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"Global Food System: Opportunities and Challenges“
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Modelling intra- and international trade in crop markets in Africa

An application to climate change adaptation

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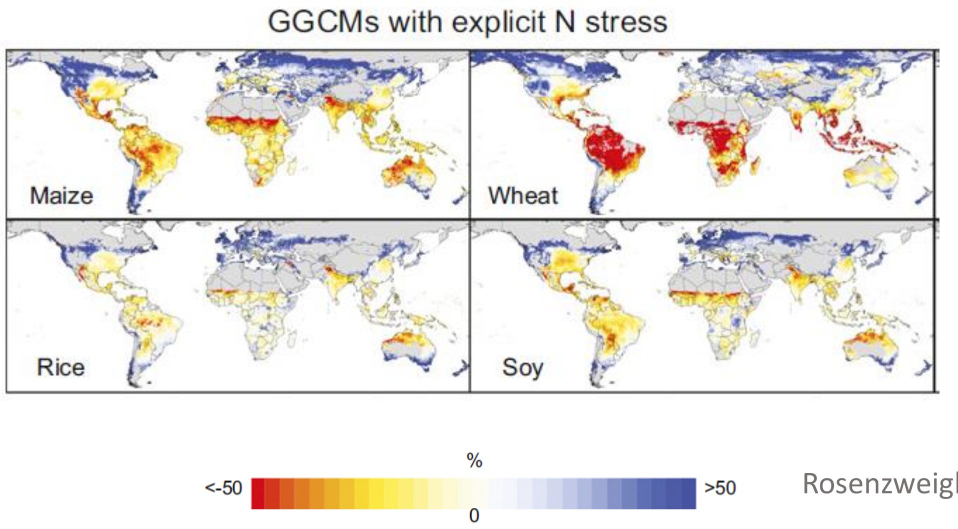
Introduction

- Variation in climate change impacts across **space** and across **time**



Rosenzweigh et al. 2014

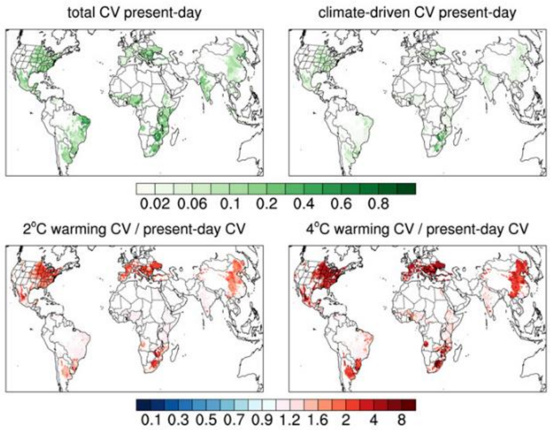


Fig. 3. Warming-induced changes in yield variability. (*Top*) Present-day CV due to all sources of variability (*Left*) and climate variability (*Right*). (*Bottom*) Ratio of changes in climate-driven CV following annual mean global warming of 2 °C (*Left*) and 4 °C (*Right*).

Tigchelaar et al. 2018

→ agricultural **trade** may be an important **adaptation** mechanism

- Unexplored dimension: explicitly linking intra- and international markets

Motivation

From **climate change** perspective

- Market-based adaptation
  - Hertel & Lobell (2014): *"When climate change hits a remote rural area particularly hard, the lack of connection to international markets means that prices will rise more sharply and nutrition outcomes will suffer more than under integrated markets (…)"*

- Differentiated risk exposure
  - Stokeld et al. (2020) demonstrate that the exposure to climate change of soy traders in Brazil varies considerably due to different subnational sourcing patterns.

From **economic** perspective

- Welfare effects of international market integration:
  - Fan (2019): *"Ignoring spatial frictions will underestimate trade's impact on the overall inequality and overestimate its impact on the aggregate skill premium"*

- Spatial specialization effects of international market integration:
  - Fajgelbaum and Redding (2014) demonstrate the role of internal trade costs in explaining lower participation of remote areas in world markets in Argentina.

Motivation

Relevance for **African** crop markets:

- Domestic trade costs in Africa are high (Porteous, 2019)
- Africa is already experiencing negative effects from climate change and is most vulnerable to future climate change
  - E.g. Southern Africa had only one normal growing season in past 5 years (WFP, 2020)
- Mixed messages on Trade & CC adaptation in Africa
  - Regional trade enhances resilience to local production shocks: Ahmed et al. 2012; Dorosh et al. 2009
  - Import dependency increases vulnerability to climate-induced supply shocks: Verschuur et al. 2021

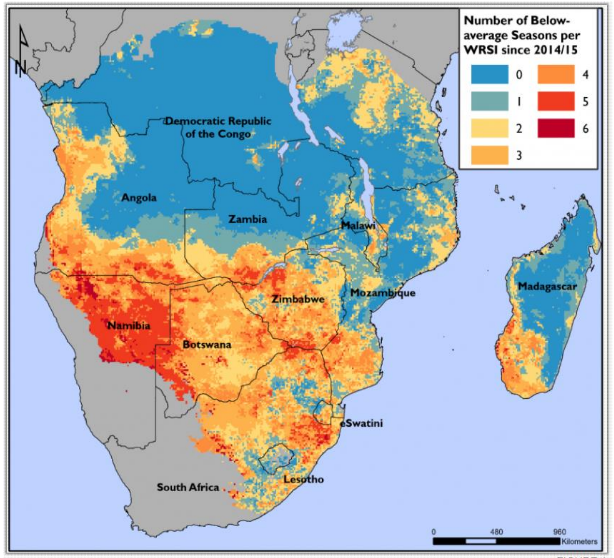


FIGURE 1
Number of below-average seasons between 2014/15 and 2019/20 according to the Water Requirement Satisfaction Index (WRSI)
Source: FEWS NET/USGS CHIRPS

Research question: Can we build a model to explain spatial specialization patterns of crop markets in Africa based on (1) between and within country **variation in yields**, and (2) the size and distribution of **trade costs** between and within countries. What is the implication for CC adaptation through trade?

