PERUVIAN ECONOMIC ASSOCIATION

Deforestation: A Global and Dynamic Perspective

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Working Paper No. 209, August 2025

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August 2025

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) population growth causes deforestation. Motivated by these facts, we build a model in which structural change and comparative advantage determine the extent, location, and timing of deforestation. Using the model, we obtain conditions under which reductions in trade costs and tariffs reduce global deforestation. Quantitatively, eliminating global agricultural tariffs has limited impacts on global forest area, leads to substantial forest reallocation across countries, and results in net welfare benefits.

Keywords: International trade, deforestation, dynamics, land use, trade policy

*We thank Dominick Bartelme, John Sturm Becko, Chad Bown, Javier Cravino, Charlotte Janssens, Sam Kortum, Ahmad Lashkaripour, Andrei Levchenko, Pablo Ottonello, Andres Rodriguez-Clare, Daniel Tannenbaum, and Mike Waugh for helpful comments, as well as Tomas Dominguez-Iino, Walter Steingress, Allan Hsiao, Bernhard Dalheimer, and Dave Donaldson for constructive discussion. We also thank seminar participants and colleagues at many institutions for their helpful comments and discussions. Sotelo and Farrokhi thank the IES at Princeton for its hospitality during part of this research. We thanks Lucas Correa and Razi Iqbal for research assistance. This document is an output from the research initiative 'Structural Transformation and Economic Growth' (STEG), a program funded by the Foreign, Commonwealth & Development Office (FCDO). The views expressed are not necessarily those of FCDO. E-mail: farrokh@bc.edu, emkang@umich.edu, hpelleg3@nd.edu, ssotelo@umich.edu.

1 Introduction

Global deforestation has gathered speed in recent decades, bringing the adverse impacts of human activity on biodiversity and the world's climate to the forefront of public debate. The expansion of agriculture—strengthened by global markets where producers expand their land use to meet international demand—is one of the key drivers of deforestation. This confluence of factors, along with the resulting calls from policymakers to restrict agricultural trade and curb deforestation, underscore the need to evaluate how trade barriers affect the extent, location, and timing of land-use changes. Such an evaluation is also necessary to determine whether agricultural trade liberalization, a traditional stumbling block in trade negotiations, is desirable when its climate costs are considered.

We offer an approach that emphasizes the global and dynamic nature 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. Similarly, population growth in one region can put pressure on land use not just locally, but also abroad. 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, a dynamic approach distinguishes between movements in the land frontier, which cause deforestation, and the existing stock of land, which is used in production. This distinction is key for understanding the timing of deforestation and associated carbon emissions, one of the main climate damages stemming from it. 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 cross-country data on land use, sectoral production, international trade, and 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. Tropical countries experienced especially large rates of deforestation and, put together, 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. Countries with more initial forest deforested more in this period, suggesting that land-clearing becomes costlier as forests dwindle. Second, agricultural land expansion was strongly associated with deforestation across countries. 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 larger forest loss between 1990 and 2020. This pattern suggests that international trade distributes global pressures on land across countries in line with their comparative advantage in agriculture. Fourth, deforestation in a country follows from its own population growth and that of its main trading partners. This fact is important on its own right, as population growth looms large in certain regions; but it is also informative about the ease with which the land frontier expands and how trade connects demand for land across countries—features of the data that we exploit in our model calibration.

Motivated by these empirical patterns, we develop a dynamic, general equilibrium model to evaluate the quantitative response of deforestation to trade policy across the world and over time. The model incorporates many countries that differ in multiple dimensions such as productivity and endowments. It also includes three broad sectors, agriculture, manufacturing, and services that are complementary in consumption. There is also a market and, therefore, a price for new land. New land is supplied by a land-clearing sector that employs labor to transform open-access forests into land. Landowners, who are forward looking, incorporate new land to their existing stock of land, which they rent to other sectors in the economy. The reallocation of labor between sectors is subject to frictions.

The equilibrium stocks of land and forests in our model are 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 and forests across countries, and together with absolute advantage, determines whether trade alleviates pressures on forests globally; and (iii) forward-looking land accumulation decisions control the pace of forest adjustments to shocks.

Using a stylized version of our model, we present a set of analytical results that apply in steady state. Our first two results indicate that the geographic scope of the analysis is key for understanding the impact of changes in trade costs on deforestation. Specifically, reducing agricultural iceberg export costs unilaterally for a small open economy leads to deforestation there (Proposition 1). This is because the country expands its production and land use, taking advantage of the high within-sector substitutability of varieties across countries. In contrast, a multilateral reduction in agricultural iceberg trade costs increases global forest area (Proposition 2). Focusing on a collection of symmetric economies—which shuts down the comparative advantage channel—we show that the change in global land use is determined by the demand elasticity across sectors. In the empirically relevant case, agriculture is complementary in consumption with non-agricultural goods, and so the trade shock drives structural change away from agriculture, increasing global forest area.

Unlike reductions in iceberg trade costs, which act as export-oriented productivity shocks, reductions in tariffs do not entail such productivity gains. We therefore characterize the conditions under which agricultural trade liberalization increases global forest area. Still in a symmetric world, our findings show that the forces of structural change are strong enough to ensure that a global tariff reduction leads to an increase in global forest area, but only if agricultural trade is sufficiently protected to begin with (Proposition 3). Lastly, we study the role of comparative advantage when the elasticity of substitution between agriculture and non-agriculture is equal to one—which shuts down the structural change channel. We show that when the correlation between comparative and absolute advantage in agriculture is positive, countries with an absolute advantage in agriculture specialize in agriculture, making the move from autarky to free trade globally land-saving (Proposition 4).[1]

Propositions 1–4 identify the mechanisms through which trade affects global deforestation in our model, but they do not yield a definitive prediction. We therefore develop a quantitative model that incorporates the mechanisms highlighted by these propositions and key features of reality, including those documented in our empirical patterns. We bring our quantitative model to data on production, trade, land use, and forest area. We disaggregate the world into 33 countries and 7 regions, and classify goods into agriculture, manufacturing, and service sectors—further dividing agriculture into main staple crops, pasture-related products, and a bundle of other agricultural goods. Our calibration measures three sets of parameters that shape the model's quantitative predictions. First, we draw on established literature to set the parameters that govern the substitution in demand across and within sectors, as well as workers' sectoral mobility. Second, we use standard model inversion methods to recover productivities and trade costs. Third, we calibrate the parameters governing land dynamics—the novel component in our model. Here, we calibrate the conversion technology of forest into land, following the logic of indirect inference, so that the model replicates the reduced-form impact of population growth on forest area over different time horizons.[2]

Having calibrated our model, we examine two counterfactual scenarios. We first examine a counterfactual policy scenario in which all agricultural tariffs on Brazilian exports are eliminated. On net, global forest area drops by roughly 0.1 percentage points, in a slow process that takes decades to unfold. Behind this global change, there is a sharp decline in forest area within Brazil, while forest leakage—the forest gain in the rest of the world for each unit of deforestation in Brazil—is large and amounts to about 50 percent.

[1] Taken together, these results extend Borlaug's famed hypothesis—that agricultural productivity growth is land-saving in a closed economy Borlaug (2000)—to the domain of international trade, explaining the consequences of changes in different types of trade barriers and highlighting that trade can lead to global forest gains.

[2] Our quantitative model features, in addition, a fallow land sector. We introduce this additional 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.

We then consider a scenario of global agricultural tariff removal. In contrast to the Brazil-specific case, removing tariffs worldwide leads to an increase of about 0.2 percentage points in global forest area. Beneath this modest aggregate gain lies a substantial reallocation of forest area across countries: deforestation occurs in countries with extensive boreal forests as well as in Brazil, but these losses are more than offset by forest gains elsewhere, particularly in other tropical countries.

We use our second policy scenario—full agricultural tariff liberalization—to illustrate the quantitative importance of the mechanisms highlighted by our theoretical propositions. First, the forces of structural change, governed by sectoral demand elasticity and emphasized in Propositions 2 and 3, are crucial. When the sectoral demand elasticity is sufficiently high, agricultural trade liberalization drives economic activity towards the agricultural sector and thus leads to global forest loss, rather than gain. Second, we show that comparative advantage in agriculture shapes the cross-sectional pattern of deforestation: countries with higher agricultural productivity relative to manufacturing experience greater forest loss (or less forest gain) in response to agricultural trade liberalization. Moreover, our calibration reveals a positive correlation between absolute and comparative advantage in agriculture. This finding underscores the relevance of Proposition 4 and implies that moving toward free trade alleviates global pressure on forests from the agricultural sector.

After establishing the quantitative importance of the key mechanisms in our model, we consider a new Business-as-usual (BAU) scenario in which each country's population grows until 2100, according to UN projections. In this new BAU scenario, many African countries experience large rates of deforestation since their growing population increases local demand for food. We find that the scope for tariff reductions to mitigate the effects of population growth on deforestation is limited, as the direct impact of population growth on food demand outweighs the reallocations induced by trade policy. Nevertheless, as we discuss next, a trade-induced reallocation of deforestation away from Africa's dense tropical forests would help reduce its environmental costs.

We conclude by evaluating the welfare gains from agricultural tariff liberalization, explicitly accounting for the carbon emission costs associated with deforestation. A multilateral liberalization of agricultural tariffs leads to 0.13 percent increase in global, aggregate real consumption. When factoring in a social cost of carbon of 200 ($\$/tCO_2$), the net global welfare gain drops to 0.09 percent. This net gain remains positive under a broad range of assumptions and measurement methods, including scenarios with higher social costs of carbon, the potential for carbon sequestration through forest regrowth, and different approaches to discounting the future. Nevertheless, this aggregate result conceals considerable heterogeneity in net welfare gains across countries. The largest gains are realized in countries that, in response to agricultural trade liberalization, expand their agricultural land at the expense of forests.

Related Literature. We contribute to three strands of research. First, our paper speaks to research at the intersection of trade, spatial economics, and the environment, such as Costinot et al. (2016), Gouel and Laborde (2021), Shapiro (2016), Farrokhi and Lashkaripour (2024), Kortum and Weisbach (2024), and Nath (2025). Closer to our research, 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. (2025) examine the relation between agricultural trade and the allocation of water use across the world. Focusing on deforestation, Dominguez-Iino (2025) examines the effects of environmental policies along supply chains in South America, while Hsiao (2025), also in a dynamic context, studies international cooperation and commitment in the market for palm oil. See Copeland and Taylor (2004) and Copeland et al. (2022) for a review of previous work. Hertel (2012) also 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, our multi-country equilibrium approach demonstrates the role of structural change and comparative advantage in shaping the deforestation impact of trade openness. We also incorporate deforestation dynamics into a quantitative general equilibrium framework to study how aggregate economic forces and international trade policy shape land use around the world.[3]

Second, we contribute to research examining the welfare impacts of agricultural trade (Donaldson, 2018; Sotelo, 2020; Pellegrina, 2022) and how agriculture relates to structural change and development (Tombe, 2015; Gollin et al., 2021; Fajgelbaum and Redding, 2022; Farrokhi and Pellegrina, 2023). 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 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 and consequences of deforestation, such as national institutions (Burgess et al., 2019), land use taxes and payment programs for forest conservation (Jayachandran et al., 2017;

[3] Other recent studies have formulated dynamic trade and migration models to evaluate the consequences of climate change (e.g. Conte et al., 2021; Desmet et al., 2021; Balboni, 2025).

Souza-Rodrigues, 2019; Assunção et al., 2020; Araujo et al., 2025b), roads and access to markets (Pfaff, 1999; Asher et al., 2020; Gollin and Wolfersberger, 2024; Araujo et al., 2025a), regional trade agreements (Abman and Lundberg, 2020; Abman et al., 2024), China's demand for food (Hansen and Wingender, 2023), the demand for wood and forest products (Foster and Rosenzweig, 2003), spatial misallocation in agricultural deforestation (Mishra, 2025), and the externalities generated by forest fires (Balboni et al., 2024). We 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). In some of our empirical facts, we present results for an aggregation of 33 countries and 7 regional aggregates, which is the sample we use in our model calibration.[4] 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 (FRA), which reflects the FAO's efforts to measure country-level forest area from national forest inventories. We focus on this data set 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 latest edition of FRA, which covers a 30-year period between 1990 and 2020 (FAO, 2020). Second, it is a key reference for policy debate on global deforestation and for assessments of the impact of deforestation on climate change (Brown and Zarin, 2013).[5]

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.

[4] Appendix Table F.1 lists the individual countries that constitute each of our regional aggregates.

[5] These data 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.

Other Country-level Data. We use data on agricultural production, land use, and international trade, disaggregated by agricultural commodity, from FAOSTAT. 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 Four 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, population growth within a country and also among its main trade partners drives deforestation in that country.

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.

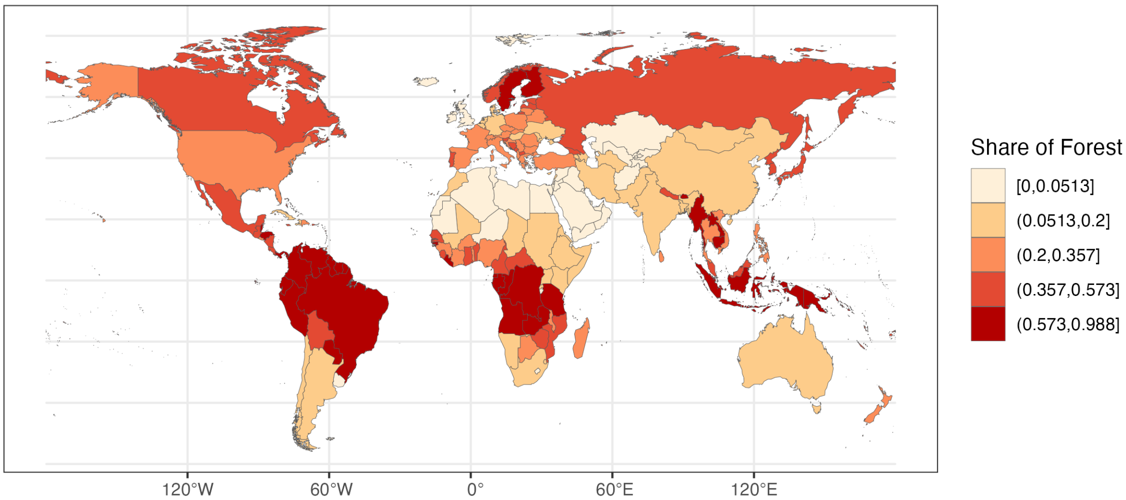
In what follows, we use "country area" as a shorthand for total area of a country net of deserts, glaciers, and lakes. Panel (a) in Figure 1 shows the share of country area covered by forest. Countries with higher forest concentration tend to be close to the North Pole, including Canada, Russia, and the Nordic countries that host large boreal forests, or near the equator, where the tropical forests of the Amazon, Congo Basin, and Southeast Asia are located. Panel (b) depicts global deforestation in 2020 relative to 1990 (as percentage points of the each country's area). The 7.1 percent loss of global forest area—from 4.07 to 3.78 billion hectares—amounts to the size of a country larger than Argentina. Deforestation was particularly large in tropical countries such as Brazil, Congo, and Indonesia where forest area fell by 17, 16, and 26 percent during this period.[6] Other countries, primarily China and many European countries, reforested over this period.

