The Impact of Global Warming on Agriculture: A Critique of the Ricardian Approach from a General Equilibrium Perspective

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Motivation

- The Ricardian approach of Mendelsohn, Nordhaus, and Shaw (1994) is the most popular approach for estimating the economic consequences of climate change on agriculture.

- Reduced-form estimation: Cross-section/panel regression of farm land values on climatic variables

- Key insights
  - Avoid focus on big field crops: specialty crops and pastures matter too.
  - Importance of within-country land heterogeneity.

- Blind spots
  - Constant crop prices.
  - International trade.

Existing approaches

- Production function
  - Adaptation by changes in crop varieties, planting/harvesting dates, etc. at constant crop mix.
  - From crop models or econometrics.
  - Attacked by Mendelsohn, Nordhaus, and Shaw (1994): “dumb farmer scenario”.
- Supply-side — Ricardian approach being the most popular.
  - Account for farmers’ adaptation at constant prices.
  - With rare exceptions (EU, a few SSA countries), at the country level.
  - Emphasis on within-country heterogeneity
- Equilibrium model
  - Account for market-mediated adaptations, including farmers’ adaptation.
  - Global models with, for most papers, little within country heterogeneity.
  - Emphasis on between-country heterogeneity

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- This paper builds on Gouel and Laborde (2018):
  - Quantitative trade model accounting for within- and between-country heterogeneity
  - Able to mimic a Ricardian approach and to show under which conditions it provides a good approximation of true welfare changes

Textbook examples

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Notations:

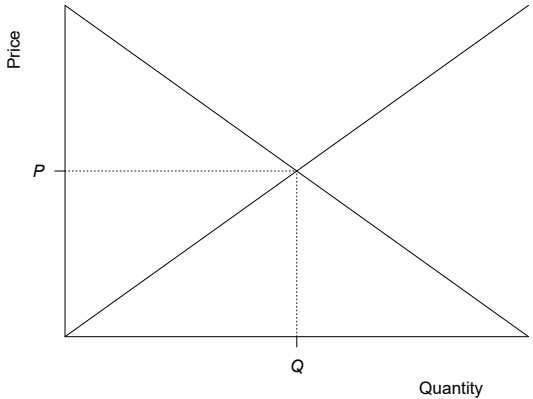
- Counterfactual values after climate change of a variable x are denoted as x'.
- Counterfactual values under the Ricardian approach are denoted x^*.
- Welfare changes decomposition:

$$\Delta W = \Delta W^* + \text{Bias}.$$

- Climate change is a shock δ to supply curve intercept or productivity shifters
  - $\delta = 1 \Rightarrow$ no shock.

Single country model

- Ex. from Mendelsohn and Nordhaus (1996) in a response to Cline's (1996) critic.
- $\eta, \epsilon > 0$: supply and demand elasticities.



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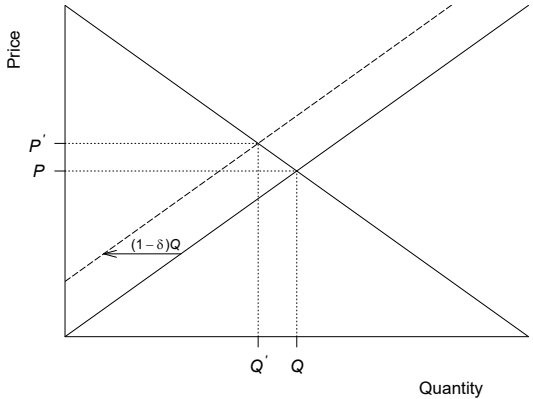