Methodology

Eaton & Kortum (2002) trade model

- Extension of **Ricardo's theory of comparative advantage** to many countries and a continuum of goods (Allen & Arkolakis, 2016):
  - Trade and specialization based on differences in productivity between countries and goods
  - Changes in trade costs affect extensive margin of trade (# goods traded)

- Main model to study **trade in perfectly competitive markets**, esp. agriculture (Allen & Arkolakis, 2016):
  - International crop trade with a continuum of crops: Reimer & Li (2010), Heerman & Sheldon (2018)
  - Intra-national crop trade with a continuum of varieties: Donaldson (2018)

This study: **international & intra-national crop trade** with crops produced by a **continuum of fields**

EK-type model of intra- and international crop trade

- **Environment**: Finite number of countries S with in each country a finite number of regions R (o for origin, d for destination). Discrete number of crops ω produced in a continuum of fields i in each region.
- **Production**: perfect competitive markets, land sole and immobile factor of production with land rental rate c_o. Spatial variation in $a_{o\omega}(i)$, productivity per unit of land, follows a Fréchet distribution:

$$F_{o\omega}(a) = \Pr(A_{o\omega} \leq a) = e^{-\boldsymbol{T_{o\omega}} a^{-\boldsymbol{\theta_\omega}}}$$

$\boldsymbol{T_{o\omega}}$: average productivity of region o for crop ω (variation across regions and crops)
$\boldsymbol{\theta_\omega}$: heterogeneity of productivity within regions for crop ω (variation across fields)

- **Consumption:** utility maximization, CD preferences over crops ω and CES preferences over fields i
- **Trade**: perfect competitive trading environment with price of crop produced in region o sold in destination market d:

$$p_{od\omega}(i) = \frac{c_o}{a_{o\omega}(i)} \tau_{od\omega}(1 + t_{od\omega})$$

EK-type model of intra- and international crop trade

- Following derivation in EK (2002) and Donaldson (2018):
  - Prices

$$p_{d\omega} = \Gamma(1 + \frac{1}{\theta_\omega}) \left[\sum_{o=1}^{R} T_{o\omega}(c_o \tau_{od\omega}(1 + t_{od\omega}))^{-\theta_\omega} \right]^{-1/\theta_\omega}$$

  - Trade flows

$$\pi_{od\omega} = \frac{X_{od\omega}}{X_{d\omega}} = \frac{T_{o\omega}(c_o \tau_{od\omega}(1 + t_{od\omega}))^{-\theta_\omega}}{\sum_{o=1}^{R} T_{o\omega}(c_o \tau_{od\omega}(1 + t_{od\omega}))^{-\theta_\omega}} \text{ and } \sum_{o} \pi_{od\omega} = 1$$

  - Trade balance

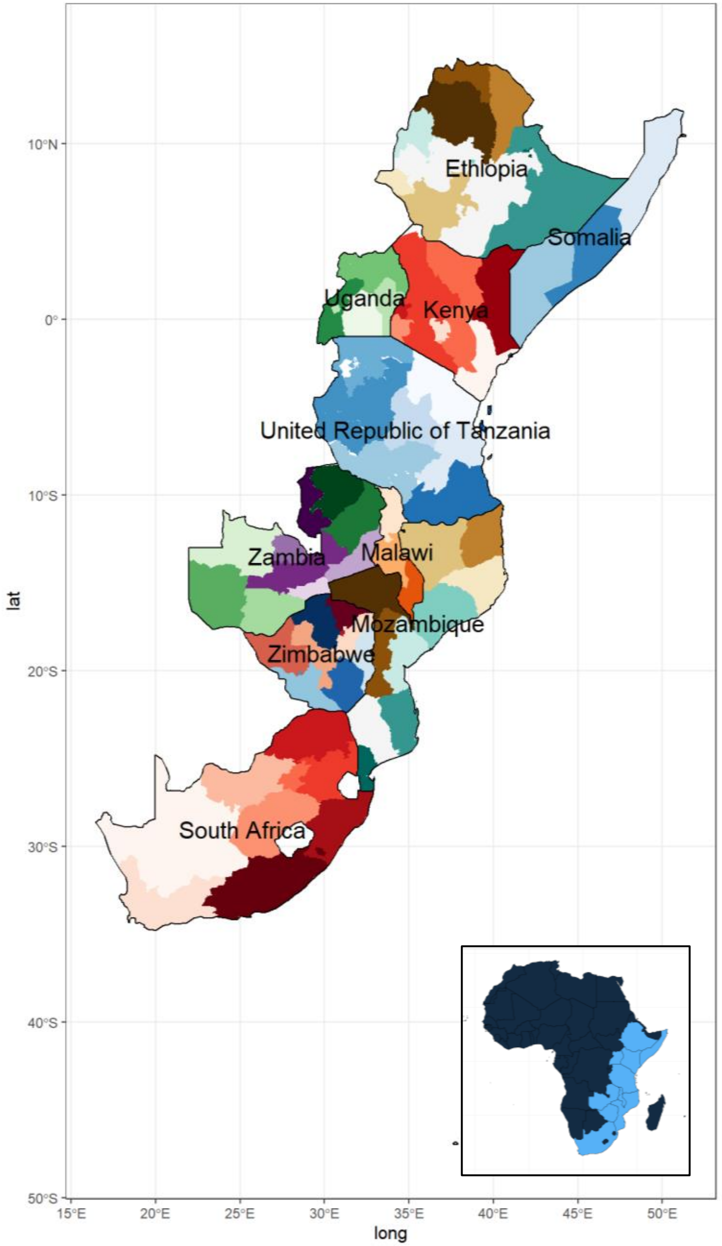
$$c_o L_o = \sum_{d} \sum_{\omega} X_{od\omega} = \sum_{d} \sum_{\omega} \pi_{od\omega} X_{d\omega} = \sum_{d} \sum_{\omega} \pi_{od\omega} \mu_{d\omega} c_d L_d$$

- Solve set of non-linear equations to find $p_{d\omega}$, $\pi_{od\omega}$ and c_o (GAMS, NLP solver)

