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

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NBER — April 30, 2020

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 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.
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A modern equilibrium model

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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

Not a new critic

- Cline (1996): Ricardian approach is biased because it neglects price changes.
  - Dismissed by Mendelsohn and Nordhaus (1996) based on a simple S/D model.
- General equilibrium models have shown the importance of terms-of-trade effects (Darwin et al., 1995; Gouel and Laborde, 2018; Baldos et al., 2019)

Ricardian approach

Key papers

Article	GS (April, 2020)
Mendelsohn, Nordhaus, and Shaw (1994), AER	2,045
Deschênes and Greenstone (2007), AER	1,290
Schlenker, Hanemann, and Fisher (2005), AER	593
Kurukulasuriya et al. (2006), WBER	496

Textbook examples

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Notations:

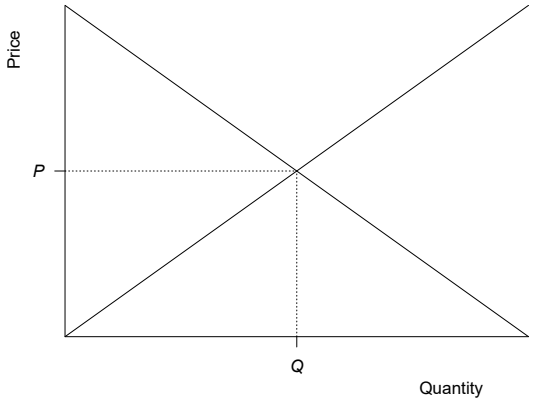
- Counterfactual values after climate change of a variable x are denoted as x'.
- Counterfactual values under the Ricardian approach are denoted x^*.
- Welfare changes decomposition:

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

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

Single country model

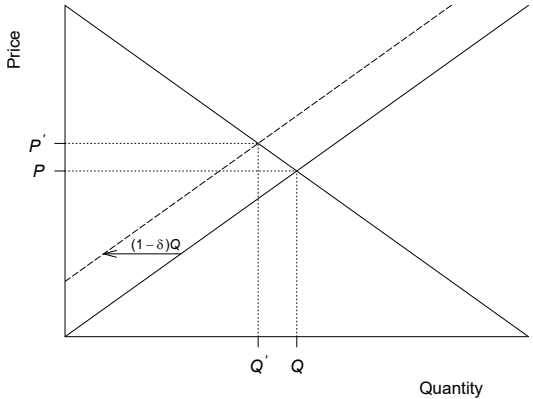
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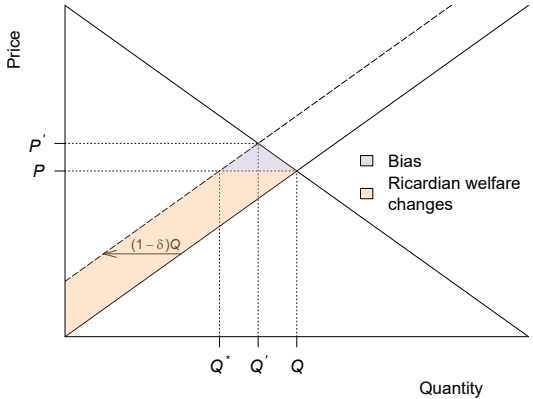
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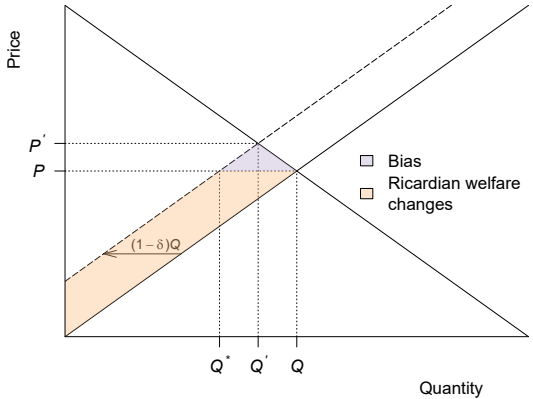
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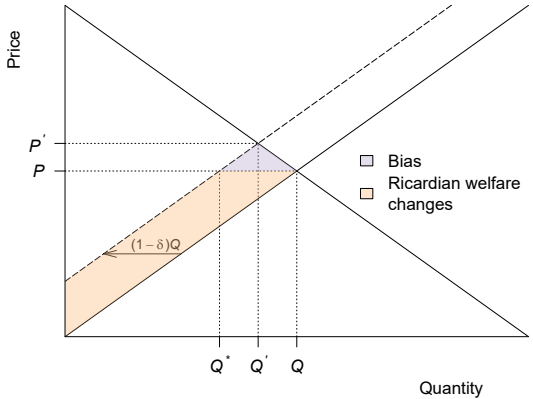


