Measuring Climate Change Impacts on Agriculture: An Equilibrium Perspective on Supply-Side Approaches

Christophe Gouel[1,2]

[1]INRAE, Paris-Saclay Applied Economics

[2]CEPII

Motivation

- Agriculture = most climate-sensitive sector $\Rightarrow$ Important to assess the economic consequences of climate change on agriculture.

Motivation

- Agriculture = most climate-sensitive sector $\Rightarrow$ Important to assess the economic consequences of climate change on agriculture.
- Econometric supply-side approaches are the most popular approaches to do it.
  - Pioneered by Mendelsohn, Nordhaus, and Shaw (1994): Ricardian approach
  - Deschênes and Greenstone (2007): panel-profit approach

Motivation

- Agriculture = most climate-sensitive sector $\Rightarrow$ Important to assess the economic consequences of climate change on agriculture.
- Econometric supply-side approaches are the most popular approaches to do it.
  - Pioneered by Mendelsohn, Nordhaus, and Shaw (1994): Ricardian approach
  - Deschênes and Greenstone (2007): panel-profit approach
- Reduced-form estimation: Cross-section/panel regression of farm land values/farm profits on climatic variables
  - In cross-section, Ricardian because based on the Ricardian theory of rent.

Motivation

- Agriculture = most climate-sensitive sector $\Rightarrow$ Important to assess the economic consequences of climate change on agriculture.
- Econometric supply-side approaches are the most popular approaches to do it.
  - Pioneered by Mendelsohn, Nordhaus, and Shaw (1994): Ricardian approach
  - Deschênes and Greenstone (2007): panel-profit approach
- Reduced-form estimation: Cross-section/panel regression of farm land values/farm profits on climatic variables
  - In cross-section, Ricardian because based on the Ricardian theory of rent.
- Key insights
  - Avoid focus on big field crops: specialty crops and pastures matter too.
  - Importance of within-country land heterogeneity.

Motivation

- Agriculture = most climate-sensitive sector $\Rightarrow$ Important to assess the economic consequences of climate change on agriculture.
- Econometric supply-side approaches are the most popular approaches to do it.
  - Pioneered by Mendelsohn, Nordhaus, and Shaw (1994): Ricardian approach
  - Deschênes and Greenstone (2007): panel-profit approach
- Reduced-form estimation: Cross-section/panel regression of farm land values/farm profits on climatic variables
  - In cross-section, Ricardian because based on the Ricardian theory of rent.
- 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 — Econometric approaches 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

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 — Econometric approaches 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

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 — Econometric approaches 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

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 — Econometric approaches 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**

A modern equilibrium model

- For lack of data availability or for computational reasons, CGE models had for years very little within-country land heterogeneity
  - Often one field per country, at best 18 different land classes (AEZs) at the world level

A modern equilibrium model

- For lack of data availability or for computational reasons, CGE models had for years very little within-country land heterogeneity
  - Often one field per country, at best 18 different land classes (AEZs) at the world level
- Costinot, Donaldson, and Smith (2016): rich within-country land heterogeneity.
  - But only 10 crops and a small share of agricultural land uses (no pastures).

A modern equilibrium model

- For lack of data availability or for computational reasons, CGE models had for years very little within-country land heterogeneity
  - Often one field per country, at best 18 different land classes (AEZs) at the world level
- Costinot, Donaldson, and Smith (2016): rich within-country land heterogeneity.
  - But only 10 crops and a small share of agricultural land uses (no pastures).
- Gouel and Laborde (2021) extend to cover almost all crops and agricultural land uses.

A modern equilibrium model

- For lack of data availability or for computational reasons, CGE models had for years very little within-country land heterogeneity
  - Often one field per country, at best 18 different land classes (AEZs) at the world level
- Costinot, Donaldson, and Smith (2016): rich within-country land heterogeneity.
  - But only 10 crops and a small share of agricultural land uses (no pastures).
- Gouel and Laborde (2021) extend to cover almost all crops and agricultural land uses.
- This paper builds on Gouel and Laborde (2021):
  - Quantitative trade model accounting for within- and between-country heterogeneity
  - Able to mimic a supply-side approach and to show under which conditions it provides a good approximation of true welfare changes

Supply-side approaches

Key papers

Article	GS (October, 2020)
Mendelsohn, Nordhaus, and Shaw (1994), AER	2,613
Deschênes and Greenstone (2007), AER	1,840
Cline (2007), Book	1,547
Schlenker, Hanemann, and Fisher (2005), AER	765
Schlenker, Hanemann, and Fisher (2006), REStat	692
Kurukulasuriya et al. (2006), WBER	642

Applications on any country with available data on agricultural land rents.

Supply-side approaches

Key principles and limits

- Supply-side approaches are based on an hedonic approach
  - The market price for land incorporates all the information about the relevant local production conditions
  - OK for local issues where changes of the amenities to affect market equilibrium with feedback effects on the estimated values of these amenities

Supply-side approaches

Key principles and limits

- Supply-side approaches are based on an hedonic approach
  - The market price for land incorporates all the information about the relevant local production conditions
  - OK for local issues where changes of the amenities to affect market equilibrium with feedback effects on the estimated values of these amenities
- Not valid for climate change: shock large enough to alter the valuation of the amenities (i.e., crop prices)
  - Problem could maybe be solved for a land-locked country where the price effect of climate change could be estimated along its yield effect
  - But not for countries integrated to world market (price in the US may be determined by climate change affecting Latin America, ex: Merener, 2015)

Contribution

- Show under which conditions a supply-side approach provides a good approximation of the welfare impacts of climate change.
  - Under a standard model calibration, low correlation between exact and supply-side welfare change
  - The supply-side approach is valid if crops are perfect substitute in consumption.

Contribution

- Show under which conditions a supply-side approach provides a good approximation of the welfare impacts of climate change.
  - Under a standard model calibration, low correlation between exact and supply-side welfare change
  - The supply-side approach is valid if crops are perfect substitute in consumption.
- 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, 2021; Baldos et al., 2019)
    - But no connection between GE and supply-side approaches

Textbook examples

Textbook examples

Notations:

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

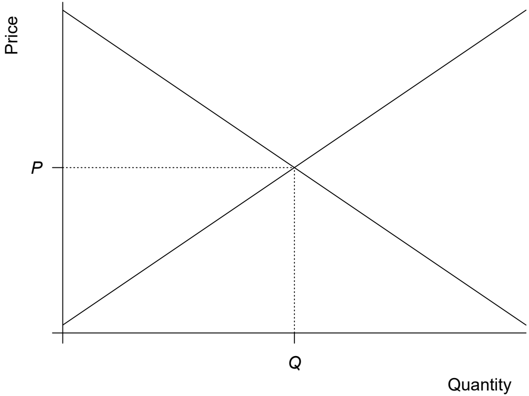
$$\Delta W = \Delta W^* + \text{Bias}.$$

- Climate change is a shock, δ, represented as pivotal shift of the supply curve or as productivity shifters
  - $\delta = 1 \Rightarrow$ no shock.