The correlation between a country's forest share in 1990 and its deforestation between 1990-2020 is sizable, equal to 0.57. In our quantitative model, we introduce a land-clearing technology whose productivity depends on the current share of forest, so as to respect this feature of the data.

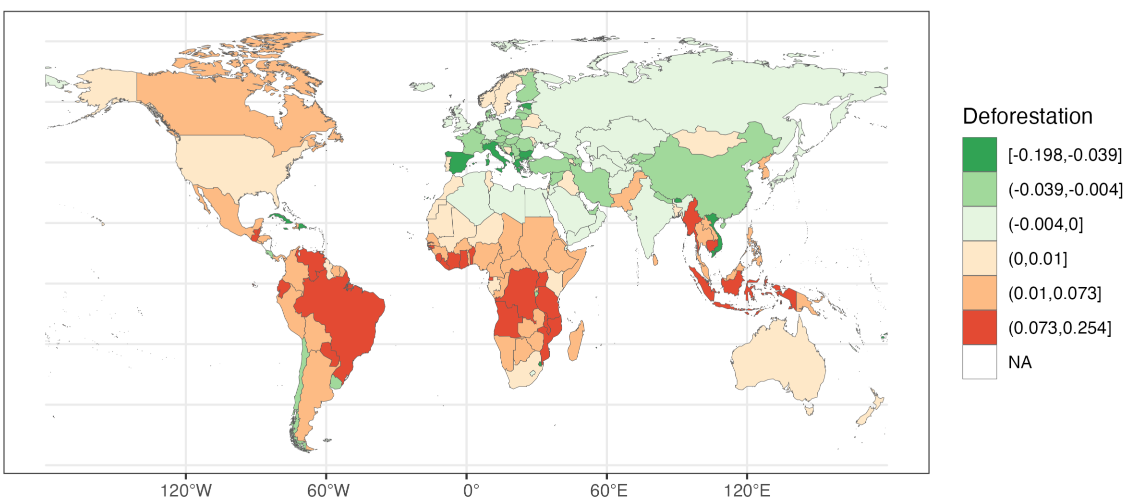
[6]The figure shows these numbers in terms of the percentage point (p.p.) change in each country's forest share rather than percentage change since the latter gives uninformatively large magnitudes in countries where forest share is tiny. The p.p. change in forest share (multiplied by 100) was -2.2 at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

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.

Appendix Table F.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

[7] Appendix Table F.3 reports these deforestation-related variables at the individual country level.

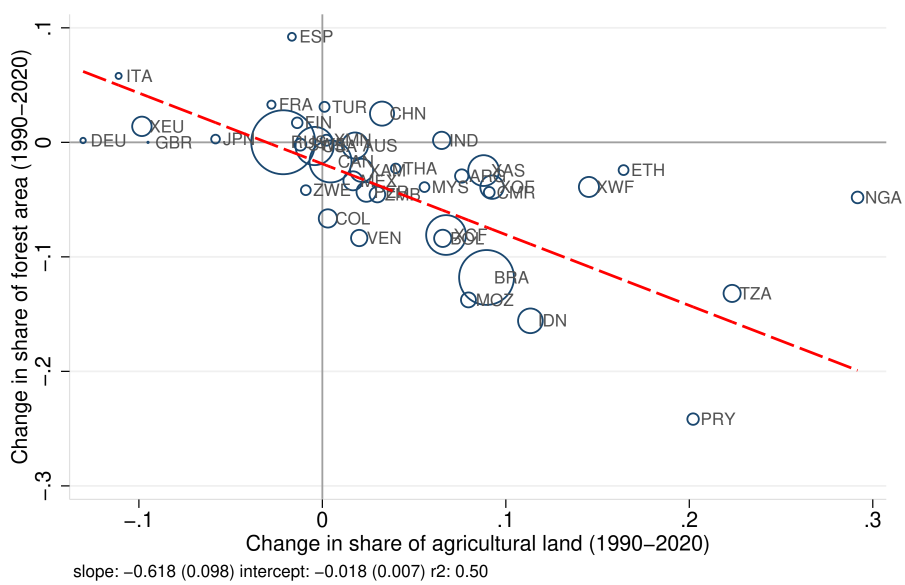
for one-third of global deforestation, followed by Central African countries and Indonesia which account together for one-fourth of global deforestation.

Before moving on, we note that forests are heterogeneous in their carbon content. Figure F.1 in the appendix depicts each country's forest carbon intensity (tons of carbon stock per hectare of forest), suggesting that the carbon emissions caused by 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).

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 our 40 regional aggregates, both measured as a share of their corresponding region area. The two variables are strongly and negatively correlated, with the share of forest area decreasing at a slope of -0.62 with respect to the share of agricultural land. That the slope is less than one in absolute value suggests that expansions in agricultural land come from other sources, in addition to forests. These findings are consistent with previous work focusing on the tropics (Pendrill et al., 2022).

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

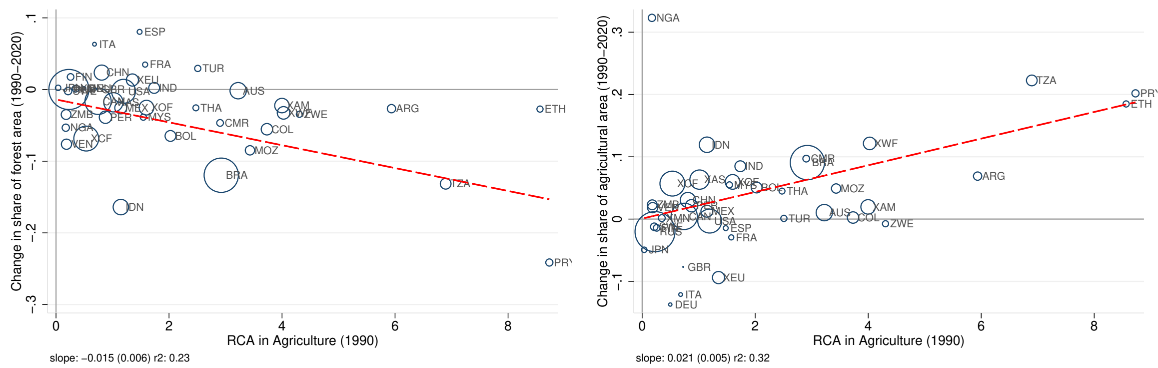


Notes: This figure shows the relationship between changes from 1990 to 2020 in agricultural land use and changes in forest area across countries, each as a share of country area, in percentage changes from 1990 to 2020. The size of circles represents the total forest area in each country. The red dashed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

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.[8] We next turn to two mechanisms driving the demand for agricultural land in a country, namely, agricultural trade and population growth.

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 forest share in country area (Panel a) and agricultural land share in country area (Panel b) against the index of revealed comparative advantage (measured in 1990) across countries.

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 comparative advantage in agriculture. To this end, we employ Balassa's index of revealed comparative advantage for each country i, defined as:

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

i.e., the degree to which a country i's exports specialize in agriculture, relative to the world's 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 was larger between

[8]See in Appendix Figure F.2 the country-level share of land under forest, agriculture, and a residual "fallow land" category that we construct as the difference between country area and the sum of forests and agricultural land (excluding water bodies and other non-productive areas, such as deserts). Fallow land takes as much as fifty percent of the land in Argentina or Australia but less than ten percent in Nigeria or Colombia. Later in the paper, we incorporate data on fallow land in the calibration of our quantitative model.

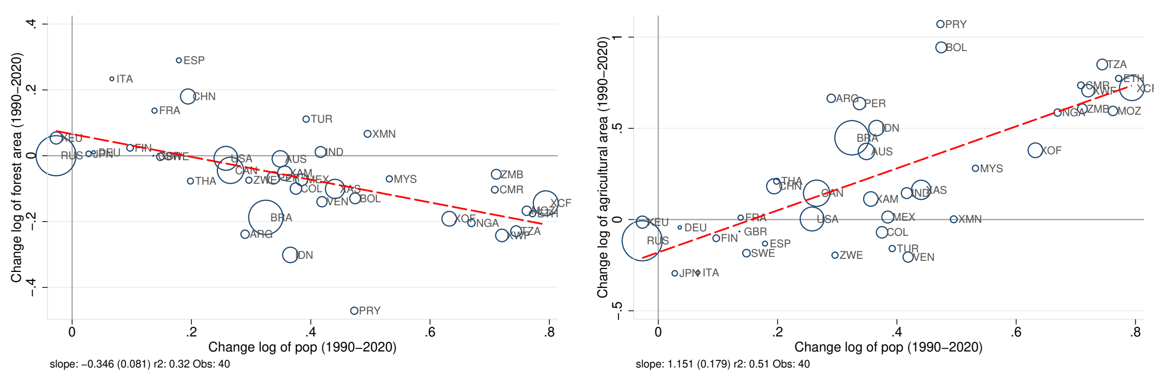
1990 and 2020. This pattern motivates a model in which comparative advantage governs the relative demand for land, and therefore the pressure on forests, across countries.

Pattern 4. Domestic population growth and that of top trading partners leads to agricultural land expansion and deforestation.

Figure 4, Panels (a) and (b) show that population growth in a country is associated with reductions in forest area and increases in agricultural land. In addition, Figure 5, Panels (a) and (b) show that when population grows in a country's top five trade partners, that country's forest area shrinks and its agricultural area expands, as well.

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

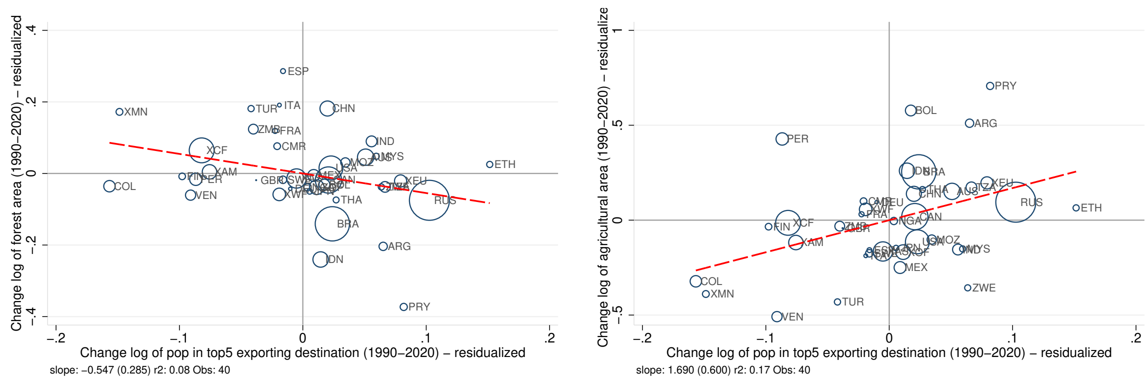
(a) Forest Area (b) Agricultural Area



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

Figure 5: Change in Forest and Agricultural Area and Top Trade Partner's Population Growth

(a) Forest Area (b) Agricultural Area



Notes: This figure shows the 1990-2020 change in log forest area (Panel a) and log agricultural land area (Panel b) against the 1990-2020 change in log population across countries. We residualize the y- and x-axis variables based on the population growth of a country's own population.

To explore this relationship more systematically, we consider the following equation:

$$\Delta \ln y_{i,t} = \beta_0 + \beta_1 s^{\text{Own}}_{i,t-1} \Delta \ln \text{Own Population}_{i,t} + \beta_2 s^{\text{Partner}}_{i,t-1} \Delta \ln \text{Partner Population}_{i,t} + \beta_X \mathbf{X}_{i,t} + \epsilon_{i,t} \quad (1)$$

where $y_{i,t}$ represents either agricultural land or forest area; Own Population$_{i,t}$ and Partner Population$_{i,t}$ measure country i's population and that of its top five trade partners, and $\mathbf{X}_{i,t}$ and $\epsilon_{i,t}$ denote control variables—see description in Table 1—and the error term for country i at time t. The Δ operator denotes 30-year time differences. The coefficients of interest are β_1 and β_2, which capture the impact of domestic population growth and that of country i's top five trade partners on net forest or agricultural land growth. We adjust these variables by the share of agricultural sales of a country to itself $s^{\text{Own}}_{i,t-1}$ and share of sales to top trading partners $s^{\text{Partern}}_{i,t-1}$ in year $t-1$, which is 1990.

An OLS estimation of equation (1) may suffer from endogeneity bias. For example, shocks to agricultural productivity can lead to a change to both population and deforestation, creating a correlation between population growth and the error term. We therefore instrument $\Delta \ln \text{Own Population}_{i,t}$ with the median age of the population, the crude birth rate per 1000 individuals, and the average age for child bearing at time period $t-1$. Likewise, we instrument $\Delta \ln \text{Partner Population}_{i,t}$ with these same three variables in country i's top trading partners.[9] Our identifying assumption is that, conditional on our set of controls (which include GDP per capita and measures of forest area protection) past demographic structure is uncorrelated with current unobserved shocks such as those to productivity, so the instruments predict population growth for purely biological reasons.

