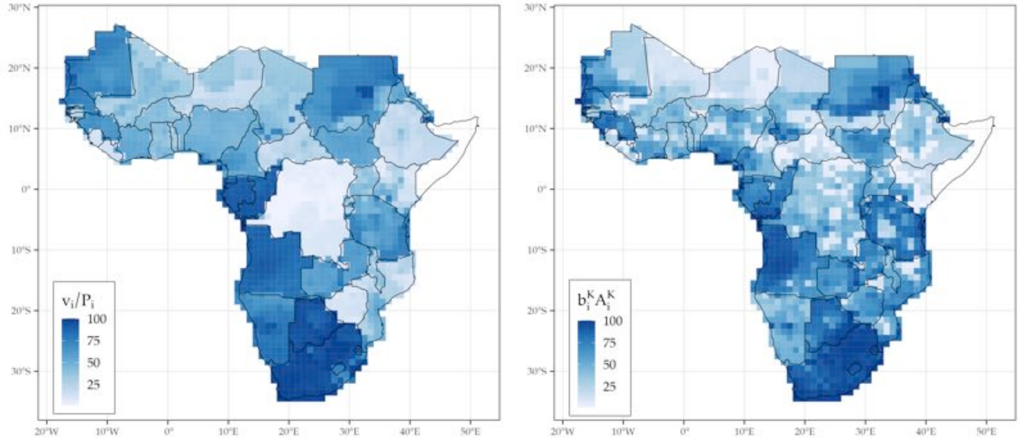
Figure 4: Results of the outer loops that solve for ϕ



Quantification Results back

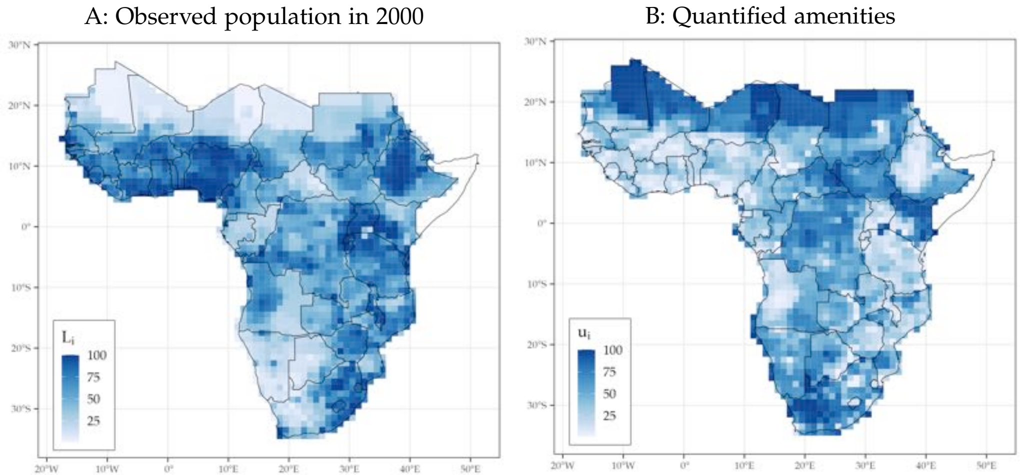
A: Observed real wages in 2000

B: Quantified non–agric. productivities



Notes: All results are shown in percentiles, where 1 (100) stands for the bottom (top) percentile of each sample. A and B document, respectively, the spatial distribution of the real wages in 2000 and the product of the quantified non–agricultural productivities productivity shifter of the non–agricultural sector.