Single country model

- Ex. from Mendelsohn and Nordhaus (1996) in a response to Cline's (1996) critic.

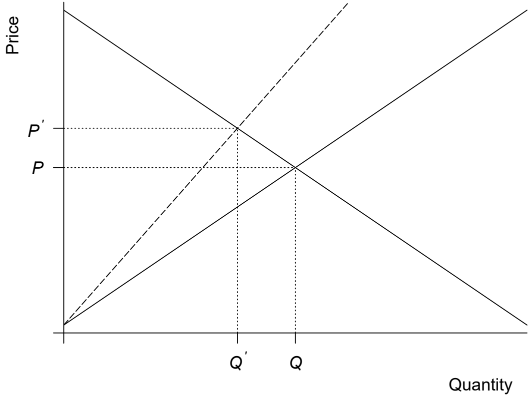
- $\eta, \epsilon > 0$: supply and demand elasticities.



Single country model

- Ex. from Mendelsohn and Nordhaus (1996) in a response to Cline's (1996) critic.

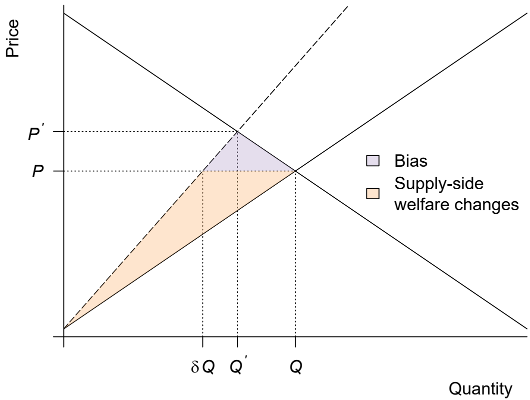
- $\eta, \epsilon > 0$: supply and demand elasticities.



Single country model

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

$$\frac{\text{Bias}}{\Delta W} = \frac{\eta(1-\delta)}{\eta+\epsilon}$$



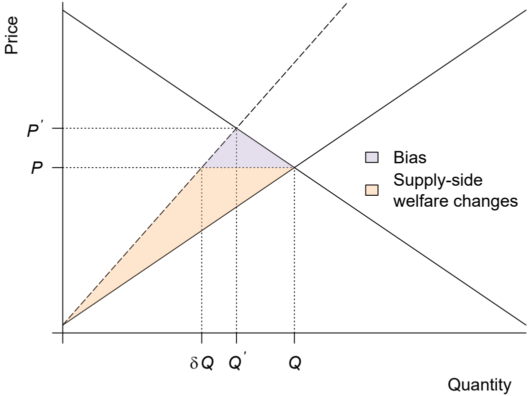
Single country model

- Ex. from Mendelsohn and Nordhaus (1996) in a response to Cline's (1996) critic.

- $\eta, \epsilon > 0$: supply and demand elasticities.

- Relative bias:

$$\frac{\text{Bias}}{\Delta W} = \frac{\eta(1-\delta)}{\eta+\epsilon} > 0 \text{ for } \delta < 1$$



Single country model

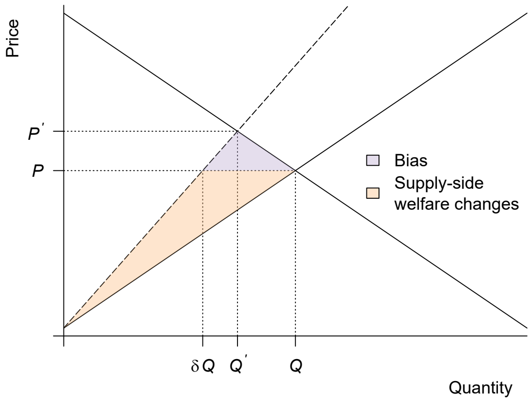
- Ex. from Mendelsohn and Nordhaus (1996) in a response to Cline's (1996) critic.

- $\eta, \epsilon > 0$: supply and demand elasticities.

- Relative bias:

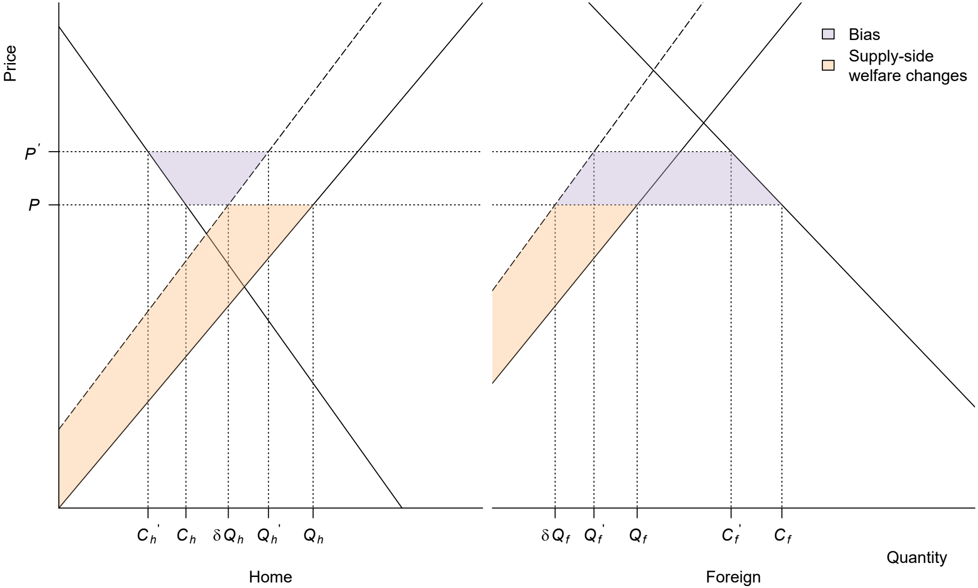
$$\frac{\text{Bias}}{\Delta W} = \frac{\eta(1-\delta)}{\eta+\epsilon} > 0 \text{ for } \delta < 1$$

