Deforestation: A Global and Dynamic Perspective

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March 2024

Abstract

We study deforestation in a dynamic world trade system. We first document that between 1990-2020: (i) global forest area has decreased by 7.1 percent, with large heterogeneity across countries, (ii) deforestation is associated with expansions of agricultural land use, (iii) deforestation is larger in countries with a comparative advantage in agriculture, and (iv) larger population growth leads to deforestation. We build a model in which structural change and comparative advantage determine the extent, location, and timing of deforestation. We show analytically and quantitatively that, if agriculture is complementary in demand to other sectors, global reductions in trade costs reduce global deforestation, even if such shocks increase deforestation when experienced only by an individual economy. In our calibrated model, a 30 percent reduction in global agricultural trade costs increases steady-state forest share for world area by 0.5 percentage points, taking decades to occur. In the cross-section, countries with a comparative advantage in agriculture expand production at the expense of more deforestation there.

Keywords: International trade, deforestation, dynamics, land use

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*We thank Dominick Bartelme, Chad Bown, Javier Cravino, Sam Kortum, Andrei Levchenko, Pablo Ottonello and Daniel Tannenbaum for helpful comments as well as Tomas Dominguez-Iino for a constructive discussion. We also thank participants in seminars at Michigan, NYU Abu Dhabi, Berkeley, LSE, UIBE, RIDGE-Bogotá, UEA, CAF, Duke, the World Bank, Nottingham, Purdue, Bristol, Essex, Cambridge, UC Santa Barbara, Penn State, SED, USDA, Shenzhen University, and Hitotsubashi-Gakushuin. Sotelo and Farrokhi thank the IES at Princeton for its hospitality during part of this research. We thanks Lucas Correa for research assistance. This document is an output from the research initiative 'Structural Transformation and Economic Growth' (STEG), a programme funded by the Foreign, Commonwealth & Development Office (FCDO). The views expressed are not necessarily those of FCDO. E-mail: ffarrokh@purdue.edu, emkang@umich.edu, hpelleg3@nd.edu, ssotelo@umich.edu.

1 Introduction

Deforestation has gathered speed in recent decades, bringing the adverse impacts of human action on the world's climate and biodiversity to the forefront of public debate.[1] Across countries, the experiences of individual countries have varied greatly and ranged from substantial deforestation in Brazil to reforestation in China. Seeking to understand these experiences, an important literature has identified several drivers of deforestation, such as international crop prices, infrastructure projects, institutional quality, and trade and environmental policies. World population, moreover, is expected to grow by 25% until 2050, which has renewed concerns about food production and pressures on global land use.[2]

In line with these considerations, and against a backdrop of increasing globalization, trade policy is emerging as a potential, feasible tool to curb climate change generally and deforestation in particular—e.g, the EU is working on legislation to ban imports of agricultural products that are linked to deforestation. Unlike in the case of manufacturing, however, agricultural tariffs remain high and have been a recurrent component in trade negotiations. This situation calls for evaluating the role of global policies to deepen integration in agricultural markets, an evaluation that is all the most important because previous work, which has thoroughly studied individual countries and industries, is less informative about the incidence of deforestation across countries and over time when government policies and global market conditions change.

We offer an approach that complements previous work by embracing a global and dynamic view of deforestation. The global dimension is crucial because international trade connects the demand for land across countries. For example, an increase in food demand in China can be met with an expansion in Brazil's agricultural frontier, instead of that of China itself. A global perspective makes such spatial linkages explicit and acknowledges that changes to policy or market conditions in one location will have repercussions elsewhere. In turn, dynamics are important for understanding the timing of deforestation and its impact on climate change. The design of policies to curb the trajectory of carbon emissions, in particular, requires an understanding of how the pace of deforestation responds to shifts in the supply and demand for food over time. An approach that is both global and dynamic is therefore important to design policies that have a bearing on deforestation, especially if they are to be applied simultaneously by many countries.

We start by collecting data on land use, sectoral production, international trade, and

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[1] For instance, global net emissions from deforestation and land-use change accounted for 11 percent of total human-caused CO_2 emissions between 2000 and 2010 (IPCC, 2014).

[2] For instance, see DeFries et al. (2010) that document a positive association between urban population growth and deforestation in the tropics.

population growth. Using these data, we document four empirical patterns that describe the geography of forests and how it relates to international agricultural markets and population growth. First, since 1990 global forest area declined by 7.1 percent—an area the size of Argentina—, with substantial heterogeneity across countries. South America, South East Asia, and Sub-Saharan Africa experienced large rates of deforestation. Put together, these regions account for about 90 percent of the world's forest loss in this period. At the same time, forest area expanded in other regions, such as Europe and China. Second, during this period deforestation across countries was strongly and positively associated with expansions in the agricultural land. This observation suggests that understanding the incentives to use land for agricultural production is crucial to studying deforestation. Third, countries that had a revealed comparative advantage in agriculture in 1990 experienced both a larger increase in agricultural land and in deforestation between 1990 and 2020. This pattern suggests that international trade distributes the global pressure on land across countries. Fourth, population growth has led to deforestation—a relation that is important on its own in the face of expected future population growth, and one that is informative for model calibration.

Next, we develop a dynamic, general-equilibrium model to evaluate the quantitative response of deforestation to trade policy and population growth across the world and over time. The model incorporates many countries, three broad sectors—agriculture, manufacturing, and services—and disaggregated activities within agriculture. There is also a market and, therefore, a price for new land. New land is supplied by a firm that employs labor to transform open-access forests into land. Landowners incorporate new land to their existing stock to rent it to other sectors in the economy. Lastly, we introduce frictions to the reallocation of labor between sectors.

The equilibrium allocation of land in our model is shaped by three mechanisms: (i) structural change determines the size of the agricultural sector and the aggregate demand for land; (ii) comparative advantage distributes pressures on agricultural land use and forests across countries, and together with absolute advantage, determines whether trade further alleviates pressures on forests; and (iii) forward-looking land accumulation decisions control the pace of forest adjustments to shocks.

To guide our quantitative analysis, we produce a set of analytical results in stripped-down versions of our model's steady state. First, reducing agricultural export costs *unilaterally* for a small open economy leads to deforestation there. The key to this result is that the world import-demand elasticity is positive and equal to the trade elasticity. Second, and in contrast to the first result, we show that when countries are symmetric—which shuts down the channel of comparative advantage—a *multilateral* trade-cost reduction in agriculture increases global forest area. This is because, when agriculture becomes relatively cheap and agriculture is complementary in consumption with non-agricultural sectors (as in the data), relative demand for agriculture shrinks. A worldwide reduction in land demand follows, which leads to larger forest area. This result extends Borlaug's hypothesis—that agricultural productivity growth is land-saving in a closed economy Borlaug (2000)—to the domain of trade barriers in open economies. Third, we study the role of comparative advantage in a setting with unitary elasticity of substitution between agriculture and non-agriculture, but where productivity differs across countries. We show that the *correlation* between comparative and absolute advantage in agriculture determines whether trade leads to a gain or loss in global forest area. When this correlation is positive, countries with an absolute advantage in agriculture specialize in agriculture, making the move from autarky to free trade globally land-saving.

We next bring our model to data. We begin by calibrating the parameters that govern the initial, static equilibrium using production, trade, and forest data from 2010. To do so, we disaggregate the world into 33 countries and 7 regions, and we divide the economy into agriculture, manufacturing, and services, further dividing agriculture into main staple crops, pasture-related products, and a bundle of other agricultural products. We choose the parameters governing the conversion of forest into land so that our model replicates the reduced-form impact of population growth on forest area, at different time horizons. Lastly, we develop a method for separately calibrating policy and non-policy driven trade costs.[3]

We then deploy our calibrated model to study several counterfactual scenarios. We compare two polar cases of trade liberalization that echo our first two analytical results: A 30 percent reduction in the policy component of export costs for Brazil only versus a global export cost reduction of the same size. In each case, we study the evolution of global forest area and its distribution across countries compared to a business-as-usual (BAU) scenario in which the economy evolves under no change in fundamentals, starting in 2010.

The first scenario is close to the small open economy case that has been prominent in the study of the impact of trade on the environment.[4] In this scenario, global forest share declines by about 0.1 percentage points in the steady state, most of it in Brazil, whose forest share declines by 3 percentage points, relative to BAU. In the global trade-cost reduction scenario, in contrast, global forest share increases by 0.5 percentage points. Structural change reduces the global demand for land, while comparative advantage in agriculture determines the cross-section of deforestation. Our data, moreover, exhibits a positive correlation between absolute and comparative advantage in agriculture, which in light of our third analytical

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[3] Our quantitative model features, in addition, a fallow land sector. We introduce this block to capture the fact that in the data fallow land is a sizable share of total land and an important source of expansion in agricultural land.

[4] For example, see Brander and Taylor (1997) and Taylor (2003) and Copeland and Taylor (2004).

result, suggests that moving toward free trade alleviates the global pressure on forests.

Having established the quantitative importance of the mechanisms in our model, we create a new BAU scenario in which each country's population grows according to the UN projection in coming decades. In this BAU, many African countries experience large rates of deforestation since their growing population increases the demand for food. We find that a multilateral trade cost reduction would substantially mitigate deforestation in Africa by reallocating land use to other regions that are relatively more efficient in agricultural production.

We conclude by evaluating the CO_2 emissions costs brought about by deforestation.[5] We do so under a broad range of assumptions, so as to highlight the role of different economic mechanisms and measurement approaches that allow for reforestation, carbon heterogeneity or carbon sequestration. In our simplest exercise, the climate costs of export costs reductions in the global versus Brazil-only scenario are roughly the same, despite the large difference in their global welfare impact. In turn, including the sequestration benefits of new forests in our calculation or considering a BAU that includes population growth turns the climate costs of global trade cost reductions into gains.

We contribute to research at the intersection of trade, spatial economics, and the environment. Costinot et al. (2016) and Gouel and Laborde (2018) study the extent to which trade mitigates the impacts of climate change. Other recent studies have formulated dynamic trade and migration models to evaluate the consequences of climate change (e.g. Desmet et al., 2018; Conte et al., 2020; Balboni, 2019). Kortum and Weisbach (2022) and Farrokhi and Lashkaripour (2024) study instead the design of optimal trade and carbon policy on global carbon emissions. Shapiro (2016) evaluates the impact of international shipping on CO_2 emissions. A few recent papers study quantitatively the relations between trade and natural resources. For example, Farrokhi (2020) studies the impact of trade-related policies in global oil markets, and Carleton et al. (2023) examine the relation between agricultural trade and the allocation of water use across the world. Focusing on deforestation, Dominguez-Iino (2021) examines the effects of environmental policies along supply chains in South America, and Hsiao (2021) studies international cooperation and commitment in the market for palm oil. See Copeland and Taylor (2004) and Copeland et al. (2021) for a review of previous work. Closer to our research is Hertel (2012), who points out that the impact of agricultural technological innovations on land use and emissions depends on the elasticity of demand faced by farmers. Relative to this literature, we are the first to incorporate deforestation dy-

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[5] This evaluation adheres to the guidelines routinely used by the International Panel on Climate Change. While we acknowledge the negative impacts of deforestation on biodiversity and amenities, we do not intend to examine them.

namics into a quantitative general equilibrium framework to study how economic forces and international trade policy shape land use around the world. Our multi-country equilibrium approach demonstrates the role of structural change and comparative advantage in shaping the deforestation impact of trade openness.

Second, we contribute to research examining the welfare impacts of agricultural trade (Donaldson, 2018; Sotelo, 2020; Pellegrina, 2020) and how agriculture relates to structural change and development (Tombe, 2015; Fajgelbaum and Redding, 2014; Farrokhi and Pellegrina, 2020; Gollin et al., 2018). Our work gives deforestation a central role in the analysis of agricultural trade, focusing on how structural change determines worldwide pressures on land use and how the resulting impact on deforestation evolves over time. We also relate to a long-standing and rich tradition, reviewed in Hertel (2002), that formulates computational general equilibrium (CGE) models to study global agricultural markets. Relative to the latter, we introduce dynamics in land development and we provide an analytical characterization of the mechanisms driving global deforestation.

Lastly, we complement a large literature that uses detailed micro-data to study different drivers of deforestation and forest management, including the role of national institutions (Burgess et al., 2019), land use taxes and payment programs for forest conservation (Jayachandran et al., 2017; Assunção et al., 2020; Souza-Rodrigues, 2019; Araujo et al., 2022), roads and access to markets (Pfaff, 1999; Asher et al., 2020), demand for wood and forest products (Foster and Rosenzweig, 2003), and externalities generated by forest fires (Balboni et al., 2020). We build on these studies, which focus on individual country experiences, to examine how incentives to deforest transmit across countries through international trade, emphasizing that government policies and market conditions in one country have the potential to drive or curb deforestation elsewhere.

2 Data sources

We combine data on global deforestation and carbon content of forests with other, more standard country-level information on trade, production, and factor employment required in global trade models. After merging these data sets, we have 150 countries in five periods (1990, 2000, 2010, 2015 and 2020). Later, we group countries into 40 countries and regional aggregates to quantify our model. Below we summarize our data. Appendix A provides additional details about each data source.

Forests and Forest Carbon Stock Since 1948, FAO has published a periodic report called Forest Resource Assessment (FAO-FRA), which reflects the FAO's efforts to measure country-level forest area from national forest inventories. We focus on these data for two reasons. First they are publicly available and they offer ample coverage in time and space. The data that we use come from the last edition of FRA, FAO (2020), which covers a 30-year period between 1990 and 2020. Second, they are the key reference for policy debate on global deforestation and for assessments of the impact of deforestation on climate change (Brown and Zarin, 2013). They are used, for example, for the estimation of CO_2 emissions from deforestation by the Intergovernmental Panel on Climate Change (IPCC). Since the 1990s, the methodology used by FAO has been improved to ensure that the measurement of forest areas are comparable over years. This is the earliest year for which we can build consistent time series.

We also employ FAO-FRA information on the carbon content of living biomass above ground—which includes all living biomass above the soil—as well as below ground—which incorporates all biomass of living roots.

Other Country-level Data. We use data on agricultural production, land use, and international trade, disaggregated by agricultural commodity, from FAO-STAT. For agriculture, manufacturing and services, we take data on employment from UN-ILO and value added, final and intermediate-input expenditures, and international trade from the GTAP database.

3 Empirical Patterns about Global Deforestation

This section documents four empirical patterns about global deforestation that motivate our modeling approach. We first document the evolution of deforestation between 1990 and 2020. Second, we show that deforestation has been strongly associated with expansions in agricultural land use. Third, deforestation was larger in countries with a comparative advantage in agriculture. Fourth, we estimate the impact of population growth on deforestation, which will later discipline the calibration of our model.

Pattern 1. Between 1990 and 2020, global forest area dropped by 7.1%. While in the tropics, forest area dropped substantially, in several non-tropical regions there was forest regrowth.

We use "country area" as a shorthand for total area of a country net of deserts, glaciers and lakes. Panel (a) in Figure 1 shows the share of country area covered by forest. Countries with higher forest concentration tend to be in regions close to the North Pole, including the large boreal forests of Canada, Russia, and the Nordic countries or areas near the equator, including the tropical forests of the Amazon, Congo Basin, and Southeast Asia. Panel

(b) depicts global deforestation in 2020 relative to 1990 (as percentage points of the each country's area). The 7.1% loss of global forest area—from 4.07 billion hectares in 1990 to 3.78 billions in 2020—amounts to the size of a country between Argentina and India. Deforestation was relatively mild in the northern countries while it was substantial in the tropics, such as in Brazil, Congo, and Indonesia where their forest area fell respectively by 17%, 16%, and 26% during 1990-2020.[6] Other countries, primarily China and several European countries, reforested over this period. The correlation between land share in 1990 and deforestation between 1990-2020 is -0.61 in the data, which motivates us to give a role to the extent to deforestation as a driver of future deforestation.

Appendix Table E.2 provides an accounting of global deforestation disaggregated by the 33 countries plus 7 aggregate regions we bring to data for quantitative analysis.[7] The table shows for each country the forest share in country area in 1990, percentage point change in forest share and percentage change in forest area during 1990-2020. It also shows each country's contribution to the global deforestation during 1990-2020. Brazil alone accounts for one-third of global deforestation, followed by Central African countries and Indonesia together accounting for one-fourth of global deforestation. Our model aims at capturing economic mechanisms driving these different deforestation.

Before moving on, we note that forests are heterogeneous in their carbon content. Figure E.1 in the appendix depicts each country's forest carbon intensity (tons of carbon stock per hectare of forest), suggesting that the carbon emission implications of deforestation depend on where it occurs. We incorporate this heterogeneity into our analysis of the climate costs of different trade integration scenarios, following the IPCC and FAO guidelines (Tubiello et al., 2020).

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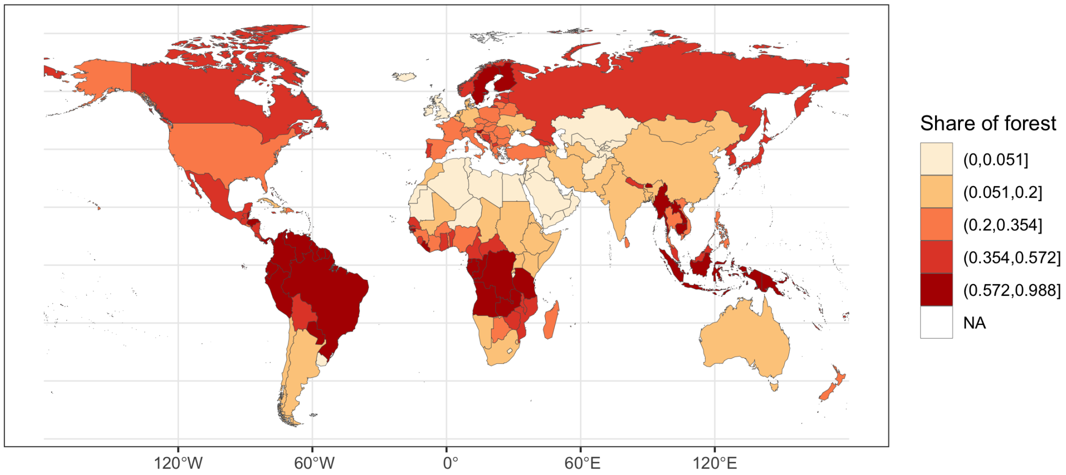
[6] The figure shows these numbers in terms of the percentage point (p.p.) change in each country's forest share rather than percentage change since the latter gives uninformatively large magnitudes in countries where forest share is tiny. The p.p. change in forest share (multiplied by 100) was -2.2 at the global level and -12.0, -10.8, and -16.4 respectively in Brazil, Congo, and Indonesia.