Table 1 shows the OLS and IV estimates of equation (1). Overall, Panel (a) reports negative elasticities of forest area to both population variables, for both OLS and IV, without any controls (Columns (1) and (4)), with controls for initial forest and agricultural area (Columns (2) and (5)) and with additional controls for natural areas under reservation and GDP per capita (Columns (3) and (6)). Our specification adjusts the population growth shock by a revenue share, so that the regressors of interest can be interpreted as local and foreign shocks to agricultural demand. Our specification also implies that the elasticity of the dependent variables to population growth is heterogenous across countries. For the average country in the sample, the share of domestic sales in total agricultural sales is 0.85, while the share of sales to its top trading partners is 0.12. Thus, the IV estimate under Column (6) implies that a 10 percent increase in own population growth reduces its forest area by $3.6 \times 0.85 = 3.06$ percent, while a 10 percent increase in the country's trading partners'

[9]To construct the population growth in partner countries, we aggregate the total population across the 5 top trading partners of a country in every year, effectively making it a larger geographic unit. To construct the instruments and controls, we take the average of the these values at $t-1$ across trading partners.

population reduces its forest area by $11.9 \times 0.12 = 1.43$ percent. This comparison shows that the elasticity of forest area to local demand is about twice as large as that in response to foreign demand.

Panel (b) retains the same structure, only placing agricultural area as a dependent variable. Across specifications, the coefficient is positive and statistically significant. For the average country in our sample, the IV estimate in Column (6) indicates that a 10 percent increase in population leads to a $8.8 \times 0.85 = 7.48$ percent increase in agricultural land use, while a 10 percent increase in population of the country's top trading partners leads to a $29.9 \times 0.12 = 3.59$ percent increase in agricultural land use. Once again, we can see that the impact of local demand on local agricultural land is about twice as large as the effect of foreign demand. Appendix Table F.6 shows that our qualitative results are largely the same if we use the full sample of countries.

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

	OLS (1)	OLS (2)	OLS (3)	IV (4)	IV (5)	IV (6)
a. DV is the log of forest area						
$s^{\text{Own}} \times \Delta$ Log(Own Pop)	-0.380***	-0.357***	-0.257*	-0.436***	-0.408***	-0.360*
	(0.072)	(0.065)	(0.151)	(0.095)	(0.084)	(0.197)
$s^{\text{Partner}} \times \Delta$ Log(Partner Pop)	-1.325*	-1.209	-1.030	-1.416**	-1.295*	-1.190*
	(0.727)	(0.742)	(0.766)	(0.708)	(0.711)	(0.721)
R2 or K-P	0.310	0.360	0.403	34.995	32.726	12.313
Obs	40	40	40	40	40	40
b. DV is the log of agricultural area						
$s^{\text{Own}} \times \Delta$ Log(Own Pop)	1.409***	1.368***	1.136***	1.427***	1.375***	0.879***
	(0.106)	(0.111)	(0.225)	(0.107)	(0.102)	(0.297)
$s^{\text{Partner}} \times \Delta$ Log(Partner Pop)	3.809***	3.629***	3.177***	3.864***	3.632***	2.986***
	(0.872)	(0.952)	(0.888)	(0.840)	(0.913)	(0.904)
R2 or K-P	0.746	0.761	0.815	34.995	32.726	12.313
Obs	40	40	40	40	40	40
Controls (Initial period value in logs)						
- Share of Agricultural area	-	Y	Y	-	Y	Y
- Share of Forest area	-	Y	Y	-	Y	Y
- Natural reserve area	-	-	Y	-	-	Y
- GDP p.c.	-	-	Y	-	-	Y

Notes: * / ** / *** denotes significance at the 10 / 5 / 1 percent level. Robust standard errors clustered at the country level in parenthesis. Instrument in columns (4) to (6) are (1) the log of the median age of the population, (2) the birth rate, and (3) the average age of child bearing in the baseline year. Kleinberg-Paap weak instrument statistic is reported in columns (4) to (6) instead of R2.

These results are important for three reasons. First, because the world population is expected to grow by 35 percent between 2020 and 2100, our results are informative about the impact of a shock that looms large in the future. Second, the estimated impact of foreign population growth cements the notion that international trade distributes pressures on land demand across countries. Third, 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 that shift agricultural demand, including those induced by changes in trade costs.

Toward a model of trade and deforestation. In sum, we have established four empirical patterns that motivate a dynamic model of global trade and land use. The pace of deforestation depends, among other forces, on a country's current forest stock (Pattern 1). Deforestation across countries is closely tied to the expansion of agricultural land (Pattern 2). Countries exploit their comparative advantage in agriculture, in part, by deforesting (Pattern 3). Lastly, international trade contributes to deforestation by connecting population dynamics in export markets, as well as domestically, to changes in forest cover (Pattern 4).

We will develop a quantitative model that incorporates these empirical patterns, along with well-established features of global production and trade. While our quantitative model is intended for careful calibration and detailed policy analysis, it is useful to first examine a simplified version. This stylized model deliberately leaves out some of these patterns to explain the core mechanisms that link trade to land use as clearly as possible. In the next section, we introduce this stylized model and derive sharp theoretical results on how trade influences deforestation. After establishing these results, we then present our full quantitative model in Section 6.

4 The Stylized Model

Consider a global economy consisting of multiple countries, indexed by $i, j = 1, ..., I$, and three sectors: agriculture (A), manufacturing (M), and land-clearing (T). Time is continuous and denoted by $t \in [0, \infty)$. Each country i is endowed with (i) a fixed amount of land H_i, which consists of agricultural land, $L_i(t)$, and forest area, $F_i(t)$, such that $H_i = L_i(t) + F_i(t)$, and (ii) a labor force $N_i(t)$, which evolves exogenously over time. Labor is perfectly mobile within each country and immobile between countries. Markets are perfectly competitive. Hereafter we drop the time index with the understanding that all variables may vary over time, and we denote the time derivative of any variable x by $\dot{x}$.

Households. Each country has a representative consumer with a two-tier constant elasticity of substitution (CES) demand. In the lower tier, national varieties of $g = \{A, M\}$ are aggregated with an elasticity of substitution η into a composite bundle of g. In the upper tier, the composite bundles of agriculture (A) and manufacturing (M) are combined into an aggregate consumption bundle, with an elasticity of substitution σ.

The lower tier gives rise to international trade flows in agriculture and manufacturing. Specifically, country j's share of expenditure on origin i's variety of $g = \{A, M\}$ equals:

$$\pi_{ij,g} = \left(\frac{p_{ij,g}}{P_{j,g}}\right)^{1-\eta}, \tag{2}$$

where $p_{ij,g}$ is the price of country i's variety delivered in country j and $P_{j,g}$ is the consumer price of g in country j:

$$P_{j,g} = \left(\sum_{n=1}^{N} p_{nj,g}^{1-\eta}\right)^{1/(1-\eta)} \tag{3}$$

The upper tier, in turn, determines the expenditure across broad sectors in the economy. Specifically, country j's expenditure share on sector $g = \{A, M\}$ is given by:

$$\beta_{j,g} = \left(\frac{P_{j,g}}{P_j}\right)^{1-\sigma}, \tag{4}$$

where P_j is the final consumer price index:

$$P_j = \left(P_{j,A}^{1-\sigma} + P_{j,M}^{1-\sigma}\right)^{\frac{1}{1-\sigma}}. \tag{5}$$

Production. Technologies are given by:

$$Q_{i,A} = Z_{i,A} L_i, \qquad Q_{i,M} = Z_{i,M} N_{i,M}, \qquad Q_{i,T} = Z_{i,T} N_{i,T}, \tag{6}$$

where agriculture uses only land, L_i, while manufacturing and land-clearing use only labor, $N_{i,M}$ and $N_{i,T}$. $Z_{i,A}$, $Z_{i,M}$, and $Z_{i,T}$ are exogenous productivity parameters. In each country, the land-clearing sector converts the forest area into the agricultural land.[10] The products of agriculture and manufacturing can be traded internationally between each origin i and destination j subject to trade costs $\tau_{ij,g} = (1 + t_{ij,g})\, d_{ij,g}$ for each $g = \{A, M\}$, where $t_{ij,g}$ denotes ad valorem import tariff rates charged by country j to country i, and $d_{ij,g} \geq 1$ represents iceberg trade costs for shipping goods from i to j (with $t_{ii,g} = 0$ and $d_{ii,g} = 1$). Consequently, the price of $g = \{A, M\}$ from origin i at destination j equals:

$$p_{ij,A} = \frac{\tau_{ij,A} r_i}{Z_{i,A}}, \qquad p_{ij,M} = \frac{\tau_{ij,M} w_i}{Z_{i,M}}; \tag{7}$$

[10] In the corner case of $F_i = 0$, the production flow of the new land becomes zero, $Q_{i,T} = 0$.

where r_i is the rental rate of land, and w_i is the wage rate in country i. In turn, the price of new land, denoted by q_i, is set domestically in the land-clearing (T) sector,[11]

$$q_i = \frac{w_i}{Z_{i,T}}. \tag{8}$$

Landowners. A continuum of symmetric landowners, who are risk-neutral and have perfect foresight, connect the land-clearing sector to the agricultural sector. Each landowner owns one unit of land that can be rented out at the rate r_i to agricultural producers. Landowners discount the future at a rate of ρ, and each unit of land "depreciates" back into forest at a rate of δ_L. Under these assumptions, the value of a plot to a landowner, v_i^L, can be expressed as:

$$\rho v_i^L = r_i - \delta_L v_i^L + \dot{v}_i^L.$$

Potential entrants purchase new land produced by the T sector when v_i^L is greater than or equal to the price of new land, q_i. We assume free entry into landowning, which ensures that $v_i^L = q_i$. Hence, the price of new land, q_i, satisfies the following asset pricing equation:

$$(\rho + \delta_L)\, q_i = r_i + \dot{q}_i. \tag{9}$$

Solving this equation delivers the price of new land as the present value of future land rents, discounted by $(\rho + \delta_L)$, a rate that accounts for both time preference and forest regrowth.[12]

Finally, agricultural land grows with the inflow of new land converted from forest by the T sector, $Q_{i,T}$, and shrinks with the outflow due to forest regrowth, $\delta_L L_i$,

$$\dot{L}_i = Q_{i,T} - \delta_L L_i. \tag{10}$$

Market clearing. National expenditure in country i, E_i, equals net payments to labor and land plus tariff revenues, T_i:

$$E_i = w_i N_i + (r_i L_i - w_{i,T} N_{i,T}) + T_i,$$

where

$$T_i = \sum_{g \in \{A,M\}} \sum_n \frac{t_{ni,g}}{1 + t_{ni,g}} X_{ni,g}.$$

[11] We write the pricing conditions (7) and (8) under the assumption that both M and T are operational, which will always be true with Armington differentiation.

[12] Specifically, $q_i(t) = \int_t^\infty e^{-(\rho+\delta_L)(s-t)} r_i(s)\, \mathrm{d}s$.

Total payments to land come from sales across the world:

$$r_i L_i = \sum_j \frac{X_{ij,A}}{1 + t_{ij,A}}, \tag{11}$$

and, likewise, for manufacturing labor:

$$w_i N_{i,M} = \sum_j \frac{X_{ij,M}}{1 + t_{ij,M}}. \tag{12}$$

Static Equilibrium. Given (i) technologies, iceberg trade costs, tariffs, and preferences $\{Z_{i,g}, d_{ij,g}, t_{ij,g}, \sigma, \eta\}$, (ii) agricultural land and national labor supplies $\{L_i, N_i\}$, and (iii) the price of new land $\{q_i\}$, a static equilibrium consists of factor rewards $\{w_i, r_i\}$, and labor allocations $\{N_{i,T}, N_{i,M}\}$, such that land markets clear according to equation (11) and labor markets clear according to equations (8) and (12).

Dynamic Equilibrium. Given (i) paths of technologies, iceberg trade costs, tariffs, preferences and national labor supplies, and (ii) initial agricultural land $\{L_i(0)\}$, a dynamic equilibrium consists of the paths of static equilibrium variables as well as price of new land and stock of agricultural land $[\{q_i(t), L_i(t)\}]$ that evolve according to equations (9) and (10).

A Steady-State Equilibrium. A steady-state equilibrium is a dynamic equilibrium in which $\dot{q}_i = \dot{L}_i = 0$.

In Section 6, we extend this stylized model in several ways to bring it to data for quantitative analysis.[13] Before doing so, however, in Section 5 we will use our model to derive four key analytical results under steady-state equilibrium. To that end, we conclude this section by showing how the steady values of the rental rate and total area of agricultural land depend on labor market outcomes. In the steady state, equations (8) and (9) imply that the rental rate of land is proportional to the wage rate through the following relationship:

$$r_i = \frac{(\rho + \delta_L) w_i}{Z_{i,T}}. \tag{13}$$

[13] These extensions include: (i) incorporating a service sector and disaggregating the agricultural sector, (ii) introducing an input-output structure to production technologies, (iii) forward-looking labor decisions with sectoral switching costs, (iv) adding a third category of land, which we refer to as "fallow," and (v) allowing the productivity in the land-clearing sector to depend on the available stock of forest and fallow land. Crucially, we also solve for the entire transitional path when evaluating policy responses.

Furthermore, replacing $Q_{i,T}$ from equation (6) into the steady state version of equation (10) establishes a link between agricultural land area and employment in the land-clearing sector,

$$L_i = \frac{1}{\delta_L} Z_{i,T} N_{i,T}. \tag{14}$$

Equations (13) and (14) arise because the agricultural land is ultimately produced using labor. In this sense, the steady state reflects the long-run outcome of the balance between human-driven, economic incentives to expand agricultural land and the natural tendency of forests to regrow.

5 Analytical Results

Using our stylized model, this section provides four analytical results regarding the impact of trade on deforestation. First, when a small open economy experiences reductions in its export costs, it loses forests. Second, in a world consisting of symmetric countries, a multilateral reduction in iceberg agricultural trade costs results in global forest gain. Third, a global reduction in agricultural tariffs results in global forest gain if (and only if) the initial level of tariffs is sufficiently high. Fourth, in a world consisting of asymmetric economies, trade leads to a global forest gain if comparative and absolute advantage in agriculture align across countries. Appendix B collects the proofs.

Our first proposition clarifies the context in which a conventional intuition—that trade leads to deforestation—can be most clearly understood. To this end, we consider country i as a small open economy á la Alvarez and Lucas (2007).

Proposition 1. *A unilateral reduction in the agricultural export costs of a small open economy i leads to an increase in its stock of land, L_i, governed by:*

$$\frac{\mathrm{d} \ln L_i}{\mathrm{d} \ln d_{i,A}} = \frac{N_{i,M}}{N_i} (1 - \eta) < 0 \quad \textit{for} \quad \eta > 1. \tag{15}$$

The response in the stock of land of the country that experiences reductions in export costs is governed by the elasticity of substitution between domestic and foreign varieties, η. Specifically, the elasticity of derived demand for land coincides with the elasticity of import demand, $(1 - \eta)$. In the empirically relevant case, this elasticity is negative. Consequently, a reduction in export costs in a small open economy leads to deforestation there.