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



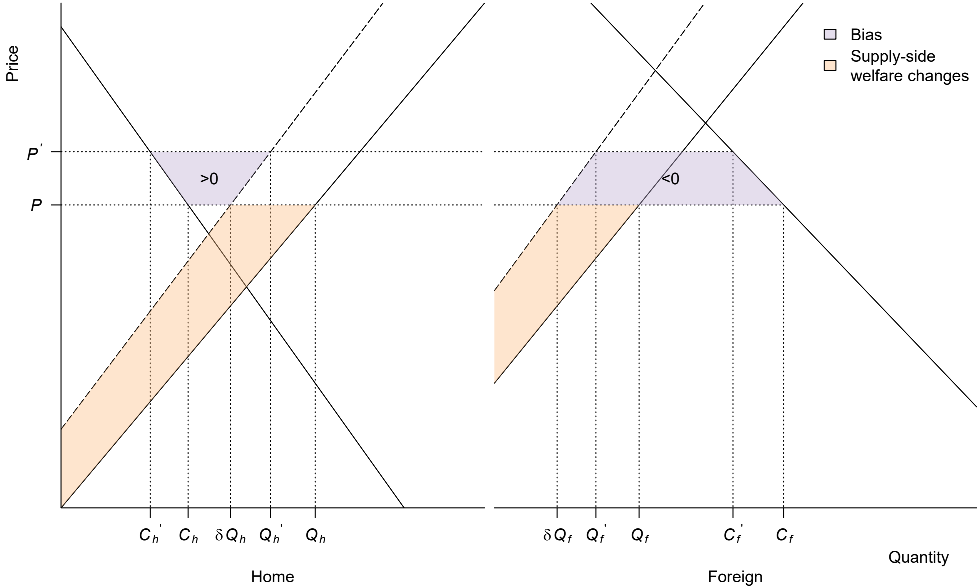
Two-country model

▸ Numerical illustration



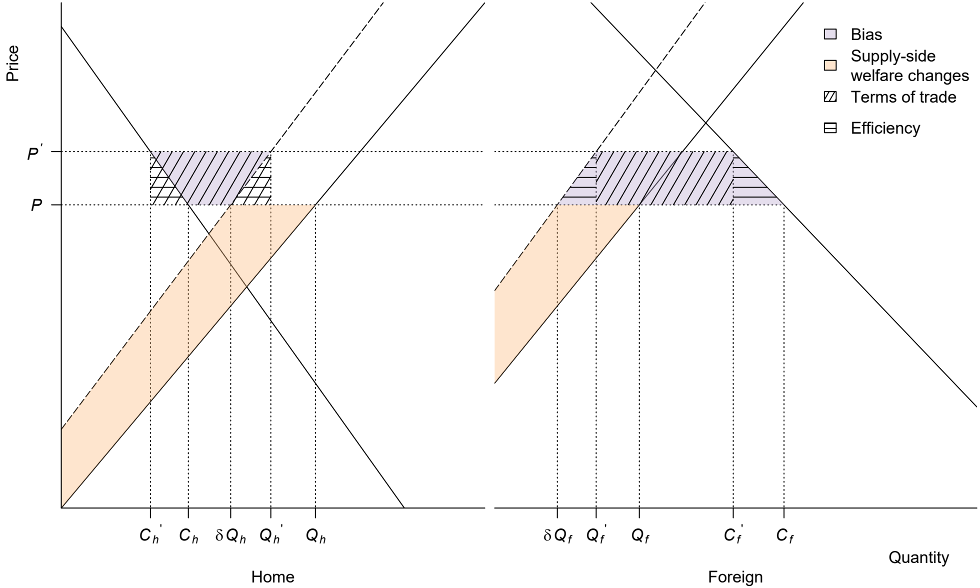
Two-country model

Numerical illustration



Two-country model

Numerical illustration

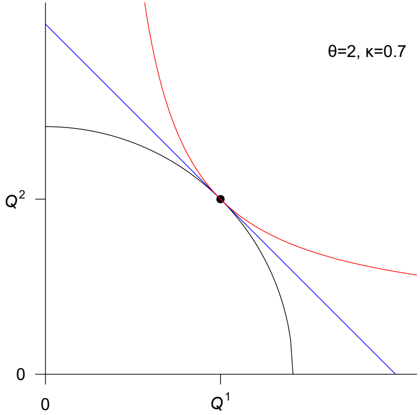


Two-crop model

▸ Numerical illustration

- 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):

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



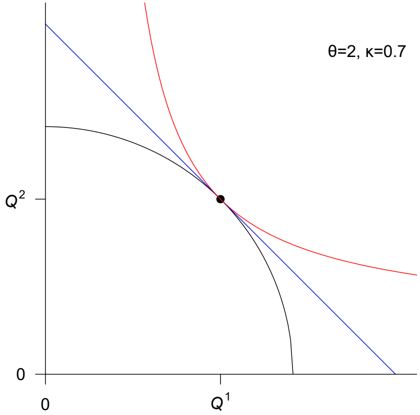
Two-crop model

Numerical illustration

- 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):

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

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



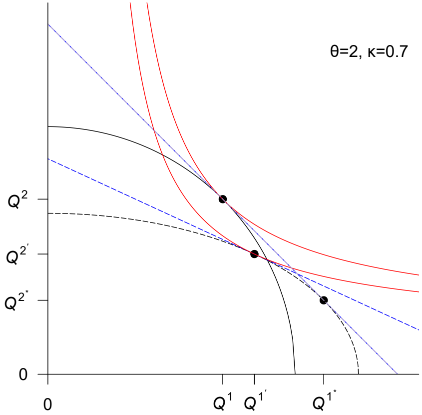
Two-crop model

Numerical illustration

- 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):

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

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



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

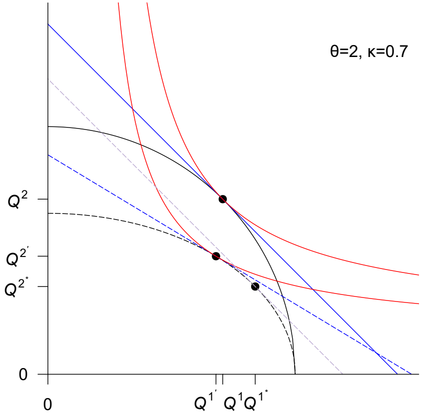
Two-crop model

Numerical illustration

- 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):

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

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



$\Delta W = -20.0\%$

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

Insights from textbook examples

Supply-side approaches lead to

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

Insights from textbook examples

Supply-side approaches lead to

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

- Potentially large under-evaluation of welfare losses because of the neglect of the imperfect substitutability of food products (κ).