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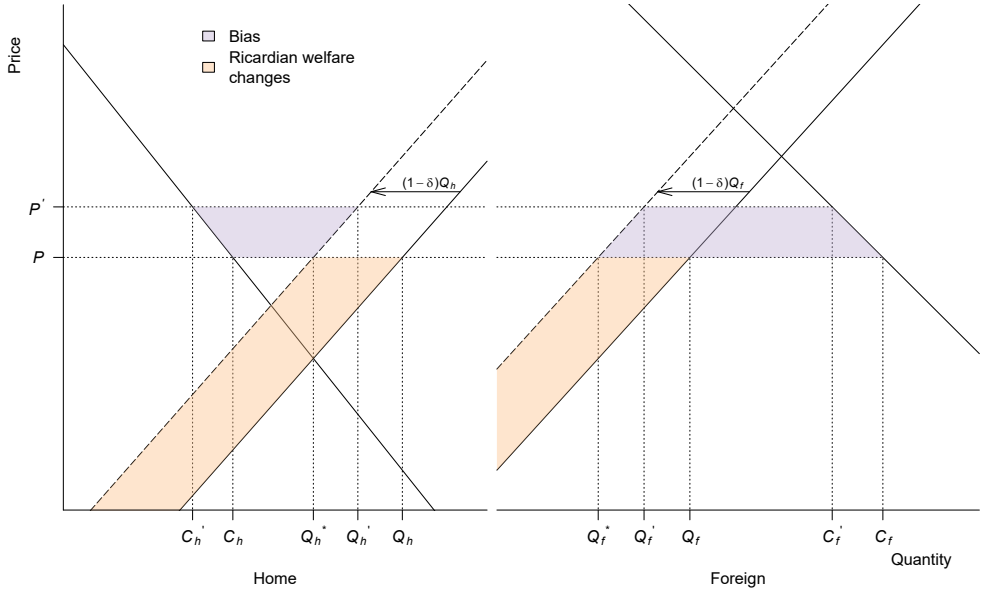
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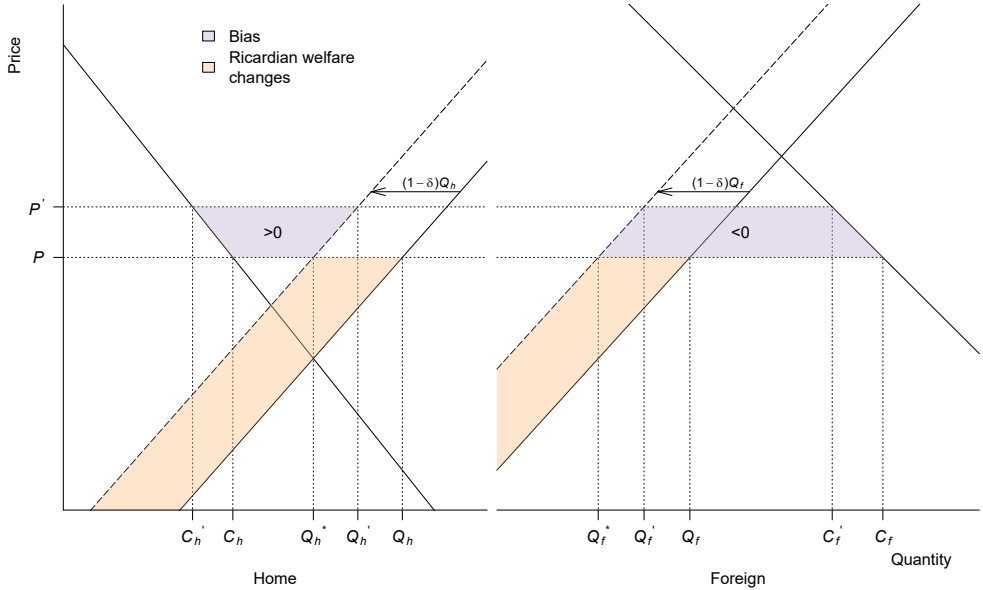
- $\lim_{\epsilon=0,\eta\to\infty} \text{Bias}/\Delta W = (1-\delta)/2$.