Expanding the scope of policy to the global level, the deforestation impact of multilateral trade cost reductions depends on the sectoral demand elasticity $(1-\sigma)$ rather than the import demand elasticity, $(1-\eta)$. To illustrate this point, suppose that all countries in the world are symmetric, in the sense that they have the same endowments, geography and productivity, and that there are no tariffs. Under symmetry, we can drop the country indicator i:

Proposition 2. *A global reduction in agricultural trade costs in a system of symmetric economies leads to a decrease in the global stock of land, governed by:*

$$\frac{\mathrm{d}\log L}{\mathrm{d}\log d_A} = \frac{N_M}{N}\left(1-\sigma\right)\left(1-\pi_A^D\right) > 0 \quad \textit{for} \quad \sigma < 1; \tag{16}$$

where π_A^D is the domestic expenditure share in the agricultural sector.

Here, the response of the land stock is governed by the elasticity of substitution between agriculture and manufacturing sectors, σ. In the empirically relevant case, agriculture and manufacturing are complements, i.e. $\sigma \in (0,1)$, and so, a multilateral 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 land clearing. In other words, at the global level, because demand for land is sufficiently inelastic, the productivity gains from trade cost reductions lead to land savings.

This result highlights one of the key mechanisms in the model—that at the global scale, the pressure on land is governed by the sectoral demand elasticity. The result relies, however, on the assumption of iceberg trade costs, so that payments for agricultural trade costs are fully received by farmers, and as a result, entirely allocated to land. Because a reduction in iceberg-type agricultural trade costs is an export-biased productivity gain, it can reduce land use beyond its impact on the land content of agricultural consumption.

The response of forests to iceberg trade costs is useful as a baseline, but does not speak to the impacts of changes in trade policy. Revisiting Proposition 1 with tariffs instead of iceberg trade costs requires replacing $(1-\eta)$ with $(-\eta)$ in equation (15), yielding the same conclusion that the country experiencing reductions in export barriers would lose forests. Revisiting Proposition 2 yields a more nuanced outcome. The next result provides conditions under which a global tariff reduction leads to either forest gain or loss.

Proposition 3. *Consider a worldwide change in agricultural (ad valorem) import tariffs in a system of symmetric economies. As a result:*

(i) The global stock of land changes according to:

$$\frac{\mathrm{d}\ln L}{\mathrm{d}\ln(1+t_A)} = \frac{N_M}{N}\left[\underbrace{\left(1-\sigma\right)\left(1-\pi_A^D\right)}_{(+)\ \textit{if}\ \sigma<1} + \underbrace{\left(\eta-1\right)\left(s_A^D-\pi_A^D\right)}_{(+)\ \textit{if}\ \eta>1} + \underbrace{\left[-\left(1-s_A^D\right)\right]}_{(-)}\right], \tag{17}$$

where s_A^D is the fraction of farmers' revenue that comes from domestic demand.

(ii) Provided that $\eta > \sigma$, the global stock of land is an increasing function of tariffs when tariffs are sufficiently low, $t_A \in [0, t_A^*)$. Conversely, it is a decreasing function of tariffs when tariffs are sufficiently high, $t_A \in (t_A^*, \infty)$. The critical tariff rate, t_A^*, satisfies:

$$t_A^* \pi_A^D (t_A^*) = \frac{\sigma}{\eta - \sigma}, \qquad \text{with} \qquad \pi_A^D (t_A) = \left[(I-1)\left(d_A (1+t_A)\right)^{1-\eta} + 1 \right]^{-1}$$

Proposition 3 introduces two new terms to equation (16), both related to changes in the share of expenditure in agriculture that is ultimately received by farmers, net of tariffs. Specifically, from each dollar spent on agriculture, the fraction collected as tariffs equals $h_A = \frac{t_A}{1+t_A}\left(1 - \pi_A^D\right)$, while the remaining share, $(1 - h_A)$, is received by farmers—i.e., the "pass-through" rate to farmers and ultimately to land. Of each dollar received by farmers, the share coming from domestic consumers is $s_A^D = \frac{\pi_A^D}{1-h_A}$, which, by construction, is larger than the domestic expenditure share, π_A^D, as long as $t_A > 0$.[14]

The pass-through rate, $(1 - h_A)$, changes for two reasons. First, holding fixed $\frac{t_A}{1+t_A}$, a higher tariff shifts agricultural demand from foreign to domestic varieties, thereby raising the pass-through to farmers. This effect corresponds to $(\eta - 1)\left(s_A^D - \pi_A^D\right)$ in equation (17), which is positive for $\eta > 0$. Second, holding fixed the imported expenditure share, $\left(1 - \pi_A^D\right)$, a higher tariff increases the fraction collected by the governments, $\frac{t_A}{1+t_A}$, lowering the pass-through rate. This effect corresponds to $\left(1 - s_A^D\right)$ in equation (17), which captures the share of farmers' revenue dependent on foreign demand. Proposition 3 shows that the stock of land has a U-shaped relationship with respect to the agricultural tariff. Specifically, a multilateral agricultural trade liberalization saves land—that is, the first two terms outweigh the last term in equation (17)—if and only if agricultural trade is sufficiently protected by tariffs.

Propositions 2 and 3 assume symmetric countries to highlight how structural change shapes the impact of trade costs on deforestation. In an asymmetric world, countries specialize according to their comparative advantage. Trade liberalization, therefore, can lead these countries to expand their agricultural frontier, which may reinforce or mitigate the above results. 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 are otherwise identical. In addition, we shut down the mechanism behind Proposition 2 by assuming that the elasticity of substitution between agriculture and manufacturing equals one ($\sigma = 1$) and

[14] For instance, suppose from one dollar spent on agriculture, 60 cents are purchased domestically (setting $\pi_A^D = 0.60$) and the remaining 40 cents are imported at a tariff rate of 25%. The amount collected as tariffs equals 8 cents ($h_A = \frac{0.25}{1.25} \times 40$). Out of the remaining 92 cents, the share coming from domestic sales equals 0.65 ($s_A^D = \frac{60}{92}$).

the additional mechanisms behind Proposition 3 by assuming that goods within each sector are homogenous ($\eta \to \infty$). Without loss of generality, we order countries in decreasing order of comparative advantage in agriculture, i.e. $Z_{i,A}/Z_{i,M}$ decreases with i.

Proposition 4. *(Comparative and absolute advantage) Suppose goods within each sector are homogeneous and preferences are Cobb-Douglas (i.e., $\eta \to \infty$ and $\sigma = 1$). A reduction of trade costs that brings the world economy from autarky to free trade has the following consequences.*

(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) Comparative and absolute advantage in agriculture are aligned: If $Z_{i,M}$ decreases in i, so does $Z_{i,A}$ (as implied by our assumption that $Z_{i,A}/Z_{i,M}$ is decreasing in the country index i), meaning that comparative and absolute advantage align in agriculture but not in manufacturing. In this case, global forest area expands when moving to free trade.

(iii) Comparative and absolute advantage in agriculture are not aligned: If $Z_{i,A}$ increases in i, so does $Z_{i,M}$, meaning comparative and absolute advantage align in manufacturing but not in agriculture. In this case, global forest area shrinks when moving to free trade.

Proposition 4 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 global land use. In particular, when countries whose comparative advantage lies in agriculture also have an absolute advantage in agriculture (and an absolute disadvantage in manufacturing), agricultural production is undertaken by the most efficient agricultural producers in the free-trade equilibrium. This specialization pattern makes free trade a land-saving policy.

Relation to Borlaug's Hypothesis. The above four propositions extend to an international setting the famed hypothesis put forward by Borlaug (2000), namely, that agricultural productivity growth in a closed economy protects forests because the demand for food is inelastic, and so is the derived demand for land. Our results show that international trade can also act as a technological improvement that leads to a lower global demand for land, whether through reductions in trade costs—modeled as export-biased productivity increases or tariff reductions—or through efficiency gains brought about by alignment between comparative and absolute advantage.

Toward a Quantitative Analysis. Propositions 1 through 4 highlight two key considerations for the impact of trade on deforestation. First, Propositions 1 and 2 show that the effect of agricultural trade policy on deforestation depends on the geographic scope of the analysis. Second, when the scope is global, Propositions 3 and 4 indicate that agricultural trade liberalization can lead to either forest gain or loss—depending, in Proposition 3, on the degree of protection in agricultural trade, and in Proposition 4, on whether countries with a comparative advantage in agriculture also possess an absolute advantage. Taken together, these propositions do not provide a definite answer, but rather clarify the conditions under which trade leads to forest loss or gain. We now take these insights to a quantitative model, which incorporates incorporates quantitatively important features of reality and which we calibrate carefully to data, to study the effects of trade on deforestation. We will return to the above propositions when interpreting our quantitative results.

6 The Quantitative Model

Our quantitative model extends the stylized model of Section 4 in five important dimensions, as outlined below. Appendix C presents the Quantitative Model in detail.

First, we incorporate a more detailed set of industries, denoted by g, consisting of a manufacturing industry, a service industry, and multiple agricultural industries, each differentiated into varieties by country of origin. Demand is structured in three CES tiers: the lower tier aggregates national varieties of each industry g with substitution elasticity η_g; the middle tier combines the agricultural industries into an agricultural composite with substitution elasticity κ; and the upper tier aggregates the composites of agriculture, manufacturing, and services into final consumption with substitution elasticity σ.

Second, we incorporate labor, land and intermediate input use into Cobb-Douglas production technologies for each good g,

$$Q_{i,g} = Z_{i,g} \left(N_{i,g}^{\gamma_{i,g}} L_{i,g}^{1-\gamma_{i,g}} \right)^{\alpha_{i,g}} (M_{i,g})^{1-\alpha_{i,g}} ,$$

where $Z_{i,g}$ is total factor productivity, $N_{i,g}$, $L_{i,g}$, and $M_{i,g}$ are, respectively, the use of labor, land, and intermediate inputs. The latter is in turn an aggregate over all industries using a tiered CES structure similar to that of final consumption, but with factor intensities specific to each using industry g. The parameter $\alpha_{i,g}$ measures the value added share, which is further divided between land and labor with shares $\gamma_{i,g}$ and $(1 - \gamma_{i,g})$.

Third, we include an additional category of land, which we refer to as "fallow land". Specifically, the cleared land L_i is divided into *usable* land U_i and *fallow* land O_i, such that

$L_i = U_i + O_i$ (and, as before, the country's total area consists of cleared land and forests, $H_i = L_i + F_i$). Accordingly, the usable land may depreciate to both forest area and fallow land.

Fourth, we allow the productivity in the land-clearing sector to depend on the available stock of forest and fallow land. Specifically, let z_i denote the share of cleared land in total country area, $z_i \equiv L_i/H_i$, and $u_i \equiv U_i/L_i$ be the share of usable land within cleared land. Usable land is generated by converting forest (F) and fallow land (O) employing labor as an input. The corresponding production technologies are expressed as:

$$Q_{i,T}^{FU} = \underbrace{\zeta_{i,F}\left(1 - z_i\right)^{\lambda}}_{\equiv J_i(z_i)} \left(N_{i,T}^{FU}\right)^{\gamma_F}, \qquad Q_{i,T}^{OU} = \underbrace{\zeta_{i,O}\left(z_i\left(1 - u_i\right)\right)^{\lambda}}_{\equiv \tilde{J}_i(z_i(1-u_i))} \left(N_{i,T}^{OU}\right)^{\gamma_O}, \tag{18}$$

where $Q_{i,T}^{FU}$ and $Q_{i,T}^{OU}$ denote the usable land produced from forests and fallow land, and $N_{i,T}^{FU}$ and $N_{i,T}^{OU}$ denote the corresponding input uses. Total production and employment of the land-clearing sector are given by:

$$Q_{i,T} = Q_{i,T}^{FU} + Q_{i,T}^{OU}, \qquad N_{i,T} = N_{i,T}^{FU} + N_{i,T}^{OU}.$$

In our specification, $J_i(\cdot)$ and $\tilde{J}_i(\cdot)$ represent the productivity of converting forest and fallow land into usable land, and $\{\gamma_F, \gamma_O\}$ denote the output elasticities with respect to labor. Furthermore, $\{\zeta_{i,F}, \zeta_{i,O}\}$ are exogenous parameters and λ is the elasticity of productivity $J_i(.)$ and $\tilde{J}_i(.)$ with respect to the available stock of forest and fallow land. The productivity $J_i(.)$ is a decreasing function, reflecting the rising cost of deforestation as a shorthand for stricter policies, terrain variability, or greater distances to markets. This property introduces convexity into the cost function, meaning that within each country, the marginal cost of deforestation is not equal to the average cost. Moreover, $J_i(1) = 0$ as no new land can be produced from forest if the entire forest is depleted. Similar properties apply to the productivity function $\tilde{J}_i(\cdot)$. The representative land-clearing producer treats these productivities as fixed and does not internalize the effects of its production decisions on them.[15]

Fifth, we introduce forward-looking workers à la Artuç et al. (2010) and Caliendo et al. (2019). Workers can switch between agriculture, manufacturing, services, and the land-clearing sector, conditional on receiving a move opportunity (which arrive with intensity ψ). Upon receiving an opportunity, they draw preference shocks from a Type-I extreme value distribution, with dispersion parameter ν, and decide whether to move from sector s to s',

[15] Our specification is rooted in the literature on renewables, e.g., Brander and Taylor (1997), who assume $Q_{i,T} \propto (1 - z_i) N_{i,T}$. This corresponds to a special case of our specification where $J_i(z_i) = 1 - z_i$ and $\gamma_F = 1$, and the category of fallow land is assumed away.

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
Elast. of substitution between goods	$\sigma = \sigma^I = 0.5$, $\kappa = \kappa^I = 3$	Comin et al. (2021), Costinot et al. (2016)
Trade elasticity	$\eta = 5$	Simonovska and Waugh (2014)
Trade costs and productivity	$d_{ij,g}, Z_{i,g}$	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	5.0%	Brazil's data (Mapbiomas)
	$\zeta_{i,F}$	L_i and F_i in 2010 to be at SS
$Q^{FU}_{i,T} = \zeta_{i,F}\left(1 - z_i\right)^{\lambda}\left(N^{FU}_{i,T}\right)^{\gamma_F}$	$\lambda = 0.9$	Population and deforestation reg.
	$\gamma_F = 0.95$	Population and deforestation reg.
	$\zeta_{i,O}$	L_i and F_i in 2010 to be at SS
$Q^{OU}_{i,T} = \zeta_{i,O}\left(\left(1 - u_i\right) z_i\right)^{\lambda}\left(N^{OU}_{i,T}\right)^{\gamma_O}$	$\lambda = 0.9$	Population and deforestation reg.
	$\gamma_O = 0.9$	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
Discount rate, ρ	0.05	
T1EV dispersion for labor	$\nu = 0.5$	Artuc et al. (2010) in SS
Arrival rates	$\psi = 1$	–

incurring a moving cost $f^N_{i,ss'}$.