Insights from textbook examples

Supply-side approaches lead to

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

- 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 based on Gouel and Laborde (2021)

- 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
    - 64,858 fields (30 arcminutes), 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) or integrated world market
  - 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)

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

- 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)

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

Mimicking a supply-side approach with the equilibrium model

The econometric approach

Supply-side approach = regression of cash rents, R_i^f, or of farmland value, $R_i^f(1+\rho)/\rho$ with ρ the discount rate, on climatic variables:

$$\text{Cross-section:} \quad R_i^f(1+\rho)/\rho s_i^f = f\left(\text{Climate}_i^f\right) + \text{Controls}_i^f + \varepsilon_i^f,$$

$$\text{Panel:} \quad R_{i,t}^f/s_i^f = f\left(\text{Climate}_{i,t}^f\right) + \mu_i^f + \mu_t + \varepsilon_{i,t}^f$$

- In cross-section, the Ricardian approach cannot account for prices,
- In panel, state-year or year FE are introduced to capture price variations.

Mimicking a supply-side approach with the equilibrium model

The econometric approach

Supply-side approach = regression of cash rents, R_i^f, or of farmland value, $R_i^f(1+\rho)/\rho$ with ρ the discount rate, on climatic variables:

$$\text{Cross-section:} \qquad R_i^f(1+\rho)/\rho s_i^f = f\left(\text{Climate}_i^f\right) + \text{Controls}_i^f + \varepsilon_i^f,$$

$$\text{Panel:} \qquad R_{i,t}^f/s_i^f = f\left(\text{Climate}_{i,t}^f\right) + \mu_i^f + \mu_t + \varepsilon_{i,t}^f$$

- In cross-section, the Ricardian approach cannot account for prices,
- In panel, state-year or year FE are introduced to capture price variations.

Mimicking a supply-side approach with the equilibrium model

The model-based approach

- In the model, supply-side approach = (land rents) changes due to climate change at constant prices.
- Land rents under the current climate:

$$R_i^f = \sum_{k \in \mathcal{K}^c} r_i^k s_i^f A_i^{fk} \Bigg[\underbrace{\frac{\left(r_i^k A_i^{fk}\right)^{\theta}}{\sum_{l \in \mathcal{K}^c} \left(r_i^k A_i^{fl}\right)^{\theta}},}_{=\pi_i^{fk},\ \text{Land-use share}} \Bigg]^{(\theta-1)/\theta}$$

  - $r_i^k = \left[\left(p_i^k\right)^{1-\eta} - \left(A_i^0 / A_i^{Nk}\right)^{1-\eta} \right]^{1/(1-\eta)}$: country-level index of land rents.
  - p_i^k: producer price

Mimicking a supply-side approach with the equilibrium model

The model-based approach

- In the model, supply-side approach = (land rents) changes due to climate change at constant prices.
- Land rents under the current climate:

$$R_i^f = \sum_{k \in \mathcal{K}^c} r_i^k s_i^f A_i^{fk} \Big[\underbrace{\frac{\left(r_i^k A_i^{fk}\right)^{\theta}}{\sum_{l \in \mathcal{K}^c} \left(r_i^k A_i^{fl}\right)^{\theta}}}_{=\pi_i^{fk},\ \text{Land-use share}}, \Big]^{(\theta-1)/\theta}$$

  - $r_i^k = \left[\left(p_i^k\right)^{1-\eta} - \left(A_i^0 / A_i^{Nk}\right)^{1-\eta} \right]^{1/(1-\eta)}$: country-level index of land rents.
  - p_i^k: producer price
- Model-consistent supply-side land rents under climate change:

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

Mimicking a supply-side approach with the equilibrium model

The model-based approach

- In the model, supply-side approach = (land rents) changes due to climate change at constant prices.
- Land rents under the current climate:

$$R_i^f = \sum_{k \in \mathcal{K}^c} r_i^k s_i^f A_i^{fk} \Bigg[\underbrace{\frac{\left(r_i^k A_i^{fk}\right)^{\theta}}{\sum_{l \in \mathcal{K}^c} \left(r_i^k A_i^{fl}\right)^{\theta}},}_{=\pi_i^{fk},\ \text{Land-use share}} \Bigg]^{(\theta-1)/\theta}$$

  - $r_i^k = \left[\left(p_i^k\right)^{1-\eta} - \left(A_i^0 / A_i^{Nk}\right)^{1-\eta} \right]^{1/(1-\eta)}$: country-level index of land rents.
  - p_i^k: producer price
- Model-consistent supply-side land rents under climate change:

$$R_i^{f*} = \sum_{k \in \mathcal{K}^c} r_i^k s_i^f A_i^{fk'} \Bigg[\frac{\left(r_i^k A_i^{fk'}\right)^{\theta}}{\sum_{l \in \mathcal{K}^c} \left(r_i^k A_i^{fl'}\right)^{\theta}}, \Bigg]^{(\theta-1)/\theta} = \sum_{k \in \mathcal{K}^c} r_i^k s_i^f A_i^{fk'} \left(\pi_i^{fk*}\right)^{(\theta-1)/\theta}$$

Welfare measures

Equilibrium model approach (equivalent variation)

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

Welfare measures

Equilibrium model approach (equivalent variation)

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

Supply-side approach

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

Welfare measures

Equilibrium model approach (equivalent variation)

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

Supply-side approach

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

Production function approach

$$\Delta W_j^\circ = \sum_{f \in \mathcal{F}_j, k \in \mathcal{K}^c} s_j^f r_j^k A_j^{fk} \left(\pi_j^{fk} \right)^{(\theta-1)/\theta} \left(\hat{A}_j^{fk} - 1 \right)$$

Welfare measures

Equilibrium model approach (equivalent variation)

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

Supply-side approach

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

Production function approach

$$\Delta W_j^\circ = \sum_{f \in \mathcal{F}_j, k \in \mathcal{K}^c} s_j^f r_j^k A_j^{fk} \left(\pi_j^{fk}\right)^{(\theta-1)/\theta} \left(\hat{A}_j^{fk} - 1\right)$$

= Productivity component of first-order approximation of ΔW_j.

Welfare measures

Equilibrium model approach (equivalent variation)

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

Supply-side approach

$$\Delta W_j^* = \sum_{k \in \mathcal{K}^c} R_j^{k*} - R_j^k = \left(\delta_j^* - 1\right) R_j,$$

$$= \sum_{f \in \mathcal{F}_j, k \in \mathcal{K}^c} s_j^f r_j^k \left[A_j^{fk'} \left(\pi_j^{fk*}\right)^{(\theta-1)/\theta} - A_j^{fk} \left(\pi_j^{fk}\right)^{(\theta-1)/\theta} \right].$$

Production function approach

$$\Delta W_j^{\circ} = \sum_{f \in \mathcal{F}_j, k \in \mathcal{K}^c} s_j^f r_j^k A_j^{fk} \left(\pi_j^{fk}\right)^{(\theta-1)/\theta} \left(\hat{A}_j^{fk} - 1\right) = \left(\delta_j - 1\right) R_j.$$

= Productivity component of first-order approximation of ΔW_j.