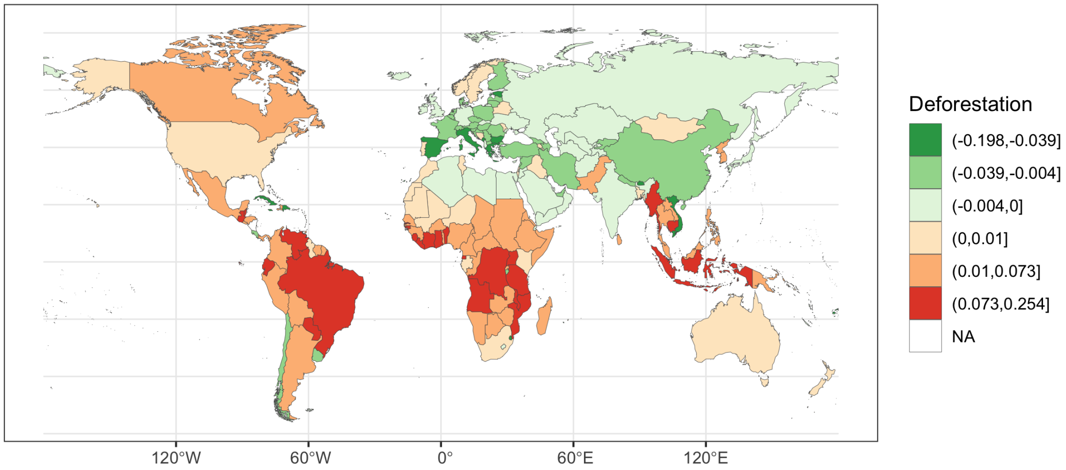
[7] Appendix Table E.4 reports these deforestation-related variables at the individual country level and Appendix Table E.1 lists the individual countries that constitute each of our regional aggregates.

Figure 1: Forest and Deforestation across the World (1990-2020)

(a) Forest share in Country Area (1990)



(b) Deforestation (2020 relative to 1990)



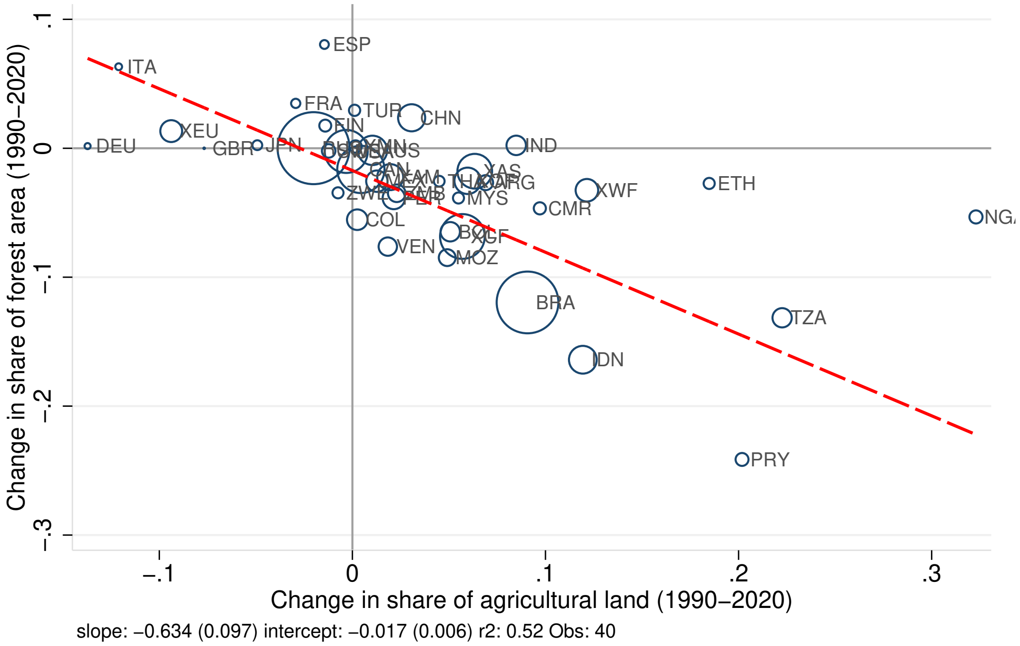
Notes: Panel (a) shows "forest share" for each country—as the share of a country's area covered by forest in 1990. Panel (b) shows the percentage point change in forest share for each country between 1990 and 2020.

Pattern 2. Changes in forest area are negatively correlated with changes in agricultural land use.

Figure 2 plots the change in forest area against the change in agricultural land use across countries, both measured as a share of their corresponding country area. The two variables are strongly and negatively correlated, with the share of forest area decreasing at a slope of -0.63 with respect to the share of agricultural land.

This empirical regularity motivates us to design a land-use model in which expansions in land use, particularly from agriculture, may come at the cost of deforestation. We next turn to two mechanisms driving the demand for agricultural land in a country, namely, agricultural trade and population growth.

Figure 2: Change in Share of Land in Forest versus Share of Land in Agriculture (1990-2020)



Notes: This figure shows the relationship between changes from 1990 to 2020 in agricultural land use and changes forest area across countries, each as a share of country area, in percentage changes from 1990 to 2020. The size of circles represents the share of forest area in each country. The red dashed line shows the linear fit weighting the observations by each country's forest area in 1990.

Pattern 3. Between 1990 and 2020, countries with a comparative advantage in agriculture experienced a larger expansion in their agricultural land use and a larger reduction in their forest area.

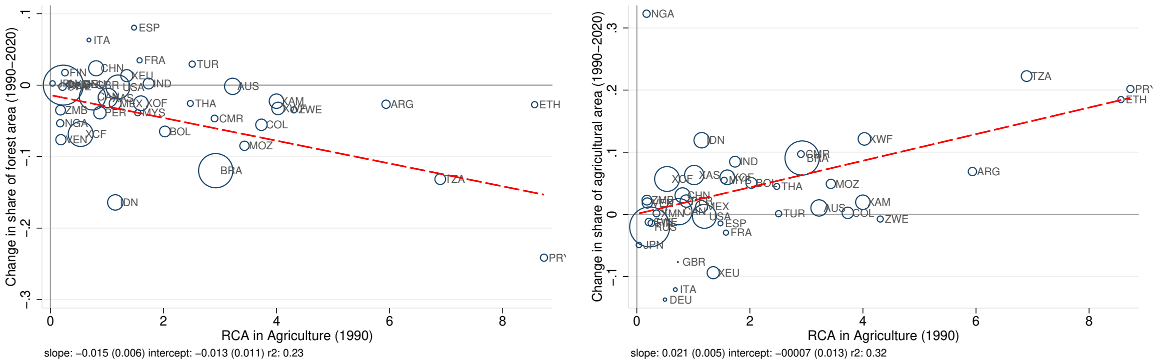
We next examine countries' change in agricultural and forest area in relation to their international position in agricultural specialization. To this end, we employ the index of *revealed comparative advantage* for each country i, defined as:

$$\text{RCA}_i^{(\text{Agr})} = \frac{(\text{Agr Exports})_i/(\text{Total Exports})_i}{(\text{World Agr Exports})/(\text{World Total Exports})}$$

Panels (a) and (b) of Figure 3 show that in countries with a higher RCA (measured in 1990) the expansion agricultural land and the reduction of forest area has been larger during 1990-

2020. This pattern motivates a model in which comparative advantage governs the relative demand for land, and therefore the pressure on forests, across countries.

Figure 3: Change in Agricultural Land and Forest Area against Comparative Advantage in Agriculture



(a) Forest area

(b) Agricultural area

Notes: This figure shows the 1990-2020 change in agricultural land share in country area (Panel a) and forest share in country area (Panel b) against the index of revealed comparative advantage (measured in 1990) across countries.

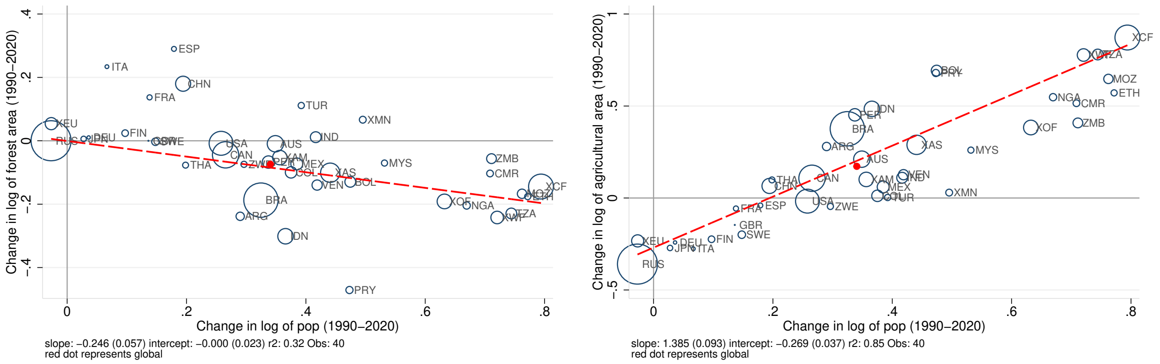
Pattern 4. Population growth leads to agricultural land expansion and deforestation.

We examine the impact of population growth on agricultural land use and forest area across countries. Figure 4 shows that between 1990 and 2020 countries with higher rates of population growth experienced a larger reduction in their forest area and a larger expansion in their agricultural land use. To explore this relationship more systematically, we consider the following equation:

$$\Delta \ln y_{i,t} = \beta_0 + \beta_1 \Delta \ln \text{Population}_{i,t} + \beta_X \mathbf{X}_{i,t} + \epsilon_{i,t} \tag{1}$$

where $y_{i,t}$ represents either agricultural land or forest area, and $\text{Population}_{i,t}$ $\mathbf{X}_{i,t}$, and $\epsilon_{i,t}$ denote population, control variables—see description in the table—, and the error term for country i at time t. The Δ operator denotes 30-year time differences. The coefficient of interest, β_1, captures the impact of population growth on net forest or agricultural land growth.

Figure 4: Change in Forest and Agricultural Area on Population Growth



(a) Forest Area

(b) Agricultural Area

slope: −0.246 (0.057) intercept: −0.000 (0.023) r2: 0.32 Obs: 40
red dot represents global

slope: 1.385 (0.093) intercept: −0.269 (0.037) r2: 0.85 Obs: 40
red dot represents global

Notes: This figure shows the 1990-2020 change in log agricultural land area (Panel a) and log forest area (Panel b) against the 1990-2020 change in log population across countries.

An OLS estimation of equation (1) may suffer from endogeneity bias. For example, shocks to agricultural productivity can lead to a rise of both population and deforestation, creating a correlation between population growth and the error term. We therefore instrument $\Delta \ln \text{Population}_{i,t}$ with the median age in country i at time period $t-1$. Our identifying assumption is that countries with a higher fraction of population in that range will tend to have more births, for purely biological reasons, and that past demographic structure is uncorrelated with future productivity shocks.

Table 1 shows the OLS and IV estimates of equation (1). Panel (a) reports a negative and statistically significant elasticity of forest area to population, for both OLS and IV, with and without controls for institutions and environmental regulations. In particular, the IV estimate under Column (4) implies that a 10 percent increase in a country's population reduces its forest area by 4.6 percent. Turning to Panel (b), it shows a positive and statistically significant response of agricultural land to population growth, which is again similar across specifications. Here, the IV estimate in Column (4) indicates that a 10 percent increase in population leads to 10.8 percent increase in agricultural land use.

These results are important in their own right, especially considering that the world population is expected to grow by 35% between 2020 and 2100. In addition, through the lens of our model, changes in population map transparently into land use pressures, both by raising the demand for food and increasing the supply of labor. We will therefore target these reduced-form results to calibrate the parameters of our land-producing sector, which governs the response of deforestation to shocks to fundamentals (including trade costs).

Table 1: The Relationship between Population Growth and Forest Area (30 years interval)

	OLS (1)	OLS (2)	IV (3)	IV (4)
a. DV is the log of Forest Area				
Δ Log(Pop)	-0.362***	-0.242**	-0.409***	-0.329*
	(0.082)	(0.123)	(0.076)	(0.189)
R2 or K-P	0.337	0.384	58.419	35.763
Obs	40	40	40	40
b. DV is the log of Agricultural Area				
Δ Log(Pop)	1.220***	1.128***	1.211***	0.933***
	(0.111)	(0.198)	(0.096)	(0.268)
R2 or K-P	0.761	0.778	58.419	35.763
Obs	40	40	40	40
Controls				
- Institutions	-	Y	-	Y
- Environmental tax	-	Y	-	Y
- GDP pc	-	Y	-	Y

Notes: Observations are weighted by forest share in 1990. Robust standard errors clustered at country level are reported in parenthesis. Columns 2 and 4 control for log of GDP per capita (linear and square), regulatory quality, government corruption, and environmental tax in the initial year. Columns 3 and 4 employ the media age (linear, square and cubic) as instruments for population growth.

4 Theory

We develop a dynamic, multi-country, multi-sector general equilibrium model of global deforestation and international trade. The main forces allocating pressures on land use are sectoral comparative advantage and structural change. To study how deforestation responds to changes in fundamentals, we introduce a forward-looking land-producing sector that converts forest area into cleared land.

4.1 Environment

Time, Commodities, and Markets. The economy consists of multiple countries, indexed by i or $j \in \mathcal{I}$. Time is continuous and indexed by t. There are three broad sectors producing tradable goods for final consumption: Agriculture, A, Manufacturing, M, and Services, S. An additional sector, which we call the land-producing sector, T, clears the forest and produces land that can be used in the production of consumption goods. We index sectors by $s \in \mathcal{S} = \{A, M, S, T\}$. The agricultural sector is disaggregated into K industries, whereas the manufacturing and service sectors consist of one industry each. Accordingly, we define each good g as a pair of industry-sector, $g \equiv (k, s) \in \mathcal{G}$, where the set $\mathcal{G}$ of goods is defined as

$$\mathcal{G} \equiv \{ \underbrace{1, ..., K}_{\text{agriculture}}, \underbrace{M}_{\text{manufacturing}}, \underbrace{S}_{\text{service}} \}$$

Shipping good g from i to j entails an iceberg cost $d_{ij,g} \geq 1$, with $d_{ii,g} = 1$. Markets are perfectly competitive. We drop the time index whenever it does not create confusion. Hereafter, we let $\dot{y} = dy/dt$ for any variable y.

Endowments and Preferences. At any point in time, each country is endowed with a working population, N_i, and total land area, H_i, which is divided between land for production, L_i, and forest available for conversion, F_i, so that $H_i = F_i + L_i$.[8]

Varieties of every good $g \in \mathcal{G}$ are differentiated by their origin. Consumers combine varieties of every good g according to CES preferences with elasticity of substitution $\eta_g > 0$ and demand shifters $b_{ij,g}$. Country j's expenditure in good g produced by country i equals

$$\pi_{ij,g} = \frac{b_{ij,g} \left(c_{i,g} d_{ij,g}\right)^{1-\eta_g}}{p_{j,g}^{1-\eta_g}}, \tag{2}$$

where $c_{i,g}$ is the marginal cost of production, and $p_{j,g}$ is the price index of good g in destination market j, given by:

$$p_{j,g} = \left[\sum_{i \in \mathcal{I}} b_{ij,g} \left(d_{ij,g} c_{i,g}\right)^{1-\eta_g} \right]^{\frac{1}{1-\eta_g}} \tag{3}$$

The bundle of agricultural consumption, in turn, is a CES aggregator across goods $k = 1, ..., K$ in the agriculture sector $s = A$, with elasticity of substitution κ and demand shifters $b_{i,k}$. The resulting within-agriculture expenditure shares equal:

$$\beta_{i,k} = b_{i,k} \left(\frac{p_{i,k}}{P_{i,A}} \right)^{1-\kappa}. \tag{4}$$

The sector-level price index of agriculture, $P_{i,A}$, follows from the CES specification between agricultural goods, and those of manufacturing and service are trivially given by their corresponding good-level price indices:

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[8] Our second empirical pattern shows that, although agricultural land use and deforestation are strongly associated, the relation is not one-to-one. Agricultural land expands from other sources as well, such as previously land left to fallow. We allow for this possibility in our quantitative analysis and discuss this extension in Appendix C.1..

$$P_{i,A} = \left[\sum_{k=1}^{K} b_{i,k} p_{i,k}^{1-\kappa} \right]^{\frac{1}{1-\kappa}}, \qquad P_{i,M} = p_{i,M}, \qquad P_{i,S} = p_{i,S} \tag{5}$$

Lastly, the upper-tier CES aggregator combines the bundles of agriculture, manufacturing, and services with substitution elasticity σ and demand shifters $b_{i,s}$. The expenditure share on sector $s \in \{A, M, S\}$ equals:

$$\beta_{i,s} = \frac{b_{i,s} P_{i,s}^{1-\sigma}}{P_i^{1-\sigma}}, \tag{6}$$

where the final consumer price is given by,

$$P_i = \left[\sum_{s \in \{A,M,S\}} b_{i,s} P_{i,s}^{1-\sigma} \right]^{\frac{1}{1-\sigma}}, \tag{7}$$

In the empirically relevant case of $\sigma < 1$, agriculture and other sectors are gross complements if $\sigma \in (0, 1)$, so expenditure shares shift away from agriculture when the price index of agriculture falls relative to that of the other sectors.

Land-Producing Sector. At any point in time, the frontier of cleared land in country i is denoted by $z_i \in [0, 1]$, which defines the fraction of the total land available for productive uses. Therefore, the cleared land area is $L_i = z_i H_i$, and forest area is $F_i = (1 - z_i) H_i$.

Given the frontier, z_i, a firm in the land-producing sector employs labor, $N_{i,T}$, and produces a flow of new land, $Q_{i,T}$, according to

$$Q_{i,T} = J_i(z_i) N_{i,T}^{\gamma_T}, \tag{8}$$

where $J_i(z_i)$ is a decreasing function of z_i, capturing the notion that it becomes more costly to deforest—be it due to policy action, terrain variation, or distance to markets—as the share of forest decreases. Moreover, $J(1) = 0$ since there can be no production of new land if the entire forest is gone. Lastly, γ_T measures the decreasing returns to labor.[9]

The firm behaves competitively and therefore the price of new land, q_i, equals its marginal

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[9] Our specification is rooted in the literature on renewables, e.g., Brander and Taylor, 1997, that assumes $Q_{i,T} \propto (1 - z_i) N_{i,T}$. This corresponds to a special case of our specification where $J_i(z_i) = 1 - z_i$ and $\gamma_T = 1$. Moreover, we implicitly assume open access to land, since we can reinterpret equation (8) as $\min \left\{ J_i(z_i) N_{i,T}^{\gamma_T}, F_i \right\}$, where sector T uses the forest without paying for it. Note that one unit of forest is then always converted to one unit of land.

cost[10]:

$$q_i = \frac{w_{i,T}}{\gamma_T J_i\left(z_i\right)} N_{i,T}^{1-\gamma_T}, \tag{9}$$

where $w_{i,T}$ denotes the wage in the land-producing sector . The land frontier evolves according to:

$$\dot{z}_i H_i = x_i - \delta_L L_i, \tag{10}$$

where δ_L is the natural rate of reforestation and x_i is the gross inflow of new land.

Landowners. There is a continuum of landowners who are risk-neutral and have perfect foresight. Each of them owns one unit of land which she rents out at a rate r_i. Landowners discount the future at a rate of ρ and, with an arrival rate of δ_L, each unit of land "depreciates", turning back into forest. Land productivity is homogeneous across different uses.