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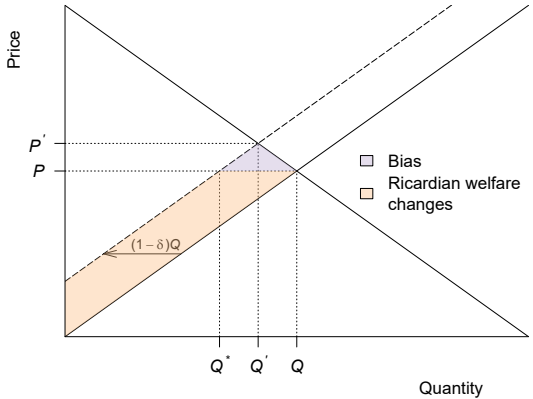

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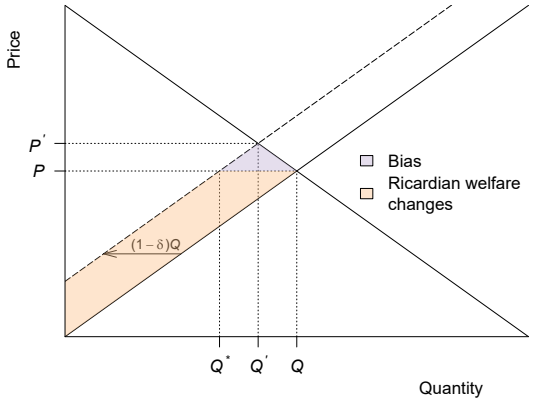

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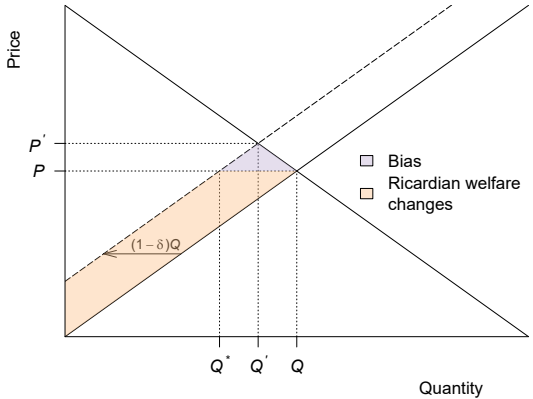
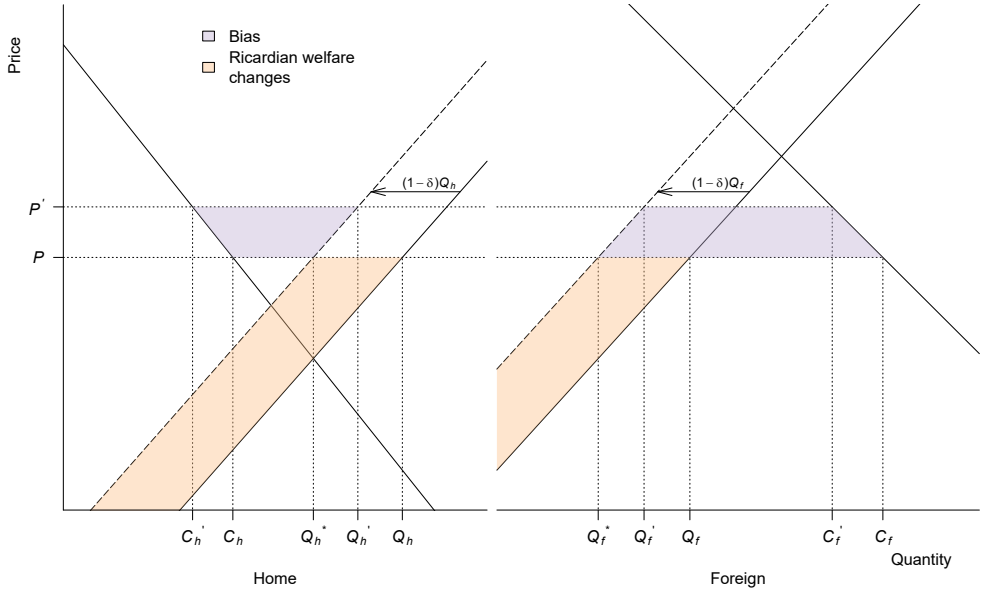
- $\lim_{\epsilon \to 0 \text{ or } \eta \to \infty} \text{Bias}/\Delta W = (1-\delta)/2$.