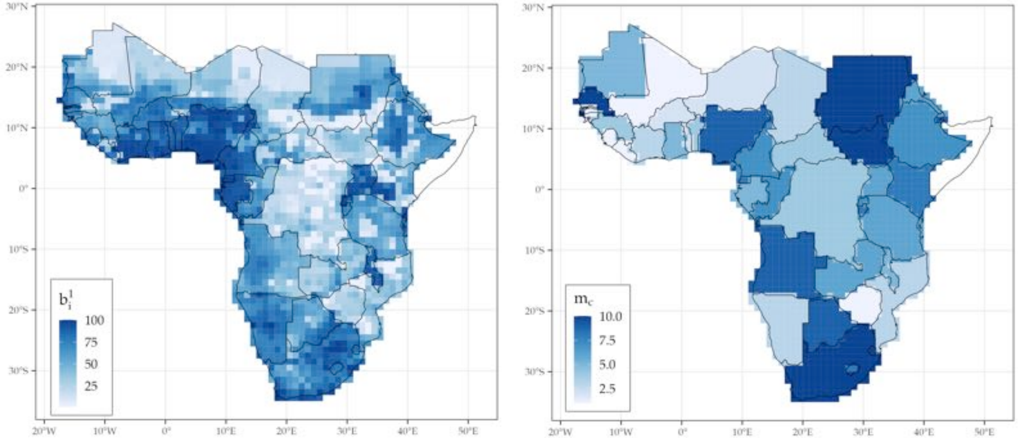
Quantification Results back



Notes: All results are shown in deciles, where 1 (100) stands for the bottom (top) decile of each sample. A and B document, respectively, the spatial distribution of observed population in 2000 and the quantified amenities .

Quantification Results back

A: Quantified shifters (cassava) B: Quantified migration barriers



Notes: All results are shown in deciles, where 1 (100) stands for the bottom (top) decile of each sample. A and B document, respectively, the spatial distribution of the quantified cassava shifters and country migration barriers (the latter in deciles).

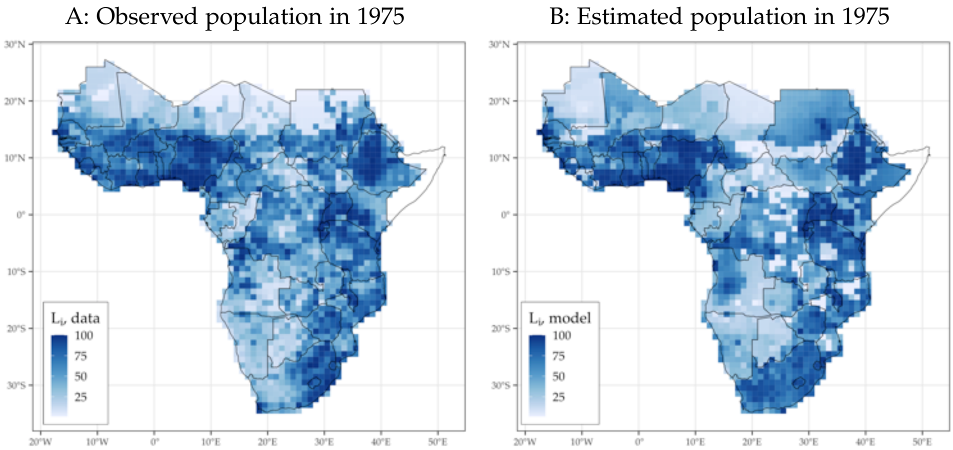
Validating the model: backcasting exercise using $\mathcal{L}$ and $\{A_i^k\}_{k \neq K}$ for 1975; check:

- model-implied population differences between 2000 and 1975
- extra: model-implied agricultural employment in 2000

Validating the model: backcasting exercise using $\mathcal{L}$ and $\{A_i^k\}_{k \neq K}$ for 1975; check:

- model-implied population differences between 2000 and 1975
- extra: model-implied agricultural employment in 2000

Figure 5: Backcasting exercise: population distribution in 1975. back



Validating the model: backcasting exercise using $\mathcal{L}$ and $\{A_i^k\}_{k \neq K}$ for 1975; check:

- model-implied population differences between 2000 and 1975
- extra: model-implied agricultural employment in 2000.