Under these assumptions, the value function v_i^L of a landowner can be expressed as:

$$\left(\rho + \delta_L\right) v_i^L = r_i + \dot{v}_i^L. \tag{11}$$

There is also a mass of potential entrants who buy new land if its value is at least as large as its cost, $v_i^L \geq q_i$. In an equilibrium with a finite flow of new land per instant, we must have equality, which we impose from now on. This corresponds to the following free entry condition:

$$v_i^L = q_i. \tag{12}$$

Using this result, we obtain the following asset pricing equation for land,

$$\left(\rho + \delta_L\right) q_i = r_i + \dot{q}_i, \tag{13}$$

which can be solved to show that the price of new land equals the present value of land rents, discounted by $(\rho + \delta_L)$, a rate that accounts for both time preference and the rate of forest regrowth, $q_i\left(t\right) = \int_t^{\infty} e^{-(\rho+\delta_L)(s-t)} r_i\left(s\right) ds$.

Workers and Sectoral Choices. Following Artuç et al. (2010) and Caliendo et al. (2019b), we assume workers are forward looking and have perfect foresight. They are endowed with

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[10] This equation can be alternatively expressed as an (inverse) supply schedule, $q_i = \bar{q}_i w_{i,T} Q_{i,T}^{\tilde{\gamma}_T}$ where $\bar{q}_i \equiv J_i(z_i)^{-\frac{1}{\gamma_T}} / \gamma_T$ and $\tilde{\gamma}_T \equiv \frac{1-\gamma_T}{\gamma_T}$ is the inverse supply elasticity. A reduction in the stock of forest shifts the supply curve upward via raising z_i. Insofar as $\gamma_T \in (0, 1)$, the price on the supply schedule remains finite unless the stock of forest is completely depleted, i.e., $z_i \to 1$.

one unit of labor, which they supply inelastically. Workers receive opportunities to move out of their current sector with an arrival rate of ψ. When an opportunity arrives, a worker draws a vector of preference shocks, $\epsilon^N_{i,s}$, from a Type-I extreme value distribution with dispersion parameter ν, and can choose to reallocate from its current sector s to another sector s', subject to moving cost $f^N_{i,ss'}$. Accordingly, the expected present value of the stream of a worker's utility who is currently in sector s, $v^N_{i,s}$, is the solution to:

$$(\rho + \psi)\, v^N_{i,s} = u\left(\frac{w_{i,s}}{P_i}\right) + \psi W_{i,s} + \dot{v}^N_{i,s}, \tag{14}$$

where $W_{i,s}$ is the expected continuation value for a worker employed in sector s who receives a moving opportunity,

$$W_{i,s} \equiv \mathbb{E}\left[\max_{s'}\left\{v^N_{i,s'} - f^N_{i,ss'} + \varepsilon^N_{i,s'}\right\}\right] = \nu \log \sum_{s' \in S} \exp\left(\frac{1}{\nu}\left(v^N_{i,s'} - f^N_{i,ss'}\right)\right). \tag{15}$$

Conditional on the arrival of the option to move, the probability of moving from sector s to s' equals:

$$\mu_{i,ss'} = \frac{\exp\left(\left(v^N_{i,s'} - f^N_{i,ss'}\right)/\nu\right)}{\sum_{l \in S} \exp\left(\left(v^N_{i,l} - f^N_{i,sl}\right)/\nu\right)}. \tag{16}$$

Technology for producing Agriculture, Manufacturing, and Services. The production technology of each good aggregates labor, land, and intermediate inputs in a Cobb-Douglas fashion. Accordingly, the marginal cost of producing good g in country i is given by:

$$c_{i,g} = \frac{1}{Z_{i,g}}\left(w_{i,g}^{\gamma_{i,g}} r_i^{1-\gamma_{i,g}}\right)^{\alpha_{i,g}} \left(p^I_{i,g}\right)^{1-\alpha_{i,g}}, \tag{17}$$

where $\alpha_{i,g}$ is the value added share divided between land and labor with shares $\gamma_{i,g}$ and $(1 - \gamma_{i,g})$. Assuming perfect labor mobility within the agriculture sector, agricultural industries pay the same wage $w_{i,A} = w_{i,1} = ... = w_{i,K}$. However, wage rates are different only between broadly-defined sectors. Moreover, $Z_{i,g}$ is total factor productivity, r_i is the rental rate of land, and $p^I_{i,g}$ is the price index of intermediate bundle used in the production of good g which is a CES aggregator of prices of all goods $g' \in \mathcal{G}$ with elasticity parameter σ^I:

$$p^I_{i,g} = \left(\sum_{g' \in \mathcal{G}} b^I_{i,g'g} p_{i,g'}^{1-\sigma^I}\right)^{\frac{1}{1-\sigma^I}} \tag{18}$$

Recall that the price $p_{i,g'}$ is determined by Equation 3. We denote the associated expenditure shares of industry g on goods produced by industry g' in country i by $\beta^I_{i,g'g}$, which equals

$b^I_{i,g'g}\left(p_{i,g'}/p^I_{i,g}\right)^{1-\sigma^I}$.

4.2 Expenditures and Market Clearing Conditions.

Country $i's$ total sales of good g equal

$$Y_{i,g} = \sum_j \pi_{ij,g} X_{j,g}, \tag{19}$$

where $X_{j,g}$ is the total expenditure on good g in destination j, comprised of final and intermediate demand:

$$X_{i,g} = \underbrace{\beta^F_{i,g} E_i}_{\text{final expenditure}} + \underbrace{\sum_{g' \in G} \beta^I_{i,g'g}\left(1-\alpha_{i,g'}\right) Y_{i,g'}}_{\text{intermediate expenditure}}. \tag{20}$$

Here, $\beta^F_{i,g}$ is the final expenditure share on each good g.[11] Labor market clearing requires the wage bill to equal payments to labor in each sector s, that is:

$$w_{i,A} N_{i,A} = \sum_{k=1}^{K} \alpha_{i,k}\gamma_{i,k} Y_{i,k}, \quad w_{i,M} N_{i,M} = \alpha_{i,M}\gamma_{i,M} Y_{i,M}, \quad w_{i,S} N_{i,S} = \alpha_{i,S}\gamma_{i,S} Y_{i,S} \tag{21}$$

Land market clearing requires total land rents to equal payments to land:

$$r_i L_i = \sum_{g \in \mathcal{G}} \alpha_{i,g}\left(1-\gamma_{i,g}\right) Y_{i,g} \tag{22}$$

The profits in the land-producing sector are given by: $\Pi_{i,T} = (1-\gamma_{i,T}) q_i Q_{i,T}$. In turn, the market clearing in the production of new land entails $Q_{i,T} = x_i$ in every country i.

Lastly, under balance of trade, final expenditure equals the sum of factor rewards,[12]

$$E_i = r_i L_i + \sum_{s=\{A,M,S\}} w_{i,s} N_{i,s}. \tag{23}$$

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[11] For manufacturing and services $g = s \in \{M, S\}$, $\beta^F_{i,g} = \beta_{i,s}$; for agricultural products $g \in (k = 1, ..., K \mid A)$, $\beta^F_{i,g} = \beta_{i,A}\beta_{i,k}$.

[12] Since the net payment to land is $(r_i L_i - w_{i,T} N_{i,T})$, the balance of budget could be equivalently expressed as $E_i = (r_i L_i - w_{i,T} N_{i,T}) + \sum_{s=\{A,M,S,T\}} w_{i,s} N_{i,s}$. Moreover, market clearing conditions ensure that final expenditure also equals aggregate value added, $E_i = \Sigma_g \alpha_{i,g} Y_{i,g}$.

4.3 Evolution of Labor, Land and Forest Area

To keep track of worker reallocation across sectors, we define the matrix, $\mathbf{M}_i$, with elements $\mathbf{M}_i[s,s'] = \psi\mu_{i,ss'}$ if $s \neq s'$, and $\mathbf{M}_i[s,s'] = -\psi(1-\mu_{i,ss})$ if $s = s'$.[13] In country i, the mass of workers in each sector evolves according to:

$$\dot{\mathbf{N}}_i = \mathbf{M}_i^T \mathbf{N}_i, \tag{24}$$

where $\mathbf{N}_i$ is the vector of employments across sectors in country i. The above equation together with the initial labor allocation, $\mathbf{N}_i(0)$, characterize the evolution of labor.

The evolution of land across uses, in turn, follows from the definition of the land frontier, $L_i = z_i H_i$. Thus,

$$\dot{L}_i = \dot{z}_i H_i = x_i - \delta_L L_i, \tag{25}$$

and hence, the evolution of forest area is given by:

$$\dot{F}_i = -\dot{L}_i = \delta_L \left(\sum_{g \in \mathcal{G}} L_{i,g} \right) - x_i \tag{26}$$

Coupled with initial stocks of productive land and forests, $L_i(0)$ and $F_i(0)$, Equations 25 and 26 characterize the evolution of land. Deforestation is the decrease in forest cover, $\dot{D}_i \equiv -\dot{F}_i$.

4.4 Equilibrium

The fundamentals of the economy are land endowments, $\{H_i\}_i$, technology and preference parameters $\mathbf{Z}(t) = \{Z_{i,g}(t)\}_{i,g}$ $\bar{\mathbf{a}} \equiv \left\{ \{b^I_{i,g'g}\}_{g,g'}, \{\alpha_{i,g}, \gamma_{i,g}\}_g, \{b_{i,k}\}_k, \{b^s_i\}_s \right\}_i$, trade costs $\mathbf{d} = \{d_{ij,g}(t)\}_{ij,g,t}$, reallocation costs for workers $\mathbf{f} = \left\{ \{f^N_{i,ss'}\}_{s,s'} \right\} i$, and constants $\mathbf{\Theta} = \left\{ \{\eta_g\}_g, \kappa, \sigma, \sigma^I, \psi, \theta, \xi, \nu, \delta_L \right\}$. At any time, the state of the economy is given by labor endowments, $\mathbf{N}(t) = \{N_i(t)\}_t$ and allocations $\mathbf{S}(t) = \left\{ F_i(t), L_i(t), \{N_{i,s}(t)\}_s \right\}_i$, satisfying resource constraints on the endowments: $\sum_{g \in \mathcal{G}} L_{i,g}(t) = L_i(t)$, $F_i(t) + L_i(t) = H_i$, and $\sum_{s \in \mathcal{S}} N_{i,s}(t) = N_i(t)$.

Definition. [Instantaneous equilibrium] Given $\{\bar{\mathbf{a}}, \mathbf{d}, \mathbf{f}, \mathbf{\Theta}\}$, the current state of the economy, $\{\mathbf{S}(t), \mathbf{Z}(t), \mathbf{N}(t)\}$, and the price of new land $\{q_i\}_i$, an instantaneous equilibrium consists of wages in each sector $\{w_{i,s}\}$, rental rates $\{r_i\}$, and new land production$\{x_i\}$, such that labor and land markets clear according to equations (21) and (22).

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[13] When population growth is nonzero, we alter the on-diagonal elements to $\mathbf{M}_i[s,s'] = -\psi(1-\mu_{i,ss}) + \delta^N_i$, where δ^N_i is country i's population growth at a point in time. This is equivalent to assuming that workers who enter the workforce do so in each sector with equal probability.

Definition. **[Dynamic equilibrium]** Given $\{\bar{\mathbf{a}}, \mathbf{d}, \mathbf{f}, \mathbf{\Theta}\}$, paths for $\mathbf{Z}$, and an initial condition $\mathbf{S}(0)$, a dynamic equilibrium consists of paths for cleared land $\{L_i\}$, labor allocations $\{N_{i,s}\}$, value functions for workers $\{v_{i,s}^N\}_{i,s}$ and for the landowners $\{v_i^L\}$, such that labor evolves according to (24), land evolves according to (25)–(26), land price $\{q_i\}$ satisfies the entry condition 12, value functions evolve according to (14), (11) and (12) with corresponding continuation values $\{W_{i,s}\}_{i,s}$ for labor by (15) and wages and rental rates satisfy the instantaneous equilibrium.

Definition. **[Steady-state equilibrium]** The allocation that satisfies the conditions of dynamic equilibrium in addition to: $\dot{N}_{i,s} = \dot{L}_i = \dot{v}_{i,s}^N = \dot{v}_i^L = 0$.

5 Analytical Results

This section uses a stripped-down version of our model to provide sharp characterizations of the impact of trade on deforestation. First, we show that when a small open economy experiences reductions in its export costs, it loses forests. Second, and in contrast to our first result, in a world consisting of symmetric countries, a multilateral reduction in agricultural trade costs results in global forest gain. Third, in a world consisting of asymmetric economies and where the elasticity of substitution between agriculture and other sectors equals one, trade leads to a global forest gain if comparative and absolute advantage in agriculture align across countries.

In the rest of this section, we suppose that (i) in addition to the land-producing sector T, there are only two sectors: agriculture A and manufacturing M, (ii) workers incur no switching costs, and (iii) A uses only land, and M and T use only labor:

$$Q_{i,A} = Z_{i,A} L_i; \qquad Q_{i,M} = Z_{i,M} N_{i,M}; \qquad Q_{i,T} = Z_{i,T} N_{i,T}.$$

We focus on the model's steady state. Appendix B collects the proofs of the propositions in this section.

Our first proposition clarifies the context in which the conventional wisdom—that trade leads to deforestation—can be most clearly understood.

Proposition 1. *(A unilateral reduction in agricultural export costs of a small open economy.) Suppose country i is a small open economy as in Alvarez and Lucas (2007)($N_i, H_i \to 0$, with $Z_{i,M}^{1-\eta}/N_i \to k_N > 0$ and $Z_{i,A}^{1-\eta}/H_i \to k_H > 0$). A reduction in country i's export costs (i) increases the relative wage of manufacturing workers with the following elasticity:*

$$\frac{\partial \log (w_M/w_T)}{\partial \log \tau_A} = -\frac{(1-\eta)}{\eta + \chi} > 0 \text{ if } \eta > 1,$$

and (ii) increases country i's stock of land:

$$\frac{\partial \log L}{\partial \log \tau_A} = -\chi \frac{(1-\eta)}{\eta+\chi} . \frac{N_M}{N} < 0 \text{ } \textit{if } \eta > 1.$$

The relevant demand elasticity for a small open economy is the elasticity of substitution between domestic and foreign varieties, η, which is empirically larger than unity. When a small open economy experiences a reduction in its agricultural export costs, the extent to which its agricultural exports expand is governed by the trade elasticity, $(1-\eta)$, which is positive. The derived demand for land also expands, causing deforestation.

In contrast, multilateral trade cost reductions can have markedly different impact on deforestation. Suppose that all countries in the world are symmetric, in the sense that they have the same endowments, geography and productivity. Under symmetry, we can drop country the indicator i and express each country's steady state land supply as:

$$L = \underbrace{N \frac{w_A^{\chi}}{\sum_s w_s^{\chi}}}_{N_T} \frac{Z_T}{\delta_L},$$

where $\chi \equiv [\nu(\rho+\psi)]^{-1}$ is the composite sectoral labor supply elasticity. The next proposition shows that, in contrast to Proposition 1, if trade liberalization is implemented multilaterally, the global forest area expands.

Proposition 2. *(A multilateral reduction in agricultural trade costs across symmetric countries.) A worldwide reduction in agricultural trade costs: (i) increases payments to workers in the manufacturing sector, with the following elasticity*

$$\frac{d\log(w_M/w_T)}{d\log \tau_A} = -\frac{(1-\sigma)}{\sigma+\chi}\left(1-\pi_A^D\right) < 0 \text{ } \textit{if } \sigma < 1,$$

and (ii) decreases stock of land with the following elasticity

$$\frac{d\log L}{d\log \tau_A} = -\chi \frac{(1-\sigma)}{\sigma+\chi} . \frac{N_M}{N} . \left(1-\pi_A^D\right) > 0 \text{ } \textit{if } \sigma < 1.$$

where π_A^D is the domestic expenditure share in agriculture.

Here, the demand elasticity that controls the response in the amount of land is governed by the elasticity of substitution between agriculture and non-agriculture sectors, σ. In the empirically relevant case, agriculture and non-agriculture are complements, i.e. $\sigma \in (0,1)$, and a trade cost reduction results in a reduction in agricultural land and hence an expansion of forest area. The reason is that, in response to the change in prices, structural change reallocates resources away from agriculture and deforestation. In other words, at the global level, demand for land is sufficiently inelastic for global trade to be a land-saving technology. This result is reminiscent of Borlaug's hypothesis, which states that in a closed economy agricultural productivity growth is land-saving because demand for food is inelastic. Proposition 2 extends Borlaug's hypothesis to an open economy setting. Accordingly, trade openness can become land-saving when it is implemented by all countries multilaterally rather than toward a single country unilaterally.

While the above two results are stark and provide guidance to unpack our quantitative results, they are subject to two caveats. First, our results assume iceberg trade costs that are paid in units of final goods. We will acknowledge in our calibration that a fraction of trade costs are not of iceberg type and can generate revenues in the form of tariffs. Second, in an asymmetric world, countries specialize according to their comparative advantage. Trade integration, therefore, can lead these countries to expand their agricultural frontier and reinforce or mitigate the results in Proposition 2. To shed light on this matter, we next illustrate the role of comparative advantage.

To state our next result in the clearest way, we consider a continuum of countries $i \in [0, 1]$ that have heterogenous productivities in agriculture and manufacturing, but identical otherwise. Without loss of generality, we order countries in increasing order of comparative advantage in agriculture, $Z_{i,A}/Z_{i,M}$. In addition, we shut down the mechanism behind Proposition 2 by assuming that the elasticity of substitution between agriculture and manufacturing is unity ($\sigma = 1$).

Proposition 3. *(Comparative and absolute advantage). Suppose goods within each sector are homogeneous and preferences are Cobb-Douglas (i.e., $\eta \to \infty$ and $\sigma = 1$). For a move from autarky to free trade:*

(i) Comparative advantage drives international specialization: There is a cutoff country i^* such that all countries $i < i^*$ specialize in agriculture, and the rest specialize in manufacturing.

(ii) Global forest area expands if comparative and absolute advantage in agriculture align across countries: (a) if $Z_{i,M}$ increases in i, global forest area expands, and (b) if $Z_{i,A}$ decreases in i, global forest area shrinks.

Proposition 3 carries two main messages. The first message, in line with standard results from trade theory, is that comparative advantage is a key determinant of cross-country patterns of specialization.

The second message, to the best of our knowledge, is novel. It states that the correlation between absolute and comparative advantage determines whether trade increases the globally-aggregate land use. When $Z_{i,M}$ increases in i, (which implies that $Z_{i,A}$ does as well), countries with comparative advantage in agriculture have also an absolute advantage in agriculture. In this case, agricultural production is undertaken by the most efficient agricultural producers in the free-trade equilibrium. Relative to autarky, the global amount of resources used in agriculture, i.e., land, decreases. If instead $Z_{i,A}$ decreases in i, trade reallocates land use toward least efficient countries in agricultural production.