Calibration

Behavioral parameters

Param.	Interpretation	Target/Source
$\epsilon = 0.5$	Elasticity of food demand	Comin et al. (2021)
$\kappa = 0.6$	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_j^{fk}	Land productivity shifter	Crop potential yield from GAEZ project (v4)
$p_i^k Q_i^k$	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 (scen: RCP 8.5, HadGEM2-ES, 2080s)

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)	Welfare change (% of GDP) Supply-side (6)	Welfare change (% of GDP) Exact (7)	$\text{Bias}_j / \Delta W_j$ (%) (8)
Asia	−5.92	1.82	0.22	12.53	0.00	0.23	−0.92	124.95
CIS	−1.49	0.77	7.83	16.22	0.06	0.13	−0.24	152.80
Europe	−5.18	0.25	−0.54	4.60	−0.00	0.01	−0.18	106.60
Latin America	23.68	0.81	−15.71	−13.01	−0.13	−0.11	0.17	162.67
Middle East and North Africa	−39.36	0.29	12.05	30.30	0.03	0.09	−0.76	111.37
Northern America	16.58	0.25	−3.42	9.36	−0.01	0.02	−0.03	169.03
Oceania	37.33	0.35	−31.37	−25.63	−0.11	−0.09	−0.01	−600.80
Sub-Saharan Africa	−3.06	1.39	−22.82	−19.87	−0.32	−0.28	−4.20	93.44
World	0	0.78	−2.15	8.32	−0.02	0.06	−0.43	115.00

Welfare results (scen: RCP 8.5, HadGEM2-ES, 2080s)

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)	Supply-side (6)	Exact (7)	$\text{Bias}_j / \Delta W_j$ (%) (8)
Asia	−5.92	1.82	0.22	12.53	0.00	0.23	−0.92	124.95
CIS	−1.49	0.77	7.83	16.22	0.06	0.13	−0.24	152.80
Europe	−5.18	0.25	−0.54	4.60	−0.00	0.01	−0.18	106.60
Latin America	23.68	0.81	−15.71	−13.01	−0.13	−0.11	0.17	162.67
Middle East and North Africa	−39.36	0.29	12.05	30.30	0.03	0.09	−0.76	111.37
Northern America	16.58	0.25	−3.42	9.36	−0.01	0.02	−0.03	169.03
Oceania	37.33	0.35	−31.37	−25.63	−0.11	−0.09	−0.01	−600.80
Sub-Saharan Africa	−3.06	1.39	−22.82	−19.87	−0.32	−0.28	−4.20	93.44
World	0	0.78	−2.15	8.32	−0.02	0.06	−0.43	115.00

- (5) = (2) x (3) and (6) = (2) x (4)

Welfare results (scen: RCP 8.5, HadGEM2-ES, 2080s)

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)	Supply-side (6)	Exact (7)	$\text{Bias}_j/\Delta W_j$ (%) (8)
Asia	−5.92	1.82	0.22	12.53	0.00	0.23	−0.92	124.95
CIS	−1.49	0.77	7.83	16.22	0.06	0.13	−0.24	152.80
Europe	−5.18	0.25	−0.54	4.60	−0.00	0.01	−0.18	106.60
Latin America	23.68	0.81	−15.71	−13.01	−0.13	−0.11	0.17	162.67
Middle East and North Africa	−39.36	0.29	12.05	30.30	0.03	0.09	−0.76	111.37
Northern America	16.58	0.25	−3.42	9.36	−0.01	0.02	−0.03	169.03
Oceania	37.33	0.35	−31.37	−25.63	−0.11	−0.09	−0.01	−600.80
Sub-Saharan Africa	−3.06	1.39	−22.82	−19.87	−0.32	−0.28	−4.20	93.44
World	0	0.78	−2.15	8.32	−0.02	0.06	−0.43	115.00

- (5) = (2) x (3) and (6) = (2) x (4)
- $\neq$ btw. (3) & (4) $\Rightarrow$ btw.-crop heterogeneity

Welfare results (scen: RCP 8.5, HadGEM2-ES, 2080s)

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)	Welfare change (% of GDP): Supply-side (6)	Welfare change (% of GDP): Exact (7)	$\text{Bias}_j/\Delta W_j$ (%) (8)
Asia	−5.92	1.82	0.22	12.53	0.00	0.23	−0.92	124.95
CIS	−1.49	0.77	7.83	16.22	0.06	0.13	−0.24	152.80
Europe	−5.18	0.25	−0.54	4.60	−0.00	0.01	−0.18	106.60
Latin America	23.68	0.81	−15.71	−13.01	−0.13	−0.11	0.17	162.67
Middle East and North Africa	−39.36	0.29	12.05	30.30	0.03	0.09	−0.76	111.37
Northern America	16.58	0.25	−3.42	9.36	−0.01	0.02	−0.03	169.03
Oceania	37.33	0.35	−31.37	−25.63	−0.11	−0.09	−0.01	−600.80
Sub-Saharan Africa	−3.06	1.39	−22.82	−19.87	−0.32	−0.28	−4.20	93.44
World	0	0.78	−2.15	8.32	−0.02	0.06	−0.43	115.00

- (5) = (2) x (3) and (6) = (2) x (4)
- $\neq$ btw. (3) & (4) $\Rightarrow$ btw.-crop heterogeneity
- (5) < (6) but same order of magnitude

Welfare results (scen: RCP 8.5, HadGEM2-ES, 2080s)

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)	Supply-side (6)	Exact (7)	$\text{Bias}_j/\Delta W_j$ (%) (8)
Asia	−5.92	1.82	0.22	12.53	0.00	0.23	−0.92	124.95
CIS	−1.49	0.77	7.83	16.22	0.06	0.13	−0.24	152.80
Europe	−5.18	0.25	−0.54	4.60	−0.00	0.01	−0.18	106.60
Latin America	23.68	0.81	−15.71	−13.01	−0.13	−0.11	0.17	162.67
Middle East and North Africa	−39.36	0.29	12.05	30.30	0.03	0.09	−0.76	111.37
Northern America	16.58	0.25	−3.42	9.36	−0.01	0.02	−0.03	169.03
Oceania	37.33	0.35	−31.37	−25.63	−0.11	−0.09	−0.01	−600.80
Sub-Saharan Africa	−3.06	1.39	−22.82	−19.87	−0.32	−0.28	−4.20	93.44
World	0	0.78	−2.15	8.32	−0.02	0.06	−0.43	115.00

