Deforestation: A Global and Dynamic Perspective

Farid Farrokhi[1] Elliot Kang[2] Heitor Pellegrina[3] Sebastian Sotelo[2,4]

[1]Boston College, [2]Michigan, [3]Notre Dame, [4]NBER

NBER SI (ITI) - July 2025

Motivation and Paper Summary

- Global forest area $\downarrow 7\%$ since 1990 $\Rightarrow$ Concerns about CO_2 emissions, wildlife
- Academic and policy discussion around international trade and deforestation
- **Research Question**: How do trade barriers impact global deforestation?

Motivation and Paper Summary

- Global forest area ↓7% since 1990 ⇒ Concerns about CO_2 emissions, wildlife
- Academic and policy discussion around international trade and deforestation
- **Research Question**: How do trade barriers impact global deforestation?
- Data on global deforestation 1990-2020: New patterns on deforestation, trade and pop growth
- Dynamic, multisector trade model
  - Location and magnitude: structural change + comparative advantage
  - Timing: forward looking agents who treat land as an asset (flow vs. stock)

Main Findings

Analytical findings

Quantitative findings

Main Findings

Analytical findings

- Global reduction in agricultural trade cost can **increase** forest area, depending on sectoral elasticity
  - Local vs. global reduction in trade cost
  - Tariffs vs. iceberg trade costs
- Correlation between comparative advantage and absolute advantage

Quantitative findings

Main Findings

Analytical findings

- Global reduction in agricultural trade cost can **increase** forest area, depending on sectoral elasticity
  - Local vs. global reduction in trade cost
  - Tariffs vs. iceberg trade costs
- Correlation between comparative advantage and absolute advantage

Quantitative findings

- Global tariff elimination in agriculture **increases** global forest area, but sectoral elasticity is key
- Welfare gains from liberalization dominate emissions costs from deforestation

Related Literature

- **Trade, spatial economics, and the environment**: Brander Taylor (1997, 98) Shapiro (2016) Copeland et al. (2022) Costinot et al. (2016) Gouel Laborde (2018) Desmet et al. (2018) Balboni (2019) Conte et al. (2020) Kortum Weisbach (2020) Farrokhi Lashkaripour (2021) Lugovsky et al. (2022) Carleton et al. (2023) Balboni et al. (2022) Haslop et al. (2023)
  Contribution: Quantitative analysis of trade and natural resources

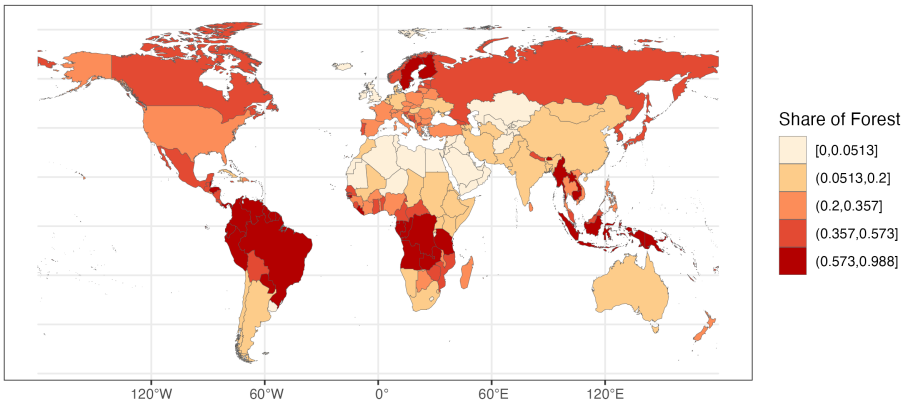
- **Agricultural productivity, trade, and structural change**: Costinot Donaldson Smith (2016) Porteous (2018) Pellegrina (2022) Sotelo (2020) Pellegrina Farrokhi (2023) Gouel Laborde (2018) Hertel (2002) Hertel (2012) Gollin et al. (2018) Chatterjee (2023) Cravino Sotelo (2018)
  Contribution: Dynamics of land use + Environmental impacts of ag-trade

- **Economics of deforestation**: Ferreira (2008) Burgess et al. (2012) Jayachandran et al. (2017) Assunção et al. (2020) Souza-Rodrigues (2019) Araujo et al. (2022) Pfaff (2019) Asher et al. (2020) Balboni et al. (2020) Dominguez-Iino (2021) Hsiao (2021) Foster Rosenzweig (2003) Hansen and Wingender (2024)
  Contribution: International trade and global deforestation