Data & Assumptions

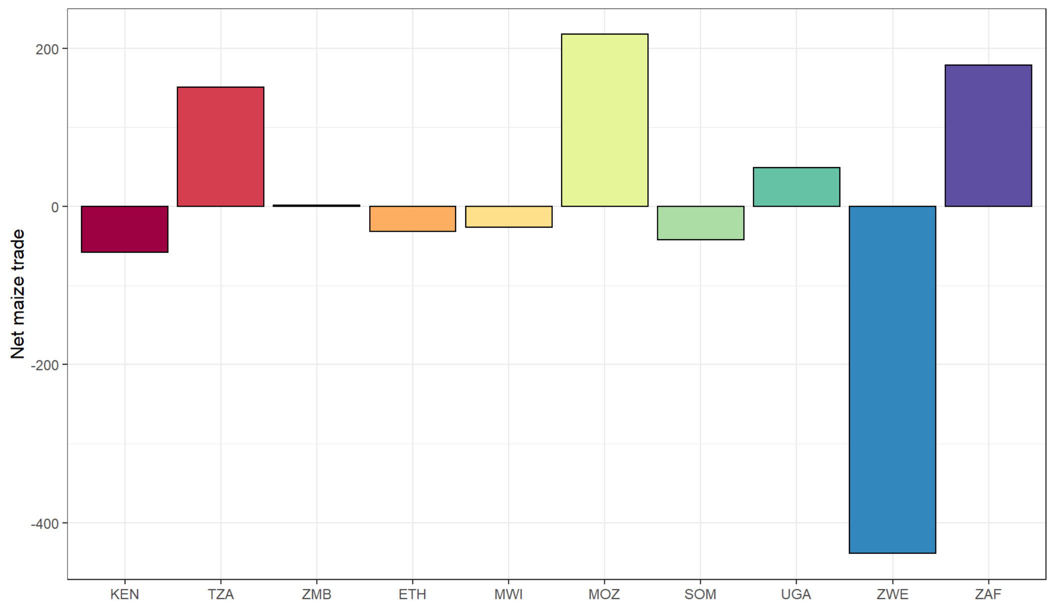
- 10 African countries and 76 administrative regions, maize & rice
- Global gridded agricultural-production maps from SPAM2010 (Yu et al. 2020)
  - Crop yield at pixel level → MLE estimation of θ_ω and $T_{o\omega}$
  - harvested area at pixel level → Land endowment L_o
- Country-level share crop in expenditure ($\mu_{d\omega}$) from FAOSTAT
- Trade costs
  - Distance is shortest route between regions' center points (44 km – 5443 km); distance elasticity φ from Porteous (2019)
  - Ad-valorem border cost 25% (Porteous, 2019) and ad valorem import tariff in 2010 from MacMap CEPII, both implemented as cost-shifters (Felbermayr et al. 2015)

$$\tau_{od\omega} = dist_{od}^{\varphi}$$
$$1 + t_{od\omega} = (1 + border\ cost_{od} * N\ border\ crossings_{od}) * (1 + tariff_{od\omega})$$

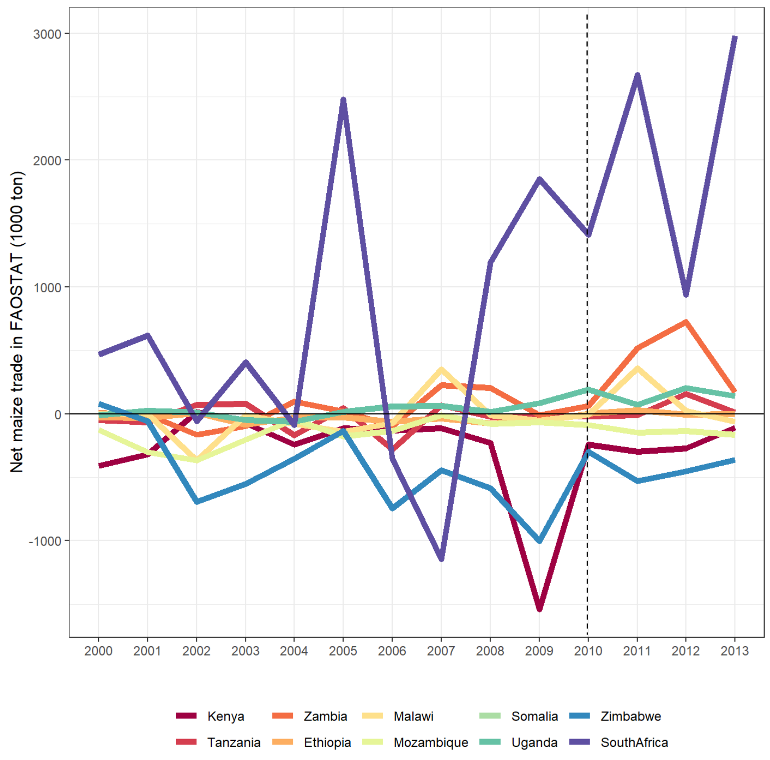


Results: model EQ vs data

MODEL EQ



DATA (2000 – 2013, FAOSTAT)