Two-country model



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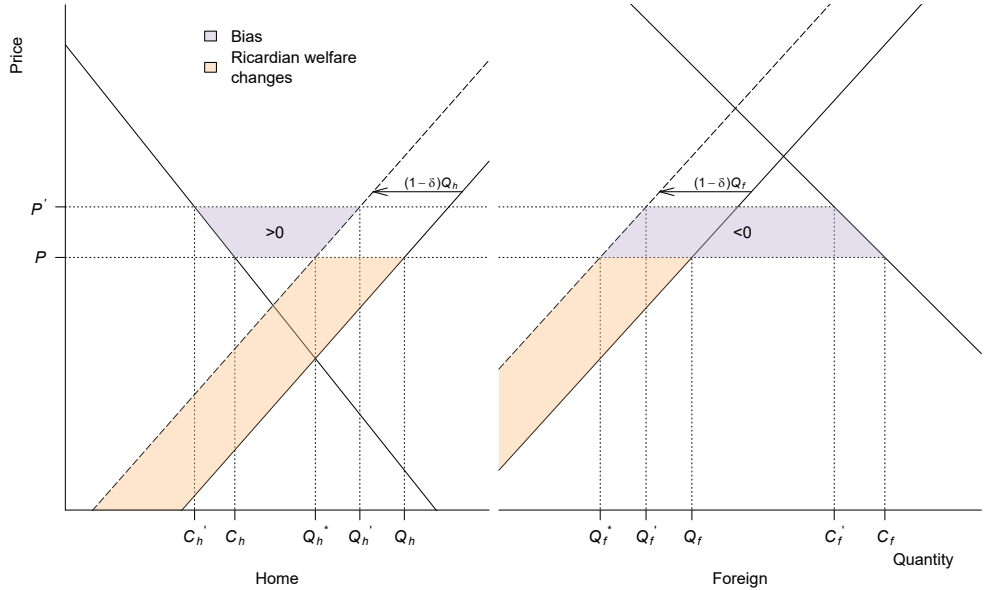

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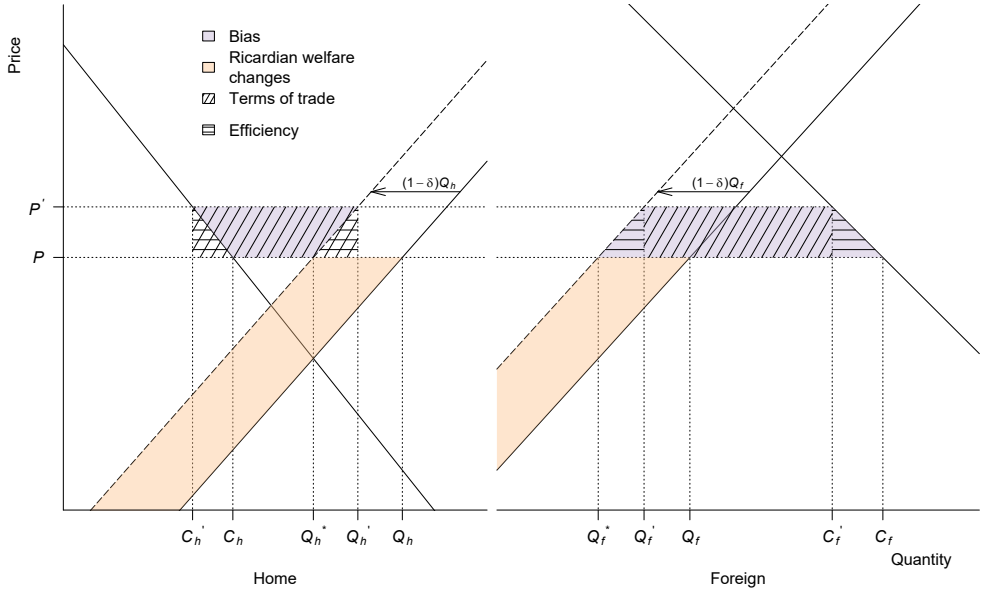
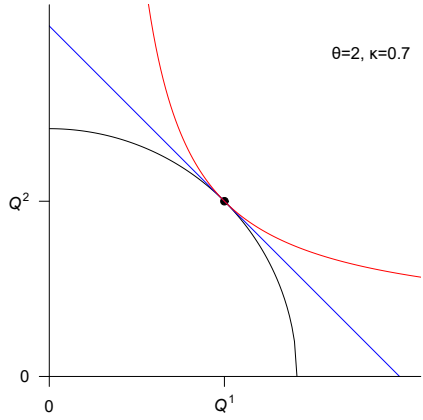