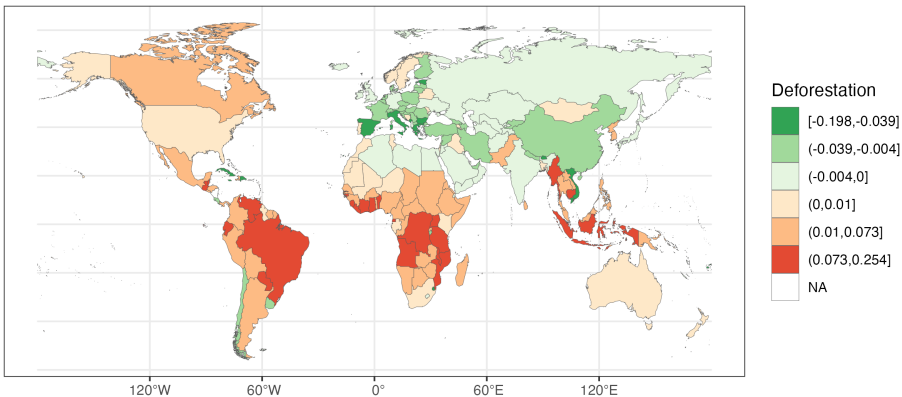
Data

- Sample:
  - 1990-2020
  - 40 countries and regional aggregates
- Global Forest Resource Assessment (GFRA-FAO)
  - Forest area — remove industrial forest
  - Forest protection
  - Carbon stock
- Additional datasets: FAOSTAT, GTAP, ILO, UN, World Bank, and OCDE

Pattern 1: Forest Share in 1990...

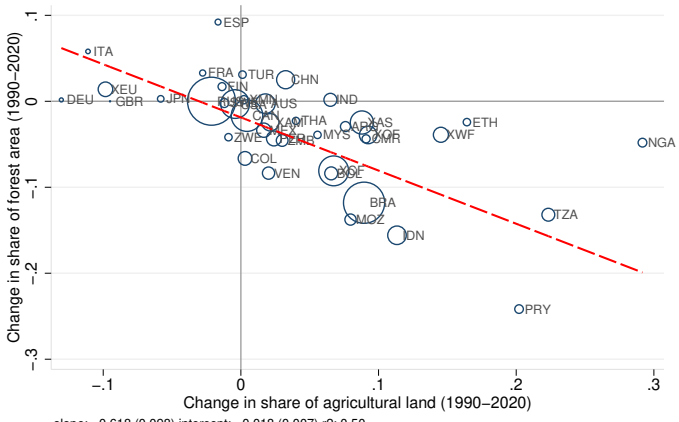


Pattern 1: ... and Deforestation 1990-2020



- Correlation is -0.61 $\Rightarrow$ incorporate in land-clearing technology

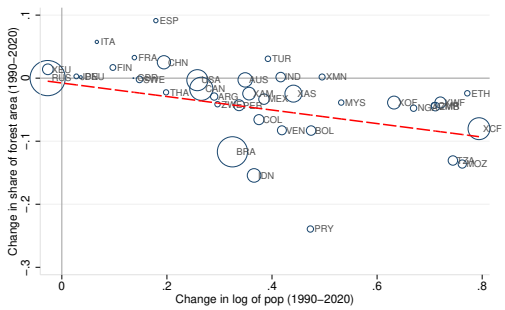
Pattern 2: Deforestation and Agricultural Expansion, 1990-2020



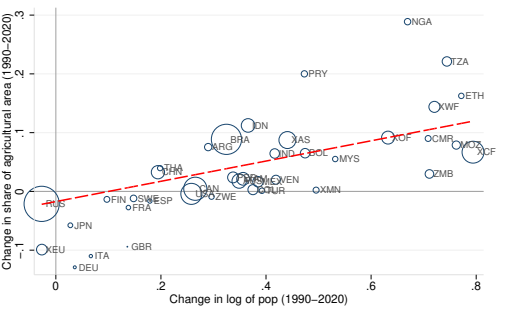
- Size of circles captures country's share in world forest

Pattern 3: Deforestation, Agriculture, and Population Growth

Forest share and Population growth



Agri land share and Population growth



- Size of circles captures country's share in world forest

Pattern 3: Forest share, Agricultural share and Population (1990-2020)

	OLS	OLS	IV	IV
a. DV is the log of forest area				
s^{Own} × Δ Log(Own Pop)	-0.380***	-0.257*	-0.436***	-0.360*
	(0.072)	(0.151)	(0.095)	(0.197)
s^{Partner} × Δ Log(Partner Pop)	-1.325*	-1.030	-1.416**	-1.190*
	(0.727)	(0.766)	(0.708)	(0.721)
R2 or K-P	0.310	0.403	34.995	12.313
Obs	40	40	40	40
b. DV is the log of agricultural area				
s^{Own} × Δ Log(Own Pop)	1.409***	1.136***	1.427***	0.879***
	(0.106)	(0.225)	(0.107)	(0.297)
s^{Partner} × Δ Log(Partner Pop)	3.809***	3.177***	3.864***	2.986***
	(0.872)	(0.888)	(0.840)	(0.904)
R2 or K-P	0.746	0.815	34.995	12.313
Obs	40	40	40	40
Controls (Initial period value in logs)				
- Share of Agricultural area	-	Y	-	Y
- Share of Forest area	-	Y	-	Y
- Natural reserve area	-	Y	-	Y
- GDP p.c.	-	Y	-	Y

$$\Delta \ln y_{i,t} = \beta_0 + \beta_1 s_{i,t}^{\text{Own}} \Delta \ln \text{Own Population}_{i,t} + \beta_2 s_{i,t}^{\text{Partner}} \Delta \ln \text{Partner Population}_{i,t} + \beta_X \mathbf{X}_{i,t} + \epsilon_{i,t}$$