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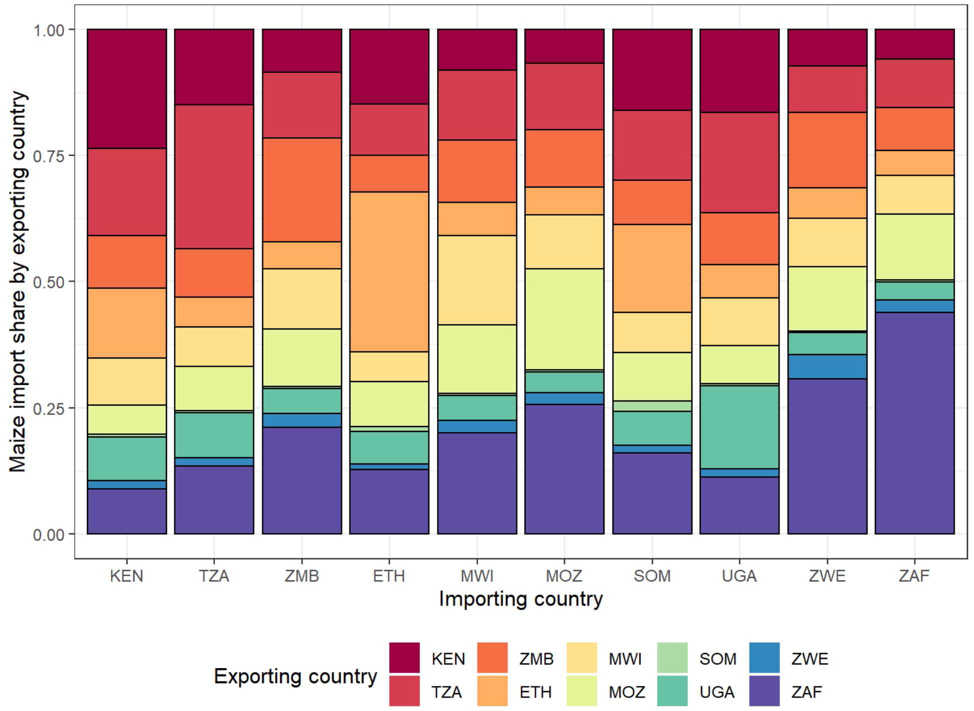
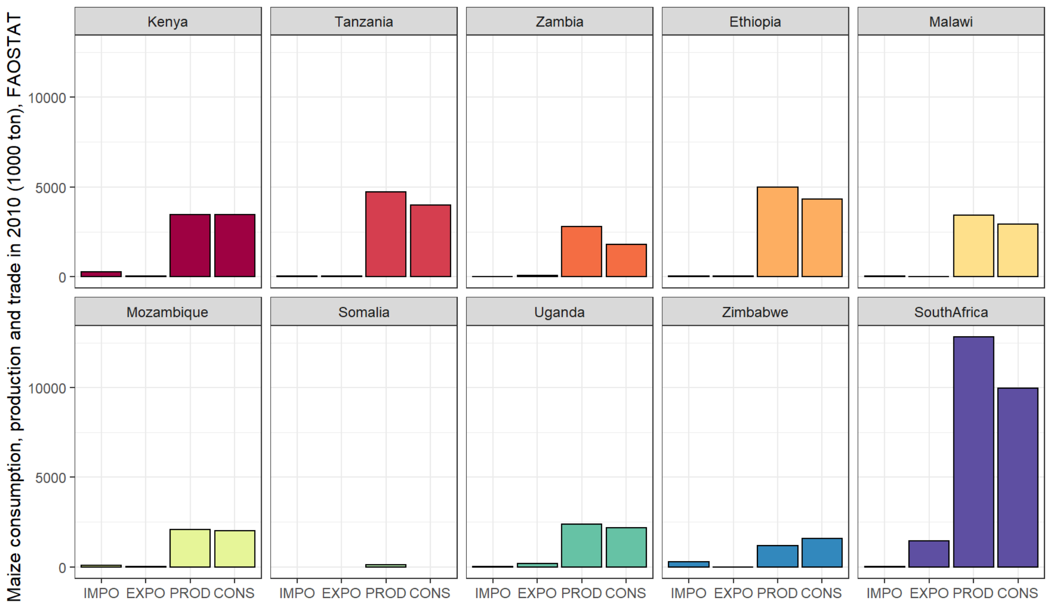
MODEL EQ

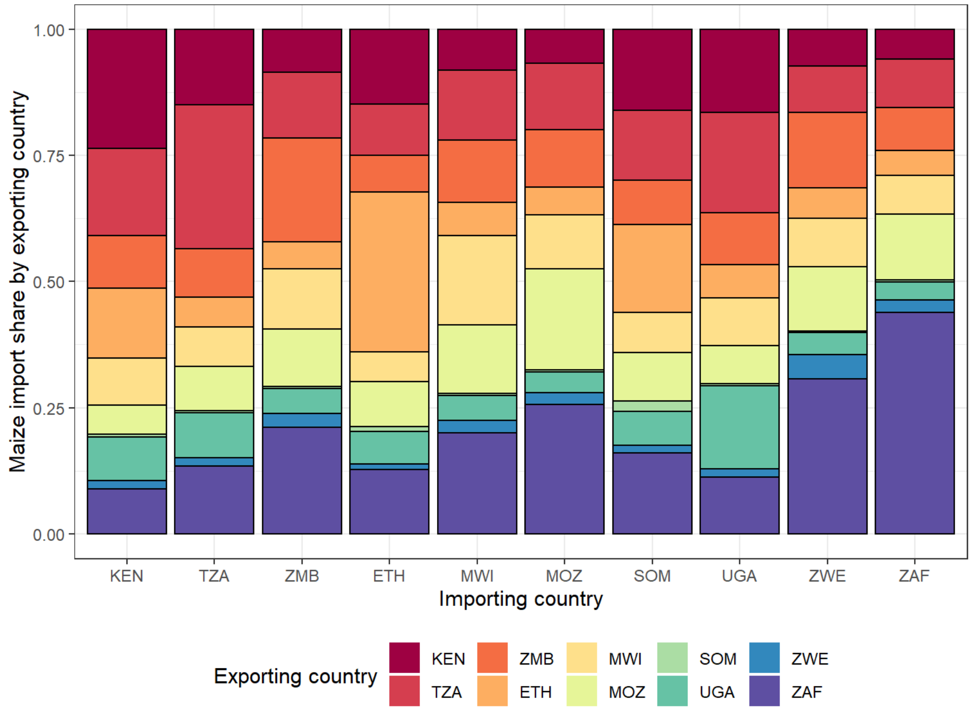


DATA (2008-2012, FAOSTAT)



Results: model EQ vs data

MODEL EQ



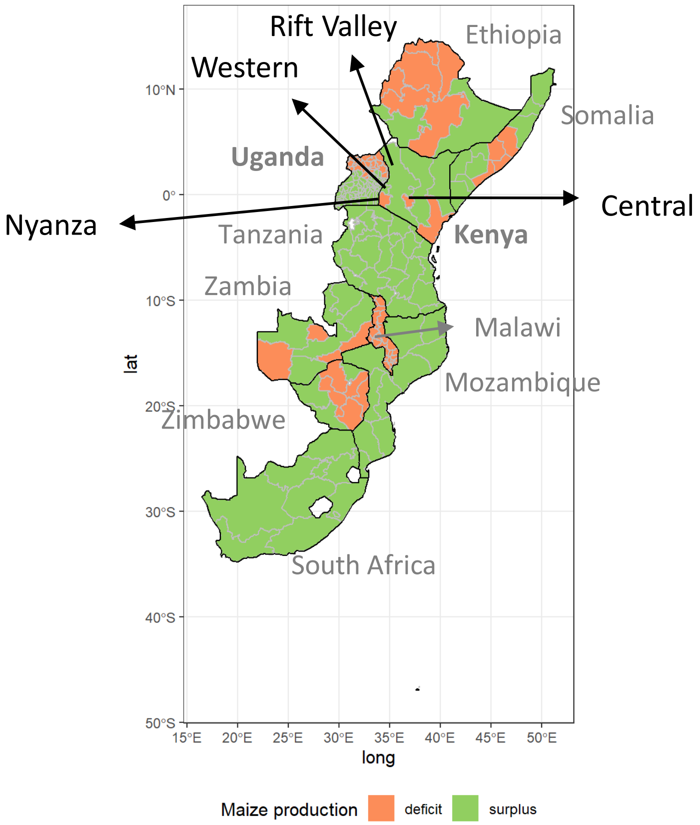
DATA (2008-2012, BACI)