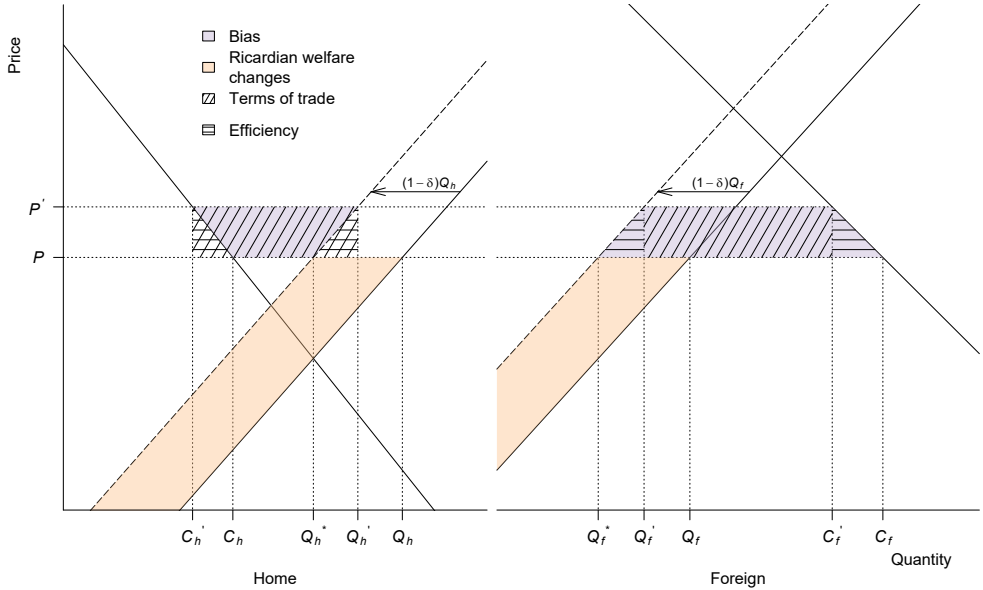
Two-country model



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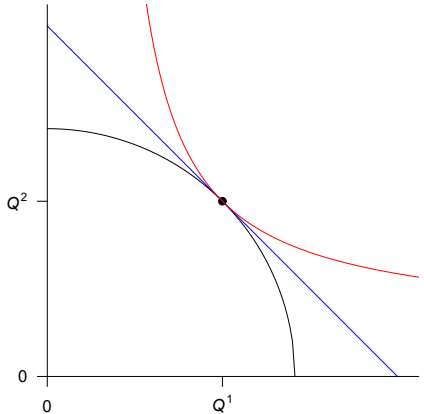
Two-country model