- $s_{i,t}^{Own}$ and $s_{i,t}^{Partner}$ $\Rightarrow$ share of sales to domestic and partner population (top 5 destination countries)
- IV is median age, birth rate and median child bearing age in 1990

Model Environment

- Basic version of the model $\Rightarrow$ Enriched later for quantitative analysis
- Countries, $i, j \in \mathcal{I}$
- Time is continuous, $t \in [0, \infty)$
- Endowments
  - Productive land $L_i(t)$, and forest area $F_i(t) = H_i - L_i(t)$
  - Labor $N_i(t)$
- Two final goods g: Agriculture, A, and Manufacturing, M
- Trade costs $\tau_{ij,g}$ and tariffs $1 + t_{ij,g}$
- Land-producing sector T converts forest into land
- (henceforth) Drop index t

Preferences

- Utility

$$U_i = \left(C_{i,M}^{\frac{\sigma-1}{\sigma}} + C_{i,A}^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}}$$

  σ controls structural change

- Armington within Agriculture and Manufacturing

$$C_{i,g} = \left(\sum_{j \in \mathcal{I}} C_{ji,g}^{\frac{\eta-1}{\eta}} \right)^{\frac{\eta}{\eta-1}} \qquad \forall g \in \{A, M\}$$

  η controls trade elasticity

Technology and Trade of Consumption Goods

- Unit cost of production in $g \in \{A, M\}$:

$$c_{i,A} = \bar{c}_A \frac{r_i}{Z_{i,A}} \qquad\qquad c_{i,M} = \bar{c}_M \frac{w_i}{Z_{i,M}}$$

  - r_i rental rate of land
  - w_i wage of labor currently
  - $Z_{i,g}$ sectoral productivity

- Trade shares

$$\pi_{ij,g} = \frac{\left((1 + t_{ij,g})\, w_i^{\gamma_g} r_i^{1-\gamma_g} \tau_{ij,g} / Z_{i,g}\right)^{1-\eta}}{\sum_{i'} \left((1 + t_{i'j,g})\, w_{i'}^{\gamma_g} r_{i'}^{1-\gamma_g} \tau_{i'j,g} / Z_{i',g}\right)^{1-\eta}},$$

$\gamma_M = 1; \gamma_A = 0$

Technology — Conversion of Forest into New Land

- Land dynamics
  - Stock of cleared land

$$L_i = z_i H_i$$

    - Frontier of productive land $z_i \in [0, 1]$
  - Flow of cleared land

$$\dot{L}_i = x_i - g_L L_i$$

    - g_L is the rate of forest regrowth

Technology — Conversion of Forest into New Land

- Land dynamics
  - Stock of cleared land

$$L_i = z_i H_i$$

    - Frontier of productive land $z_i \in [0, 1]$
  - Flow of cleared land

$$\dot{L}_i = x_i - g_L L_i$$

    - g_L is the rate of forest regrowth
- Firm in sector T converts one unit of forest (F_i) into new land (x_i) using

$$x_i = \zeta_i N_{iT}$$

  - Price of new land q_i equals marginal cost $\Rightarrow q_i = w_i/\zeta_i$
  - Similar to harvest sector with open access (Brander and Taylor, 1997,1998)
- Price of land must equal present value of rents $\Rightarrow q_i = \int_0^\infty e^{-(\rho+g_L)s} r_i(s)\, ds$ landowners

Equilibrium

- **Static Equilibrium.**
  - Given (i) trade costs and preferences, (ii) land and labor supplies $\{L_i, N_i\}$, and (iii) the price of land $\{q_i\}$
  - An equilibrium is factor payments $\{w_i, r_i\}$, labor allocations, $\{N_{i,g}\}$, and new land production $\{x_i\}$ such that
    - Land market clears
    - Labor market clears
    - Land producing sector maximizes profits $\Rightarrow$ mg. cost equals price of new land
- **Dynamic Equilibrium.**
  - Given (i) paths for trade costs, preferences and labor supply, (ii) initial conditions for land and labor $\{L_i(0), N_i(0)\}$, and (iii) static equilibrium pricing functions
  - An elbrm is paths for land $\{L_i\}$, value functions for land $\{v_i\}$, and land prices $\{q_i\}$ such that
    - Laws of motion hold
    - Free entry of farmers hold

4 Analytical Results

- Analysis: the impact of trade cost reductions on **the stock of land in S.S.**

4 Analytical Results: Local vs. Global (Iceberg)

Result 1 - Assume country i is a SOE (Alvarez and Lucas, 2007)