- (5) = (2) x (3) and (6) = (2) x (4)
- $\neq$ btw. (3) & (4) $\Rightarrow$ btw.-crop heterogeneity
- (5) < (6) but same order of magnitude
- Large bias

Welfare results (scen: RCP 8.5, HadGEM2-ES, 2080s)

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)	Supply-side (6)	Exact (7)	$\text{Bias}_j/\Delta W_j$ (%) (8)
Asia	−5.92	1.82	0.22	12.53	0.00	0.23	−0.92	124.95
CIS	−1.49	0.77	7.83	16.22	0.06	0.13	−0.24	152.80
Europe	−5.18	0.25	−0.54	4.60	−0.00	0.01	−0.18	106.60
Latin America	23.68	0.81	−15.71	−13.01	−0.13	−0.11	0.17	162.67
Middle East and North Africa	−39.36	0.29	12.05	30.30	0.03	0.09	−0.76	111.37
Northern America	16.58	0.25	−3.42	9.36	−0.01	0.02	−0.03	169.03
Oceania	37.33	0.35	−31.37	−25.63	−0.11	−0.09	−0.01	−600.80
Sub-Saharan Africa	−3.06	1.39	−22.82	−19.87	−0.32	−0.28	−4.20	93.44
World	0	0.78	−2.15	8.32	−0.02	0.06	−0.43	115.00

- (5) = (2) x (3) and (6) = (2) x (4)
- $\neq$ btw. (3) & (4) $\Rightarrow$ btw.-crop heterogeneity
- (5) < (6) but same order of magnitude
- Large bias

- Wrong welfare signs

Welfare results (scen: RCP 8.5, HadGEM2-ES, 2080s)

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)	Welfare change (% of GDP): Supply-side (6)	Welfare change (% of GDP): Exact (7)	$\text{Bias}_j/\Delta W_j$ (%) (8)
Asia	−5.92	1.82	0.22	12.53	0.00	0.23	−0.92	124.95
CIS	−1.49	0.77	7.83	16.22	0.06	0.13	−0.24	152.80
Europe	−5.18	0.25	−0.54	4.60	−0.00	0.01	−0.18	106.60
Latin America	23.68	0.81	−15.71	−13.01	−0.13	−0.11	0.17	162.67
Middle East and North Africa	−39.36	0.29	12.05	30.30	0.03	0.09	−0.76	111.37
Northern America	16.58	0.25	−3.42	9.36	−0.01	0.02	−0.03	169.03
Oceania	37.33	0.35	−31.37	−25.63	−0.11	−0.09	−0.01	−600.80
Sub-Saharan Africa	−3.06	1.39	−22.82	−19.87	−0.32	−0.28	−4.20	93.44
World	0	0.78	−2.15	8.32	−0.02	0.06	−0.43	115.00

- (5) = (2) x (3) and (6) = (2) x (4)
- $\neq$ btw. (3) & (4) $\Rightarrow$ btw.-crop heterogeneity
- (5) < (6) but same order of magnitude
- Large bias

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

Welfare results (scen: RCP 8.5, HadGEM2-ES, 2080s)

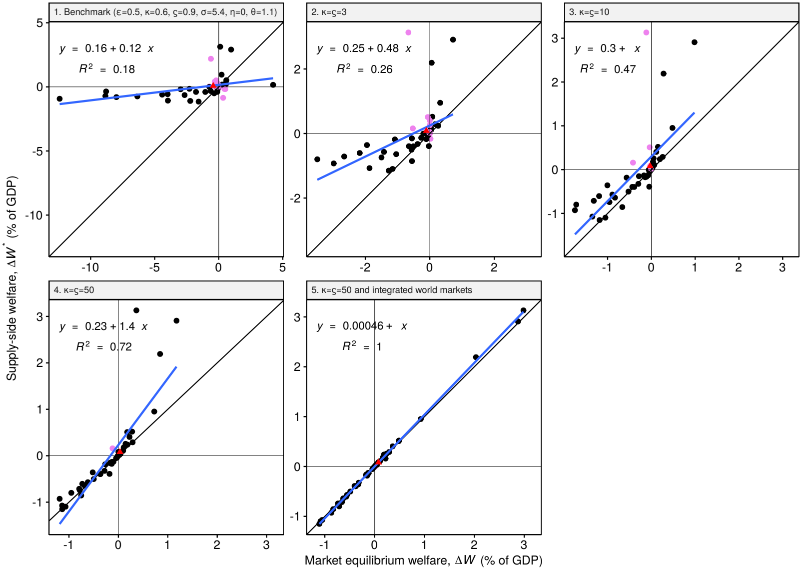
Region	Net ag. trade as % of ag. prod. (1)	Land rents as % of GDP (2)	$\delta_j - 1$ (%) (3)	$\delta_j^* - 1$ (%) (4)	Welfare change (% of GDP) Production fn. (5)	Supply-side (6)	Exact (7)	$\text{Bias}_j/\Delta W_j$ (%) (8)
Asia	−5.92	1.82	0.22	12.53	0.00	0.23	−0.92	124.95
CIS	−1.49	0.77	7.83	16.22	0.06	0.13	−0.24	152.80
Europe	−5.18	0.25	−0.54	4.60	−0.00	0.01	−0.18	106.60
Latin America	23.68	0.81	−15.71	−13.01	−0.13	−0.11	0.17	162.67
Middle East and North Africa	−39.36	0.29	12.05	30.30	0.03	0.09	−0.76	111.37
Northern America	16.58	0.25	−3.42	9.36	−0.01	0.02	−0.03	169.03
Oceania	37.33	0.35	−31.37	−25.63	−0.11	−0.09	−0.01	−600.80
Sub-Saharan Africa	−3.06	1.39	−22.82	−19.87	−0.32	−0.28	−4.20	93.44
World	0	0.78	−2.15	8.32	−0.02	0.06	−0.43	115.00

- (5) = (2) x (3) and (6) = (2) x (4)
- $\neq$ btw. (3) & (4) $\Rightarrow$ btw.-crop heterogeneity
- (5) < (6) but same order of magnitude
- Large bias