Table: Share of maize imports across exporting countries. ROW versus Eastern and Southern Africa (ESA), and individual countries as share of total ESA imports (BACI trade volume in tons, 2008 - 2012)

Importing country ↓	Exporting region or country											
	ROW	ESA	ESA									
			ETH	KEN	MWI	MOZ	SOM	TZA	UGA	ZMB	ZWE	ZAF
Ethiopia	85%	15%	/	4%	0%	0%	0%	0%	0%	0%	0%	96%
Kenya	26%	74%	0%	/	14%	2%	0%	7%	11%	6%	0%	60%
Malawi	27%	73%	0%	0%	/	59%	0%	1%	0%	13%	0%	27%
Mozambique	5%	95%	0%	0%	8%	/	0%	0%	0%	8%	0%	84%
Somalia	18%	82%	0%	12%	0%	0%	/	11%	4%	0%	0%	73%
Tanzania	38%	62%	0%	14%	2%	3%	0%	/	43%	15%	0%	23%
Uganda	37%	63%	0%	9%	10%	0%	0%	76%	/	3%	0%	2%
Zambia	3%	97%	0%	1%	10%	0%	0%	0%	0%	/	0%	89%
Zimbabwe	1%	99%	0%	0%	23%	1%	0%	0%	0%	32%	/	44%
SACU (ZAF)	52%	48%	0%	0%	1%	12%	0%	0%	0%	85%	3%	/

Results: model EQ vs data

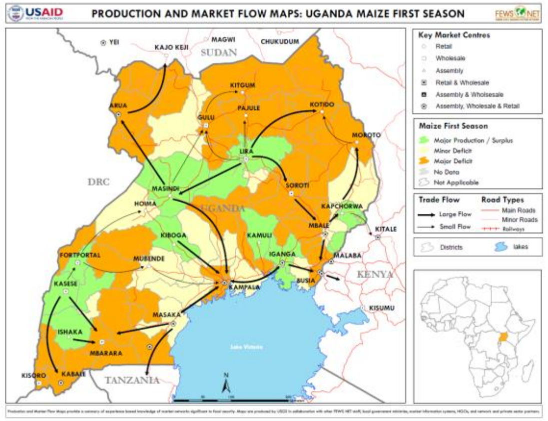
MODEL EQ



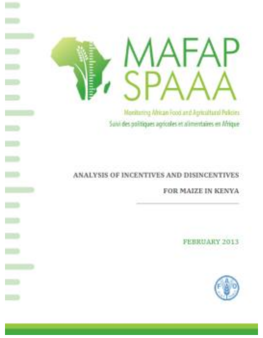
DATA (country studies)

- Uganda

(FEWS, 2011)

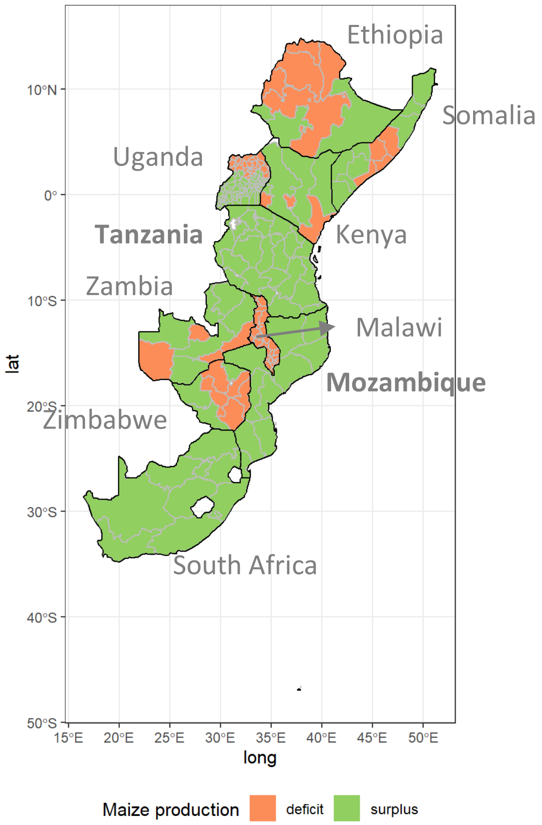


- Kenya
  - Surplus regions: Rift valley, Western
  - Deficit regions: Nairobi, Nyanza



Results: model EQ vs data

MODEL EQ



DATA (country studies)

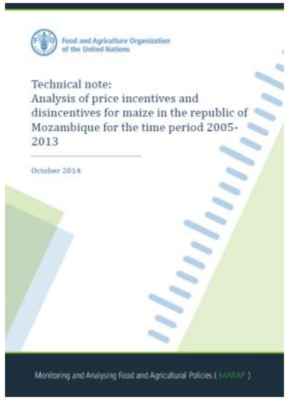
- Tanzania

Figure 1: Maize surplus and deficit regions in Tanzania CGE model

Source: Authors.