- Then a local *decline* in iceberg τ_A **increases** the stock of land

$$\frac{d \log L}{d \log \tau_A} \propto (1 - \eta) < 0 \qquad \text{for } \eta > 1$$

  - η is, e.g. the substitution between American and Brazilian soybean

Result 2 - Assume countries are symmetric and $t_A = 0$

- Then a global *decline* in iceberg τ_A **reduces** the stock of land

$$\frac{d \log L}{d \log \tau_A} \propto (1 - \sigma)(1 - \pi_{A,D}) > 0 \qquad \text{for } \sigma < 1$$

  - σ is the substitution between agriculture and non-agriculture
  - $\pi_{A,D}$ is the share of expenditure on domestic goods

4 Analytical Results: Iceberg vs. Tariff (Global)

Result 2 - Assume countries are symmetric and $t_A = 0$

- Then a global *decline* in iceberg τ_A **reduces** the stock of land

$$\frac{d\log L}{d\log \tau_A} \propto (1-\sigma)(1-\pi_{A,D}) > 0 \qquad \text{for } \sigma < 1$$

  - σ is the substitution between agriculture and non-agriculture
  - $\pi_{A,D}$ is the share of expenditure on domestic goods

Result 3 - Assume countries are symmetric and $t_A \geq 0$

- Then a global *decline* in tariffs t_A has **ambiguous effects** on the stock of land

$$\frac{d\log L}{d\log(1+t_A)} \propto \underbrace{(1-\sigma)(1-\pi_{A,D})}_{\text{Sectoral Expenditure}>0} + \underbrace{(\eta-1)(s_{A,D}-\pi_{A,D})}_{\text{Trade Expenditure}>0} - \underbrace{(1-s_{A,D})}_{\text{Direct Effect}<0} \gtrless 0$$

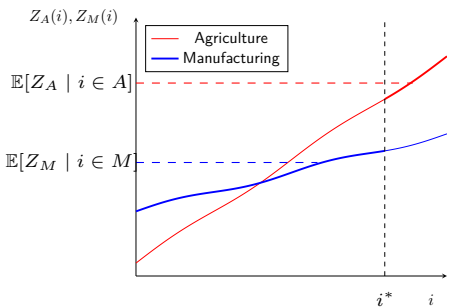
  - $s_{A,D}$ is the share of sales to domestic consumers ($s_{A,D} \geq \pi_{A,D}$)

4 Analytical Results: Absolute and Comparative Advantage

Result 4 - Assume a continuum $i \in [0,1]$ of asymmetric countries

1. Productivities $Z_A(i), Z_M(i)$, ordered $\frac{\partial Z_A(i)/Z_M(i)}{\partial i} > 0$
2. Cobb-Douglas preferences ($\sigma = 1$) and homogeneous goods ($\eta = 1$), then

If $Z'_M(i) > 0$ (Agricultural CA and AA are aligned), free trade $\downarrow$ global land use and $\uparrow$ forests



Check

Analytical Results: Discussion

- What was the impact of the green revolution on deforestation?
  - Increase in yields $\Rightarrow$ more deforestation (elastic demand) - Jevons Paradox
  - Increase in yields $\Rightarrow$ less deforestation (inelastic demand) - Borlaug's hypothesis
- Borlaug's Hypothesis in the open economy
  - Global trade costs reductions can reduce the total land required to produce the same amount of food
  - An inelastic demand for food will contribute to a global forest expansion

Taking the Model to Data

- 40 countries or regions - Target year 2010
- Additional features in quantitative model
  1. Input-Output linkages + Non-tradable sectors + 3 ag-sectors (staples, pasture and rest of agr.)
  2. All sectors use labor, land, intermediates
  3. Forward looking labor decisions with sectoral switching costs
  4. Land production with convex cost + Fallow land module Check
  5. Distinguish between policy and non-policy trade barriers Check
- Calibration
  - Technology and preference parameters → literature
  - Productivities, preferences and trade costs shifters → inversion to match GDP and trade flows
  - Technology for land producing sector → "Steady state" in 2010 + RF moments

Calibration of Land Producing Function

- Assume

$$x_i = \zeta_i \left(1 - z_i\right)^{\lambda} N_{i,T}^{\gamma_T}$$

  - Analogous functional form for fallow land
  - Set ζ_i so that forest in $t = 0$ equals forest in $t = SS$

- Search for λ and γ_T so that model matches the RF dynamics of deforestation

$$\underbrace{\log\left(y_{i,t}\right) - \log\left(\mathsf{y}_{i,1990}\right)}_{\text{different time lags}} = \beta_0 + \beta \underbrace{\left[\log\left(\mathsf{Pop}_{i,2020}\right) - \log\left(\mathsf{Pop}_{i,1990}\right)\right]}_{\text{30 years lag}} + \epsilon_i \tag{1}$$