7 Taking the Model to Data

This section explains how we calibrate our model calibration and bring it to data. We disaggregate the world into the 40 countries or regional aggregates, as described in Section 3. We calibrate our model parameters in three steps. First, we calibrate the parameters related to the static equilibrium using data circa 2010. 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 (which we presented as motivation in Section 3). We next explain each step. Table 2 summarizes our calibrated parameters.

7.1 Calibration of static equilibrium

In this first 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 $\kappa = \kappa^I = 3$, following Costinot et al. (2016). For the cost share parameters, we use GTAP database 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 land share of urban areas (available from FAOSTAT).

Then, taking GTAP database from 2014 on international trade flows, gross output by industry and input-output matrices, we apply standard inversion methods to back out productivity shifters $\{Z_{i,g}\}$, and demand shifters, given trade costs $\{\tau_{ij,g}\}$, which we explain how we parameterize next.

Trade Costs. The contrast between Propositions 2 and 3 motivates us to distinguish between policy and non-policy components of trade costs. Specifically, we express trade costs $\tau_{ij,g}$ as:

$$\tau_{ij,g} = \tau_{ij,g}^{\text{(non-policy)}} \times \tau_{ij,g}^{\text{(policy)}},$$

where tariffs are included in the policy component, $\tau_{ij,g}^{\text{(policy)}}$, and other barriers, such as distance, are included in the non-policy component, $\tau_{ij,g}^{\text{(non-policy)}}$. In the agriculture sector, due to the widespread use of specific tariffs and the frequent occurrence of missing tariff entries in standard data sources, reported ad valorem tariff rates are not reliable indicators of effective ad valorem tariff levels (Teti, 2024; Bouët et al., 2008). For this reason, we adopt a gravity estimation approach, similar to Nath (2025), to estimate the policy component of trade costs. Specifically, we regress our calibrated trade costs $\tau_{ij,g}$ on observable policy variables, such as tariff rates, free trade agreements, and import fees to isolate $\tau_{ij,g}^{\text{(policy)}}$. We then bring in data on the ratio of tariff revenues to imports to pin down the level of effective ad valorem tariff equivalents, which result in an unweighted average of 13%. See Appendix D.1 for details.

7.2 Calibration of labor dynamics

In this second step, we set the sectoral labor supply elasticity at $1/\nu = 2$ and the labor mobility costs, $f_{ss'}^N = f^N$, in line with previous work on labor mobility.[16] We also set arrival

[16] Caliendo et al. (2019) report that the yearly equivalent of their labor elasticity equals our choice of $1/\nu = 2$. For the 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.

rates of move opportunities ψ to 1.[17]

7.3 Calibration of the land dynamics

The land dynamics module is the new component that we integrate into the standard modules of production, trade, and labor mobility. Motivated by Pattern 4, we choose parameters so that the model can replicate the empirical relations between population growth, land use, and deforestation.

In the third and final step, our calibration of the parameters in the land-producing sector follows a nested approach. In the inner nest, given values of the elasticities $\{\lambda, \gamma_F, \gamma_O\}$, we recover the productivity shifters $\{\zeta_{i,F}, \zeta_{i,O}\}$ that ensure that the model's steady state values of agricultural land, fallow land, and forest area match their observed values in the initial year of our sample. In the outer nest, in the spirit of indirect inference, we search for the values of the elasticities $\{\lambda, \gamma_F, \gamma_O\}$ so that our model mimics the reduced-form dynamic responses of deforestation and land use to population shocks.

Specifically, after recovering $\{\zeta_{i,F}, \zeta_{i,O}\}$, (i) we shock the model with 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) in Empirical Pattern 4 but exploiting the timing of the impact of the population shock:

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

where we choose $t = \{2000, 2010, 2020\}$ allowing for the dependent variables to vary at 10, 20, and 30 year horizons, and $y_{i,t}$ is either forest area or agricultural land area. The different coefficients β_t^y across time horizons t allow us to capture the total response of agricultural land and forests to the shock, as well as how quickly this response unfolds. The distinction between the two allows us to separate $\{\gamma_F, \gamma_O\}$ from λ.

Stacking all the coefficients $\{\beta_t^y\}_{t,y}$ in a vector β, we search for values of $\{\lambda, \gamma_F, \gamma_O\}$ to minimize

$$\left(\beta^{(\text{data})} - \beta^{(\text{model})}\right)^\top \left(\beta^{(\text{data})} - \beta^{(\text{model})}\right),$$

where $\beta^{(\text{data})}$ is the vector of parameters estimated using the actual data, and $\beta^{(\text{model})}$ is the vector of parameters estimated using model-generated data.

[17] Our calibration approach imposes that the stock of cleared land in the initial year equals its steady-state value in the absence of any changes in fundamentals. The stock of workers in each sector, however, is not constrained and does evolve from the starting point to the steady state. Appendix Figure F.9 documents this aspect of our calibration.

Our procedure separately pins down the three above elasticity parameters. First, in the data fallow land accounts for a sizable share of a country area, and it is a source of expansion of agricultural land (recall Appendix Figure F.2). Therefore, in response to population growth, agricultural land may expand partly at the expense of forests and partly by converting fallow land. This distinction separately identifies the parameters that govern the expansion from forest, γ_F, from those that control the expansion from fallow land, γ_O. Second, our regressions reveal that land expansions respond differently at various time horizons to a 30-year change in population, capturing the persistence built into the land conversion function via $J_i(.)$ and $\tilde{J}_i(.)$. This variation helps us pin down the labor elasticities separately from the initial condition elasticity, i.e., λ. Higher labor elasticities scale up the overall deforestation responses, whereas higher area elasticities, λ, reduce future land-clearing productivity, and makes short-run responses relatively larger.[18]

7.4 Model validation

Before moving on to the quantitative analysis, we briefly discuss four exercises that validate the performance of our model. First, we show that the fallow land module is essential to match the reduced-form evidence on the impact of population on agricultural land. Without fallow land as an additional source of agricultural land expansion, the model substantially underestimates the response of cleared land to population growth (Appendix Figure F.6).

Second, although our calibration only targets the impact of own population growth, the model closely reproduces the reduced-form impact of foreign population growth, as documented in Pattern 4 (Appendix Table F.8). This finding means that the role of international trade as a transmission mechanism of land pressures across countries—a central mechanism in our paper—is aligned in the quantitative model and our reduced-form results.

Third, the calibrated values of the forest conversion productivity shifters, $\zeta_{i,F}$, effectively capture cross-country variation in institutional regulations that protect forests (Appendix Figure F.7). That is, in the absence of a richer formulation of institutional differences across countries, the calibrated values of productivity of land-clearing sector reflect real-world differences in the ease to deforest.

Fourth, the model-implied yields correlate well with actual data on yields, which we do not use in calibration (Appendix Figure F.8). This means that our calibrated model captures actual cross-country differences in the productivity and land intensity of agriculture, a sector that is key to studying deforestation.

[18] Appendix Figures F.4 and F.5 show the objective function as a function of γ_O, γ_F and λ. They indicate a clear local minimum.

Overall, our calibrated model replicates key features of the data (including several untargeted moments) on trade, land productivity, forest protection, and deforestation dynamics, making it a useful laboratory to study the impact of trade barriers on forests.

8 Counterfactual Policy Analysis

In this section, we examine the quantitative consequences of reducing agricultural trade barriers on land use and deforestation around the world. We focus on scenarios that eliminate agricultural import tariffs, as such scenarios are rooted in policy considerations.[19] We present results, first, starting from a baseline without population growth, and then incorporate population growth forecasts up to the year 2100. We conclude by evaluating the welfare gains from agricultural trade liberalization net of the climate costs of deforestation.

8.1 Removing agricultural import tariffs

We conduct two counterfactual policy scenarios, both of them involving the elimination of agricultural tariffs.

Counterfactual Scenario 1. We consider what would happen if every country removed its import tariffs only on agricultural products coming from Brazil.

Counterfactual Scenario 2. We examine the impact of removing all agricultural import tariffs globally.

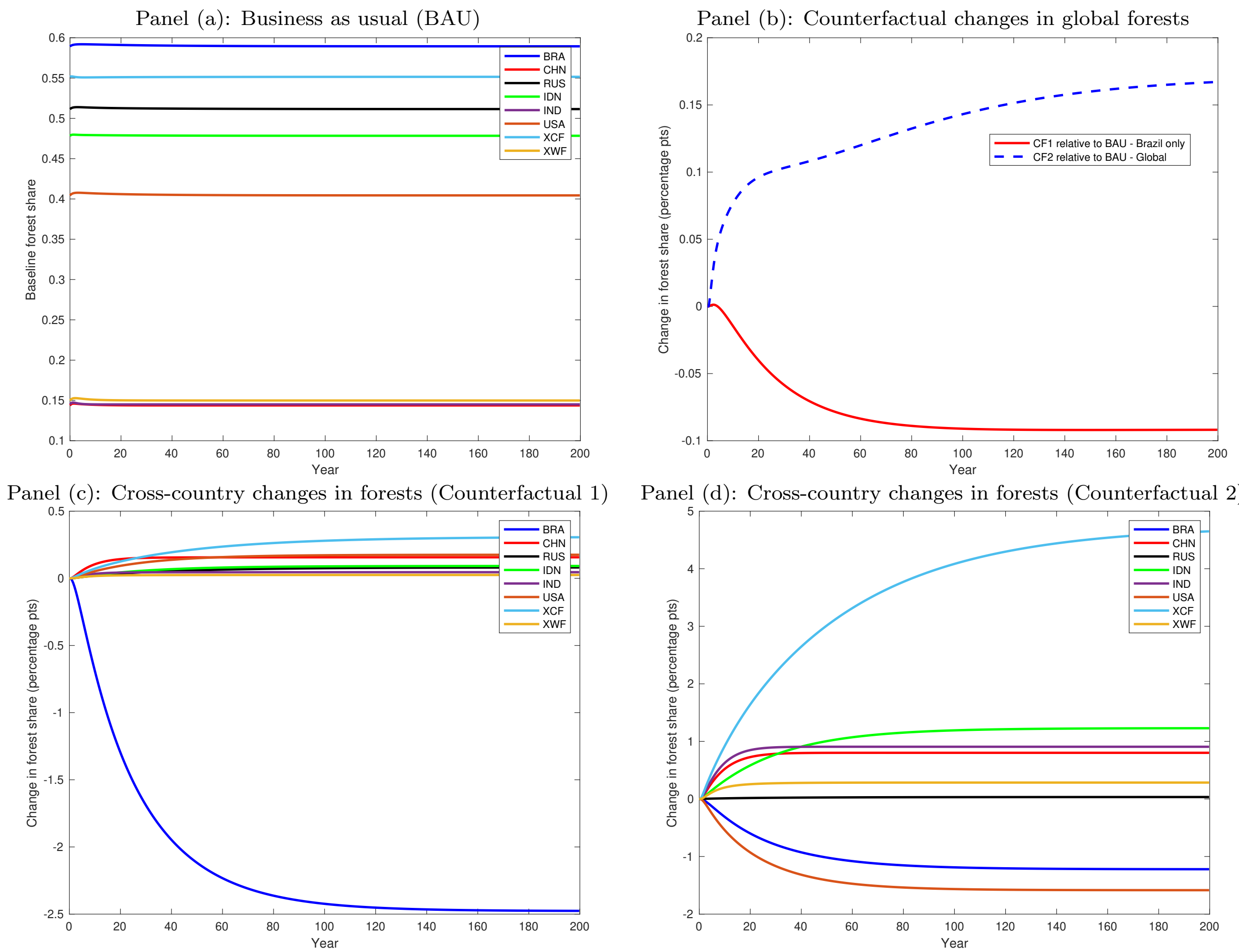
These two scenarios are important in their own right, as they illustrate different ways trade liberalization could take place in agricultural markets. Scenario 1 examines unilateral integration for a country like Brazil, a global leader in agricultural exports and home to vast rainforests. Scenario 2 reflects the outcome of a multilateral agreement, with all countries reducing their agricultural tariffs. The different geographic scopes of the two scenarios—local in Scenario 1, global in Scenario 2—also highlight the quantitative importance of general equilibrium adjustments, via structural change and comparative advantage, as fleshed out in Propositions 1 through 4.

8.1.1 The path of forests

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 change or any other

[19] For comparison, we also report the effects of lowering iceberg trade costs in in Appendix E.

Figure 6: Multilateral vs Unilateral Tariff Elimination: Change in Forest Area Relative to Baseline (Global and Selected Countries)



Notes: Panel (b), (c) and (d) shows at time t the difference in forest share in the counterfactual relative to BAU shown in Panel (a). XCF and XWF stand for the aggregate regions in Central Africa and the rest of West Africa. See Table F.1 for the mapping of individual countries to aggregate regions.

shock is introduced. Panel (a) in Figure 6 shows this path for select countries. As a consequence of our approach to calibration, the land frontier remains almost constant across countries and globally.[20]

Figure 6 displays the percentage point changes in forest share relative to the BAU, both at the level of the world and for select countries. As shown in Panel (b), removing tariffs only on Brazilian agricultural exports leads to a reduction in global forest area. In contrast, eliminating agricultural tariffs worldwide results in an expansion of global forest area.

Recall from Proposition 3 that a global reduction in tariffs has an ambiguous effect on global forest area. Our quantitative findings show that the land-saving forces, primarily driven by structural change, dominate the negative, direct effect of tariff reductions on forest area.[21]

Panels (c) and (d) show the heterogeneous responses of forests in a selected set of countries. In Scenario 1 (Brazil only), the forest area falls sharply in Brazil whereas it increases elsewhere. The forest loss in Brazil amounts to 1 p.p. after 14 years, 2 p.p. after 42 years, and 2.5 p.p. at the steady state—the reduction in tariff equals 8.6 p.p. An important benefit of our global and dynamic perspective is that it is well-suited to capture leakage effects. The steady-state forest-leakage, i.e., the long-run forest gain in the rest of the world for each unit of forest loss in Brazil, equals about 50 percent (see Appendix Figure F.12). This response comes about because Brazil displaces other countries in agricultural markets, and the optimal response of these countries is to devote less resources to agriculture. Leakage is larger in the short run, as Brazil cannot immediately reallocate workers to land-clearing in response to the shock.