Two-crop model

- Closed economy general equilibrium model
- 2 crops: $k = 1, 2$
- 1 factor of production: land, with fixed endowment.
- CES preferences with elast. κ.
- Heterogeneity of land with param. θ.
- Relative bias (α^k initial budget shares):

$$\frac{\text{Bias}}{\Delta W} = 1 - \frac{\left[\sum_{k=1}^{2} \alpha^k \left(\delta^k\right)^{\theta}\right]^{1/\theta} - 1}{\left[\sum_{k=1}^{2} \alpha^k \left(\delta^k\right)^{1/[1/\theta+1/(\kappa-1)]}\right]^{1/\theta+1/(\kappa-1)} - 1}$$



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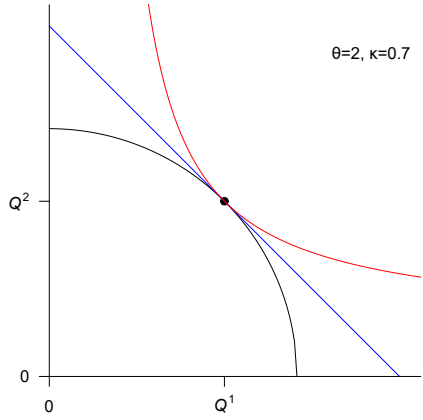
$\frac{\text{Bias}}{\Delta W} \geq 0 \Rightarrow$ under-evaluation of welfare losses.



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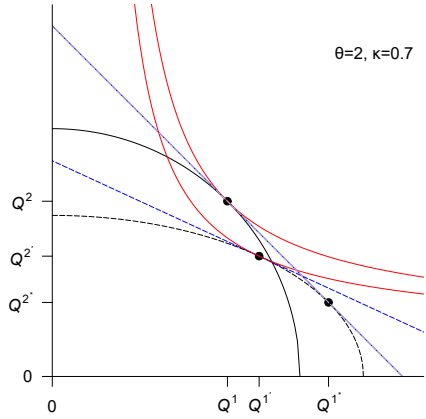

$\Delta W = -11.4\%$

$\text{Bias}/\Delta W = 100\%$

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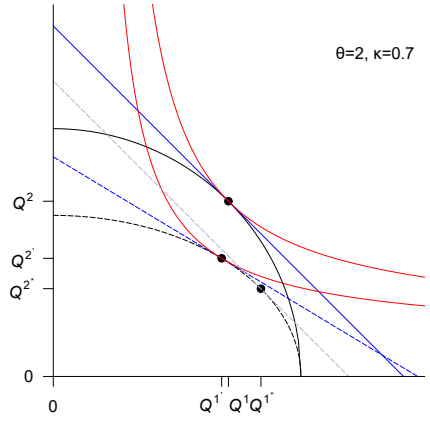