Two-crop model

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

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

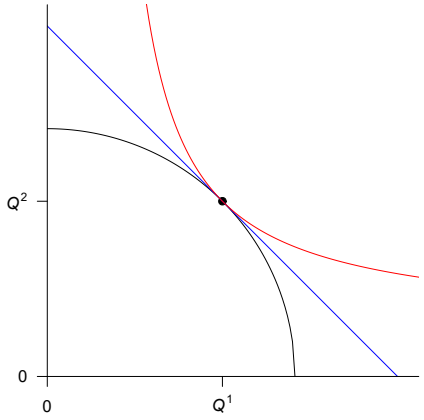


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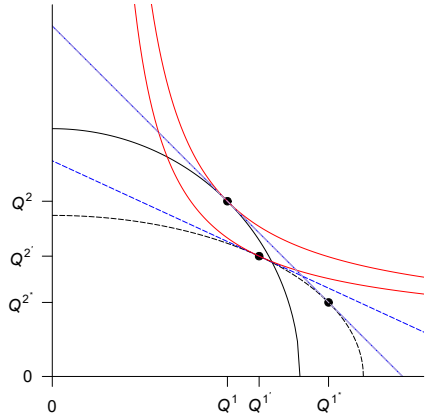


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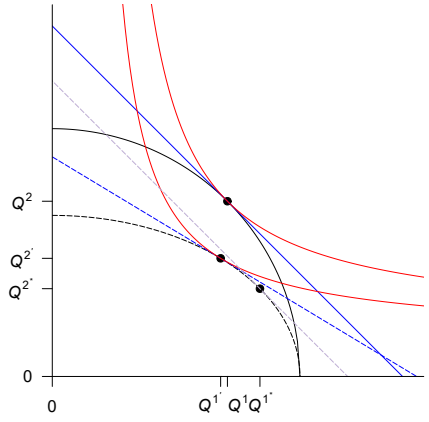
$\Delta W = -11.4\%$
$\text{Bias}/\Delta W = 100\%$

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$\Delta W = -20.0\%$

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

Insights from textbook examples

- Small under-evaluation of welfare losses because of the neglect of the overall supply and demand reaction (ϵ and η).

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- Potentially large under-evaluation of welfare losses because of the neglect of the imperfect substitutability of food products (κ).
- Over-evaluation of welfare losses for food-exporting countries and under-evaluation for food-importing countries because of terms-of-trade changes.
  - But terms-of-trade changes cancel globally.

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

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

- 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
  - Feed = CES function of crops (including grass)

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

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- Ricardian production under climate change

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

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

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= Productivity component of first-order approximation of ΔW_j.

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Ricardian approach

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

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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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- Large bias;
- Wrong welfare signs;

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- Wrong welfare signs;
- Under-evaluation of welfare losses in average;

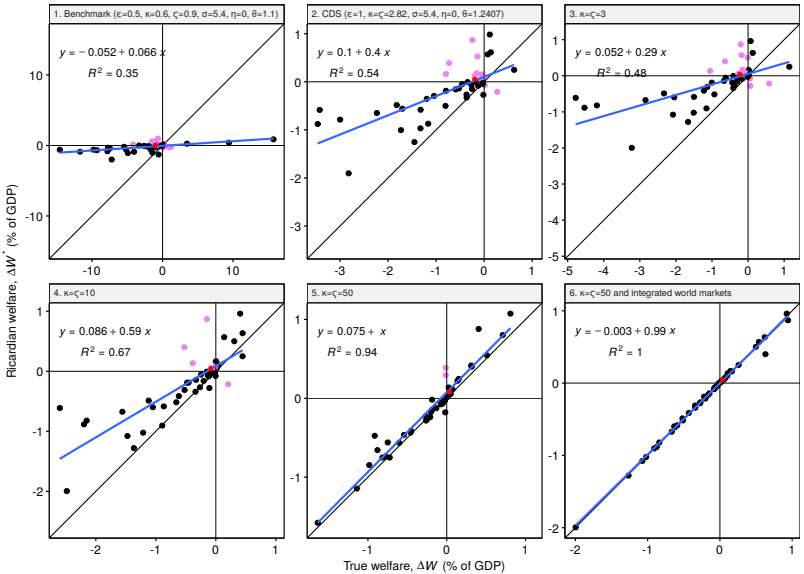
Welfare results

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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



Conclusion

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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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