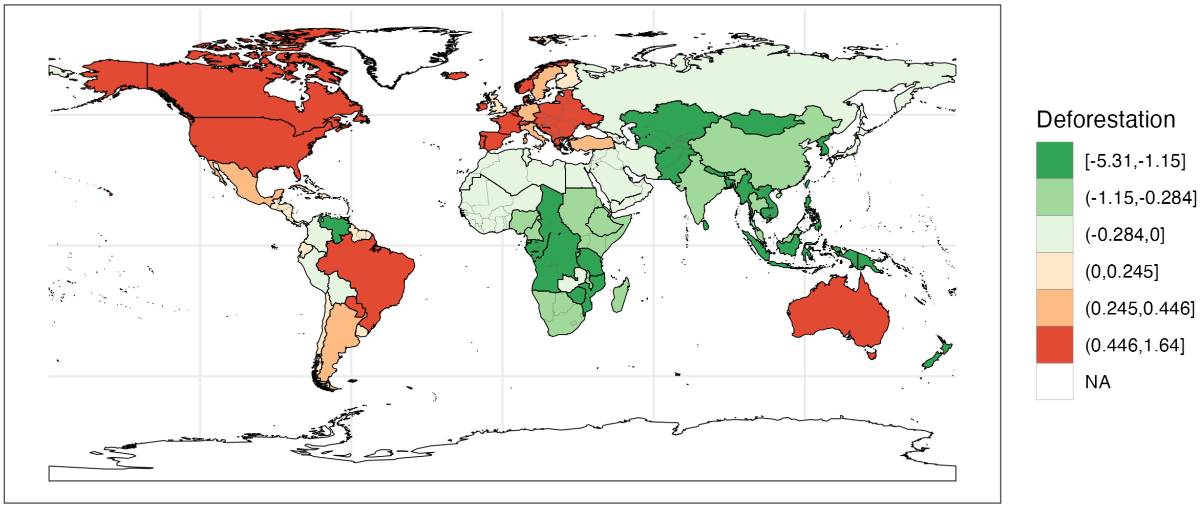
Panel (d) reports analogous results for Scenario 2 (multilateral tariff liberalization). The forest area expands in Central Africa (labeled as "XCF") and South East Asia, whereas North America and Brazil experience relatively large rates of deforestation. Although structural change leads to aggregate reforestation, countries that have a comparative advantage in agriculture or that are geographically well positioned to serve economies that specialize in non-agriculture, take advantage of the tariff reduction by expanding their agricultural sector at the expense of their forests.

To illustrate the geography of deforestation in response to multilateral agricultural tariff removals, Figure 7 shows the steady-state changes in forest area (as a share of country area)

[20] 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.

[21] Analogous reductions in iceberg trade costs, instead of import tariffs, result in a larger increase in global forest area (see Appendix E). This quantitative finding is consistent with Propositions 2 and 3, which highlight the attenuating effect of tariff reductions compared to iceberg trade cost reductions.

Figure 7: The Impact of Eliminating Tariffs on Forests Across the World



Notes: This figure shows the changes in forest area in the steady state following a multilateral reduction in global agricultural tariffs. Bold lines indicate the 40 regions analyzed in the paper, while thinner lines denote country-level boundaries.

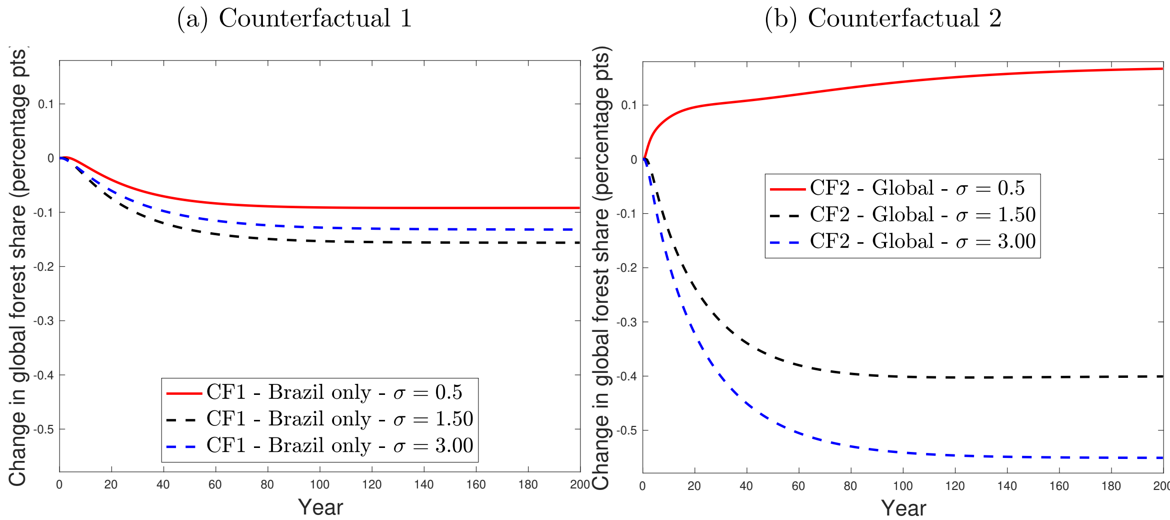
on a global map. Forest area increases in all tropical countries except Brazil, which has a particularly strong comparative advantage in agriculture. For a similar reason, boreal forests tend to experience significant forest loss. This pattern stands in sharp contrast to the actual deforestation of recent decades, which was widespread across tropical countries and less prevalent in boreal regions.

8.1.2 The roles of structural change and comparative advantage

We examine the quantitative importance of structural change and comparative advantage as adjustment mechanisms in response to the multilateral trade liberalization of agriculture. To do so, we focus on Scenario 2, whose global scope makes it an ideal lab to study these general-equilibrium mechanisms.

Structural Change To illustrate the contribution of structural change, in Figure 8 we display the counterfactual path of forests under three values of the sectoral elasticity of substitution, $\sigma \in \{0.5, 1.5, 3.0\}$. Increasing σ limits the scope of structural change for reducing land demand, by muting the complementarity and turning it into higher substitutability between the agricultural and non-agricultural sectors. A larger value of σ reverts the path of global forest area in Scenario 2 but does not qualitatively change that of Scenario 1. These quantitative results show that the relevant elasticity of demand for agricultural goods depends on the geographic scope of trade-cost shock. For an individual exporter, demand is elastic due to trade, and largely unrelated to structural change; but in the global economy, demand is largely inelastic, precisely due to structural change.

Figure 8: The Role of the Sectoral Elasticity of Substitution, σ



Notes: This figure reports counterfactual changes in forest share across alternative values of the sectoral elasticity of substitution. Panel (a) displays the change in global forest share under Scenario 1, whereas Panel (b) presents the change in global forest share under Scenario 2. In both panels, changes are expressed in percentage points.

Comparative Advantage To explore quantitatively the role of comparative advantage, Figure 9, Panel (a) relates the comparative advantage in agriculture relative to manufacturing as measured in the model (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 clear their forests.

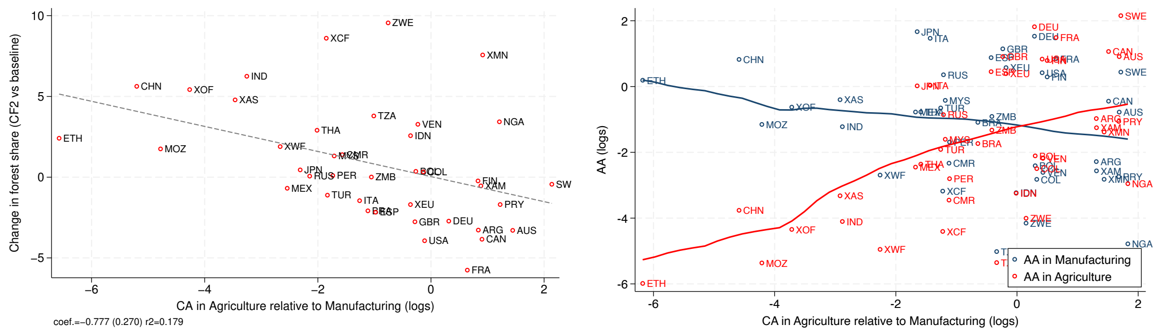
In addition, Figure 9, Panel (b) shows that across countries relative productivity in agriculture, $Z_{i,A}/Z_{i,M}$, is positively correlated with absolute agricultural productivity, $Z_{i,A}$, while it is only weakly correlated with absolute manufacturing productivity, $Z_{i,M}$, (both recovered via model inversion), which means that trade reallocates agricultural production to the most efficient agricultural producers. Through the lens of Proposition 4, the figure suggests that expanding agricultural trade leads to global land savings.[22]

[22]Given our calibrated trade costs, our calibration procedure pins down the set of productivities, $Z_{i,A}$ and $Z_{i,M}$, that make our baseline economy match observed trade flows and production. Altering the distribution of productivities, in an attempt to isolate the role of the absolute advantage channel, would also induce other changes in our baseline economy and prevent us from isolating this channel.

Figure 9: The Role of Comparative Advantage

(a) Deforestation in the cross-section

(b) Absolute and Comparative Advantage in Agriculture



Notes: Panel (a) shows the correlation between the comparative advantage of a country in agriculture (average of implied TFPs across goods) relative to manufacturing and the change in forest area in steady state between BAU and a multilateral reduction in global agricultural tariffs. Panel (b) shows the correlation between comparative and absolute advantage in agriculture, relative to manufacturing.

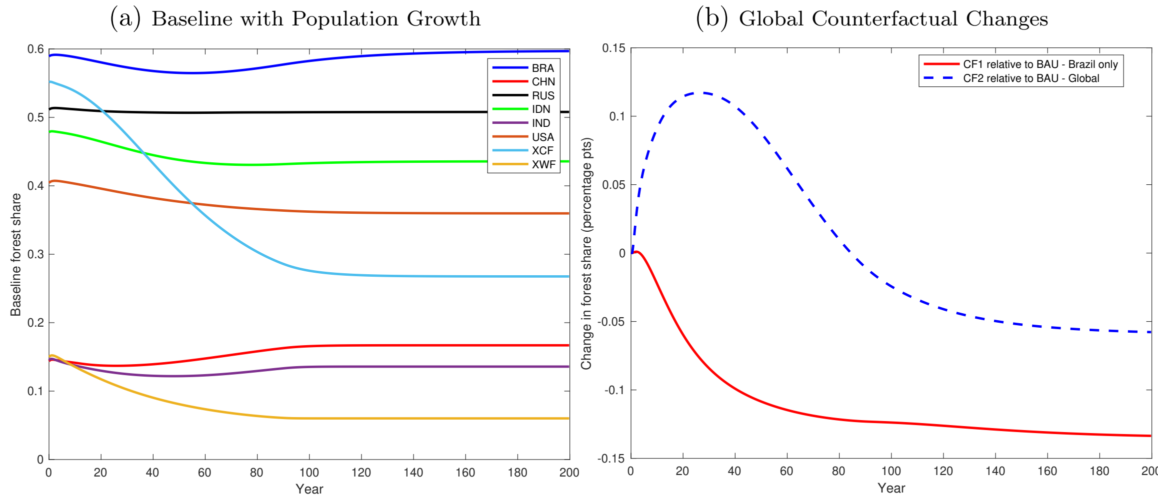
8.2 Incorporating population growth

This section expands our analysis in two directions. First, we examine the impact of population growth on deforestation, by focusing on an alternative business-as-usual scenario that incorporates UN population growth projections until 2100. Average population growth will be large and uneven across countries: The average will be 35 percent, 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. Since population growth, as we discuss below, is a key determinant of pressures on land, understanding this new scenario is important in itself. Second, we reevaluate the scope of trade policy to mitigate deforestation and its associated costs, under this new BAU scenario, showing that although its impact on global forests is small, it induces important reallocation across countries.

Panel (a) of Figure 10 displays our new BAU scenario. There are large increases in the amount of cleared land (and hence, reductions in forest) in countries in which population 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 is then partially reverted as countries with higher population growth develop new land to serve their growing domestic demand for agricultural goods. This is in line with the theoretical predictions of our model, which suggest that population size is one of the key drivers of land stock in equilibrium.[23] Appendix Figure F.13 shows, for our whole sample, that countries

[23]Consider, for example, Appendix equation (B.13), which implies that the elasticity of land stock to population is equal to 1, in the context of a collection of symmetric economies. In our quantitative model, these effects are modulated by the curvature of the function $J(.)$.

Figure 10: The Role of Population Growth



Notes: Panel (a) shows the path of forest share for individual countries under the baseline incorporating population growth. Panel (b) reports the counterfactual changes in global forest share under Scenarios 1 and 2.

with larger population growth experience larger deforestation (steady-state relative to 2010) in the new BAU. Table F.4 in the Appendix reports the corresponding values.

Panel (b) of Figure 10 shows that, relative to this new BAU, our counterfactual scenarios remain qualitatively similar to those without population growth: Global forest area shrinks with the elimination of tariffs faced by Brazil, whereas a global tariff elimination leads to much smaller, albeit slightly positive, global deforestation. That trade policy has limited scope for curbing global deforestation reflects, in part, the larger importance of population growth as a driver of deforestation. Equally important for our results, however, in the multilateral tariff elimination scenario, there is substantial reallocation of land pressure—and, therefore, of reforestation—across countries. As we show below, this reallocation yields a reduction in the deforestation costs of the policy (relative to a scenario without population growth), because on average forests with higher carbon content are protected, even if global forest cover decreases marginally.

Our results show the different impacts on forest area globally and across countries in response to trade costs, highlighting the importance of general-equilibrium forces, such as structural change and comparative advantage. In particular, starting from both our BAU scenarios with and without population, our simulations show that tariff elimination induces substantial reallocation of deforestation across countries (see Figure 6, Panel (d) and Appendix Figure F.11, Panel (b)). Together with the substantial heterogeneity in carbon content of forests we have documented (Appendix Figure F.1), such reallocation suggests that the welfare costs of tariff elimination will depend on the details of which countries end up deforesting more. We turn now to an evaluation of the costs of deforestation, comparing them with the welfare gains of trade liberalization implied in these scenarios.