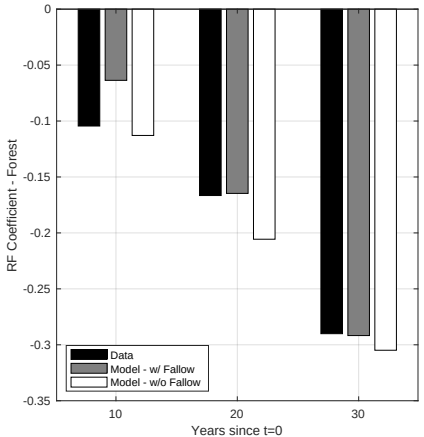
  - $y_{i,t}$: Forest area or agricultural land
  - Estimate β for different $t = 2000, 2010, 2020$ and for agricultural land

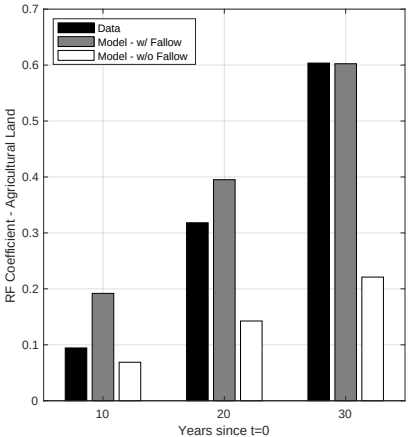
Model Validation

- We validate the model along four dimensions of the data

1. **Dynamics of deforestation**
2. **Trade and deforestation (replication of reduced-form patterns)**
3. Correlation between natural forest reserves and ζ_i (*in the paper*)
4. Correlation between model-implied yields and data (*in the paper*)

Validation 1: Dynamics of Deforestation (Targeted)





- Figure for calibration $\gamma_T = 0.9$, $\gamma_F = 0.97$ and $\lambda = 2$ Fallow land details

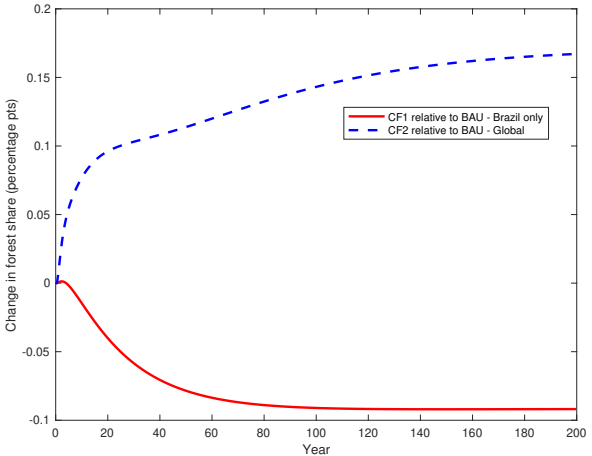
Validation 2: Trade and Deforestation (Non-Targeted)

	Data (1)	Model (2)
a. DV is the log of forest area		
$s^{\text{Own}} \times \Delta$ Log(Own Pop)	-0.408***	-0.470***
	(0.084)	(0.088)
$s^{\text{Partner}} \times \Delta$ Log(Partner Pop)	-1.295*	-1.686**
	(0.711)	(0.825)
R2 or K-P	32.726	0.844
Obs	40	40
b. DV is the log of agricultural area		
$s^{\text{Own}} \times \Delta$ Log(Own Pop)	1.375***	0.748***
	(0.102)	(0.038)
$s^{\text{Partner}} \times \Delta$ Log(Partner Pop)	3.632***	2.446***
	(0.913)	(0.499)
R2 or K-P	32.726	0.972
Obs	40	40
Controls (Initial period value in logs)		
- Share of Agricultural area	Y	Y
- Share of Forest area	Y	Y

Counterfactual Exercises

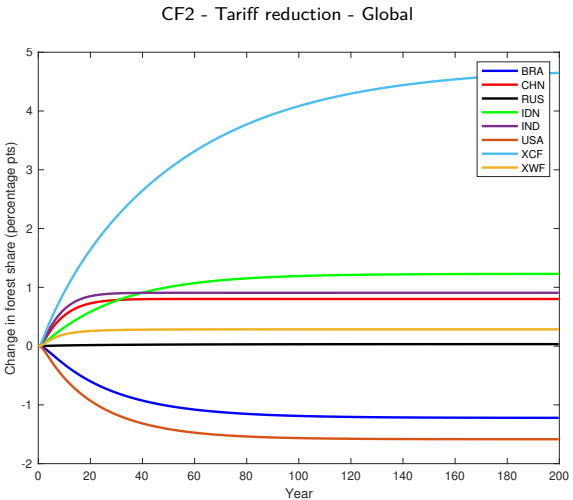
- *Results today*
  - Complete trade liberalization in *agricultural tariffs*
    - **CF1**: Only Brazil faces lower tariffs
    - **CF2**: All countries face lower tariffs
  - Compare to baseline trajectory: all fundamentals are fixed + no population growth
- *In the paper*
  - Iceberg vs Tariff
  - Baseline trajectory with population forecast
  - Tariff hike