$\Delta W = -20.0\%$

$\text{Bias}/\Delta W = 21.8\%$

Model

Model setup

A static general equilibrium Armington trade model

- 50 countries, indexed $i \in \mathcal{I}$
- 3 types of good, indexed $k \in \mathcal{K}$
  - 35 crops, $k \in \mathcal{K}^c \subset \mathcal{K}$
  - 1 livestock sector, $k = l$
  - 1 outside good, $k = 0$
- 2 factors of production
  - Labor: endowment N_i
  - Land
    - 11,801 fields (1 degree), indexed $f \in \mathcal{F}_i$
    - No possibility to expand over non-agricultural land use

International trade

- Armington for all agricultural products except grass (non-tradable)
  - Elasticity σ.
- Iceberg trade costs
- No trade policy
- Outside good is freely traded

Model setup

Crops production

- Each field f of area s_i^f composed of a continuum of parcels indexed by $\omega \in [0, 1]$.

- Substitutability between land and labor:

$$Q_i^{fk}(\omega) = \left[\left(A_i^{fk}(\omega) L_i^{fk}(\omega) \right)^{(\eta-1)/\eta} + \left(A_i^{Nk} N_i^{fk}(\omega) \right)^{(\eta-1)/\eta} \right]^{\eta/(\eta-1)},$$

  - Grass (pastures) does not require any labor so default choice.

- Productivity shifter of land: $A_i^{fk}(\omega) \sim$ Fréchet with shape $\theta > 1$ and scale $\gamma A_i^{fk} > 0$
  - $\Rightarrow A_i^{fk} = \mathrm{E}[A_i^{fk}(\omega)]$

Model setup

Final demand

- Quasi-linear utility with respect to aggregate agricultural good consumption (price P_i)

$$U_i = C_i^0 + \beta_i^{1/\epsilon} \begin{cases} C_i^{1-1/\epsilon} / (1 - 1/\epsilon) & \text{if } \epsilon \neq 1, \\ \ln C_i & \text{if } \epsilon = 1, \end{cases}$$

- CES function between agricultural products

$$C_i = \left[\sum_{k \in \mathcal{K}^a} \left(\beta_i^k \right)^{1/\kappa} \left(C_i^k \right)^{(\kappa-1)/\kappa} \right]^{\kappa/(\kappa-1)}.$$

Model setup

Non-crop supply

- Outside good (numeraire): produced using labor only
- Livestock production
  - Leontief function of feed and labor

$$Q_i^{\mathrm{l}} = \min\left(\frac{x_i}{\mu_i}, \frac{N_i^{\mathrm{l}}}{\nu_i^{\mathrm{l}}}\right),$$

  - Feed = CES function of crops (including grass)

$$x_i = \left[\sum_{k \in \mathcal{K}^c} \left(\beta_i^{k,\mathrm{feed}}\right)^{1/\varsigma} \left(x_i^k\right)^{(\varsigma-1)/\varsigma}\right]^{\varsigma/(\varsigma-1)}.$$

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  - p_i^k: producer price
  - r_i^k: index of land rents

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- Ricardian production under climate change

$$Q_i^{fk*} = s_i^f A_i^{fk\prime} \underbrace{\left[\frac{\left(r_i^k A_i^{fk\prime}\right)^\theta}{\sum_{l \in \mathcal{K}^c} \left(r_i^k A_i^{fl\prime}\right)^\theta}, \right]}_{=\pi_i^{fk*}}^{(\theta-1)/\theta} \left(\frac{r_i^k}{p_i^k}\right)^\eta.$$

Welfare measures

Equivalent variation

$$\Delta W_j = \underbrace{R_j\left(\hat{R}_j - 1\right)}_{\text{Producer surplus}} \underbrace{- P_j C_j \begin{cases} (\hat{P}_j^{1-\epsilon} - 1)/(1-\epsilon) & \text{if } \epsilon \neq 1, \\ \ln \hat{P}_j & \text{if } \epsilon = 1. \end{cases}}_{\text{Consumer surplus}}$$

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Ricardian approach

$$\begin{aligned} \Delta W_j^* &= \sum_{k \in \mathcal{K}^c} R_j^{k*} - R_j^k \\ &= \sum_{f \in \mathcal{F}_j, k \in \mathcal{K}^c} s_j^f r_j^k \left[A_j^{fk\prime} \left(\pi_j^{fk*}\right)^{(\theta-1)/\theta} - A_j^{fk} \left(\pi_j^{fk}\right)^{(\theta-1)/\theta} \right]. \end{aligned}$$

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= Productivity component of first-order approximation of ΔW_j.