6 Taking the Model to Data

This section presents our model calibration and explains how we enrich the model in Section 4 before taking it to the data. We divide agriculture into main staple crops, pasture-related products, and the rest. We disaggregate the world into the 40 countries and regional aggregates described in Section 3. We calibrate our model parameters in three steps. First, we calibrate the parameters related to the static equilibrium using data from the year 2010 (the exception are the observations taken from GTAP, which are for 2014). Second, we calibrate the labor-dynamics parameters based on previous literature. Third, we calibrate the technology in the land-producing sector so that the model matches reduced-form relationships between population growth and growth in agricultural land and forest area (some of which we presented as motivation in Section 3). We next explain each step. Table 2 summarizes our calibrated parameters.

6.1 Calibration of the baseline static equilibrium

In this step we exploit the property that, in each time t, our model behaves like a static trade model with fixed employment of labor and land. We set the elasticity of substitution between agriculture, manufacturing and services, both in production and consumption, at $\sigma = \sigma^I = 0.5$, following Comin et al. (2021); the trade elasticity in each of the sectors, $\eta - 1 = 4$, following Simonovska and Waugh (2014), and the elasticity of substitution between crops at $\kappa = 3$, following Sotelo (2020). For the cost share parameters, we use GTAP dataset to directly calibrate the share of value added in gross output ($\alpha_{i,g}$) for all sectors and the labor share in value added ($\gamma_{i,g}$) for agriculture. For non-agricultural sectors, the GTAP dataset does not provide information on the land share in value added. We, therefore, set the land share in value added ($1 - \gamma_{i,g}$) to match the global share of urban areas.

Then, taking GTAP data from 2014 on international trade flows, gross output by industry and input-output matrices, we apply standard inversion methods to back out productivity shifters ($Z_{i,g}$), trade costs ($d_{ij,g}$), and demand shifters ($b_{ij,g}$, $b_{i,s}$, $b^I_{i,g'g}$ and $b_{i,k}$).

Table 2: Parameter calibration

Parameter	**Value**	**Source**
a. Technology and Preferences		
Cost share of VA and labor, $\alpha_{i,g}, \gamma_{i,g}$	–	GTAP, FAOSTAT
Discount rate, ρ	0.05	
Elast. of substitution	$\sigma = 0.5$, $\kappa = 3$, $\eta = 5$	Comin et al. (2021), Sotelo (2020) Simonovska and Waugh (2014)
Trade costs and productivity	$d_{ni,g}, Z_{i,g}$	Model inversion in 2010
b. Technology for the production of new-land		
Forest regrowth rate, δ_f	0.5%	Brazil's data (Mapbiomas)
Fallow land regrowth rate, δ_o	0.5%	Brazil's data (Mapbiomas)
$x_i = \underbrace{\zeta_i \left(1 - z_i\right)^{\lambda}}_{J_i(z_i)} N_{i,T}^{\gamma_T}$	ζ_i	L_i in 2010 to be at steady state
	$\lambda = 2.0$	Population and deforestation reg.
	$\gamma_T = 0.9$	Population and deforestation reg.
c. Dynamics of Labor and Land		
Transition costs for labor, $f^N_{i,ss'}$	$5 \cdot (\text{annual income}_{US})$	Artuc et al. (2010) in SS
T1EV dispersion for labor	$\nu = 0.5$	Artuc et al. (2010) in SS
Arrival rates	$\psi = 1$	–

6.2 Calibration of dynamics-related parameters

For the dynamic components of the labor market, we set the sectoral labor supply elasticity at $1/\nu = 2$ and the labor mobility costs, f^N, in line with previous work on labor mobility.[14] We also set arrival rates of move opportunities ψ to 1.

6.3 Calibration of the land-producing technology

We extend our model to incorporate a margin for fallow land, as detailed in Appendix C.1. Let the cleared land L_i be divided into *usable* land $L_{i,u}$ and *fallow* land $L_{i,o}$, with country area specified as $H = F + L_{i,u} + L_{i,o}$.[15] We begin by parametrizing $J_i\left(z_i\right) = \zeta_{i,f} \times \left(1 - z_i\right)^{\lambda_f}$ in equation (8), the production of usable land from forest can be rewritten as:

$$Q_{i,Tf} = \zeta_{i,f} \times \left(1 - z_i\right)^{\lambda_f} \times N_{i,Tf}^{\gamma_f} \tag{27}$$

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[14] Caliendo et al. (2019b) report that the yearly equivalent of their labor elasticity equals our choice of $1/\nu = 2$. For labor mobility cost, f^N, we follow McLaren (2017) who reports estimates of about five times yearly real income, which we target for US service workers in the steady state.

[15] Our goal is to provide accurate quantitative responses of deforestation in several trade-cost scenarios. The fallow land module we introduce here provides us with a simple way to capture a first-order feature of the data, which is the existence of other sources, besides forests, that feed the expansion of land in production, including fallow land.

where $\zeta_{i,f}$ is a country-specific productivity shifter, λ_f denotes the elasticity of J_i with respect to country i's land share of forest $F_i/H_i \equiv (1 - z_i)$, and γ_f is the output elasticity of labor. Next, we define $u_i \equiv L_{i,u}/L_i$ as the share of usable land in cleared land. With this definition, we introduce a production function of usable land from fallow land, in a manner symmetric to 27:

$$Q_{i,To} = \zeta_{i,o} \times (z_i (1 - u_i))^{\lambda_o} \times N_{i,To}^{\gamma_o} \tag{28}$$

where $\zeta_{i,o}$ is a productivity shifter, λ_o controls the extent to which the productivity falls with increases in country i's land share of fallow land $L_{i,o}/H_i \equiv u_i (1 - z_i)$, and γ_f is the output elasticity of labor. Total employment and total production in the land-producing sector are given by $N_{i,T} = N_{i,Tf} + N_{i,To}$ and $Q_{i,T} = Q_{i,Tf} + Q_{i,To}$.

Our calibration of the parameters in the land-producing sector follows two steps. First, we recover the productivity shifters $(\zeta_{i,o}, \zeta_{i,f})$ such that the model prediction of agricultural land, fallow land, and forest area in the steady state match their observed values in the initial year of our sample.

Second, in the spirit of indirect inference, we choose values of the elasticities $(\lambda_f, \gamma_f, \lambda_o, \gamma_o)$ so that our model mimics the reduced-form responses of deforestation and land use to population shocks. Specifically, (i) we simulate the model under the UN population growth projection until 2100, and (ii) using these simulated data, we run a set of regressions along the lines of equation (1). We search for the elasticity parameters that minimize the distance between the regression coefficients of the simulated data versus those of the actual data.[16] Appendix Figure E.2 shows our model fit.

Our procedure can separately pin down the four above elasticity parameters. First, in the data fallow land accounts for a sizable share of a country area and, as suggested by Empirical Pattern 2, it is a source of expansion of agricultural land. Therefore, a population shock can lead to an expansion of agricultural land not fully accounted for by a reduction in forest area. This distinction separately identifies the parameters that govern the expansion from

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[16] Specifically, we target the coefficients of the following regression:

$$\underbrace{\log\left(\text{Forest}_{i,t}\right) - \log\left(\text{Forest}_{i,s}\right)}_{\text{different time lags}} = \beta_0 + \beta_{t,s} \underbrace{\left[\log\left(\text{Pop}_{i,2020}\right) - \log\left(\text{Pop}_{i,1990}\right)\right]}_{\text{30 years lag}} + \epsilon_i,$$

where we chose t and $s > t$ among $\{1990, 2000, 2010, 2020\}$, so as to construct intervals of different lengths. Writing β as the vector containing $\beta_{t,s}$, we pick $(\lambda_f, \gamma_f, \lambda_o, \gamma_o)$ to minimize

$$M = \left(\beta^{(\text{data})} - \beta^{(\text{model})}\right) W \left(\beta^{(\text{data})} - \beta^{(\text{model})}\right)'$$

where W is a weighting matrix, $\beta^{(\text{data})}$ is the vector of parameters estimated using the actual data, and $\beta^{(\text{model})}$ is the vector of parameters estimated using model-generated data. We pick the diagonal elements of the inverse of the variance-covariance matrix of $\beta^{(\text{model})}$ as W.

forest, (λ_f, γ_f), from those that control the expansion from fallow land, (λ_o, γ_o). Second, our regressions reveal that agricultural land responds differently at various time horizons to a 30-year change in population, with a longer time horizon associated with a larger response. This variation helps us pin down the labor elasticity separately from the area elasticity, i.e., γ_f versus λ_f and γ_o versus λ_o. Higher labor elasticities scale up the overall deforestation responses, whereas higher area elasticities, λ_f and λ_o, reduce future land-clearing productivity, and makes short-run responses relatively larger.

Lastly, pick the regrowth rate of forest δ_f and δ_o from MAPBIOMAS for Brazil, which separates gross losses and gains in forest.[17]

6.4 Components of trade costs

Our calibration of trade costs distinguishes the components of trade costs that are associated with policy barriers. To do so, we adopt the following parametrization of $d_{ij,g}$,

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

where $\kappa_{ij,g}$ is an iceberg trade cost unrelated to policy, $t^{ice}_{ij,g}$ is an iceberg trade cost generated by policy, and $t^{rev}_{ij,g}$ is a revenue-generating non-iceberg trade cost. We provide here a brief description of the method that we employ to recover each of these terms, relegating details to Appendix D.1.

Our procedure consists of three steps. First, following common practices in the trade literature, we recover $d_{ij,g}$ from the residuals generated by the estimation of gravity equations. Second, similar to Nath (2020), we regress $d_{ij,g}$ on observables related to policy barriers, including the number of days to import, tariffs, and import fees in destination j, and an indicator for trade agreements between i and j. This second step allows us to separate $\kappa_{ij,g}$ from $t^{ice}_{ij,g}$ and $t^{rev}_{ij,g}$. Third, we calibrate the relative magnitude of $t^{ice}_{ij,g}$ with respect to $t^{rev}_{ij,g}$ so that the model-implied tariff revenues per agricultural GDP in each country matches this same statistic in the data.

7 Counterfactual Analysis

In this section, we examine the implications of agricultural trade cost reductions for deforestation and welfare around the world. We specifically study the impacts of a global trade

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[17] MAPBIOMAS provides information on the full transition of land between uses—pasture, forest, fallow and cropland—across years in municipalities in Brazil. We pick the average share of cleared land that transitions to forest area. See Araujo et al. (2022) for a detailed description of the MAPBIOMAs data.

cost reduction, which we contrast with a scenario in which countries open up to trade only toward Brazil.

7.1 The path of forests

Business as usual. We begin by reporting the frontier of cleared land in the business as usual (BAU) scenario—which is the baseline outcome of our model where no policy or shock is introduced. Panel (a) in Figure 5 shows this path for select countries, as well as for the global economy. As a consequence of our approach to calibration, the land frontier remains almost constant across countries and globally.

We emphasize that this baseline is not a forecast based on our model. In our baseline scenario, productivity, population, and land remain constant over time, while one would need to know their future paths to forecast the future of forests. In subsection 7.3, we incorporate population growth into an alternative BAU scenario and evaluate how it affects our quantitative conclusions.

Counterfactual #1: Reduction in Brazil's Export Costs. We begin by considering a 30 percent reduction in policy-related trade costs of agricultural goods produced in Brazil.[18] As shown in Figure 5, Panel (b) global forest area monotonically decreases over time. Figure 6, Panel (a) disaggregates this global trend into the experiences of individual countries, and Appendix Table E.3 presents the details. The reason global forest area falls is that Brazil's forest (as share of country area) drops by 3 percentage points; regrowth in the rest of the world, while attenuating the aggregate impact of Brazil's response, does not offset it completely.

Counterfactual #2: Multilateral trade cost reductions. We now turn to a policy scenario in which countries agree to liberalize trade in agriculture multilaterally. We implement this policy in a simple way by considering a 30% reduction in trade costs of agricultural goods across all countries. This shock has starkly different implications compared to the previous one.

Worldwide, the forest share would grow by 0.7 percentage points in the steady state following the multilateral trade cost reduction. Turning to individual countries, forest area would grow in Central Africa, as well as China and Indonesia; whereas North America and Brazil would experience a decline in their forest area (Figure 6, Panel (b) and Appendix Table E.3). This cross-country variation highlights a key mechanism in our model. As we

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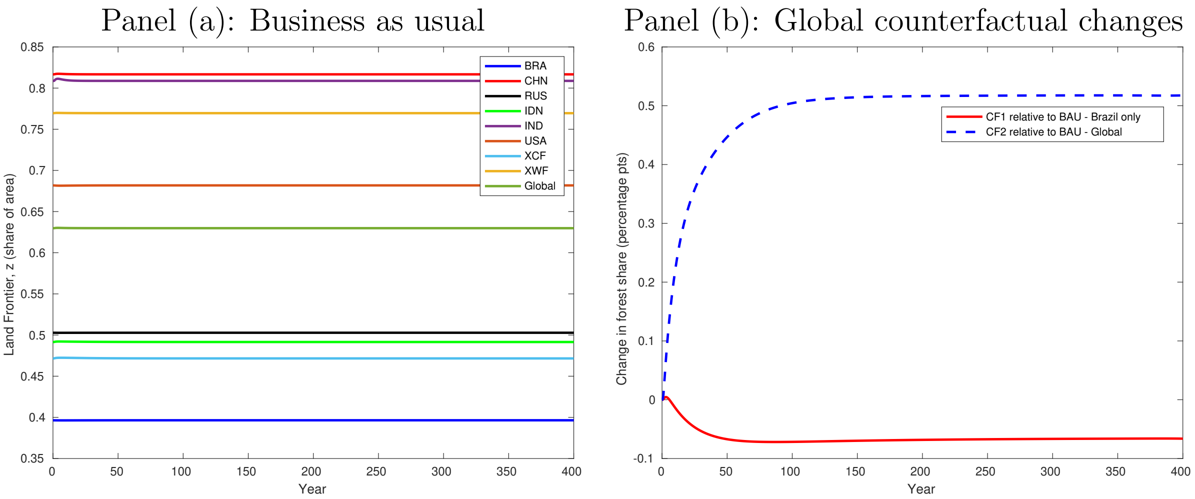
[18] Specifically, we adjust the reductions in $\left(1 - t_{ij,g}^{ice}\right)$ and $\left(1 - t_{ij,g}^{rev}\right)$ by $(0.70)^{1/2}$ so that each term accounts for half of the 30% reduction in trade costs.

Figure 5: Multilateral vs Unilateral Trade Cost Reduction: Change in Global Forest Area Relative to Baseline



explain below, although structural change leads to aggregate reforestation, countries that have a comparative advantage in agriculture or that are geographically well-positioned to serve economies that specialize in non-agriculture, as the shock ensues, take advantage of the trade cost reduction by expanding their agricultural sector and deforesting more.

Figure 6, Panel (b) shows that half of the effects unfold in the first 50 years, although it takes substantially more to approach the steady state. Moreover, the figure highlights another key feature: Since (i) some countries tend to reforest and forest regrowth takes time, and (ii) the land use across countries are linked through international trade, deforestation cannot be too quick, resulting in a slow convergence to the steady state.

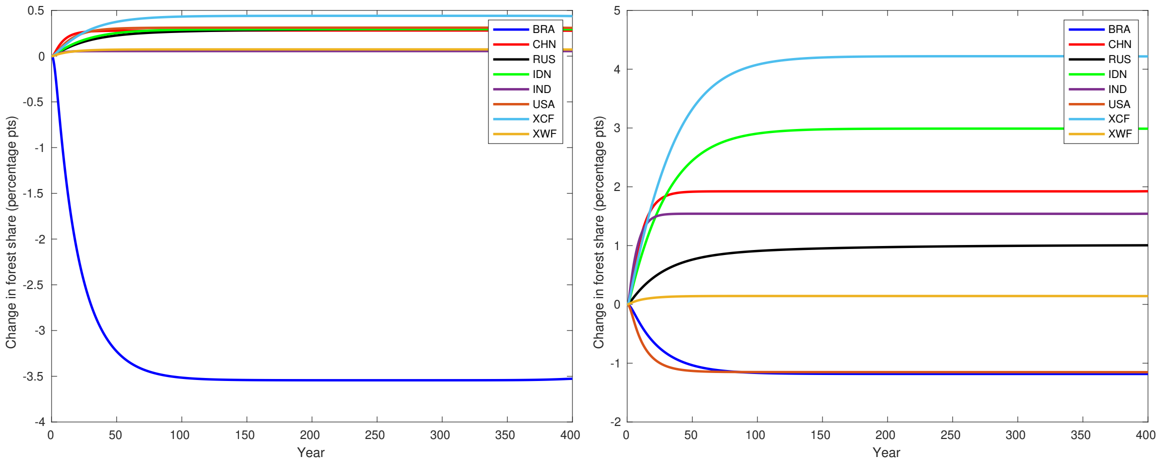
7.2 The roles of structural change and comparative advantage

We next examine the quantitative importance of structural change and comparative advantage as adjustment mechanisms.

7.2.1 Structural Change

To illustrate the contribution of structural change, in Figure 7 we display the counterfactual path of forests under larger values of the elasticity of substitution, $\sigma \in \{0.5, 1.1, 1.75\}$. Doing so limits the scope of structural change for reducing land demand, by muting the complementarity between agriculture and non-agriculture sectors. The figure demonstrates that, a larger value of σ reverts the path of forests in Counterfactual #2 but does not change that of Counterfactual #1. These quantitative results—which are in line with Propositions

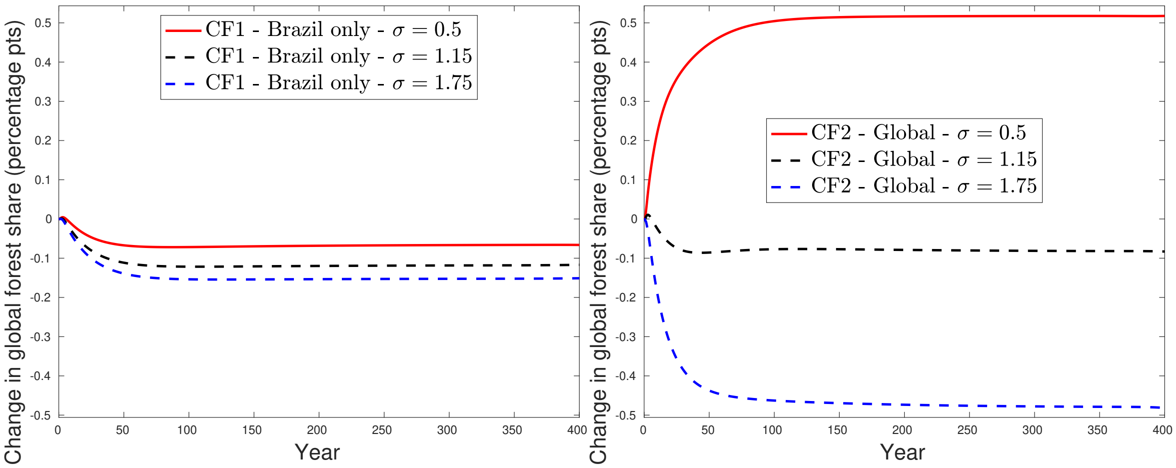
Figure 6: Multilateral vs Unilateral Trade Cost Reduction: Select Countries


(a) Counterfactual 1

(b) Counterfactual 2

1 and 2—show that the relevant elasticity of demand for agricultural goods depends on the geographic scope of trade-cost shock. For a small open economy, demand is elastic, due to trade; globally it is inelastic, due to structural change.