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

Role of demand parameters

Other params



Sensitivity analysis

▸ To conclusion

Sensitivity analysis

1. Different benchmark calibration.
2. Intensive margin.
3. Climate scenario.
4. Marginal climate shock.

Different benchmark calibration

CDS much higher elasticities ($\epsilon = 1, \kappa = \varsigma = 2.82, \theta = 1.239$ instead of $\epsilon = 0.5, \kappa = 0.6, \varsigma = 0.9, \theta = 1.1$)

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)	Supply-side (6)	Exact (7)	$\text{Bias}_j/\Delta W_j$ (%) (8)
Asia	−5.92	1.82	−0.01	13.96	−0.00	0.25	−0.11	330.20
CIS	−1.49	0.77	6.66	29.79	0.05	0.23	−0.01	1970.36
Europe	−5.18	0.25	−0.88	11.38	−0.00	0.03	−0.03	191.40
Latin America	23.68	0.81	−16.01	−6.14	−0.13	−0.05	−0.07	28.53
Middle East and North Africa	−39.36	0.29	10.80	30.35	0.03	0.09	−0.18	147.09
Northern America	16.58	0.25	−4.00	8.82	−0.01	0.02	−0.02	195.20
Oceania	37.33	0.35	−31.42	−25.01	−0.11	−0.09	−0.06	−54.17
Sub-Saharan Africa	−3.06	1.39	−23.72	−18.62	−0.33	−0.26	−1.15	77.65
World	0	0.78	−2.50	10.90	−0.02	0.08	−0.09	198.63

Fit: $R^2 = 0.3$

Intensive margin

	Global welfare change (% of GDP)		R^2 of
Model	Supply-side	Exact	$\Delta W^* \sim \Delta W$
Benchmark ($\kappa = 0.6, \varsigma = 0.9, \eta = 0$)	0.08	-0.43	0.18
$\eta = 0.05$	0.08	-0.34	0.18
$\eta = 0.1$	0.08	-0.26	0.17
$\eta = 0.2$	0.08	-0.14	0.13
$\eta = 1$	0.08	0.17	0.04
$\kappa = \varsigma = 50$	0.08	0.03	0.72
$\kappa = \varsigma = 50, \eta = 0.05$	0.08	0.03	0.77
$\kappa = \varsigma = 50, \eta = 1$	0.08	0.03	0.84

Climate scenarios

Climate model	RCP scenario	Global welfare ch. (% of GDP) Supply-side	Exact	R^2 of $\Delta W^* \sim \Delta W$
GFDL-ESM2M	2.6	0.06	0.00	0.10
GFDL-ESM2M	4.5	0.08	−0.01	0.17
GFDL-ESM2M	6.0	0.07	−0.06	0.28
GFDL-ESM2M	8.5	0.09	−0.21	0.03
HadGEM2-ES	2.6	0.11	0.02	0.07
HadGEM2-ES	4.5	0.09	−0.07	0.10
HadGEM2-ES	6.0	0.09	−0.08	0.03
HadGEM2-ES	8.5	0.08	−0.43	0.18
IPSL-CM5A-LR	2.6	0.07	−0.01	0.09
IPSL-CM5A-LR	4.5	0.06	−0.47	0.37
IPSL-CM5A-LR	6.0	0.05	−0.14	0.09
IPSL-CM5A-LR	8.5	0.00	−0.65	0.17
MIROC-ESM-CHEM	2.6	0.09	0.01	0.11
MIROC-ESM-CHEM	4.5	0.12	−0.02	0.09
MIROC-ESM-CHEM	6.0	0.07	−0.29	0.05
MIROC-ESM-CHEM	8.5	0.09	−0.38	0.18
NorESM1-M	2.6	0.08	0.03	0.06
NorESM1-M	4.5	0.11	0.03	0.05
NorESM1-M	6.0	0.12	0.02	0.04
NorESM1-M	8.5	0.10	−0.12	0.05

Marginal climate shock

Trade assumption	Share of yield shock (%)	Global welfare change (% of GDP)		R^2 of
		Supply-side	Exact	$\Delta W^* \sim \Delta W$
Armington	100.0	8.1×10^{-2}	-4.3×10^{-1}	0.18
Armington	1.0	4.3×10^{-4}	3.5×10^{-4}	0.48
Armington	0.1	3.1×10^{-5}	3.1×10^{-5}	0.53
Integrated world market	100.0	8.1×10^{-2}	-2.1×10^{-2}	0.20
Integrated world market	1.0	4.3×10^{-4}	4.2×10^{-4}	0.74
Integrated world market	0.1	3.1×10^{-5}	3.1×10^{-5}	0.73

Marginal climate shock

Trade assumption	Share of yield shock (%)	Global welfare change (% of GDP)		R^2 of
		Supply-side	Exact	$\Delta W^* \sim \Delta W$
Armington	100.0	8.1×10^{-2}	-4.3×10^{-1}	0.18
Armington	1.0	4.3×10^{-4}	3.5×10^{-4}	0.48
Armington	0.1	3.1×10^{-5}	3.1×10^{-5}	0.53
Integrated world market	100.0	8.1×10^{-2}	-2.1×10^{-2}	0.20
Integrated world market	1.0	4.3×10^{-4}	4.2×10^{-4}	0.74
Integrated world market	0.1	3.1×10^{-5}	3.1×10^{-5}	0.73

- For a marginal shock, the bias disappears at the world level

Marginal climate shock

Trade assumption	Share of yield shock (%)	Global welfare change (% of GDP)		R^2 of
		Supply-side	Exact	$\Delta W^* \sim \Delta W$
Armington	100.0	8.1×10^{-2}	-4.3×10^{-1}	0.18
Armington	1.0	4.3×10^{-4}	3.5×10^{-4}	0.48
Armington	0.1	3.1×10^{-5}	3.1×10^{-5}	0.53
Integrated world market	100.0	8.1×10^{-2}	-2.1×10^{-2}	0.20
Integrated world market	1.0	4.3×10^{-4}	4.2×10^{-4}	0.74
Integrated world market	0.1	3.1×10^{-5}	3.1×10^{-5}	0.73

- For a marginal shock, the bias disappears at the world level
- But not at the country level, because of terms-of-trade changes

Conclusion

Conclusion

- Econometric supply-side approaches (e.g., the Ricardian approach) are simple reduced-form approaches
  - 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

Conclusion

- Econometric supply-side approaches (e.g., the Ricardian approach) are simple reduced-form approaches
  - 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 supply-side welfare change
  - Several countries with welfare changes of the wrong sign.