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$$\begin{aligned} \Delta W_j^* &= \sum_{k \in \mathcal{K}^c} R_j^{k*} - R_j^k = \left(\delta_j^* - 1\right) R_j, \\ &= \sum_{f \in \mathcal{F}_j, k \in \mathcal{K}^c} s_j^f r_j^k \left[A_j^{fk\prime} \left(\pi_j^{fk*}\right)^{(\theta-1)/\theta} - A_j^{fk} \left(\pi_j^{fk}\right)^{(\theta-1)/\theta} \right]. \end{aligned}$$

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Calibration

Behavioral parameters

Param.	Interpretation	Target/Source
$\epsilon = 0.5$	Elasticity of food demand	Comin et al. (2015)
$\kappa = 0.6$	Subst. elast. between food products	Typical food demand elasticity in the literature (Muhammad et al., 2011)
$\varsigma = 0.9$	Subst. elast. between feed crops	Rude and Meilke (2000)
$\sigma = 5.4$	Armington elasticity	Costinot et al. (2016)
$\eta = 0$	Subst. elast. between land and non-land inputs	Berry and Schlenker (2011)
$\theta = 1.1$	Shape of the Fréchet distribution	Supply elast. of 0.4 for US maize and soybean (Miao et al., 2016)

Calibration

Initial equilibrium

Var.	Interpretation	Target/Source
A_i^{fk}	Land productivity shifter	Crop potential yield from GAEZ project
$p_i^k Q_i^k$	Value of production	FAOSTAT for crops, except grass, and GTAP 9.2 for the rest
R_i^k	Land rents	$p_i^k Q_i^k$ times share of land in production costs from GTAP
X_{ij}^k	Value of imports	FAOSTAT for crops and GTAP for livestock
$P_i^k x_i^k$	Value of feed consumption	FAOSTAT, except for grass from GTAP
$P_j^k C_j^k$	Value of consumption	FAOSTAT for crops and GTAP for livestock
r_i^k	Price index of land rents	From FOC using A_i^{fk} and R_i^k
π_i^{fk}	Land-use shares	From FOC using r_i^k and A_i^{fk}

Results

Welfare results

Region	Net ag. trade as % of ag. prod. (1)	Land rents as % of GDP (2)	$\delta_j - 1$ (%) (3)	$\delta_j^* - 1$ (%) (4)	Welfare change (% of GDP) Production fn. (5)	Ricardian (6)	Exact (7)	$\text{Bias}_j / \Delta W_j$ (%) (8)
Asia	−5.93	1.82	−8.84	15.90	−0.16	0.29	−1.73	116.74
CIS	−1.68	0.77	−2.76	9.84	−0.02	0.08	−0.70	110.76
Europe	−5.15	0.25	−10.67	0.04	−0.03	0.00	−0.80	100.01
Latin America	23.86	0.80	−34.47	−31.12	−0.28	−0.25	0.18	237.45
Middle East and North Africa	−38.46	0.29	−26.01	−19.17	−0.08	−0.06	−2.41	97.66
Northern America	16.47	0.25	−16.06	−3.75	−0.04	−0.01	−0.16	94.15
Oceania	37.30	0.35	−20.91	−18.55	−0.07	−0.06	0.23	127.62
Sub-Saharan Africa	−3.09	1.38	−39.87	−35.81	−0.55	−0.49	−6.58	92.49
World	0	0.78	−13.18	5.77	−0.10	0.04	−1.00	104.47