8.3 Carbon heterogeneity, dynamics, and reforestation

In this section, we evaluate the welfare implications of agricultural trade liberalization. We first consider the climate costs of deforestation resulting from the two policy scenarios presented earlier. This is calculated as the welfare cost of CO_2 emissions released from deforestation, following the IPCC guidelines.[24] Each hectare of forest loss in a country and year results in a corresponding CO_2 emission released to the atmosphere.[25] We assign a monetary value to these emissions at each point in time by applying a social cost of CO_2 of either \$200 or \$350 per ton.[26] We obtain the discounted present value of the stream of these costs using a 5 percent discount rate, and to put them in context, we express them as a fraction of US GDP in 2010. Next, we use these climate costs to compute climate-adjusted welfare gains from agricultural trade liberalization. These gains are calculated as the change in the present discounted value of aggregate real consumption, adjusted for the climate costs of deforestation, at the global level.[27]

Table 3 presents both the climate costs and climate-adjusted welfare gains for the world as a whole, across several specifications. Panels (a) and (b) correspond to Scenarios 1 and 2. In our main specification, the sectoral elasticity σ is set to 0.5. To illustrate the impact of structural change, Panel (c) shows results for Scenario 2 with a higher sectoral elasticity of $\sigma = 1.5$.

As a starting point, Column (1) evaluates the effects of tariff reductions under the assumption of a zero social cost of carbon. This scenario simply elicits the real consumption gains. In Scenario 1, Brazil experiences real consumption gains, but these are more than

[24] 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.

[25] 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.

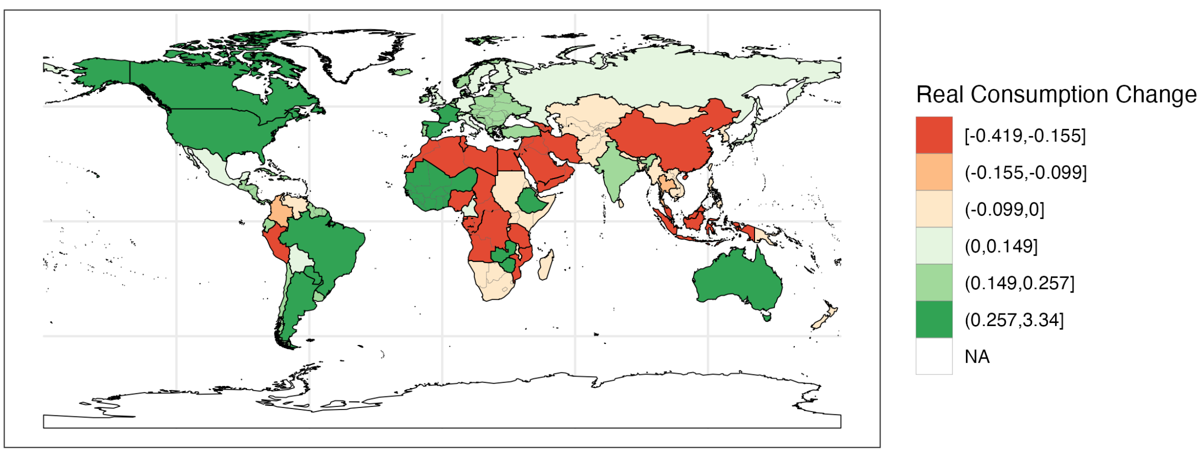
[26] The values of 200 and 350 (\$/tCO2) are consistent with the the latest release of the United States Environmental Protection Agency (EPA)'s Final Report on the Social Cost of Greenhouse Gas.

[27] We specify the global climate-adjusted welfare as $C - \varphi Z$, where C represents world real consumption, Z denotes global emissions, and φ measures the marginal disutility per unit of global emissions. Assuming a constant marginal disutility allows for a simple calibration of the social cost of carbon, and a transparent calculation of climate-adjusted welfare gains for each scenario of deforestation-related changes to emissions. See Appendix D.2 for details.

offset by losses elsewhere, leading to an aggregate loss overall. In Scenario 2, which features multilateral liberalization, real consumption gains around the world outweigh the losses, resulting in an aggregate gain.

Column (2) repeats the analysis, this time applying a social cost of 200 (\$/tCO_2). In both policy scenarios, some countries experience forest loss compared to the business-as-usual (BAU) case, while others see forest regrowth. For countries with regrowth, we make the assumption that there is no carbon sequestration (consistent with Tubiello et al., 2020). Consequently, overall climate costs are positive, even in Scenario 2, which features a modest global increase in forest area. These climate costs amount to about 2 in Scenario 1 and 9 in Scenario 2, as percent of the US GDP in 2010. In Scenario 2, the climate costs are outweighed by the benefits of trade liberalization, resulting in a net positive gain.

Figure 11: Real Consumption Change from Multilateral Agricultural Trade Liberalization



Notes: This figure displays the change in real consumption between the steady state in the BAU scenario versus the counterfactual scenario in which there is a full agricultural trade liberalization.

Figure 11 illustrates that there is significant variation across countries in the welfare gains from eliminating agricultural tariffs. These gains are positively correlated with the extent of deforestation in response to the policy change. This relationship arises because, as a country reduces the size of its agricultural sector, its land stock declines, leading to lower real GDP per worker. Thus, while global tariff elimination increases aggregate real consumption, the gains are unevenly distributed and some countries may still experience losses.

We consider two additional scenarios, both of which suggest that a multilateral liberalization brings larger benefits than climate costs. Column (3) repeats the analysis, by pricing carbon at 350 ($\$/tCO_2$), and shows that the climate-adjusted welfare gains remain positive. Column (4) uses this higher price of carbon in the BAU that includes population growth. Note that the climate costs become smaller now, i.e., in Column (4) relative to (3), even if global forest area decreases (as shown in Figure 10). The reason is that, with population growth, deforestation occurs in the BAU in countries that are relatively forest intensive, such as those in Africa. A multilateral trade liberalization shifts deforestation away from these countries to forests that are on average less dense in carbon content, lowering the overall climate costs. In this new scenario, a multilateral tariff liberalization continues to generate a net positive welfare gain.

Remarks and robustness Although these simulations suggest that, across several scenarios, the net impact of multilateral liberalizations on global welfare is positive, we emphasize that our approach brings broader messages. One of our key messages is the role of general equilibrium forces in determining the impact of deforestation. To shore up this message, we recompute our counterfactual scenarios setting $\sigma = 1.5$, which changes the direction in which structural change operates (See Propositions 2 and 3). Doing so suggests, wrongly, much larger deforestation and associated climate costs in response to multilateral trade liberalizations.[28] We also consider non-homothetic preferences, using the formulation from Comin et al. (2021), and find little change in our quantitative findings. Results are reported in Appendix Table F.13.

A second message is that, given our calibration of the structural change and comparative advantage forces, tariff hikes lead to worse global outcomes, especially when applied broadly. As shown in Appendix Table F.9, Panel B, in our main calibration a 10 fold increase in tariff rates worldwide leads to net welfare losses, across all carbon cost and population growth scenarios.

Third, a general feature of our simulations is that the responses of forests vary across countries, with some of them often regrowing their forests. On the one hand, such heterogeneity suggests that to obtain a full picture of the evaluation of a policy, one must incorporate the responses of all countries involved (as we do in our calculations). On the other hand, it also suggests that the details of the valuation of forests will have a bearing on our final calculations. Following IPCC guidelines, our main specification calculates the costs of deforestation assuming no sequestration, meaning that forest regrowth does not capture carbon from the atmosphere. In a less extreme calibration, in which we assume a 30 percent sequestration, our model suggests even larger gains from a multilateral liberalization

[28]While we report the welfare outcomes for completeness, note that since the elasticity of substitution is different, one cannot compare the welfare outcomes between the two specifications.

(Appendix Table F.10).[29]

Finally, Appendix Table F.12 presents the climate costs and net welfare gains under different assumptions about discount rates, to decompose the importance of dynamics. We measure the climate costs and welfare gains for several horizons truncated at $t \in \{5, 10, 20, 50, 200\}$. The table shows that, because deforestation unfolds over many years, a substantial fraction of the costs and gains from liberalization occur well into the future. For example, the first 5 years after the shock account for only one tenth of the entire present value of the total climate costs associated with global tariff reductions. Even for the first 20 years, only 78 percent of the full costs are realized. These results underscore the importance of properly accounting for the dynamics of land use when measuring the impacts of trade liberalization on forests and, through them, on welfare.

Table 3: Costs and Benefits of Eliminating Agricultural Tariffs

	(1)	(2)	(3)	(4)
Panel A: Brazil				
Climate Costs (as fraction of US GDP)	0.000	1.977	3.460	4.827
Welfare gains (percentual change)	-0.090	-0.100	-0.107	-0.009
Panel B: All countries				
Climate Costs (as fraction of US GDP)	0.000	8.788	15.380	4.535
Welfare gains (percentual change)	0.131	0.086	0.053	0.159
Panel C: All countries ($\sigma = 1.5$)				
Climate Costs (as fraction of US GDP)	0.000	37.456	65.548	67.763
Welfare gains (percentual change)	1.267	1.144	1.052	-0.171
Economic Assumptions				
- SCC = 0	Y	-	-	-
- SCC = 200	-	Y	-	-
- SCC = 350	-	-	Y	Y
- Population Growth	-	-	-	Y

Notes: This table shows the present value of the gains in real GDP and the present value of the costs in terms of carbon emissions of different policy counterfactuals using different assumptions on the costs of carbon emissions from deforestation. Column (1) and (2) compute such gains and costs by comparing the counterfactual scenario with the baseline trajectory of GDP and environmental costs in a scenario with no population growth. Columns (3) and (4) proceeds analogously using the baseline scenario in which there is population growth. To compute costs and gains, we weight countries based on their population.

9 Conclusions

We have developed a framework to study—analytically and quantitatively—the impact of trade policy on deforestation. 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

[29] Specifically, we assume that forest regrowth sequestrate carbon from the atmosphere at a 30 percent rate, which means that, relative to the initial carbon stock per hectare in the data, every hectare of forest recovered absorbs 30 percent of that initial carbon density.

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.

References

Abman, R. and Lundberg, C. (2020). Does free trade increase deforestation? the effects of regional trade agreements. *Journal of the Association of Environmental and Resource Economists*, 7(1):35–72.

Abman, R., Lundberg, C., and Ruta, M. (2024). The effectiveness of environmental provisions in regional trade agreements. *Journal of the European Economic Association*, 22(6):2507–2548.

Alvarez, F. and Lucas, R. J. (2007). General equilibrium analysis of the eaton-kortum model of international trade. *Journal of Monetary Economics*, 54(6):1726–1768.

Araujo, R., Assunção, J., and Bragança, A. (2025a). Transportation infrastructure and deforestation in the amazon. *Journal of Development Economics*, page 103559.

Araujo, R., Costa, F., and SantAnna, M. (2025b). Efficient conservation of the brazilian amazon: Estimates from a dynamic model. *Review of Economic Studies*, page rdaf031.

Artuç, E., Chaudhuri, S., and McLaren, J. (2010). Trade shocks and labor adjustment: A structural empirical approach. *American Economic Review*, 100(3):1008–45.

Asher, S., Garg, T., and Novosad, P. (2020). The ecological impact of transportation infrastructure. *The Economic Journal*, 130(629):1173–1199.

Assunção, J., Gandour, C., Rocha, R., and Rocha, R. (2020). The effect of rural credit on deforestation: evidence from the brazilian amazon. *The Economic Journal*, 130(626):290–330.

Balboni, C. (2025). In harm's way? infrastructure investments and the persistence of coastal cities. *American Economic Review*, 115(1):77–116.

Balboni, C., Burgess, R., and Olken, B. A. (2024). The origins and control of forest fires in the tropics. *Review of Economic Studies*, Forthcoming.

Borlaug, N. (2000). The green revolution revisited and the road ahead. Special 30th Anniversary Lecture, The Norwegian Nobel Institute, Oslo.

Bouët, A., Decreux, Y., Fontagné, L., Jean, S., and Laborde, D. (2008). Assessing applied protection across the world. *Review of International Economics*, 16(5):850–863.

Brander, J. and Taylor, S. (1997). International trade and open-access renewable resources: The small open economy case. *The Canadian Journal of Economics*, 30(3).

Brown, S. and Zarin, D. (2013). What does zero deforestation mean? *Science*, 342(6160):805–807.

Burgess, R., Costa, F., and Olken, B. A. (2019). The brazilian amazon's double reversal of fortune.

Caliendo, L., Dvorkin, M., and Parro, F. (2019). Trade and Labor Market Dynamics: General Equilibrium Analysis of the China Trade Shock. *Econometrica*, 87(3):741–835.

Carleton, T., Crews, L., and Nath, I. (2025). Agriculture, trade, and the spatial efficiency of global water use. *Working Paper*.

Comin, D., Lashkari, D., and Mestieri, M. (2021). Structural change with long-run income and price effects. *Econometrica*, 89(1):311–374.

Conte, B., Desmet, K., Nagy, D. K., and Rossi-Hansberg, E. (2021). Local sectoral specialization in a warming world. *Journal of Economic Geography*, 21(4):493–530.

Copeland, B. R., Shapiro, J. S., and Scott Taylor, M. (2022). Globalization and the environment. In Gopinath, G., Helpman, E., and Rogoff, K., editors, *Handbook of International Economics: International Trade, Volume 5*, volume 5 of *Handbook of International Economics*, pages 61–146. Elsevier.

Copeland, B. R. and Taylor, M. S. (2004). Trade, growth, and the environment. *Journal of Economic literature*, 42(1):7–71.

Costinot, A., Donaldson, D., and Smith, C. (2016). Evolving comparative advantage and the impact of climate change in agricultural markets: Evidence from 1.7 million fields around the world. *Journal of Political Economy*, 124(1):205–248.

Desmet, K., Kopp, R. E., Kulp, S. A., Nagy, D. K., Oppenheimer, M., Rossi-Hansberg, E., and Strauss, B. H. (2021). Evaluating the economic cost of coastal flooding. *American Economic Journal: Macroeconomics*, 13(2):444–486.

Dominguez-Iino, T. (2025). Efficiency and redistribution in environmental policy: An equilibrium analysis of agricultural supply chains. *Journal of Political Economy*, Forthcoming.