Figure 7: The role of the elasticity of substitution, σ


(a) Counterfactual 1

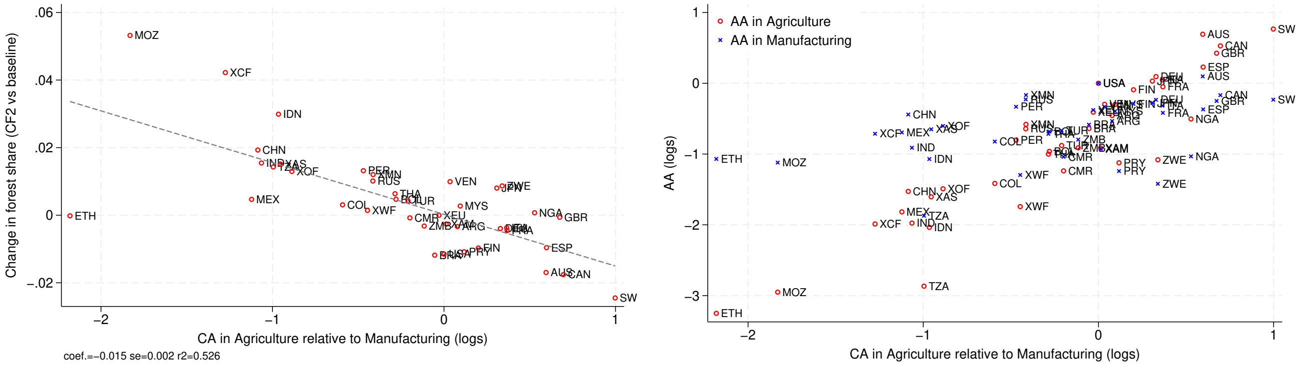
(b) Counterfactual 2

7.2.2 Comparative Advantage

To explore quantitatively the role of comparative advantage, Figure 8a relates Balassa's revealed comparative advantage (RCA) index in Agriculture in 2010, the initial year of our calibration (on the x-axis) and the counterfactual change in the forest share in the steady state (on the y-axis) for our main specification at $\sigma = 0.5$. Comparative advantage governs the cross-sectional responses: Upon a reduction in trade costs, countries with a comparative advantage in agriculture take advantage of the new trade opportunities and, to expand their agricultural sector, they cut into their forests.

In addition, Proposition 3 suggests trade is land-saving. Figure 8b shows that across countries relative productivity in agriculture, $Z_{i,A}/Z_{i,M}$, is positively correlated with absolute agricultural productivity, $Z_{i,A}$ (recovered via model inversion), which means that trade reallocates agricultural production to the most efficient agricultural producers.

Figure 8: The Role of Comparative Advantage



(a) Deforestation in the cross-section

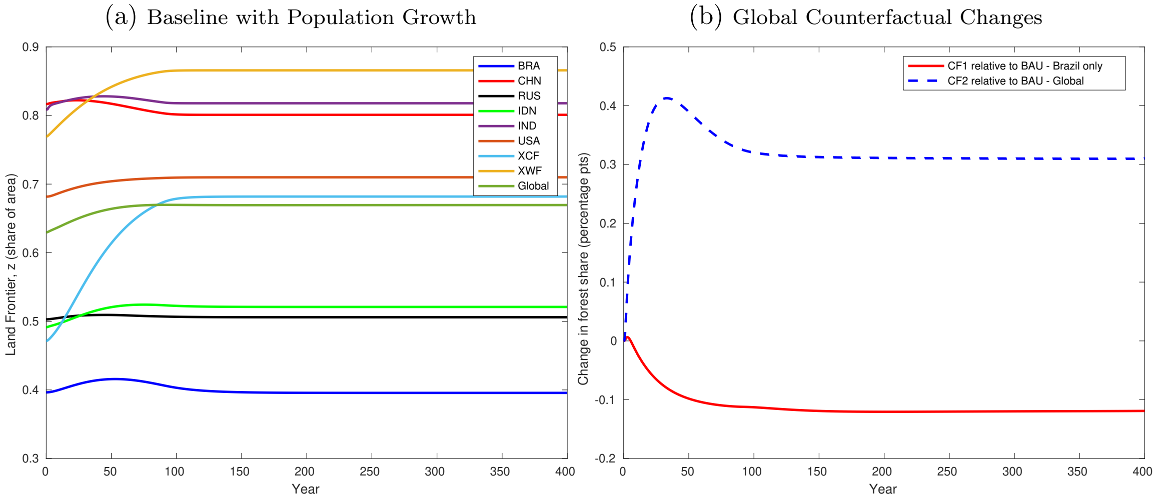
(b) Absolute and Comparative Advantage in Agriculture

7.3 Incorporating population growth

This section examines Counterfactuals #1 and #2 under an alternative business-as-usual scenario that incorporates population growth according to the UN projections between until 2100. There are two main reasons to study this new scenario. First, population size is a key determinant of the equilibrium amount of cleared land and forest, as it fuels both demand for agricultural goods and the availability of labor needed to sustain cleared land. This is all the more relevant since population is expected to grow substantially over the course of the following decades, and unevenly so across countries. Average population growth until the end of this century will be 35%, and it will range from population reductions in Japan to more than 300 percent increases in parts of Africa, where large forests areas remain untouched. As we show next, these heterogenous rates of population growth will alter the allocation of land use across countries. Second, as we show next, population growth is expected to be larger in countries with a comparative *disadvantage* in agriculture, which means that global trade cost reductions will have additional leverage to reduce deforestation.

Panel (a) of Figure 9 displays our new BAU scenario. We see large increases in the amount of cleared land (and hence, reductions in forest) in countries in which population

Figure 9: The Role of Population Growth

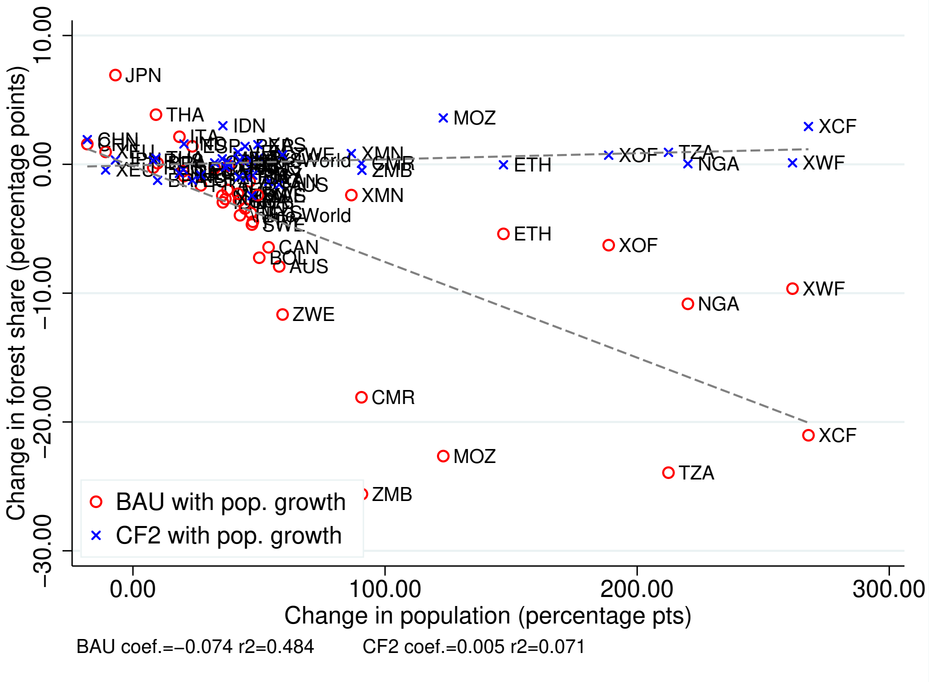

(a) Baseline with Population Growth

(b) Global Counterfactual Changes

growth is projected to be largest. Countries such as Brazil and Indonesia, where population growth is smaller, experience early but moderate expansion in their cleared land, which are then partially reverted as countries with higher population growth develop new land to serve their growing domestic demand for agricultural goods. Figure 10 shows, for our whole sample, that countries with larger population growth experience larger deforestation (steady-state relative to 2010) in the new BAU. Table E.3 in the Appendix reports the corresponding values.

Panel (b) of Figure 9 shows that, relative to this new BAU, our counterfactual scenarios remain qualitatively similar to those without population growth: A global trade cost reduction mitigates pressures on land and economizes on forests at the global scale, whereas the global forest area shrinks in the Brazil-only scenario. Figure 10, however, shows an important difference. Global trade cost reductions (Counterfactual #2) mitigate deforestation that would otherwise occur in the business-as-usual, especially in African countries, since trade reallocates land use toward regions of the world that produce agriculture more efficiently (recall Figure 8b).

Figure 10: Change in Forest Share versus Population



7.4 The deforestation impact of raising trade costs

To complement our previous analysis, we consider two additional counterfactual scenarios wherein instead of reducing trade costs, we increase them. In Counterfactual #3, countries raise their agricultural trade costs when they import from Brazil by 30%, as trade penalties on a country whose agricultural exports are linked to deforestation. In Counterfactual #4, agricultural trade costs are raised by 30% globally, representing a move away from globalization in agriculture. Appendix Figure E.3 shows the results.

In Counterfactual #3, global forest area rises by 0.4% and 0.6% relative to the BAU scenarios without and with population growth. These aggregate results come from a sizable reforestation in Brazil, which is partially offset by deforestation elsewhere. In Counterfactual #4, global forest area decreases by 0.3% in the no population growth scenario and it increases by less than 0.6% in the case with population growth. Therefore, unilateral trade penalties imposed on Brazil's agricultural exports save a larger amount of global forest area than a worldwide increase in agricultural trade costs. The key to understanding this results is the relevant elasticities of substitution. When trade costs increase globally (Counterfactual #4), the low elasticity of substitution between agriculture and non-agriculture increases the relative demand for agriculture putting additional pressure on forests. These results reinforce our previous findings by highlighting that multilateral coordination on agricultural trade policy matters for reductions in deforestation.

7.5 Carbon heterogeneity, dynamics, and reforestation.

We evaluate the impact of changes in trade costs on the implied CO_2 emissions from deforestation. [19] In our simplest exercise, we follow the guidelines used by the IPCC to calculate the climate costs from deforestation-related CO_2 emissions. Each hectare of forest loss per country and year corresponds to an implied CO_2 emission released to the climate.[20] We put a cost on the global level of CO_2 emissions at any point in time using a social cost of CO_2 set at 51 \$/tC, based on the 2021 report by the United States Interagency Working Group on Social Cost of Greenhouse Gases, and compute the discounted present value of the stream of these costs. To benchmark the results, we present them relative to the total cost of CO_2 emissions from agriculture in 2010.

Table 3 compares these costs across multiple parameterizations and assumptions on carbon content of forests. Panel (a) focuses on our main parameterization with $\sigma = 0.5$. Column (1) presents the results that emerge from the above method. In this case, the emissions costs of global trade cost reductions are slightly lower than those of trade cost reductions only for Brazil, despite the large difference in the scale of the shocks. Panel (b), which assumes instead that goods are substitutes, with $\sigma = 1.75$, shows much larger costs of global trade cost reductions. This result is expected as the demand elasticity for agriculture is set at a substantially larger value. Column (2) shows that ignoring Brazil's rich carbon intensity would lead to substantial underestimation of lowering its export costs. We next acknowledge that the carbon content of forests is not limited to their above- and under-ground biomass, which are the basis of our calculation in Columns (1) and (2). Accordingly, Column (3) shows the emission costs associated with carbon contained in the forest biomass plus its soil and litter.

A feature of the IPCC guidelines we have used so far is that it does not take into account the possibility of carbon sequestration from forest regrowth. Columns (4) and (5) show that

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[19] Our evaluation does not incorporate other costs associated with deforestation. These other costs stem from the loss of wildlife endemic to each forest, the change in landscape that increases the likelihood of flooding, the amenity value of forests, and desertification. Additionally, we abstract away from the costs associated with reforestation such as the adverse health effects of pollen.

[20] Specifically, following the guidelines described in Tubiello et al. (2020), we use the following equation to compute CO_2 emissions from deforestation: $NFC_{i,t} = -\frac{B_{i,t-1}}{A_{i,t-1}} \min\left[A_{i,t} - A_{t,t-1}, 0\right] \frac{44}{12}$,where $NFC_{i,t}$ is the net deforestation, expressed in tonnes of CO_2. The term $\frac{44}{12}$ converts C to CO_2—it is the ratio of the molecular weight of carbon dioxide, which equals 44, to that of carbon, which equals 12. Note that this is a somewhat pessimistic approach since (i) it assumes when a hectare of forest is lost, all the carbon previously stored in that hectare is immediately released, and (ii) it does not account for reforestation.

this assumption can have important consequences, as under full and partial sequestration scenarios, the balance of gains and losses in forests across countries turn to a positive net gain in the global trade cost scenario (Counterfactual #2).[21] In fact, in Column (5), a global trade cost reduction entails the minimal cost among all four counterfactual scenarios, which was not the case in the no-sequestration scenarios, which do not value reforestation and therefore make trade cost increases look more desirable.

Columns (6)-(8) shift attention to the scenarios that include population growth, retaining the assumption of partial carbon sequestration. Column (6) shows that, when we consider population growth, losses in Counterfactual #2 decrease. The reason is that with population growth deforestation occurs in the baseline, and trade cost reductions avoid deforestation, which the IPCC guidelines value more than reforestation. Column (7) increases the social cost of carbon to \$200/ton, while Column (8) shows that ignoring dynamics would lead us to overestimate the costs of reducing Brazil's export costs, but underestimate the gains of global trade cost reductions.

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[21] In the full sequestration scenario, net reforestation absorbs from the atmosphere all the CO2 that would be released by the same amount of net deforestation. In the no sequestration scenario, net reforestation does not absorb any CO2 from the atmosphere. In the partial sequestration scenario, we use the simple rule that net reforestation absorbs from the atmosphere 30% of all the CO2 emissions that would be released by the same amount of net deforestation.

Table 3: Social Costs of Deforestation under different Trade Integration Scenarios

	Cost as % of Ag Emissions in 2010							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A: Complements ($\sigma = 0.5$)								
CF - Brazil only reduction	39.79	61.59	87.42	37.86	14.59	32.76	128.47	382.56
CF - Worldwide reduction	51.07	51.43	149.58	-0.27	-88.81	-63.29	-248.19	-189.32
CF - Brazil only increase	9.97	8.45	22.45	-16.89	-43.91	-13.66	-53.57	33.44
CF - Worldwide increase	82.19	72.12	134.46	38.19	-8.90	-34.97	-137.14	-567.32
Panel B: Substitutes ($\sigma = 1.75$)								
CF - Brazil only reduction	38.91	59.49	85.03	27.80	8.88	62.08	243.44	578.07
CF - Worldwide reduction	119.29	117.36	322.00	78.49	42.82	304.65	1194.72	1996.03
CF - Brazil only increase	4.28	3.49	9.62	-31.05	-56.62	-20.16	-79.07	-48.34
CF - Worldwide increase	23.63	23.08	38.49	-24.51	-80.54	-150.78	-591.28	-1215.63
Carbon Density Assumptions								
- Above-below ground biomass	Y	Y	Y	Y	Y	Y	Y	Y
- Carbon in soil and litter	-	-	Y	Y	Y	Y	Y	Y
- Homogenous density	-	Y	-	-	-	-	-	-
Carbon Sequestration Assumptions								
- None	Y	Y	Y	-	-	-	-	-
- Partial	-	-	-	-	Y	Y	Y	Y
- Full	-	-	-	Y	-	-	-	-
Economic Assumptions								
- Population Growth	-	-	-	-	-	Y	Y	Y
- SSC = 51	Y	Y	Y	Y	Y	Y	-	-
- SSC = 200	-	-	-	-	-	-	Y	Y
- Ignore dynamics	-	-	-	-	-	-	-	Y

Notes: This table shows the gains in terms of real gdp and the costs in terms of carbon emissions of different policy counterfactuals using different parametrizations of the model. For column 1, we compute the present value of all the future flows of real GDP and compare that value with the present value of all the future flows in the BAU. For column 2 to 4, we present the total gains and costs measured relative to the cost of total agricultural emissions in 2010. We compute the climate costs of deforestation using the methodology of IPCC described in Section 2.

8 Conclusions

Global deforestation drives carbon emissions and reduces biodiversity, which poses an important challenge for policy. Meanwhile, the potential for agricultural trade liberalizations raises the concern over the impact on deforestation. We have developed a framework to study, analytically and quantitatively, the deforestation impact of trade policy. The key insight of our paper is that in a trading world, structural change and comparative advantage interact to determine aggregate land use and how it is distributed across countries. Our results provide a new rationale for international cooperation in trade policy, by showing that multilateral trade liberalization can help circumvent trade offs between the gains from trade and preservation of the forests.

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A Details on Data

Forest Area. Our main source of information on forest area comes from FAO-FRA (FAO Global Forest Resources Assessment), which is based on questionnaires that are submitted to the agricultural agencies of every country. Since the 1990s, these data have been compared with measures of forest cover identified from satellite imagery such as Landsat (MacDicken, 2015). Nowadays, about 70% of national forest inventories utilize remote sensing to validate at least some portion of the inventory.

The FRA data are available for the years of 1990, 2000, 2005, 2010, 2015 and 2020 and they provide different measures of forest area.[22] When available, we use information on the naturally regenerating forest, which excludes forest area related to industrial forests planted for the production of, for example, paper. Our statistics sometimes diverge slightly from the ones reported by FAO-FRA since they report net deforestation, which incorporates both forest regeneration and forest plantation and we exclude the second from our measure. For our empirical analysis in Section 3, we grouped islands (e.g., Virgin Islands and Gibraltar), small regions (e.g., as Monaco and the Vatican), and countries with negligible forest areas (e.g., Kuwait and Bahrain) into larger regions. Appendix Table E.4 documents summary statistics for all countries in our final data.

In addition to FRA, another increasingly used source of data comes from Hansen et al. (2013b), who measures global deforestation using satellite imagery at a high spatial resolution (30 meters). Different from the data from FAO-FRA, which is designed to measure forest area based on land use classifications, the data from Hansen et al. (2013b) measures forest area based on forest cover. As such, Hansen et al. (2013b) tends to capture transitory changes in forest area such as the ones related to fires and insect outbreaks, even when there are no changes in land use, which is the concept that we use in the formulation of our model.[23][24]

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[22] The main definition of forest is any land spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10 percent, or trees able to reach these thresholds on site—it does not include land that is predominantly under agricultural or urban land use. The data, however, also provides information on planted trees and naturally regenerating forest.