Welfare results

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Asia	−5.93	1.82	−8.84	15.90	−0.16	0.29	−1.73	116.74
CIS	−1.68	0.77	−2.76	9.84	−0.02	0.08	−0.70	110.76
Europe	−5.15	0.25	−10.67	0.04	−0.03	0.00	−0.80	100.01
Latin America	23.86	0.80	−34.47	−31.12	−0.28	−0.25	0.18	237.45
Middle East and North Africa	−38.46	0.29	−26.01	−19.17	−0.08	−0.06	−2.41	97.66
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Welfare results

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- Under-evaluation of welfare losses in average

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World	0	0.78	−13.18	5.77	−0.10	0.04	−1.00	104.47

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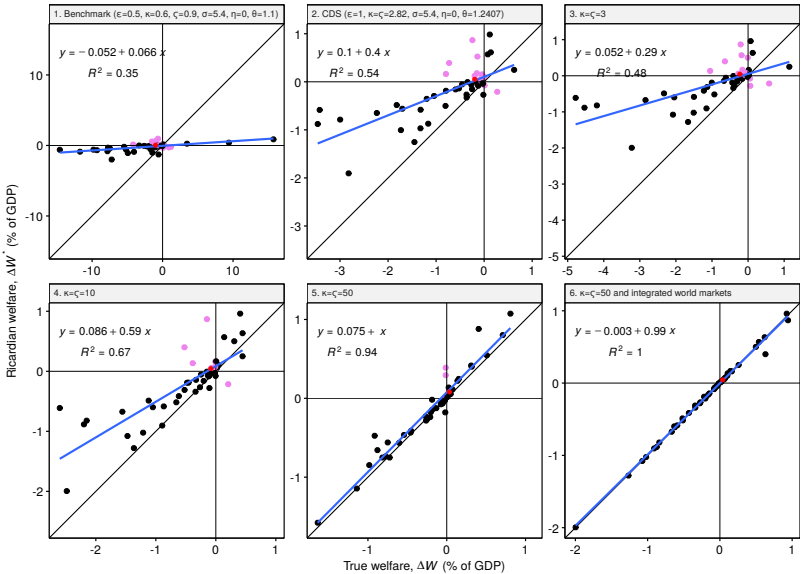
- Large bias

- Wrong welfare signs
- Under-evaluation of welfare losses in average
- Strong role for terms of trade

Role of demand parameters

Other params



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  - No need to combine results from crop models with an equilibrium model that depends on many parameters
  - Focus on ag. land market adjustment to climate change neglecting equilibrium on crop market

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  - No need to combine results from crop models with an equilibrium model that depends on many parameters
  - Focus on ag. land market adjustment to climate change neglecting equilibrium on crop market

- Cost of this simplicity
  - Under-estimate cost of climate change (in average): because of the assumption that crops are perfectly substitutable.
  - But over-estimate for food exporting countries, because of neglect of terms-of-trade changes.
  - Low correlation between exact and Ricardian welfare change
  - Several countries with welfare changes of the wrong sign.

Welfare results with CDS calibration

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Asia	−5.93	1.82	−8.87	17.10	−0.16	0.31	−0.24	228.41
CIS	−1.68	0.77	−3.03	9.61	−0.02	0.07	−0.07	198.50
Europe	−5.15	0.25	−10.73	−0.35	−0.03	−0.00	−0.12	99.23
Latin America	23.86	0.80	−34.54	−29.84	−0.28	−0.24	−0.20	−21.39
Middle East and North Africa	−38.46	0.29	−26.07	−18.05	−0.08	−0.05	−0.46	88.56
Northern America	16.47	0.25	−16.33	−3.73	−0.04	−0.01	−0.03	72.21
Oceania	37.30	0.35	−20.69	−17.54	−0.07	−0.06	−0.01	−868.16
Sub-Saharan Africa	−3.09	1.38	−40.35	−34.27	−0.56	−0.47	−2.22	78.65
World	0	0.78	−13.25	6.70	−0.10	0.05	−0.20	126.53

Role of remaining parameters

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