Figure 6: Model goodness of fit: backcasting results for differences in population and labor shares in agriculture for 2000. back

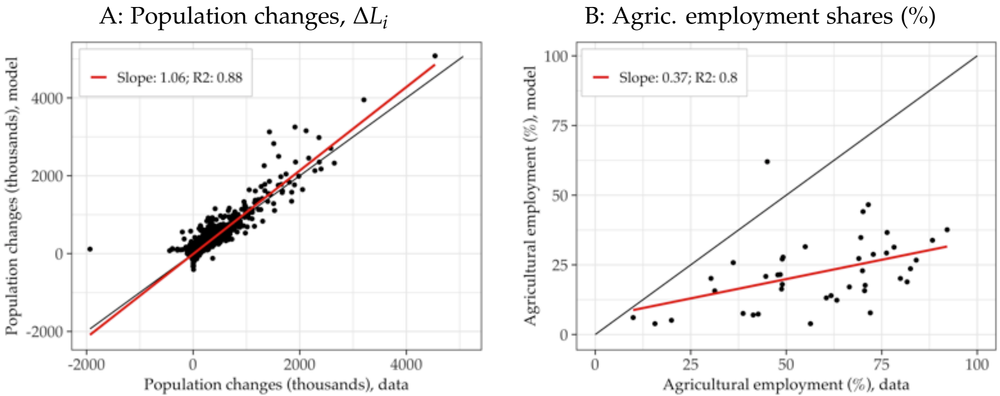


Figure 7: Change in agricultural suitabilities in SSA. back

A: Change in average suitability to agriculture (1975–2000).

B: Change in average suitability to agriculture (2000–2080).