[23] As identified by Curtis et al. (2018), about 23% of global forest disturbances between 2001 and 2015 can be attributed to wildfires. This driver of forest loss has been the dominant one in Russia, Australia and New Zealand. In contrast, agricultural-related activities have been the main source of deforestation in South America, Africa and Southeast Asia. Urbanization accounts for a minimal share of the changes in forest area. In addition, as discussed in Keenan et al. (2015), since Hansen et al. (2013b) use difference methodologies to measure deforestation and reforestation, one must interpret net changes in forest area coming from Hansen et al. (2013b) with caution.

[24] Moreover,Coulston et al. (2014) found that measures of forest land and forest land cover in the south-eastern USA are poorly correlated and suggest that these measures are better correlated in tropical areas. Recent papers that exploit the high-resolution data from Hansen et al. (2013b) to identify the reduced-form impact of different policies on deforestation are unlikely to be affected by these considerations about the limitations of satellite based data sets, since they focus on deforestation in tropical countries.

Agricultural Area and Fallow Land. We construct the total area in cropland using data from FAOSTAT on total harvested area. These data do not provide, however, information on the total area dedicated to cattle grazing. To recover that information, we multiply data on the total cattle stock by a simple conversion rate of 0.75 hectares per cattle, which we define as the pasture land.[25] Based on that information, we then compute the fallow land as the residual land, that is, the total land in the country minus the artificial surface, the watersurface, the forest area, the cropland, and the pasture land.

To compute the share of forest in a country, we use the total area of the country, as reported by FRA, which already excludes the water surface in a country. In addition, using data from FAOSTAT on land cover, we remove from the total area of the country the snow cover and the barren land—which includes desert areas. We refer to this resulting variable as "country area".

Trade Costs. To calibrate the trade costs generated by policy, we use data on (i) tariffs from the World Bank World Development Indicators—specifically, we use the simple unweighted average of the effectively applied rates for all products subject to tariffs—, (ii) import fees and days to import from the World Bank Doing Business, and (iii) trade agreements from CEPII Gravity Database—we take the country-destination specific free trade agreement indicator for year 2010, which is the dummy variable that takes the value of 1 if the country pair is engaged in a regional trade agreement. For the trade costs generated by geography, we use data from CEPII, which includes data on contiguity, distance, common language, and colonial relationships.

Carbon Stock. Our main data source for the carbon stock of forests is FAO-FRA. FRA contains data on six carbon pools: above- and below-ground carbon stock, dead wood, litter, soil, organic carbon, and harvested wood products. In our simplest exercise, we use the information on above- below-ground carbon stock, which is the typical approach when measuring the CO2 emissions from deforestation (IPCC, 2006). The definition of carbon in above-ground biomass is all carbon in living biomass above the soil, including stems, stumps, branches, bark, seeds, and foliage, whereas the definition of carbon in below-ground biomass is all carbon in all biomass of live roots (fine roots of less than 2 mm diameter are excluded, because these often cannot be distinguished empirically from soil organic matter or litter).

For a more thorough analysis, in addition to the carbon in above and below ground, we incorporate the following into our measurement: The carbon in litter, which is all the carbon

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[25] According to the agricultural census of Brazil, the total cattle stock per pasture area in hectares equals approximately 0.30, whereas technical reports give 0.6 units per hectare in the UK and almost 1 in the US.

in all non-living biomass with a diameter less than the minimum diameter for dead wood (e.g. 10 cm), lying dead in various states of decomposition above the mineral or organic soil, as well as measures of carbon in mineral and organic soils (including peat) and measures of carbon in woody biomass not contained in the litter, either standing, lying on the ground, or in the soil.

Our calculation of the climate cost of deforestation is limited to its implied carbon emissions. We do not incorporate other types of greenhouse emissions, such as methane and oxides of nitrogen which may matter where forest fires play a significant role in forest degradation. We also highlight that the emissions coming from these other gases are typically an order of magnitude smaller than the ones associated with CO_2 (Federici et al., 2015).

B Proofs

B.1 Section 4

B.1.1 Proof of Proposition 1

Our definition of a small open economy follows that of Alvarez and Lucas (2007). Labor and land market equilibria in country i, which we treat as a small open economy, are given by

$$w_{i,M}N_{i,M} = \sum_n \frac{\left(w_{i,M}\tau_{ni,M}/Z_{i,M}\right)^{1-\eta}}{P_{n,M}^{1-\eta}} \left(\frac{P_{n,M}}{P_n}\right)^{1-\sigma} X_n$$

$$r_i L_i = \sum_n \frac{\left(r_i\tau_{ni,A}/Z_{i,A}\right)^{1-\eta}}{P_{n,A}^{1-\eta}} \left(\frac{P_{n,A}}{P_n}\right)^{1-\sigma} X_n$$

We apply $N_i A_{i,M}^{1-\sigma} \to \delta_i$ as $N_i \to 0$, and suppose that $w_i \to w_i^*$, with $0 < w_i^* < \infty$ (which we verify later). Then equations 3 and 7 imply that country i becomes a price taker relative to the rest of the world,

$$P_{i,s} \to \bar{P}_{i,s}, \qquad s = \{A, M\}$$

and

$$P_i \to \bar{P}_i.$$

Using the above factor market equilibrium conditions and noting that the small economy is infinitesimal as a source of expenditure in its own demand, we solve for $w_{i,M}$ and r_i:

$$w_{i,M} = \left[\left(\frac{N_{i,M}}{N_i}\right)^{-1} \delta_i^{-1} X_{n,M}^F\right]^{1/\eta} \tag{B.1}$$

$$r_i = \left[\left(\frac{L_i}{H_i} \right)^{-1} \gamma_i^{-1} X_{n,A}^F \right]^{1/\eta}, \tag{B.2}$$

where

$$X_{F,M} \equiv \sum_{n \neq i} \frac{(\tau_{ni,M})^{1-\eta}}{P_{n,M}^{1-\eta}} \left(\frac{\bar{P}_{n,M}}{\bar{P}_n} \right)^{1-\eta} X_n \tag{B.3}$$

and

$$X_{F,A} = \sum_{n \neq i} \frac{(\tau_{ni,A})^{1-\eta}}{P_{n,A}^{1-\eta}} \left(\frac{\bar{P}_{n,A}}{\bar{P}_n} \right)^{1-\eta} X_n. \tag{B.4}$$

These equations verify that $w_{i,M}$ and r_i converge to a finite, positive values.

Land supply in country i can be expressed as:

$$L_i = \delta_L^{-1} Z_{i,T} \left(\frac{w_{i,T}^{\chi}}{\Upsilon_i^{\chi}} \right) N_i, \tag{B.5}$$

where the steady-state wage rate in the land-producing sector, $w_{i,T}$, is given by:

$$w_{i,T} = \frac{r_i Z_{i,T}}{\rho + \delta_L}.$$

Using this equation and B.2 we solve for $w_{i,T}$,

$$w_{i,T} = \frac{L_i^{-1/\eta} \left(H_i \gamma_i^{-1} X_{F,A} \right)^{1/\eta}}{\rho + g_L}. \tag{B.6}$$

Finally, supposing that the share of employment in the land-producing sector is negligible, we can use equations B.6 and B.5 to obtain:

$$\frac{d \log w_{i,T}}{d \log X_{F,A}} = \frac{1}{\chi + \eta},$$

and using equation B.4, we arrive at:

$$\frac{d \log w_{i,T}}{d \log \tau_A} = \frac{1 - \eta}{\chi + \eta}$$

Combining this result and equation B.5, we can then derive the main equation in Proposition 1.

B.1.2 Proof of Proposition 2

We proceed in three steps. First we derive the sectoral labor supply elasticity in the steady state. Second, we show that relative payments to land and labor are determined by sectoral relative productivities and trade openness. Third, we connect these relative payments to land supply and, consequently, to deforestation.

Labor supply in the steady state. Under the assumptions we made in Section 5, in the steady state equations 14 and 15 become

$$\left(\rho+\psi\right)v_{i,s}^{N}=\underbrace{\log\left(\frac{w_{i,s}}{P_i}\right)}_{u_{i,s}}+\psi W_{i,s} \tag{B.7}$$

$$W_{i,s}=\nu\log\sum_{s'}\exp\left(\frac{1}{\nu}v_{i,s'}^{N}\right). \tag{B.8}$$

Here, $u_{i,s}$ is the instantaneous utility for a worker in sector s, and the last equation implies that $W_{i,s}=W_i$, $\forall s$. Substituting B.7 into B.8, we can solve for W_i:

$$W_i=\log\left\{\sum_{s'}c_{i,s}^{\chi}\right\}^{\frac{1}{\rho\chi}},$$

where $\chi=\left[\nu\left(\rho+\psi\right)\right]^{-1}$ and $c_{i,s}=w_{i,s}/P_i$. Considering that W_i does not vary across sectors, the moving shares in equation 16 collapse to:

$$\mu_{i,ss'}\equiv\mu_{i,s'}=\frac{w_{i,s'}^{\chi}}{\sum_l w_{i,l}^{\chi}}, \tag{B.9}$$

which are not anymore a function of the origin sector s.

Finally, the value function of working in sector s reflects the flow value of working in the current sector and the option value of drawing an opportunity to move, where the discount rate reflects the arrival rate of such opportunities. Rewriting equation B.7, we obtain

$$\begin{aligned}
v_{i,s}^{N}&=\frac{1}{\rho+\psi}u_{i,s}+\frac{\psi}{\rho+\psi}W_i\\
&=\frac{1}{\rho+\nu}u_{i,s}+\frac{\psi}{\rho+\nu}\log\left\{\sum_{s'}c_{i,s}^{\chi}\right\}^{\frac{1}{\rho\chi}}.
\end{aligned}$$

In turn, equation B.9 gives the steady-state values of labor supply. To see this, note that in the steady state $\dot{N}_{i,s} = 0, \forall i, s$, and therefore equation 24 implies

$$0 = \psi \left(-\sum_{l \neq s} \mu_{i,sl} \right) N_{i,s} + \psi \sum_{l \neq s} \mu_{i,ls} N_{i,l}, \qquad \forall s, i.$$

Since $\mu_{i,sl} = \mu_{i,l}$, after a little manipulation, we can obtain that:

$$N_{i,s} = \mu_{i,s} N_i.$$

Relative payments to land and labor. Before proceeding, note that without intermediate input use and under perfect competition, total payments to each factor equal the sum of value added in the sectors that employ it. Furthermore, with symmetric countries, the market clearing conditions for manufacturing and agricultural goods can be expressed in relative terms as:

$$\frac{w_M N_M}{rL} = \frac{b_M}{b_A} \left(\frac{P_M}{P_A} \right)^{1-\sigma}, \tag{B.10}$$

where we have dropped country indexes due to symmetry. Since we have assumed that land is only used in agriculture, the above equation already imposes that $r_A = r$. However, since labor is employed in both manufacturing and land-producing sectors, we carry sector-specific wages. In addition, we can express the sectoral price index, P_s, as a function of the domestic expenditure share, π_s^D, the trade elasticity, $(\eta - 1)$, and the marginal costs, that are w_M / Z_M in manufacturing and r / Z_A in agriculture. Thus, the price indexes of manufacturing and agriculture are given by:

$$P_M = \frac{w_M}{Z_M} \left(\pi_M^D \right)^{\frac{1}{\eta - 1}}, \qquad P_A = \frac{r}{Z_A} \left(\pi_A^D \right)^{\frac{1}{\eta - 1}}, \tag{B.11}$$

where the domestic expenditure share can be expressed as (due to symmetry),

$$\pi_s^D = \left[(I - 1) \tau_s^{1-\eta} + 1 \right]^{-1}, \qquad s \in \{A.M\}$$

Finally, substituting B.11 into B.10, and solving for relative factor payments, we obtain the manufacturing wage-to-rent ratio:

$$\frac{w_M}{r} = \left(\frac{b_M}{b_A} \frac{L}{N_M} \right)^{\frac{1}{\sigma}} \left(\frac{Z_A}{Z_M} \right)^{\frac{1-\sigma}{\sigma}} \left(\frac{\pi_M^D}{\pi_A^D} \right)^{\frac{1}{\eta-1} \frac{1-\sigma}{\sigma}} \tag{B.12}$$

Connecting factor supplies to factor rewards. In the steady state, the law of motion equation 10 implies

$$L = \frac{Z_T N_T}{\delta_L}.$$

where we have used our simplifying assumption that $J_i(z) = Z_{i,T}$ and $\gamma_T = 1$. Using the steady-state labor supply equation B.9, we obtain the steady state supply of land:

$$L = N \frac{w_T^{\chi}}{\sum_l w_l^{\chi}} \frac{Z_T}{\delta_L}. \tag{B.13}$$

Combining this equation with equation B.9, we obtain the ratio of land to manufacturing labor,

$$\frac{L}{N_M} = \left(\frac{w_T}{w_M}\right)^{\chi} \frac{Z_T}{\delta_L}. \tag{B.14}$$

At this point, recall the steady state relationship between the price of new land and the rental rate per unit of agricultural land,

$$q = \frac{r}{\rho + \delta_L}. \tag{B.15}$$

Using the equilibrium pricing in the land-producing sector, 9, the rental rate of land can be expressed as a function of the wage rate in the land-producing sector:

$$r = (\rho + \delta_L)\, w_T / Z_T.$$

Finally, substituting the above equation and B.14 into B.12, the relative wage of manufacturing to that of land-producing sector equals:

$$\frac{w_M}{w_T} = \left[\frac{(\rho + \delta_L)}{Z_T}\left(\frac{Z_T}{\delta_L}\right)^{\frac{1}{\sigma}}\left(\frac{b_M}{b_A}\right)^{\frac{1}{\sigma}}\left(\frac{Z_A}{Z_M}\right)^{\frac{1-\sigma}{\sigma}}\left(\frac{\pi_M^D}{\pi_A^D}\right)^{\frac{1}{\eta-1}\frac{1-\sigma}{\sigma}}\right]^{\frac{\sigma}{\sigma+\chi}} \tag{B.16}$$

Equations B.13 and B.16 deliver the general equilibrium elasticities presented by Proposition 2.

B.1.3 Proof of Proposition 3

In steady state, and under the assumptions of the proposition, the technology to produce agricultural goods boils down to

$$c_{i,A} = \frac{1}{Z_{i,A} Z_{i,T}/\delta} w_i.$$

Further, under the assumptions in the proposition, countries only differ in their productivity to produce agriculture and manufacturing, $Z_{i,A}$ and $Z_{i,M}$. Note that, because we assume that $Z_{i,T}$ is the same across countries, the productivity of the land-producing sector is not a source of comparative or absolute advantage in agriculture.

Recall that preferences are Cobb-Douglas with equal weights between agriculture and manufacturing, and varieties within each sector are perfectly substitutable. Moreover, compared to the previous two propositions, here we assume that labor is the only factor of production, and so, agriculture also uses labor.

Under autarky, each country allocates half its labor to each sector, because of Cobb-Douglas preferences.

To characterize the free trade equilibrium we proceed as follows. Note first that under free trade, there is a single relative price of agriculture that prevails in equilibrium, which we denote by p^*. In free trade equilibrium, all countries whose autarkic relative price of agriculture lower than p^* completely specialize in agriculture, while the rest completely specialize in manufacturing:

$$\begin{cases} \text{Country } i \text{ produces manufacturing} & \text{if } \frac{Z_{i,M}}{Z_{i,A}} \leq p^* \\ \text{Country } i \text{ produces agriculture} & \text{if } \frac{Z_{i,M}}{Z_{i,A}} > p^* \end{cases}$$

Let country i^* be the the marginal country for which the above holds with equality:

$$p^* = \frac{Z_{i^*,M}}{Z_{i^*,A}} \tag{B.17}$$

Next, note that with Cobb-Douglas preferences, global expenditure on agriculture is the same as that on manufacturing. Therefore, market clearing requires:

$$p^* = \frac{\int_0^{i^*} Z_{i,M} di}{\int_{i^*}^1 Z_{i,A} di}. \tag{B.18}$$

An equilibrium consists of a cutoff country i^* and an equilibrium relative price of agriculture p^*, such that these equations B.17 and B.18 jointly hold. The right-hand side of equation B.17 is decreasing in i^* by our choice of ordering. The right-side of equation B.18 is strictly increasing, and moreover, equals zero at $i^* = 0$ and tends to infinity as $i^* \to 1$. This means the equilibrium exists and is unique. This proves result (i) in Proposition 3.

To determine the total demand for factors under free trade, we rearrange equation B.18 as

$$\frac{1 - n_A}{n_A} = \frac{\mathbb{E}\left[Z_{i,A} | i \geq i^*\right] / Z_{i^*,A}}{\mathbb{E}\left[Z_{i,M} | i < i^*\right] / Z_{i^*,M}}. \tag{B.19}$$

where $n_A \equiv N_N/N$ is the labor share in agriculture. Since all countries have the same size, free trade increases the amount of labor in agriculture relative to autarky if $n_A > 1/2$. Therefore, we focus on sufficient conditions such that the right hand side of B.19 is greater or smaller than one. When there is positive selection into sector $g \in \{A, M\}$, the average country specializing in that sector is more productive than the marginal country, i.e.,

$$\mathbb{E}\left[Z_{i,g}|i \geq i^*\right]/Z_{i^*,g} > 1,$$

while the opposite is true with negative selection.

We distinguish two cases to obtain result (ii) in Proposition 3. First, suppose $Z_{i,M}$ is increasing in i. Given our ordering of countries this implies that $Z_{i,A}$ is also increasing in i at a larger rate than $Z_{i,M}$. Since countries with $i > i^*$ fully specialize in agriculture, this ensures that both $\mathbb{E}\left[Z_{i,A}|i \geq i^*\right]/Z_{i^*,A} > 1$ and $\mathbb{E}\left[Z_{i,M}|i < i^*\right]/Z_{i^*,M} < 1$, which yields part (a). To obtain part (b), proceed analogously supposing instead that $Z_{i,A}$ is decreasing in i.

C Extensions

C.1 Fallow Land

This section provides an extension to our model for incorporating *fallow* land. For a clearer exposition, we drop country subscript i. The country area, H, is the sum of forest area, F, and *cleared* land, L, which is itself classified into *usable* land L_u and *fallow* land L_o,

$$H = F + L, \qquad L = L_u + L_o.$$

As before, we denote the cleared land's frontier by z, and (new to this extension) the utilization rate in the cleared land by u. Namely:

$$z = \frac{L}{H}, \qquad u = \frac{L_u}{L}.$$

Land-producing sector. Land-producing firms seek to produce usable land for agricultural use by converting (1) forest or (2) fallow land. Production in each of these two sub-sectors requires the employment of labor under decreasing-returns-to-scale technologies. Labor is freely mobile between the two sub-sectors, and so, the marginal product of labor must equalize between them. Moreover, we assume that the flows of land-conversion from forest or fallow land provide homogeneous land, and so, at any point in time, there is a single market price q for purchases that add to the usable land.