(Diao & Kennedy, 2016)

- Mozambique
  - Surplus regions: Central, Northern
  - Deficit regions: Southern

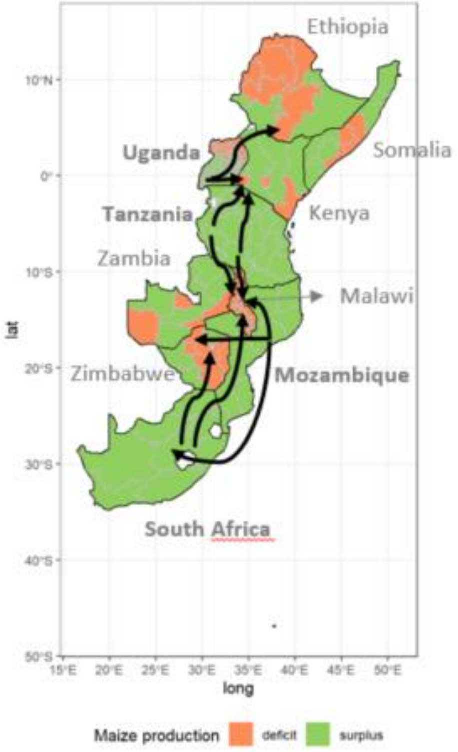


Results: model EQ vs data

MODEL EQ

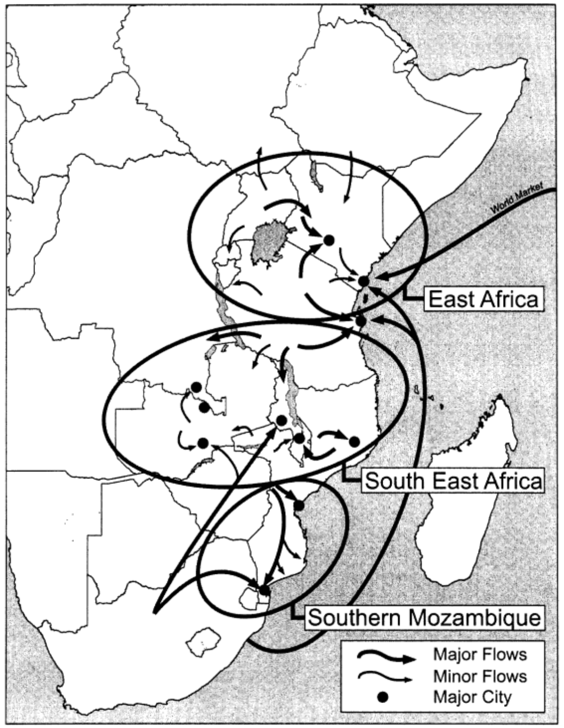
Largest modelled cross-border trade flows from the net exporting countries

- **ZAF** (Free State, Mpumalanga, North-West) to **ZWE** (Mashonaland West, East and Midlands) and **MWI** (Central)
- **MOZ** (Zambezia) to **MWI** (Central), **ZAF** (Free State) and **ZWE** (Mashonaland West)
- **TZA** (Southern Highlands, Western, Lake) to **MWI** (Central) and **KEN** (Nyanza)
- **UGA** (Western, Eastern) to **ETH** (Oromia) and **KEN** (Nyanza)



DATA (World Bank: Haggblade et al. 2008)

Figure 2. Maize Market Sheds in Eastern and Southern Africa



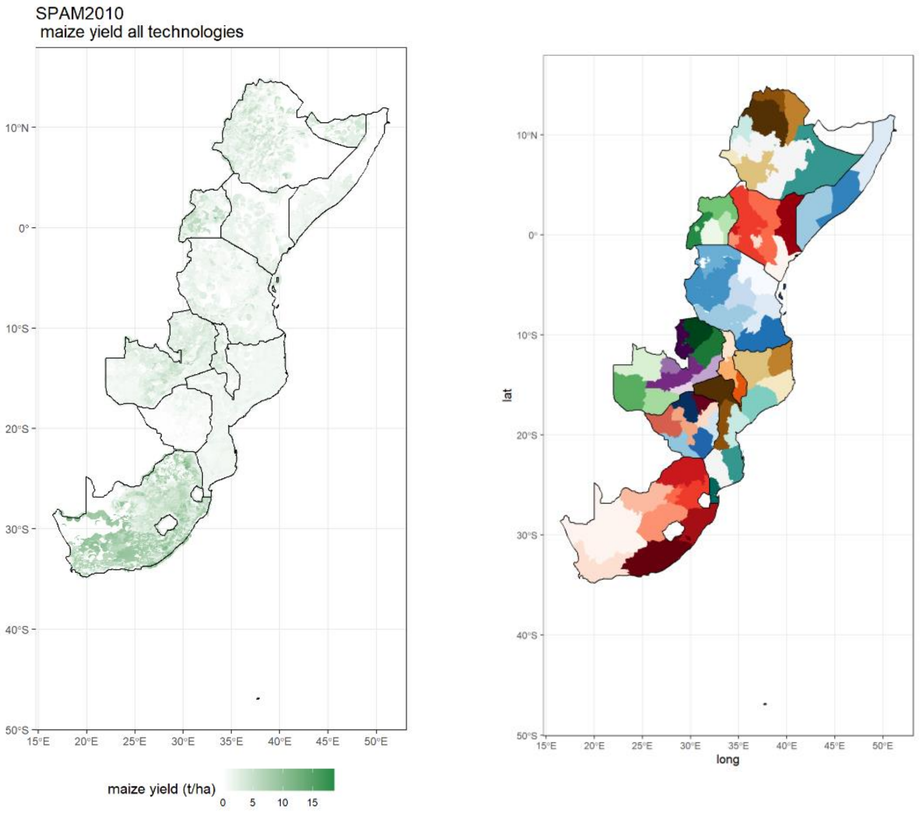
Source: Govereh et al. (2008).