Illustration of bias in a two-country model

Back

Case $(\delta, \epsilon, \eta, x_h)$	Home bias $\text{Bias}_h/\Delta W_h$ (%)	Foreign bias $\text{Bias}_f/\Delta W_f$ (%)	World bias (%)
1. $(0.90, 0.5, 0.5, 0.25)$	-25.6	23.6	5.0
2. $(0.90, 1.0, 0.5, 0.25)$	-15.2	16.7	3.3
3. $(0.90, 0.2, 0.5, 0.25)$	-43.2	31.3	7.1
4. $(0.90, 0.5, 1.0, 0.25)$	-38.8	30.0	6.7
5. $(0.90, 0.5, 0.2, 0.25)$	-12.6	14.6	2.9
6. $(0.90, 0.5, 0.5, 0.25, \delta_h = 0.95)$	-106.3	19.5	5.0
7. $(0.90, 0.2, 0.5, 0.25, \delta_h = 0.95)$	-322.5	26.3	7.1
8. $(0.90, 0.5, 1.0, 0.25, \delta_h = 0.95)$	-240.1	24.9	6.7
9. $(0.90, 0.5, 0.5, 0.25, \delta_h = 0.85)$	-11.1	33.8	5.0
10. $(0.90, 0.5, 0.5, 0.50)$	-85.1	36.1	5.0
11. $(0.75, 0.5, 0.5, 0.25)$	-14.0	29.0	12.5
12. $(0.75, 0.5, 0.5, 0.50)$	-63.3	40.2	12.5
13. $(0.75, 0.5, 0.5, 0.25, \delta_h = 0.90)$	-326.1	27	12.5
14. $(0.75, 0.5, 0.5, 0.50, \delta_h = 0.90)$	333.3	34.9	12.5

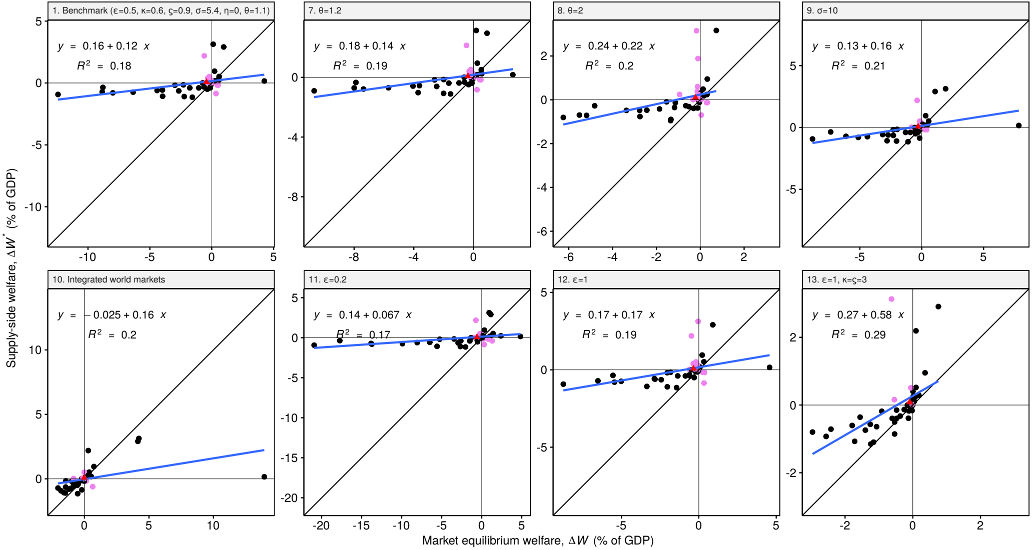
Illustration of bias in a two-crop model

Back

Case $(\theta, \kappa, \delta^1, \delta^2)$	$\delta - 1$ (%)	$\Delta W^*/L$ (%)	$\Delta W/L$ (%)	Bias$/\Delta W$ (%)
1. (2.0, 0.5, 1.00, 0.80)	−10.0	−9.4	−10.9	13.6
2. (2.0, 0.5, 0.90, 0.90)	−10.0	−10.0	−10.0	0
3. (2.0, 0.5, 1.10, 0.70)	−10.0	−7.8	−13.7	43.1
4. (2.0, 0.5, 0.85, 0.65)	−25.0	−24.3	−26.1	6.8
5. (2.0, 0.5, 1.20, 0.80)	0	2.0	−3.3	159.1
6. (2.0, 1.5, 1.00, 0.80)	−10.0	−9.4	−10.3	8.6
7. (2.0, 5.0, 1.00, 0.80)	−10.0	−9.4	−9.8	3.8
8. (1.5, 0.5, 1.00, 0.80)	−10.0	−9.7	−11.0	11.4
9. (3.0, 0.5, 1.00, 0.80)	−10.0	−8.9	−10.9	18.3
10. (9.0, 0.5, 1.00, 0.80)	−10.0	−6.1	−10.9	43.7
11. (2.0, 0.7, 1.00, 0.65)	−17.5	−15.7	−20.0	21.8
12. (2.0, 0.7, 1.26, 0.65)	−4.7	0	−11.4	100.0

Role of remaining parameters

Back



Producer surplus

Supply-side approaches are even worse at assessing the effects on producer surplus

Producer surplus

Supply-side approaches are even worse at assessing the effects on producer surplus

	Welf. ch. (% of GDP)		Welf. decomp. (% GDP)	
Region	Supply-side (1)	Exact (2)	Producer (3)	Consumer (4)
Asia	0.24	−0.92	0.77	−1.68
CIS	0.23	−0.24	0.55	−0.79
Europe	0.03	−0.18	0.26	−0.43
Latin America	−0.06	0.17	1.31	−1.14
Middle East and North Africa	0.09	−0.76	0.40	−1.17
Northern America	0.02	−0.03	0.13	−0.16
Oceania	−0.09	−0.01	0.37	−0.38
Sub-Saharan Africa	−0.28	−4.20	7.70	−11.89
World	0.08	−0.43	0.63	−1.06

Producer surplus

Supply-side approaches are even worse at assessing the effects on producer surplus

	Welf. ch. (% of GDP)		Welf. decomp. (% GDP)	
Region	Supply-side (1)	Exact (2)	Producer (3)	Consumer (4)
Asia	0.24	−0.92	0.77	−1.68
CIS	0.23	−0.24	0.55	−0.79
Europe	0.03	−0.18	0.26	−0.43
Latin America	−0.06	0.17	1.31	−1.14
Middle East and North Africa	0.09	−0.76	0.40	−1.17
Northern America	0.02	−0.03	0.13	−0.16
Oceania	−0.09	−0.01	0.37	−0.38
Sub-Saharan Africa	−0.28	−4.20	7.70	−11.89
World	0.08	−0.43	0.63	−1.06