Production of usable land via forest conversion. Land-producing firms can employ labor to convert forest into usable land:

$$x^{f \to u} = \phi_f \times N_f^{\gamma_f}; \qquad \textit{where} \quad \phi_f \equiv \bar{\phi}_f \times F^{\lambda_f}, \quad \gamma_f \in (0, 1)$$

The production technology is decreasing-returns-to-scale implying an upward-sloping supply curve with an inverse supply elasticity of $(1 - \gamma_f)/\gamma_f > 0$. The productivity parameter, ϕ_f, depends on the current stock of forest. Each land-producing firm, however, takes the stock of forest as given, and so, it does not internalize the deforestation effects of its production decision on its future productivity. The extent to which forest stock affects the productivity of the forest-to-land-conversion is governed by parameter $\lambda_f > 0$. The above equation can be equivalently expressed as:

$$x^{f \to u} = \zeta_f \times (1 - z)^{\lambda_f} \times N_f^{\gamma_f}, \qquad \gamma_f \in (0, 1) \tag{C.20}$$

where $\zeta_f \equiv \bar{\phi}_f H^{-\lambda_f}$ is a constant. Note, under $J(z) = \zeta_f \times (1 - z)^{\lambda_f}$, the above resembles equation 8.

Production of usable land via fallow land. Land-producing firms can also employ labor to convert fallow land into usable land:

$$x^{o \to u} = \phi_o \times N_o^{\gamma_o}; \qquad \text{where} \quad \phi_o \equiv \bar{\phi}_o \times L_o^{\lambda_o}, \quad \gamma_o \in (0, 1)$$

The functional form which we have adopted for the conversion of fallow land to usable land is similar to that of forest to usable land. The parameters, however, are different reflecting the differences in the quantitative behavior of the two activities. Similarly, we can express the above equation as:

$$x^{o \to u} = \zeta_o \times (z(1 - u))^{\lambda_o} \times N_o^{\gamma_o}, \qquad \gamma_o \in (0, 1) \tag{C.21}$$

where $\zeta_o \equiv \bar{\phi}_o H^{-\lambda_o}$ is a constant.

Wage and price in the land-producing sector. Since labor is freely mobile within the land-producing sector, the marginal product of labor equalizes between the two sub-sectors, which in turn pins down the wage rate w_T,

$$w_T \;=\; \gamma_o \zeta_o \times (z(1 - u))^{\lambda_o} \times N_o^{\gamma_o - 1} \;=\; \gamma_f \zeta_f \times (1 - z)^{\lambda_f} \times N_f^{\gamma_f - 1} \tag{C.22}$$

Moreover, since the two sub-sectors produce a homogenous usable land, they face the same price level q which intersects the supply curves of the two sub-sectors. This relationship can be expressed as:

$$q \;=\; \frac{w_T}{\gamma_f \zeta_f \left(1-z\right)^{\lambda_f}} N_f^{1-\gamma_f} \;=\; \frac{w_T}{\gamma_v \zeta_v \left(z(1-u)\right)^{\lambda_v}} N_v^{1-\gamma_v} \tag{C.23}$$

Free entry condition & Value function. Let v_f and v_o denote the per-unit discounted present value of usable land when converted, respectively, from forest and fallow land. The no-arbitrage condition requires the return to land-conversion to be equal between the two sub-sectors, $v_f = v_o = v$, and the free entry condition requires:

$$v = q. \tag{C.24}$$

Similar to the model in Section 4, the value function is given by:

$$\rho v = r + \dot{v} - (\delta_o + \delta_f) \tag{C.25}$$

where r is (as before) the rental rate of usable land, and (new to this extension) δ_o and δ_f are respectively the regrowth rates of fallow land and forest.

Law of motion. The fallow land evolves according to:

$$\dot{L}_o = -x^{o\to u} + \delta_o \overbrace{uzH}^{L_u}, \tag{C.26}$$

where $(x^{o\to u})$ is the out-flow and $(\delta_o L_u)$ is the in-flow. Similarly, the forest area evolves according to:

$$\dot{F} = -x^{f\to u} + \delta_f uzH \tag{C.27}$$

The above two equations, in turn, pin down the law of motion for usable land:

$$\dot{L}_u = x^{f\to u} + x^{o\to u} - (\delta_o + \delta_f) uzH \tag{C.28}$$

Here, in contrast to the model presented in Section 4, generically $\dot{L}_u \neq -\dot{F}$. Under this extension, therefore, the expansion of agricultural land use can be different from the loss of forest area. For our quantitative analysis, this is an important consideration because our empirical findings suggest that in response to demand shocks the agricultural land use may expand at a different rate than the rate of deforestation.

D Details of Calibration

D.1 Trade costs

Our calibration of trade costs follows a three step procedure. Recall that we parametrize trade costs as follows

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

where $\kappa_{ij,g}$ is an iceberg trade cost unrelated to policy, $t^{ice}_{ij,g}$ is an iceberg trade cost generated by policy, and $t^{rev}_{ij,g}$ is a non-iceberg trade cost that generates revenues.

Step 1 - Recover trade costs $d_{ij,g}$ from gravity equations.

In the first step, we follow common practices in the empirical gravity literature and estimate the following regression:

$$\log (X_{ij,g}) = \alpha_{i,g} + \beta_{j,g} + \epsilon_{ij,g}$$

where $\alpha_{i,g}$ is an origin fixed effect, $\beta_{j,g}$ is a destination fixed effect and $\epsilon_{ij,g}$ is the residual. Here, the residual equals $(1 - \sigma_g) \log (d_{ij,g})$. Assuming that $d_{ii,g} = 1$, we recover $d_{ij,g} = exp \left(\widehat{\epsilon}_{ij,g} / (1 - \sigma_g)\right)$, where $\widehat{\epsilon}_{ij,g}$ are the estimates of the residual term.

Step 2 - Separate policy trade costs from non-policy trade costs.

In the second step, we run regressions of $d_{ij,g}$ against observables related to policy barriers. We start by defining

$$d_{ij,g} = \underbrace{\tilde{d}_{ij,g} \exp\left(\gamma X^{geography}_{ij,g}\right)}_{\equiv (1+\kappa_{ij,g})} \underbrace{\exp\left(\beta X^{policy}_{ij,g}\right)}_{\equiv \left(1+t^{ice}_{ij,g}\right)\left(1+t^{rev}_{ij,g}\right)},$$

where $X^{policy}_{ij,g}$ are observables related to policy barriers and $X^{geography}_{ij,g}$ are observables related to geography. For convenience, we re-define the policy variables $X^{policy}_{ij,g}$ so that $X^{policy}_{ij,g} = 0$ represents the "no-policy" barrier case.[26] Taking logs, we estimate

$$\log (d_{ij,g}) = \gamma X^{geography}_{ij,g} + \beta X^{policy}_{ij,g} + \log \left(\tilde{d}_{ij,g}\right)$$

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[26] For example, our "free trade agreement" dummy variable is defined as 1 if a country does not have a free-trade, and 0 otherwise.

which gives $\widehat{\gamma}$, $\widehat{\beta}$, and $\widehat{\log\left(\tilde{d}_{ij,g}\right)}$. Lastly, by setting $X_{ij,g}^{policy} = 0$, we can recover the trade barriers that are unrelated to policy

$$(1+\kappa_{ij,g}) = \exp\left(\widehat{\gamma} X_{ij,g}^{geography} + \log\left(\tilde{d}_{ij,g}\right)\right).$$

Using the above expression, we can recover the policy barriers as:

$$\left(1+t_{ij,g}^{ice}\right)\left(1+t_{ij,g}^{rev}\right) = \frac{d_{ij,g}}{(1+\kappa_{ij,g})}.$$

Step 3 - Separate iceberg trade costs from non-icerberg trade costs generated by policy.

In the third and final step, we make the assumption that $t_{ij,g}^{ice}$ is proportional to $t_{ij,g}^{rev}$

$$t_{ij,g}^{ice} = \omega_j t_{ij,g}^{rev}.$$

We calibrate ω_j so that the model matches, for each destination country, the tariff revenues per agricultural GDP observed in the data.

E Additional Tables and Figures

Table E.1: Mapping of Countries to Regions

ISO	Region	Individual Country
ARG	Argentina	ARG
AUS	Australia	AUS
BOL	Bolivia	BOL
BRA	Brazil	BRA
CAN	Canada	CAN
CHN	China	CHN
CMR	Cameroon	CMR
COL	Colombia	COL
DEU	Germany	DEU
ESP	Spain	ESP
ETH	Ethiopia	ETH
FIN	Finland	FIN
FRA	France	FRA
GBR	United Kingdom	GBR
IDN	Indonesia	IDN
IND	India	IND
ITA	Italy	ITA
JPN	Japan	JPN
MEX	Mexico	MEX
MOZ	Mozambique	MOZ
MYS	Malaysia	MYS
NGA	Nigeria	NGA
PER	Peru	PER
PRY	Paraguay	PRY
RUS	Russia	RUS
SWE	Sweden	SWE
THA	Thailand	THA
TUR	Turkey	TUR
TZA	Tanzania	TZA
USA	USA	USA
VEN	Venezuela	VEN
XAM	Rest of America	ABW, AIA, ATG, BES, BHS, BLM, BLZ, BMU, BRB, CHL CRI, CUB, CUW, CYM, DMA, DOM, ECU, FLK, GRD, GTM GUF, GUY, HND, HTI, JAM, KNA, LCA, MAF, MSR, NIC PAN, PRI, SJM, SLV, SPM, SUR, SXM, TCA, TTO, URY VCT, VGB, VIR
XAS	Rest of Asia	AFG, ASM, BGD, BRN, BTN, COK, FJI, FSM, GUM, HKG KAZ, KGZ, KHM, KIR, KOR, LAO, LKA, MDV, MHL, MMR MNG, MNP, NCL, NIU, NPL, NRU, NZL, PAK, PCN, PHL PLW, PNG, PRK, PYF, SGP, SLB, TJK, TKL, TKM, TLS TON, TUV, TWN, UZB, VNM, VUT, WLF, WSM
XCF	Central Africa	AGO, CAF, COD, COG, GAB, GNQ, RWA, STP, TCD
XEU	Rest of Europe	ALB, AND, AUT, BEL, BGR, BIH, BLR, CHE, CZE, DNK EST, FRO, GGY, GIB, GRC, HRV, HUN, IMN, IRL, ISL JEY, LIE, LTU, LUX, LVA, MCO, MDA, MKD, MLT, MNE NLD, NOR, POL, PRT, ROU, SMR, SRB, SVK, SVN, UKR VAT
XMN	Rest of Mena	ARE, ARM, AZE, BHR, CYP, DZA, EGY, ESH, GEO, IRN IRQ, ISR, JOR, KWT, LBN, LBY, MAR, OMN, PSE, QAT SAU, SYR, TUN, YEM
XOF	Other Africa	BDI, BWA, COM, DJI, ERI, KEN, LSO, MDG, MUS, MWI MYT, NAM, SDN, SOM, SSD, SWZ, SYC, UGA, ZAF
XWF	Rest of West Africa	BEN, BFA, CIV, CPV, GHA, GIN, GMB, GNB, LBR, MLI MRT, NER, SEN, SHN, SLE, TGO
ZMB	Zambia	ZMB
ZWE	Zimbabwe	ZWE

Table E.2: Summary Statistics by Regions (1990-2020)

		% of Global		Forest share	Change in Forest			% of Global
		Forest	Land	in 1990	%	p.p.	Total	Deforestation
ISO	Region	(1)	(2)	(3)	(4)	(5)	(6)	(7)
RUS	Russia	19.50	12.60	48.62	0.02	0.01	0.00	-0.05
BRA	Brazil	14.33	6.43	70.03	-17.07	-11.96	-3.33	34.32
CAN	Canada	8.41	7.00	37.79	-4.33	-1.64	-0.50	5.11
XCF	Central Africa	7.54	4.65	50.88	-13.44	-6.84	-1.38	14.21
USA	USA	6.97	7.04	31.10	-0.79	-0.24	-0.07	0.77
XAS	Rest of Asia	4.54	7.69	18.55	-9.58	-1.78	-0.59	6.10
AUS	Australia	3.25	5.91	17.29	-0.94	-0.16	-0.04	0.43
IDN	Indonesia	2.90	1.44	63.06	-26.01	-16.40	-1.03	10.58
CHN	China	2.77	7.25	11.99	19.73	2.37	0.74	-7.66
XOF	Other Africa	2.62	5.68	14.49	-17.41	-2.52	-0.62	6.39
XAM	Rest of America	2.55	1.85	43.32	-5.16	-2.24	-0.18	1.85
XWF	Rest of West Africa	1.91	3.96	15.15	-21.50	-3.26	-0.56	5.76
PER	Peru	1.87	0.98	59.52	-6.49	-3.86	-0.16	1.70
XEU	Rest of Europe	1.79	2.35	23.99	5.56	1.33	0.14	-1.40
MEX	Mexico	1.73	1.50	36.29	-7.03	-2.55	-0.17	1.70
COL	Colombia	1.59	0.85	58.46	-9.48	-5.54	-0.20	2.11
IND	India	1.43	2.29	19.58	1.15	0.22	0.02	-0.23
BOL	Bolivia	1.41	0.83	53.34	-12.14	-6.47	-0.23	2.41
TZA	Tanzania	1.39	0.68	64.16	-20.49	-13.15	-0.39	4.00
VEN	Venezuela	1.26	0.68	58.50	-13.04	-7.63	-0.22	2.31
ZMB	Zambia	1.16	0.57	63.70	-5.48	-3.49	-0.09	0.89
MOZ	Mozambique	1.06	0.61	55.11	-15.39	-8.48	-0.22	2.29
ARG	Argentina	0.84	2.11	12.58	-21.20	-2.67	-0.24	2.51
SWE	Sweden	0.69	0.31	68.90	-0.30	-0.20	-0.00	0.03
NGA	Nigeria	0.64	0.70	28.83	-18.47	-5.32	-0.16	1.67
PRY	Paraguay	0.63	0.31	64.27	-37.55	-24.14	-0.32	3.29
XMN	Rest of Mena	0.57	8.97	2.00	6.88	0.14	0.05	-0.55
CMR	Cameroon	0.55	0.36	47.56	-9.80	-4.66	-0.07	0.76
FIN	Finland	0.54	0.23	71.98	2.44	1.76	0.02	-0.18
TUR	Turkey	0.47	0.59	25.00	11.78	2.94	0.08	-0.78
ETH	Ethiopia	0.46	0.86	16.90	-16.14	-2.73	-0.10	1.05
MYS	Malaysia	0.46	0.25	56.87	-6.78	-3.86	-0.04	0.44
ZWE	Zimbabwe	0.46	0.30	48.27	-7.16	-3.45	-0.04	0.46
THA	Thailand	0.43	0.39	34.53	-7.40	-2.55	-0.04	0.45
JPN	Japan	0.36	0.28	40.22	0.60	0.24	0.00	-0.03
FRA	France	0.32	0.43	23.70	14.69	3.48	0.06	-0.66
ESP	Spain	0.29	0.38	23.94	33.64	8.05	0.13	-1.38
ITA	Italy	0.17	0.23	24.01	26.34	6.32	0.06	-0.64
DEU	Germany	0.14	0.27	16.20	1.05	0.17	0.00	-0.02
GBR	United Kingdom	0.01	0.19	1.42	0.00	0.00	0.00	0.00
World		100.00	100.00	31.42	-7.13	-2.24	-9.71	100.00

Notes: This table reports summary statistics of changes in forest area between 1990 and 2020 based on the Forest Resource Assessment report of 2020 from FAO. Column 1 is based on forest area as of 1990. Column 2 shows percentage change in forest area between 1990 and 2020. Column 3 shows percentage change in agricultural land use area year. Column 4 shows the share of global forest coming from each region.

Table E.3: Counterfactual Changes in Forest Area

		Baseline			Baseline + Pop. growth			
ISO	Region	BAU(pp)	C1(pp)	C2(pp)	BAU(pp)	C1(pp)	C2(pp)	Pop. growth(%)
ARG	Argentina	-0.00	0.07	-0.32	-1.32	0.07	-0.25	46.3
AUS	Australia	-0.00	0.30	-1.60	-7.93	0.26	-1.53	58.0
BOL	Bolivia	-0.00	0.14	0.55	-7.25	0.13	0.58	50.1
BRA	Brazil	-0.00	-3.51	-1.10	0.09	-3.72	-1.19	9.8
CAN	Canada	-0.00	0.35	-2.02	-6.44	0.26	-1.57	53.8
CHN	China	-0.00	0.27	1.93	1.57	0.26	1.96	-18.1
CMR	Cameroon	-0.00	0.10	-0.04	-18.08	0.05	0.09	90.6
COL	Colombia	-0.00	0.13	0.43	-0.30	0.13	0.24	32.4
DEU	Germany	-0.00	0.14	-0.36	-0.53	0.14	-0.37	19.9
ESP	Spain	-0.00	0.22	-0.87	1.40	0.26	-1.20	23.6
ETH	Ethiopia	-0.00	0.02	-0.00	-5.40	0.01	-0.03	147.0
FIN	Finland	-0.00	0.30	-0.85	-0.17	0.29	-0.91	45.2
FRA	France	-0.00	0.21	-0.38	-1.63	0.21	-0.80	26.9
GBR	United Kingdom	0.02	0.01	-0.05	-0.11	0.01	-0.05	38.0
IDN	Indonesia	-0.00	0.28	3.00	-2.95	0.25	3.03	35.7
IND	India	-0.00	0.05	1.57	-0.91	0.05	1.61	20.2
ITA	Italy	-0.00	0.18	-0.30	2.14	0.19	-0.64	18.4
JPN	Japan	-0.00	0.17	1.05	6.93	0.23	0.89	-6.9
MEX	Mexico	-0.00	0.16	0.15	-2.43	0.14	0.15	35.4
MOZ	Mozambique	-0.00	0.78	4.88	-22.65	0.45	3.60	123.1
MYS	Malaysia	-0.00	0.19	0.34	-3.78	0.17	0.36	46.8
NGA	Nigeria	-0.00	0.00	0.08	-10.83	0.00	0.04	220.1
PER	Peru	-0.00	0.06	1.32	-3.43	0.06	1.40	44.5
PRY	Paraguay	-0.00	0.15	-1.05	-4.46	0.16	-0.82	47.6
RUS	Russia	-0.00	0.28	1.10	-0.25	0.29	0.44	8.0
SWE	Sweden	-0.00	0.32	-2.31	-4.68	0.35	-2.41	47.2
THA	Thailand	-0.00	0.35	0.72	3.85	0.32	0.56	9.1
TUR	Turkey	-0.00	0.20	0.55	-1.98	0.18	0.34	37.5
TZA	Tanzania	-0.00	0.04	1.46	-23.94	0.03	0.94	212.4
USA	USA	-0.00	0.30	-0.98	-2.83	0.22	-0.85	42.0
VEN	Venezuela	-0.00	0.25	0.99	-2.29	0.22	0.97	41.6
XAM	Rest of America	-0.00	0.20	-0.13	-2.69	0.18	-0.10	36.7
XAS	Rest of Asia	-0.00	0.16	1.61	-2.39	0.14	1.62	49.6
XCF	Rest of Central Africa	-0.00	0.42	4.12	-21.03	0.28	2.96	268.0
XEU	Rest of Europe	-0.00	0.16	0.06	0.96	0.18	-0.37	-10.8
XMN	Rest of Mena	-0.00	0.08	1.12	-2.39	0.06	0.84	86.6
XOF	Rest of Other Africa	-0.00	0.07	1.23	-6.28	0.04	0.72	188.7
XWF	Rest of West Africa	-0.00	0.07	0.18	-9.65	0.03	0.13	261.6
ZMB	Zambia	-0.00	0.05	-0.29	-25.60	0.04	-0.46	90.8
ZWE	Zimbabwe	-0.00	0.12	0.94	-11.66	0.12	0.81	59.3
World		-0.00	-0.08	0.54	-3.95	-0.12	0.35	42.5

Notes: Columns 1 to 3 report results from our first baseline scenario (in percentage points). Column "BAU" reports the change in steady state relative to time 0; Columns "C1" and "C2" report the steady state change in each counterfactual, relative to the steady state in BAU. Columns 4 to 6 repeat the same results, for the baseline scenario that includes population growth. The last column contains the changes in population we feed into the model, in percentage terms relative to time 0.