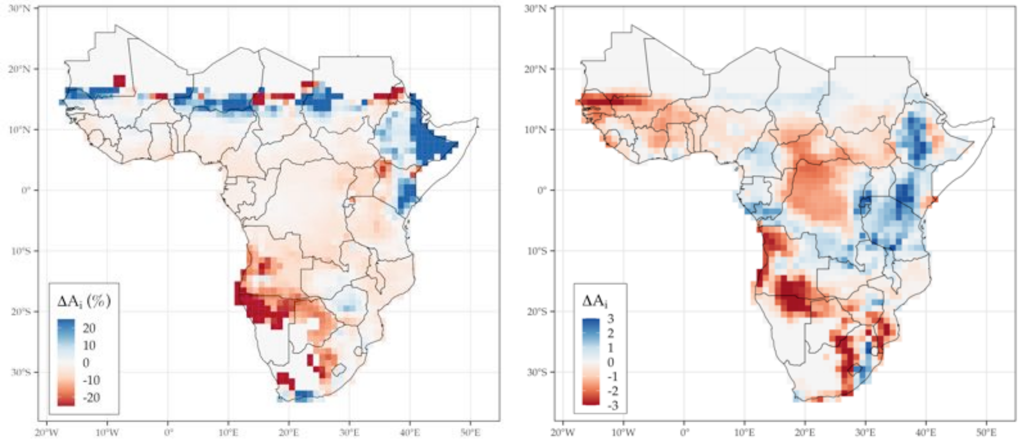


Figure 8: Climate migration in SSA – baseline results for 2080. back

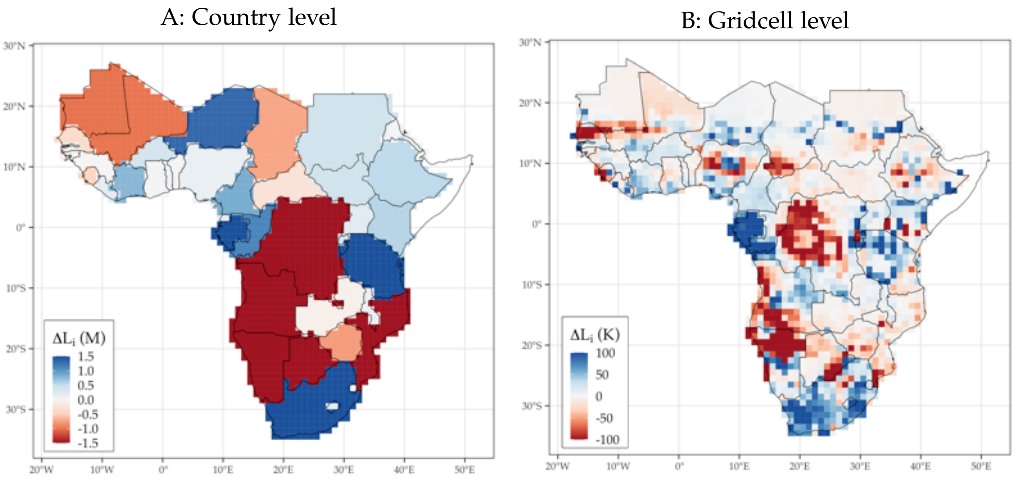


Figure 9: Climate change impact on non-agricultural employment. back

A: Country level

B: Gridcell level

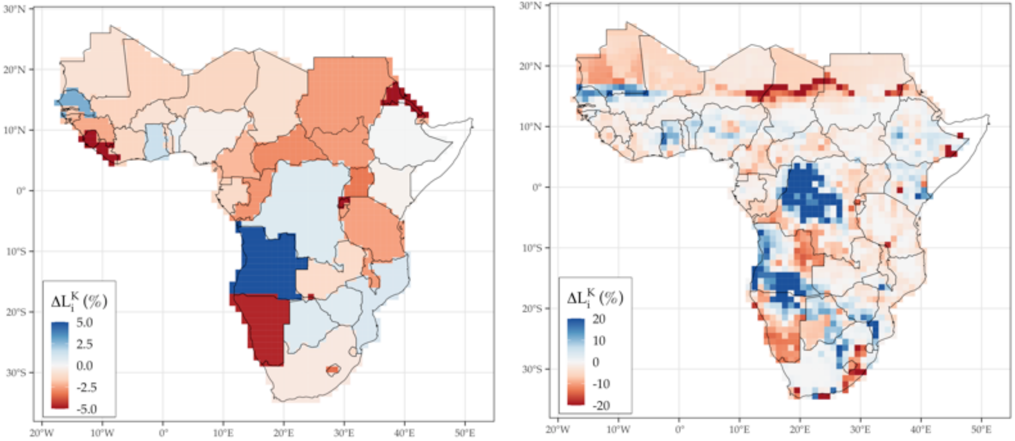


Figure 10: Climate change impact on real GDP per capita. back

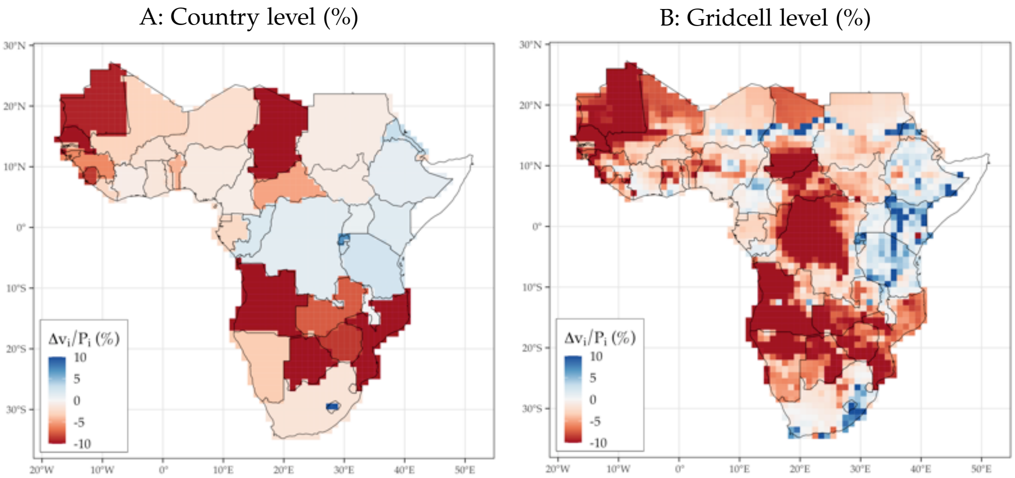
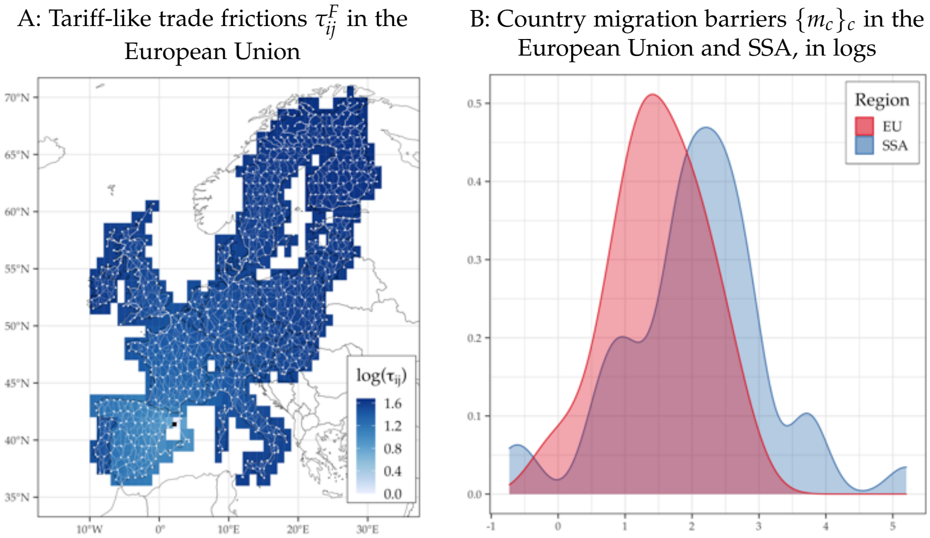
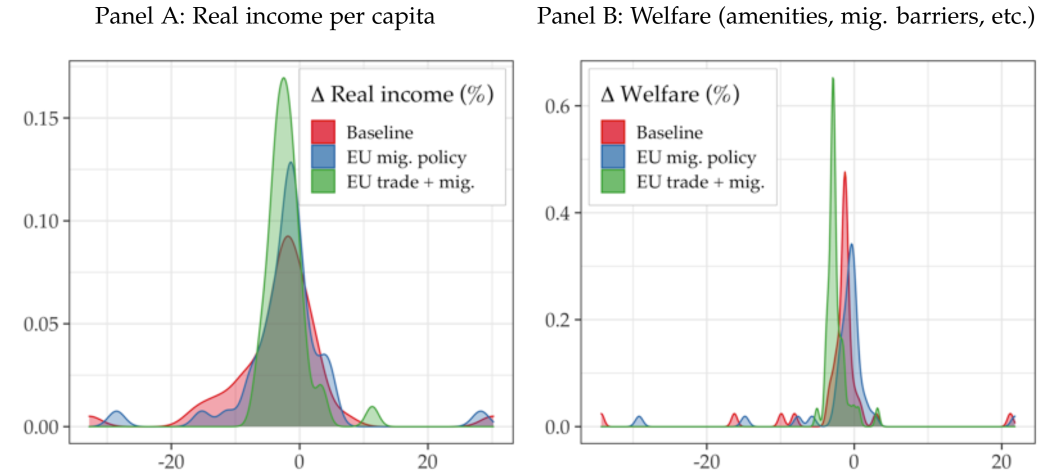


Figure 11: Estimated trade and migration frictions in the European Union back



Notes: Panel A presents trade frictions in the EU as done for SSA in Figure 3 (in this context, trade frictions are relative to Barcelona (Spain), represented by the black dot). Panel B plots the distribution of country migration barriers $\{m_c\}_c$ in SSA and the EU.

Figure 12: Welfare effects of climate change for the baseline and different EU policies back



Notes: Panel A and B plot the country-level distributions of welfare in three different policy scenarios for SSA: baseline, EU migration policy, and EU trade and migration policy. Panel A refers to the baseline welfare measure (real income per capita). Panel B refers to an alternative welfare measure that also account for mobility barriers and congestion.

	(1) With climate change	(2) No climate change	(3) Climate change effect (%)
Panel A - Welfare W_R:			
Baseline	1.01	1.00	1.16
EU mig. policy	0.88	0.87	1.18
EU trade policy	1.65	1.69	-2.12
Both policies	1.84	1.90	-3.32
No mig. barriers ($\bar{m}_{ij} = 1$)	5.34	5.39	-0.89
Panel B - Real income per capita v_j/P_j:			
Baseline	0.98	1.00	-1.76
EU mig. policy	1.18	1.19	-1.01
EU trade policy	1.35	1.36	-1.31
Both policies	1.63	1.65	-1.41
No mig. barriers ($\bar{m}_{ij} = 1$)	1.32	1.32	-0.66

Notes: Columns 1 and 2 document the aggregate welfare and real income in levels normalized to the baseline, no climate change scenario. Column 3 refers to their percentage difference. back