Local vs. Global Reductions in Tariffs



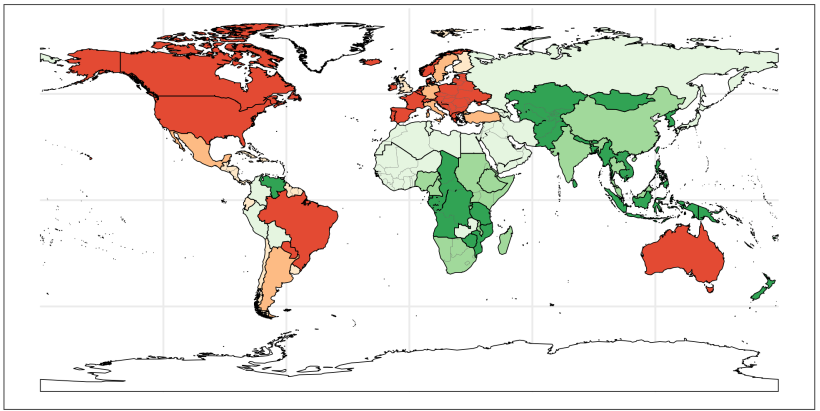
This panel shows at time t the difference in forest share in the counterfactual relative to BAU BAUdetails

The Counterfactual Paths of Forests



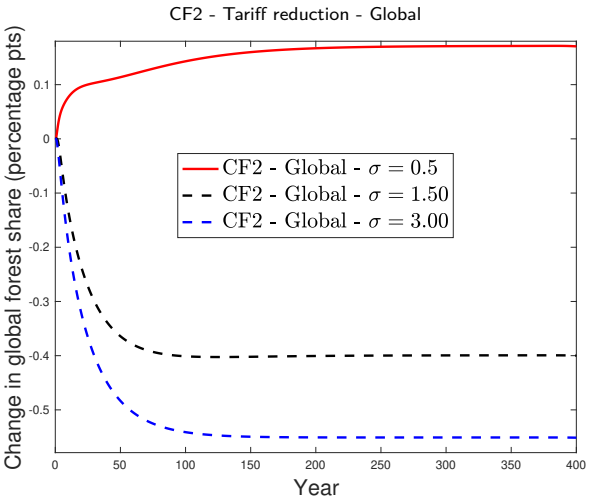
Each figure shows at each time t the difference in forest share in the counterfactual relative to BAU

The Global Impact of Agricultural Trade Liberalization

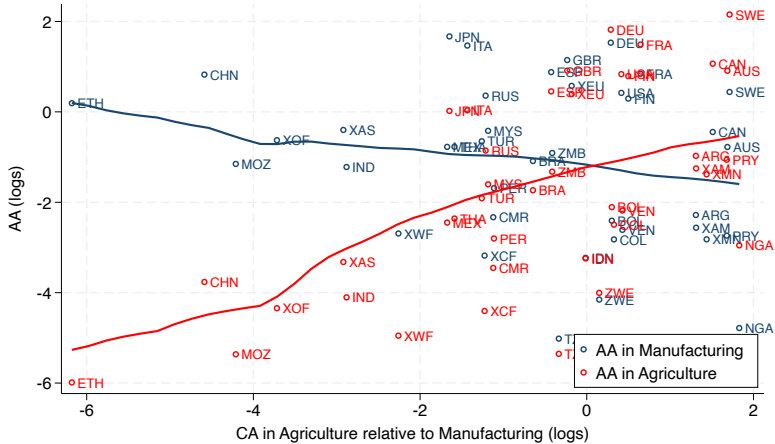


Effects on SS values. Correlation between comparative advantage and deforestation $= 0.43$

The Role of the Sectoral Elasticity σ



The Role of Comparative Advantage and Absolute Advantage



- Trade is a land saving technology?

CO2 Emissions and the Social Cost of Carbon

- Use IPCC method to convert deforestation into CO2 emissions
- Period utility is $U_{i,t} - \varphi E_{i,t}$ and calibrate φ to Social Cost of Carbon