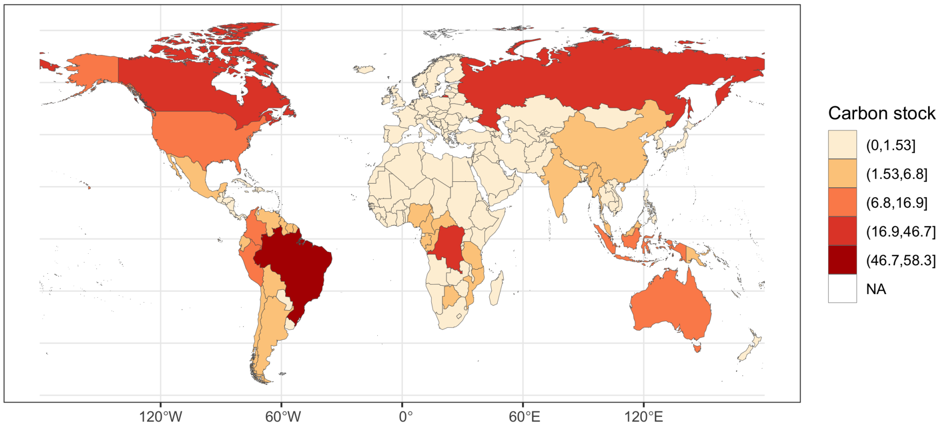
Table E.4: Summary Statistics by Country (1990-2020) - First Part

	% of Global		Forest share	Change in Forest			% of Global
	Forest	Land	in 1990	%	p.p.	Total	Deforestation
Country	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Russia	19.50	12.60	48.62	0.02	0.01	0.00	-0.05
Brazil	14.33	6.43	70.03	-17.07	-11.96	-3.33	34.32
Canada	8.41	7.00	37.79	-4.33	-1.64	-0.50	5.11
USA	6.97	7.04	31.10	-0.79	-0.24	-0.07	0.77
DRC	3.69	1.74	66.42	-16.26	-10.80	-0.82	8.41
Australia	3.25	5.91	17.29	-0.94	-0.16	-0.04	0.43
Indonesia	2.90	1.44	63.06	-26.01	-16.40	-1.03	10.58
China	2.77	7.25	11.99	19.73	2.37	0.74	-7.66
Angola	1.92	0.96	62.81	-15.97	-10.03	-0.42	4.29
Peru	1.87	0.98	59.52	-6.49	-3.86	-0.16	1.70
Mexico	1.73	1.50	36.29	-7.03	-2.55	-0.17	1.70
Colombia	1.59	0.85	58.46	-9.48	-5.54	-0.20	2.11
India	1.43	2.29	19.58	1.15	0.22	0.02	-0.23
Bolivia	1.41	0.83	53.34	-12.14	-6.47	-0.23	2.41
Tanzania	1.39	0.68	64.16	-20.49	-13.15	-0.39	4.00
Venezuela	1.26	0.68	58.50	-13.04	-7.63	-0.22	2.31
Zambia	1.16	0.57	63.70	-5.48	-3.49	-0.09	0.89
Mozambique	1.06	0.61	55.11	-15.39	-8.48	-0.22	2.29
Myanmar	0.96	0.50	60.00	-28.25	-16.95	-0.37	3.80
Papua New Guinea	0.89	0.35	80.24	-1.50	-1.20	-0.02	0.19
Argentina	0.84	2.11	12.58	-21.20	-2.67	-0.24	2.51
Central Africa	0.81	1.01	25.21	-3.71	-0.94	-0.04	0.42
Sweden	0.69	0.31	68.90	-0.30	-0.20	-0.00	0.03
Nigeria	0.64	0.70	28.83	-18.47	-5.32	-0.16	1.67
Paraguay	0.63	0.31	64.27	-37.55	-24.14	-0.32	3.29
Gabon	0.58	0.20	92.10	-0.97	-0.89	-0.01	0.08
Sudan	0.57	1.44	12.56	-22.26	-2.80	-0.17	1.79
Cameroon	0.55	0.36	47.56	-9.80	-4.66	-0.07	0.76
Republic of Congo	0.54	0.26	65.17	-1.66	-1.08	-0.01	0.13
Finland	0.54	0.23	71.98	2.44	1.76	0.02	-0.18
Turkey	0.47	0.59	25.00	11.78	2.94	0.08	-0.78
Ethiopia	0.46	0.86	16.90	-16.14	-2.73	-0.10	1.05
Botswana	0.46	0.44	33.18	-18.87	-6.26	-0.12	1.22
Malaysia	0.46	0.25	56.87	-6.78	-3.86	-0.04	0.44
Zimbabwe	0.46	0.30	48.27	-7.16	-3.45	-0.04	0.46
Guyana	0.46	0.15	94.50	-1.00	-0.95	-0.01	0.06
Thailand	0.43	0.39	34.53	-7.40	-2.55	-0.04	0.45
South Africa	0.40	2.77	4.54	-6.04	-0.27	-0.03	0.34
Laos	0.40	0.18	70.35	-8.70	-6.12	-0.05	0.49
Suriname	0.38	0.12	98.49	-1.19	-1.17	-0.01	0.06
Japan	0.36	0.28	40.22	0.60	0.24	0.00	-0.03
Ecuador	0.36	0.19	58.74	-15.09	-8.86	-0.07	0.76
Mongolia	0.35	1.20	9.24	-1.27	-0.12	-0.01	0.06
Chile	0.33	0.57	18.29	10.49	1.92	0.05	-0.49
Madagascar	0.33	0.45	23.14	-9.99	-2.31	-0.04	0.46
Mali	0.33	0.94	10.89	-4.24	-0.46	-0.02	0.19
France	0.32	0.42	23.57	14.80	3.49	0.06	-0.66
Norway	0.30	0.23	39.89	-0.49	-0.20	-0.00	0.02
Spain	0.29	0.38	23.94	33.64	8.05	0.13	-1.38
Mena	0.29	4.21	2.14	11.47	0.25	0.04	-0.46
Cambodia	0.27	0.14	61.96	-31.75	-19.68	-0.12	1.19
Ghana	0.24	0.18	43.40	-22.13	-9.61	-0.07	0.75
Senegal	0.23	0.15	48.15	-13.32	-6.41	-0.04	0.42
Poland	0.22	0.24	29.01	6.77	1.96	0.02	-0.21
Namibia	0.21	0.63	10.65	-24.29	-2.59	-0.07	0.73
Vietnam	0.21	0.24	27.84	19.27	5.36	0.06	-0.57
Liberia	0.21	0.07	88.50	-10.95	-9.69	-0.03	0.32
Somalia	0.20	0.48	13.20	-27.81	-3.67	-0.08	0.79
Other South America	0.20	0.07	85.69	-1.50	-1.29	-0.00	0.04
Cote Divoire	0.19	0.24	24.67	-64.01	-15.79	-0.17	1.72
New Zealand	0.19	0.20	29.78	-0.42	-0.13	-0.00	0.01
Burkina Faso	0.19	0.21	28.15	-21.59	-6.08	-0.06	0.57
Phillipines	0.18	0.23	25.11	-9.08	-2.28	-0.02	0.23
Guinea	0.18	0.19	29.45	-15.26	-4.49	-0.04	0.38
Italy	0.17	0.23	24.01	26.34	6.32	0.06	-0.64
Honduras	0.17	0.09	62.45	-8.99	-5.62	-0.02	0.22
Chad	0.16	0.97	5.34	-36.11	-1.93	-0.08	0.83
Belarus	0.16	0.16	32.40	-0.32	-0.10	-0.00	0.01
Nicaragua	0.16	0.09	53.17	-47.78	-25.41	-0.10	1.05
Romania	0.14	0.18	25.40	3.27	0.83	0.01	-0.07
North Korea	0.14	0.09	48.02	-12.79	-6.14	-0.02	0.25
Germany	0.14	0.27	16.20	1.05	0.17	0.00	-0.02
Nepal	0.14	0.11	38.95	2.82	1.10	0.01	-0.05
Morocco	0.13	0.34	11.58	-1.15	-0.13	-0.00	0.02
Oceania	0.13	0.07	58.47	1.35	0.79	0.00	-0.02

Table E.5: Summary Statistics by Country (1990-2020) - Second Part

	% of Global		Forest share	Change in Forest			% of Global
	Forest	Land	in 1990	%	p.p.	Total	Deforestation
Country	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Benin	0.12	0.09	42.77	-35.47	-15.17	-0.06	0.59
Guatemala	0.12	0.08	44.39	-29.04	-12.89	-0.05	0.47
Pakistan	0.12	0.59	6.14	-26.64	-1.64	-0.04	0.43
Ukraine	0.12	0.45	8.13	2.87	0.23	0.00	-0.05
South Korea	0.11	0.07	47.64	-13.32	-6.34	-0.02	0.21
Panama	0.11	0.06	61.83	-9.75	-6.03	-0.01	0.15
Turkmenistan	0.10	0.36	8.78	0.00	0.00	0.00	0.00
Balkans	0.10	0.11	28.61	26.07	7.46	0.04	-0.36
Kenya	0.09	0.44	6.51	-6.68	-0.43	-0.01	0.08
Uganda	0.08	0.15	16.98	-45.01	-7.64	-0.05	0.53
Portugal	0.08	0.07	37.10	-2.56	-0.95	-0.00	0.03
Malawi	0.08	0.07	35.67	-35.59	-12.69	-0.04	0.41
Greece	0.08	0.10	24.68	18.30	4.52	0.02	-0.20
Sierra Leone	0.08	0.06	43.23	-19.44	-8.40	-0.02	0.21
Costa Rica	0.07	0.04	56.42	2.34	1.32	0.00	-0.02
Latvia	0.07	0.05	45.97	3.03	1.40	0.00	-0.03
Georgia	0.07	0.05	38.83	1.93	0.75	0.00	-0.02
Kazakhstan	0.06	2.08	0.98	14.69	0.14	0.01	-0.13
Czech Republic	0.06	0.06	34.06	1.81	0.62	0.00	-0.02
Bhutan	0.06	0.03	65.25	8.72	5.69	0.01	-0.07
Serbia	0.06	0.07	26.00	14.64	3.81	0.01	-0.11
Guinea-Bissau	0.05	0.02	79.41	-11.37	-9.03	-0.01	0.09
Bosnia	0.05	0.04	43.16	-1.00	-0.43	-0.00	0.01
Sri Lanka	0.05	0.05	33.38	-11.00	-3.67	-0.01	0.08
Austria	0.05	0.06	24.68	9.37	2.31	0.01	-0.07
Estonia	0.05	0.03	46.26	10.54	4.88	0.01	-0.07
Niger	0.05	0.97	1.50	-49.54	-0.74	-0.03	0.32
Bangladesh	0.05	0.10	14.18	-6.49	-0.92	-0.00	0.04
Hungary	0.04	0.07	20.04	13.18	2.64	0.01	-0.08
Croatia	0.04	0.04	31.41	6.42	2.02	0.00	-0.04
Cuba	0.04	0.08	16.45	58.35	9.60	0.03	-0.34
Belize	0.04	0.02	70.06	-20.23	-14.17	-0.01	0.11
Dominican Republic	0.04	0.04	32.58	24.16	7.87	0.01	-0.13
Lithuania	0.04	0.05	24.49	3.65	0.89	0.00	-0.02
Uzbekistan	0.03	0.33	3.19	4.92	0.16	0.00	-0.02
Togo	0.03	0.04	24.66	-14.34	-3.54	-0.01	0.07
West Africa	0.03	1.00	0.94	-16.68	-0.16	-0.01	0.07
Afghanistan	0.03	0.50	1.85	0.00	0.00	0.00	0.00
Slovakia	0.03	0.04	24.20	1.17	0.28	0.00	-0.00
Eritrea	0.03	0.08	11.29	-11.25	-1.27	-0.00	0.04
West Europe	0.03	0.03	23.88	14.38	3.43	0.00	-0.05
Kyrgyzstan	0.02	0.15	5.10	11.12	0.57	0.00	-0.04
Timor Leste	0.02	0.01	64.77	-4.36	-2.82	-0.00	0.01
Caribbean	0.02	0.02	41.88	-1.89	-0.79	-0.00	0.01
Macedonia	0.02	0.02	36.16	9.81	3.55	0.00	-0.03
Albania	0.02	0.02	28.79	0.01	0.00	0.00	-0.00
El Salvador	0.02	0.02	34.22	-20.13	-6.89	-0.00	0.05
Azerbaijan	0.02	0.06	7.89	26.74	2.11	0.01	-0.06
Uruguay	0.01	0.13	3.41	42.21	1.44	0.01	-0.09
Denmark	0.01	0.03	12.66	18.25	2.31	0.00	-0.03
Jamaica	0.01	0.01	47.32	14.83	7.02	0.00	-0.03
Tunisia	0.01	0.12	3.16	-0.57	-0.02	-0.00	0.00
Gambia	0.01	0.01	40.80	-41.66	-17.00	-0.01	0.06
Brunei	0.01	0.00	78.18	-9.04	-7.07	-0.00	0.01
Haiti	0.01	0.02	13.46	-15.00	-2.02	-0.00	0.02
Netherlands	0.01	0.03	10.25	7.00	0.72	0.00	-0.01
United Kingdom	0.01	0.19	1.42	0.00	0.00	0.00	0.00
Armenia	0.01	0.02	11.28	-3.43	-0.39	-0.00	0.00
Puerto Rico	0.01	0.01	36.11	54.94	19.84	0.01	-0.06
Swaziland	0.01	0.01	17.29	33.06	5.72	0.00	-0.03
Tajikistan	0.01	0.11	2.13	3.77	0.08	0.00	-0.00
Belgium	0.01	0.02	7.63	8.70	0.66	0.00	-0.01
Libya	0.01	1.35	0.12	0.00	0.00	0.00	0.00
Rwanda	0.00	0.02	8.27	-38.24	-3.16	-0.00	0.03
East Africa	0.00	0.01	26.56	-4.87	-1.29	-0.00	0.00
Moldova	0.00	0.03	5.44	-6.31	-0.34	-0.00	0.00
Ireland	0.00	0.05	1.18	32.68	0.39	0.00	-0.01
Egypt	0.00	0.77	0.04	2.67	0.00	0.00	-0.00
Central America	0.00	0.00	45.31	-3.32	-1.51	-0.00	0.00
Lesotho	0.00	0.02	0.85	0.00	0.00	0.00	0.00
Singapore	0.00	0.00	20.88	5.01	1.05	0.00	-0.00
Iceland	0.00	0.08	0.10	12.18	0.01	0.00	-0.00
Djibouti	0.00	0.02	0.24	0.00	0.00	0.00	0.00
Maldives	0.00	0.00	2.73	0.00	0.00	0.00	0.00
Other Northern Europe	0.00	0.05	0.00	0.00	0.00	0.00	0.00
World	100.00	100.00	31.42	-7.13	-2.24	-9.71	100.00

Figure E.1: Carbon Stock per Hectare across the World



Notes: This figure shows, for each country, the carbon content of forests, measured as tons of carbon per hectare of forest, which we use to compute the CO_2 emissions from deforestation. Data comes from FRA-FAO.

Figure E.2: Model Fit

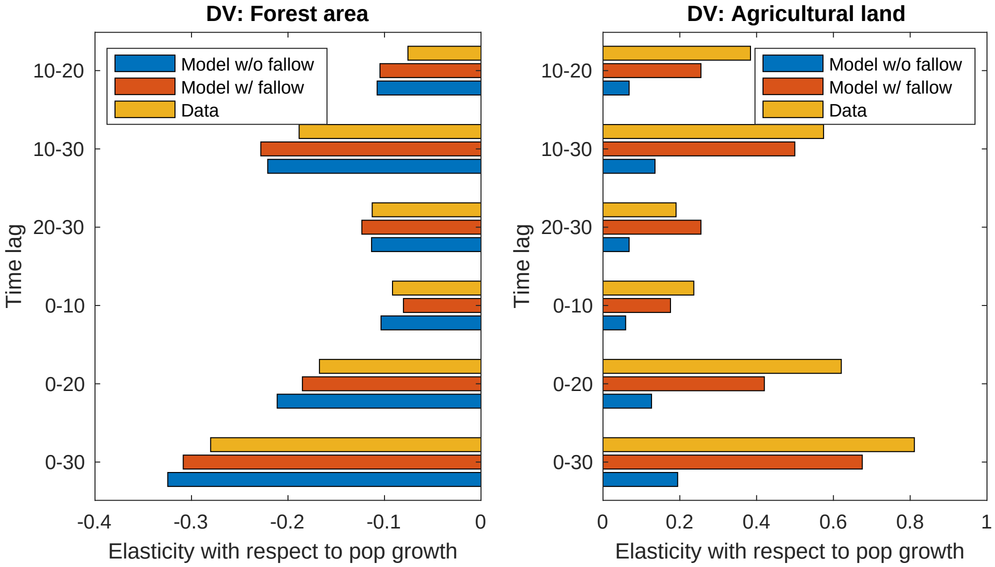
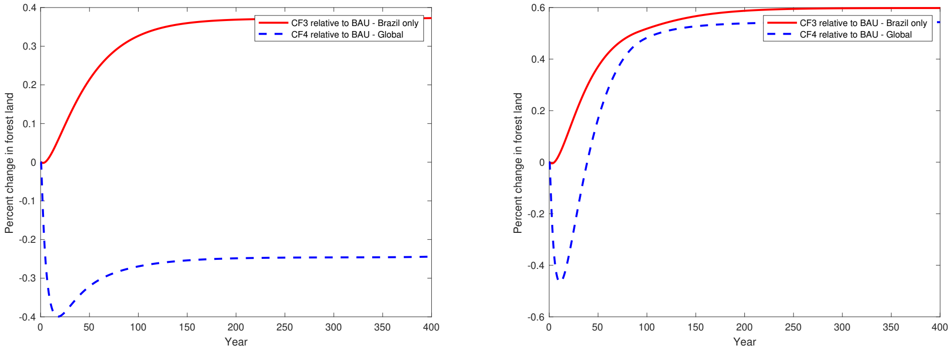


Figure E.3: Multilateral vs Unilateral Trade Cost Increase: Change in Global Forest Area


Panel (a): No Population Growth
Panel (b): With Population Growth

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