Analysis: reflection on model assumptions

- Fréchet distribution accurate to reflect spatial variation of crop yield within regions?

$$\textit{Fréchet cdf}: \Pr(X \le x) = e^{-\left(\frac{x}{s}\right)^{-\alpha}}$$

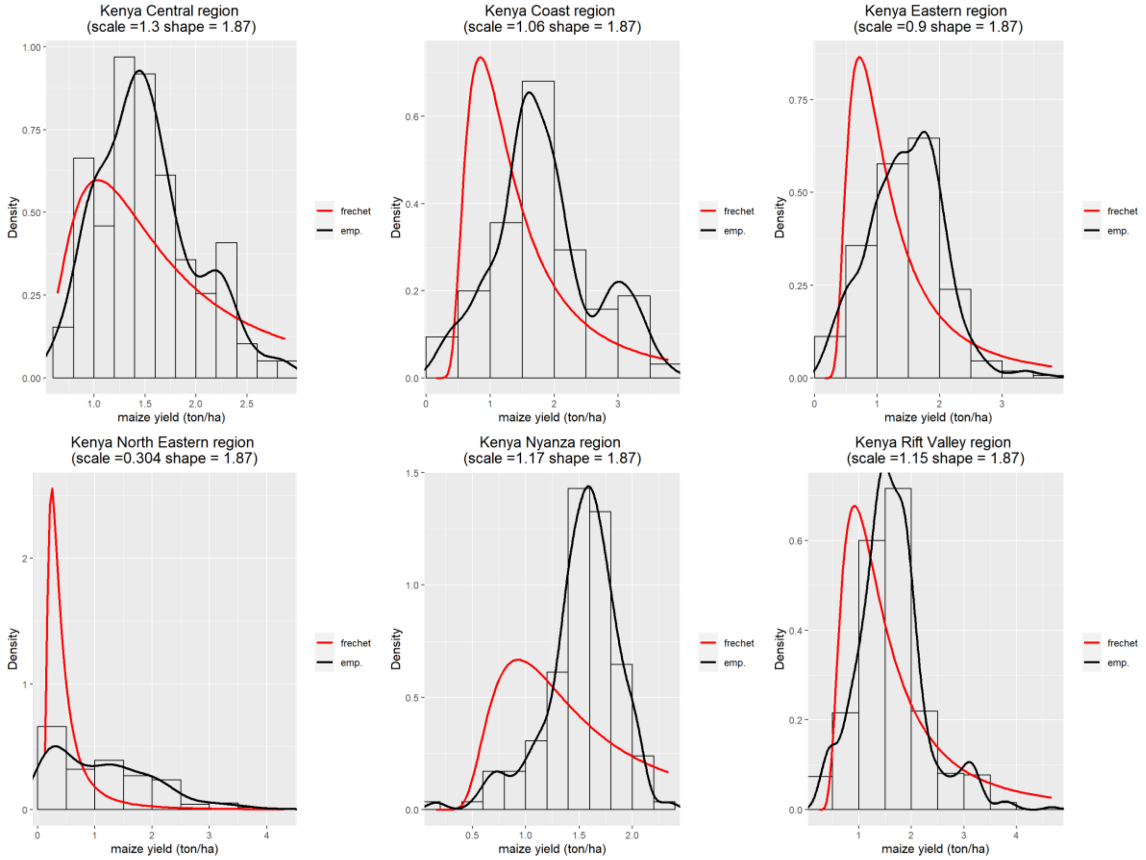
with $\boldsymbol{s}$ *scale and* $\boldsymbol{\alpha}$ *shape parameter*



Analysis: reflection on model assumptions

- Fréchet distribution accurate to reflect spatial variation of crop yield within regions?

Shape parameter <u>constant</u> across regions

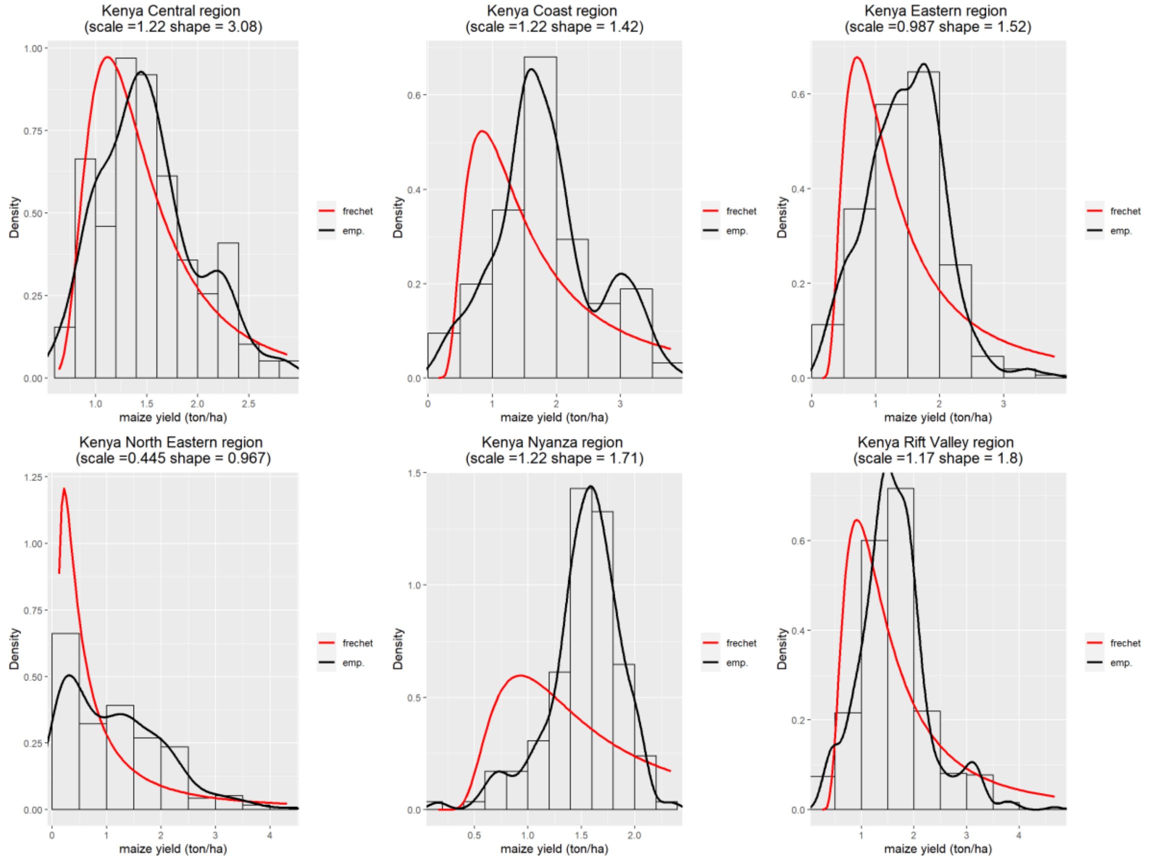


Data: SPAM2010, maize yield, all technologies

Analysis: reflection on model assumptions

- Fréchet distribution accurate to reflect spatial variation of crop yield within regions?