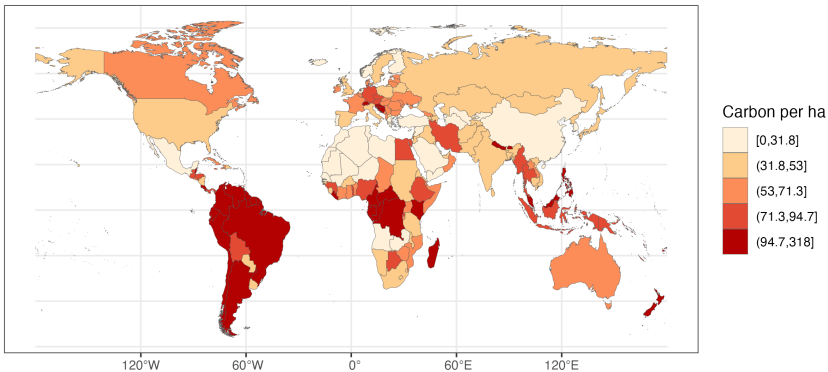
	(1)	(2)	(3)
Panel A: Brazil			
Environmental Costs (as fraction of US GDP)	0.000	1.925	2.772
Welfare gains (percentual change)	-0.090	-0.100	0.000
Panel B: All countries ($\sigma = 0.5$)			
Environmental Costs (as fraction of US GDP)	0.000	5.915	2.536
Welfare gains (percentual change)	0.131	0.101	0.167
Panel C: All countries ($\sigma = 1.5$)			
Environmental Costs (as fraction of US GDP)	0.000	35.594	39.853
Welfare gains (percentual change)	1.267	1.150	-0.090
Economic Assumptions			
- SCC $= 0$	Y	-	-
- SCC $= 200$	-	Y	Y
- Population Growth	-	-	Y

Conclusion

- Large heterogeneity in deforestation across the world
- International trade shapes deforestation
- Dynamic, global trade model motivated by these patterns
- Global reduction in agricultural tariffs has limited effects on global forest area
  - Low **sectoral elasticity** is key for aggregate deforestation
  - Location is determined by **comparative advantage**
  - Quantitatively, global forest area can **increase**
- A call for multilateralism in agricultural trade negotiations

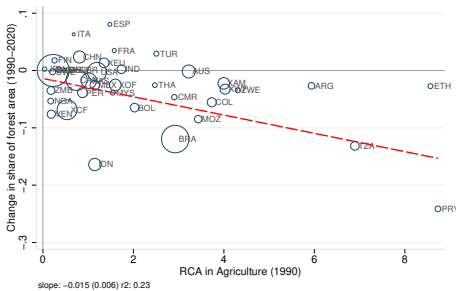
Appendix

Pattern 1: Heterogeneous Carbon Content of Forest

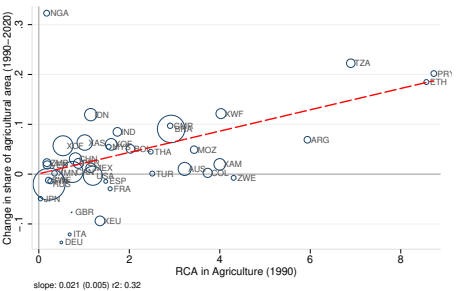


Pattern 3: Deforestation and RCA

Forest share and RCA in Agriculture



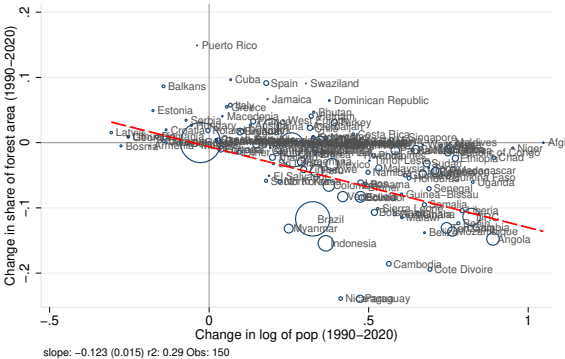
Agri land share and RCA in Agriculture

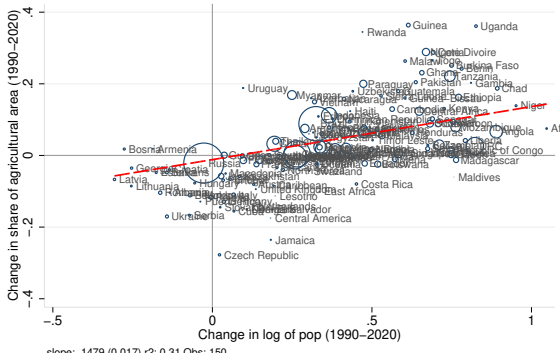


- Size of circles captures country's share in world forest

Go back

Pattern 3 – Full sample





CA vs AA

- In closed economy, we have

$$\frac{N_A}{1-N_A} = \frac{b}{1-b}$$

  - where b is the expenditure share in agriculture

- In open economy, we have

$$\frac{N_A}{1-N_A} = \frac{b}{1-b} \times \frac{Z_{\bar{i},A}/E\left(Z_{i,A}|i > \bar{i}\right)}{Z_{\bar{i},M}/E\left(Z_{i,M}|i \leq \bar{i}\right)}$$

  - $\bar{i}$ is the cutoff country above which there is specialization in agriculture
  - N_A is the total employment in agriculture

- As long as $\frac{Z_{\bar{i},A}/E_A\left(Z_{i,A}|i > \bar{i}\right)}{Z_{\bar{i},M}/E_A\left(Z_{i,A}|i \leq \bar{i}\right)} < 1$ then we have reduction in the stock of land

Go back

Technology — Landowners

- Continuum of holdings (each with one plot), with simple management problem

$$\rho v_i = r_i + \dot{v}_i - g_L v_i$$

- Mass of potential entrants

$$v_i^E = \max\{v_i - q_i, 0\}$$

- Free entry of farmers ensures that

$$v_i = q_i$$

- Delivers standard asset pricing equation

$$(\rho + g_L)\, q_i = r_i + \dot{q}_i$$

$$q_i = \int_0^\infty e^{-(\rho+g_L)v} r_i\,(v)\, dv$$

Go back

Calibration details

- Recover wedges:
  - trade costs
  - productivity shifters
  - IO coefficients
- To match
  - trade shares
  - gross output
  - IO matrices
- Assume 2010 is steady state and back out ζ_i
  - Implies N_{iT} in line with GFRA estimates on employment in forestry

back

Fallow land module summary

- Accounting

$$H = F + L_{i,u} + L_{i,o}$$

- Technologies

$$Q_{i,Tf} = \zeta_{i,f} \times (1 - z_i)^{\lambda} \times N_{i,Tf}^{\gamma_f}$$
$$Q_{i,To} = \zeta_{i,o} \times (z_i (1 - u_i))^{\lambda} \times N_{i,To}^{\gamma_o}, \qquad L_{i,o}/H_i \equiv u_i (1 - z_i)$$

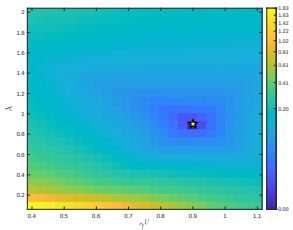
- Asset value

$$\rho v = r + \dot{v} - (\delta_o + \delta_f)$$

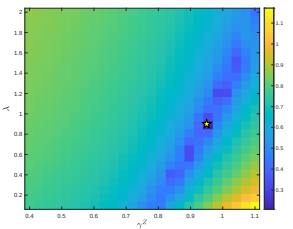
back

Identification

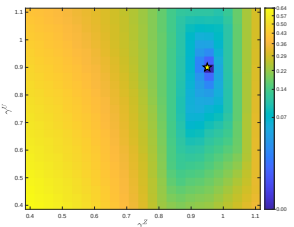
Given γ_Z



Given γ_U



Given λ



back

Trade Barrier Calibration

- Split residuals as

$$d_{ij,g} = (1 + \kappa_{ij,g}) \left(1 + t^{ice}_{ij,g}\right) \left(1 + t^{rev}_{ij,g}\right)$$

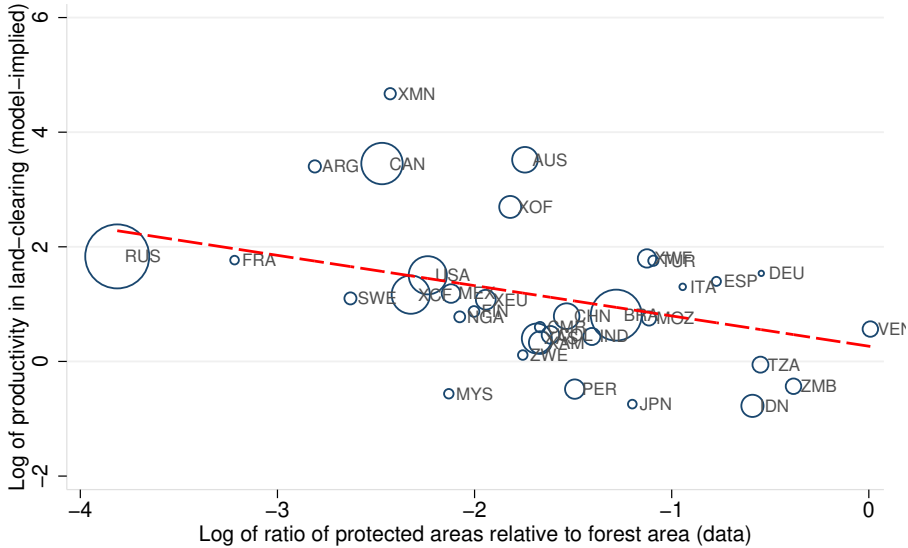
  where
  - $\kappa_{ij,g}$ is a pure iceberg cost
  - $t^{ice}_{ij,g}$ is a policy driven iceberg cost
  - $t^{rev}_{ij,g}$ is a policy wedge that generates revenues

- Proceed in steps

1. Recover wedges $d_{ij,g}$ from gravity equations
2. Regress policy barriers on policy-related observables to separate $\kappa_{ij,g}$
3. Separate t^{ice} from t^{rev} to match total tariff revenues in agriculture

back

Land conversion productivity and regulations



slope: −0.528 (0.185) r2: 0.23