Shape parameter <u>variable</u> across regions



Data: SPAM2010, maize yield, all technologies

Analysis: historical drought event

- In 2009, Kenya experienced a **major drought**. Low rainfalls affected maize yields particularly in Eastern, Coast and part of Rift Valley provinces (GIEWS, 2009). At the national level, maize yield reduced by 29% (FAOSTAT).
- As a response, Kenya waived the import duty (50%) on international maize imports, leading to **huge increase in imports from South-Africa**.
- Yield were also affected in other countries leading to temporary **maize export bans**, including in Kenya’s neighbouring trade partners Tanzania and Uganda (GIEWS country brief, Kenya, 15-September 2009)
- Estimated **3.8 million people** were highly **food insecure** in Kenya

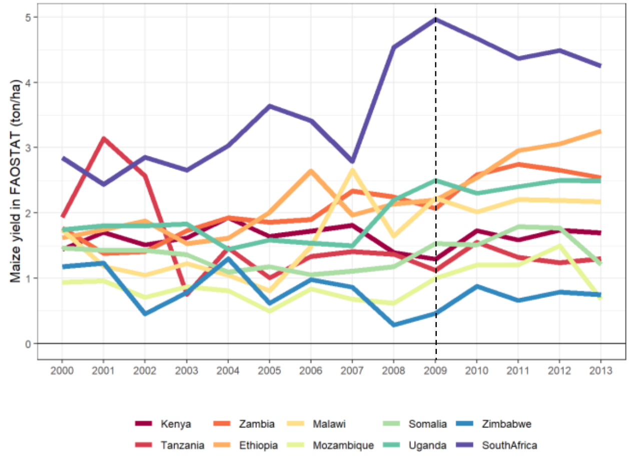
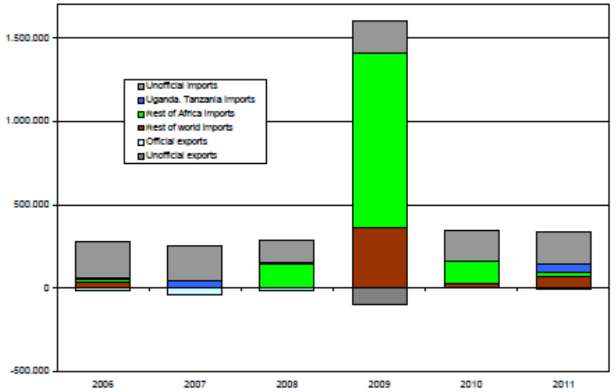


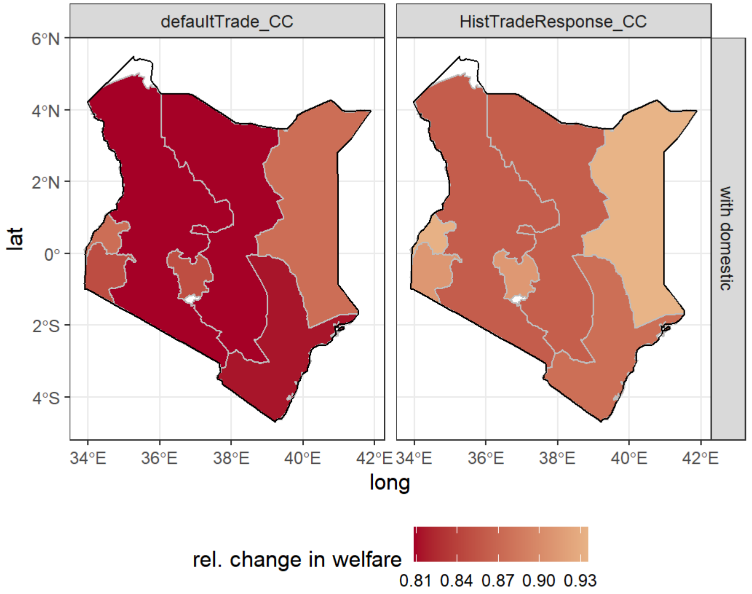
Figure 1: Official and Unofficial Maize Trade in Kenya by Region, 2006 – August 2011 (tonnes)

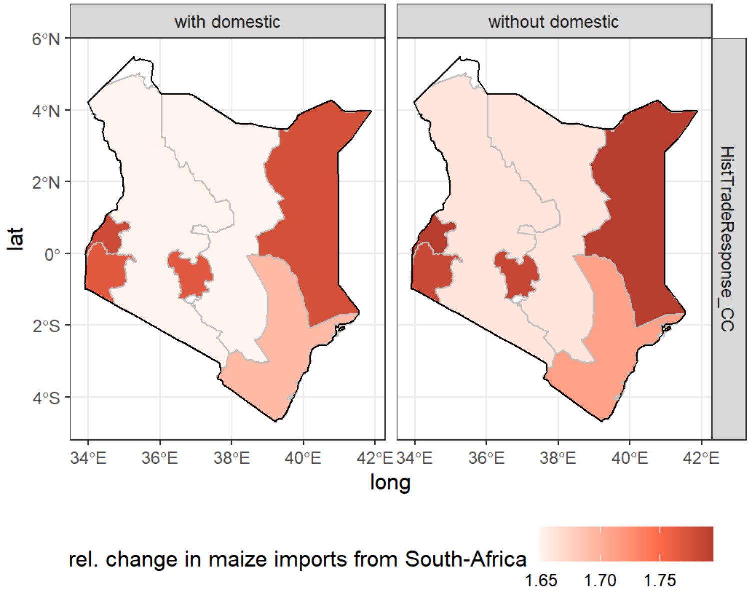


FAO (2012) Analysis of incentives and disincentives for maize in Kenya

Analysis: counterfactual experiment

- 2 counterfactuals (model implementation with or without domestic trade costs)
  - CC: impact drought 2009 on yields
  - CC + TLIB: impact drought 2009 on yields + no import tariff on maize imports in Kenya from South-Africa





Conclusion

- With current model assumptions and scope we reflect specific patterns, but further model refinements are needed to improve match of the full intra-national and international specialization and trade pattern.

- Incorparating intra-national trade and trade costs may affect the role of international trade in CC adaptation. Without representation of sub-national trade, results might be either upward or downward biased.

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