Donaldson, D. (2018). Railroads of the raj: Estimating the impact of transportation infrastructure. *American Economic Review*, 108(4-5):899–934.

Fajgelbaum, P. and Redding, S. J. (2022). Trade, structural transformation, and development: Evidence from argentina 1869–1914. *Journal of political economy*, 130(5):1249–1318.

FAO (2020). Guide for country reporting for fra 2015. *FRA 2020 Working Paper 184*.

Farrokhi, F. (2020). Global sourcing in oil markets. *Journal of International Economics*, page 103323.

Farrokhi, F. and Lashkaripour, A. (2024). Can trade policy mitigate climate change? *Working Paper*.

Farrokhi, F. and Pellegrina, H. S. (2023). Trade, technology, and agricultural productivity. *Journal of Political Economy*, 131(9):2509–2555.

Foster, A. D. and Rosenzweig, M. R. (2003). Economic Growth and the Rise of Forests*. *The Quarterly Journal of Economics*, 118(2):601–637.

Gollin, D., Hansen, C. W., and Wingender, A. M. (2021). Two blades of grass: The impact of the green revolution. *Journal of Political Economy*, 129(8):2344–2384.

Gollin, D. and Wolfersberger, J. (2024). Agricultural trade and deforestation: the role of new roads. *Working Paper*.

Gouel, C. and Laborde, D. (2021). The crucial role of domestic and international market-mediated adaptation to climate change. *Journal of Environmental Economics and Management*, 106:102408.

Hansen, C. W. and Wingender, A. (2023). Who fed china? Technical report, CEPR Discussion Papers.

Hertel, T. (2012). Implications of agricultural productivity for global cropland use and ghg emissions: Borlaug vs jevons". Technical Report 69, GTAP.

Hertel, T. W. (2002). Applied general equilibrium analysis of agricultural and resource policies. *Handbook of agricultural economics*, 2:1373–1419.

Hsiao, A. (2025). Coordination and Commitment in International Climate Action: Evidence from Palm Oil. *Working Paper*.

Jayachandran, S., De Laat, J., Lambin, E. F., Stanton, C. Y., Audy, R., and Thomas, N. E. (2017). Cash for carbon: A randomized trial of payments for ecosystem services to reduce deforestation. *Science*, 357(6348):267–273.

Kortum, S. and Weisbach, D. A. (2024). Optimal unilateral carbon policy. *Working Paper*.

McLaren, J. (2017). Globalization and labor market dynamics. *Annual Review of Economics*, 9:177–200.

Mishra, P. (2025). The global allocative efficiency of deforestation. *Working Paper*.

Nath, I. (2025). Climate change, the food problem, and the challenge of adaptation through sectoral reallocation. *Journal of Political Economy*, 133(6):1705–1756.

Pellegrina, H. S. (2022). Trade, productivity, and the spatial organization of agriculture: Evidence from brazil. *Journal of Development Economics*, 156:102816.

Pendrill, F., Gardner, T. A., Meyfroidt, P., Persson, U. M., Adams, J., Azevedo, T., Bastos Lima, M. G., Baumann, M., Curtis, P. G., De Sy, V., et al. (2022). Disentangling the numbers behind agriculture-driven tropical deforestation. *Science*, 377(6611):eabm9267.

Pfaff, A. S. (1999). What drives deforestation in the brazilian amazon?: Evidence from satellite and socioeconomic data. *Journal of Environmental Economics and Management*, 37(1):26–43.

Shapiro, J. S. (2016). Trade costs, CO2, and the environment. *American Economic Journal: Economic Policy*, 8(4):220–54.

Simonovska, I. and Waugh, M. E. (2014). The elasticity of trade: Estimates and evidence. *Journal of International Economics*, 92(1):34–50.

Sotelo, S. (2020). Domestic trade frictions and agriculture. *Journal of Political Economy*, 128(7):2690–2738.

Souza-Rodrigues, E. (2019). Deforestation in the amazon: A unified framework for estimation and policy analysis. *The Review of Economic Studies*, 86(6):2713–2744.

Teti, F. (2024). Missing tariffs. Technical Report 11590, CESifo Working Paper Series.

Tombe, T. (2015). The missing food problem: Trade, agriculture, and international productivity differences. *American Economic Journal: Macroeconomics*, 7(3):226–258.

Tubiello, F. N., Pekkarinen, A., Marklund, L., Wanner, N., Conchedda, G., Federici, S., Rossi, S., and Grassi, G. (2020). Carbon emissions and removals by forests: New estimates 1990. *Sci. Data Discuss.*

Appendices for "Deforestation: A Global and Dynamic Perspective"

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A Details of 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

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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.[30] When available, we use information on 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. Our main sample contains 40 large countries or aggregate regions, which we use to present our empirical findings in Section 3 and model calibration. Table F.1 shows how individual countries are mapped to aggregate regions in our sample. Additionally, and for robustness, we work with a sample with 150 individual countries.[31] Appendix Table F.3 documents summary statistics for all countries in our final data set.

In addition to FRA, another source of deforestation data comes from Hansen et al. (2013b), who measure global deforestation using satellite imagery at a high spatial resolution (30 meters). Different from the FAO-FRA data set, 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 boundary such as the ones related to fires and insect outbreaks, even when there are no changes in the economic use of the land. For that reason, we use FAO-FRA because it specifically reports land use allocations which is the concept that aligns with the formulation of our model.[32] Furthermore, FAO-FRA provides a longer panel of data, which is particularly useful to capture longer term adjustments, a feature that is key to our analysis.

[30]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 dataset also provides information on planted trees and naturally regenerating forest.

[31]For this disaggregated sample, we still group 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.

[32]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 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 different methodologies to measure deforestation and reforestation, one must interpret net changes in forest area coming from Hansen et al. (2013b) with caution.

Agricultural Area and Fallow Land. Using land cover data from FAOSTAT, we remove snow cover and barren land (which includes deserts) from the total area of each country (which already excludes water surfaces). We refer to this resulting variable as "country area". By accounting, country area consists of cropland, pasture land, forest area, and fallow land, which we measure as follows.

We construct total area in "cropland" using data from FAOSTAT on total harvested area. These data, however, do not provide information on the total area dedicated to pasture land. 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 "pasture land".[33] As explained before, we obtain data on "forest area" from FAO-FRA. Lastly, we compute "fallow land" as the residual land, that is, the country area net of forest area, cropland, and pasture land.

Trade Costs. To calibrate the trade costs generated by policy, we use data on (i) tariffs from the World Bank World Development Indicators (TRAINS)—specifically, we use the simple unweighted average of the effectively applied rates for all products subject to tariffs—(ii) import fees (e.g., document, registration, and terminal handling fees beyond tariffs) 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 CO_2 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

[33] According to the agricultural census of Brazil, the total cattle stock per pasture area in hectares equals approximately 0.30, depending on the region, whereas technical reports give 0.6 units per hectare in the UK and almost 1 in the US. Given the lack of more systematic data across countries, based on these values, we set that measure to 0.75 as an approximate global average.

incorporate the following into our measurement: The carbon in litter, which is all the carbon 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 deforestation-related 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

In this section, we provide the proofs for Propositions 1 through 4, which are derived for the stylized model presented in Section 4. We begin by characterizing a few key endogenous outcome in the steady state, which applies to all propositions, and then we take each proposition in turn.

B.1 Characterizing the steady state

In the steady state, the stock of land is pinned down by setting $\dot{L}_i = 0$ in equation (10), which yields:

$$\delta_L L_i = Z_{i,T} N_{i,T}. \tag{B.1}$$

In turn, setting $\dot{q} = 0$ in equation (9) and using the pricing equation (8), we obtain the steady state rental rate of land:

$$r_i = \frac{(\rho + \delta_L)\, w_i}{Z_{i,T}}. \tag{B.2}$$

The last two equations imply the following relationship between payments to labor in the land-producing sector and payments to land:

$$r_i L_i = \frac{\rho + \delta_L}{\delta_L} w_i N_{i,T}. \tag{B.3}$$

In what follows, we also assume that $L_i < H_i$, that is, we assume the land frontier has room to expand in each country i.

B.2 Proof of Proposition 1

Our definition of a small open economy (SOE) follows that of Alvarez and Lucas (2007). Specifically, country i is considered a SOE in a limiting case where (i) $N_i, Z_{i,A}, Z_{i,M} \to 0$ and (ii) $Z_{i,M}^{\eta-1}/N_i \to \kappa_{i,M} > 0$, $Z_{i,A}^{\eta-1}/N_i \to \kappa_{i,A} > 0$.

Substituting this relation into market clearing for land, equation (11), we obtain

$$w_i N_{i,T} = \frac{\delta_L}{\rho + \delta_L} \sum_j \frac{1}{1 + t_{ij,A}} \left(\frac{w_i d_{ij,A} \left(1 + t_{ij,A}\right) / Z_{i,A}}{P_{j,A}} \right)^{1-\eta} X_{j,A}. \tag{B.4}$$

In turn, the market clearing for the manufacturing sector pins down the payments to labor there:

$$w_i N_{i,M} = \sum_j \frac{1}{1 + t_{ij,M}} \left(\frac{w_i d_{ij,M} \left(1 + t_{ij,M}\right) / Z_{i,M}}{P_{j,M}} \right)^{1-\eta} X_{j,M} \tag{B.5}$$

where in the above two equations, recall, $P_{j,s}$ and $X_{j,s}$ for $s \in \{A, M\}$ denote the CES price indices and industry-level expenditures in destination j.

First, let us show that the wage rate in the SOE, w_i, converges to a positive number. We guess that w_i converges to a positive and finite constant, and then we will verify our guess. From our SOE assumption (i), it follows the the sectoral price indexes in each country and sector are independent of fundamentals in country i:

$$P_{j,s} \to \left(\sum_{i' \neq i} \left(w_{i'} d_{i'j,s} \left(1 + t_{i'j,s}\right) / Z_{i',s} \right)^{1-\eta} \right)^{\frac{1}{1-\eta}},$$

since $Z_{i,s} \to 0$. A similar argument shows that aggregate expenditure in each country and sector is independent of fundamentals in country i.

Next, noting that $N_{i,T} + N_{i,M} = N_i$, we can combine equations (B.4) and (B.5) and taking the limit defined by assumptions (i) and (ii), we verify that $w_i \in (0, \infty)$:

$$w_i^\eta \to \sum_{j \neq i} \frac{\left(d_{ij,M} \left(1 + t_{i'j,M}\right)\right)^{1-\eta}}{P_{j,M}^{1-\eta}} \kappa_{i,M} X_{j,M} + \frac{\delta_L}{\rho + \delta_L} \sum_{j \neq i} \frac{\left(d_{ij,A} \left(1 + t_{i'j,A}\right)\right)^{1-\eta}}{P_{j,A}^{1-\eta}} \kappa_{i,A} X_{j,A},$$

since $X_{i,s} \to 0$, $\forall s$ and because each term of the right-hand side is a positive constant that does not depend on country i's wage.

Having established that $w_i \in (0, \infty)$, we can now divide equation (B.4) by equation (B.5), where the wages are canceled out to deliver:

$$N_{i,T} = N_{i,M} \frac{g_L}{\rho + g_L} \frac{d_{i,A}^{1-\eta}}{d_{i,M}^{1-\eta}} \frac{(1+t_{i,A})^{-\eta}}{(1+t_{i,M})^{-\eta}} \frac{\bar{X}_{-i,A}}{\bar{X}_{-i,M}}, \qquad \text{where} \qquad \bar{X}_{-i,s} \equiv \sum_{j \neq i} Z_{i,s}^{\eta-1} P_{j,s}^{\eta-1} X_{j,s};$$

Note that, here, for a clearer exposition, we let country i's exports costs be common across all destinations, $d_{ij,s} = d_{i,s}$ and $t_{ij,s} = t_{i,s}$ for all $j \neq i$. Using the above expression, we obtain the effect of a uniform increase in country i's export costs on the employment in the land-producing sector:

$$\frac{\mathrm{d} \ln N_{i,T}}{\mathrm{d} \ln d_{i,A}} = \frac{N_{i,M}}{N_i} (1-\eta); \tag{B.6}$$

Using equation (B.6) and the steady-state stock of land, $L_i = \frac{1}{g_L} Z_{i,T} N_{i,T}$, the impact on the stock of land can be similarly expressed as:

$$\frac{\mathrm{d} \ln L_i}{\mathrm{d} \ln d_{i,A}} = \frac{N_{i,M}}{N_i} (1-\eta). \tag{B.7}$$

Likewise, the responses of employment in the land-clearing sector and of cleared land to a change in tariffs are given by

$$\frac{d \ln N_{i,T}}{d \ln (1+t_{i,A})} = -\frac{N_{i,M}}{N_i} \eta$$

and

$$\frac{d \ln L_i}{d \ln (1+t_{i,A})} = -\frac{N_{i,M}}{N_i} \eta.$$

B.3 Proofs of Propositions 2 and 3

We derive here an expression that we use as a starting point for both Propositions 2 and 3. Consider I symmetric large open economies. Due to symmetry, we drop country subscripts.

We begin by noting that with symmetric economies, sectoral revenue equals sectoral expenditure country by country (because there is no motive for sectoral net exports). Next substituting the definition of sectoral expenditure shares from equation (4), together with our assumptions on production technology, and with the equilibrium sectoral price indexes,

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

we obtain that land market clearing in each country is given by

$$rL = (1-h_A) \times b_A r^{1-\sigma} Z_A^{-(1-\sigma)} \left(\pi_A^D\right)^{-\frac{1-\sigma}{1-\eta}} E \tag{B.8}$$

while labor market clearing in manufacturing is given by

$$wN_M = (1 - h_M) \times b_M w^{1-\sigma} Z_M^{-(1-\sigma)} \left(\pi_M^D\right)^{-\frac{1-\sigma}{1-\eta}} E. \tag{B.9}$$

Here, E denotes national expenditure, and π_s^D is the "domestic expenditure share" in sector s, which is, under symmetry, equal to:

$$\pi_s^D = \frac{1}{(I-1)\left[d_s \times (1+t_s)\right]^{1-\eta} + 1} \tag{B.10}$$

where I denotes the number of countries. Note that the trade barrier is inclusive of iceberg component, $d_s \geq 1$, and ad valorem equivalent import tariff, $(1+t_s)$. Lastly, $(1-h_s)$ denotes the share of expenditure on varieties of sector s received by farmers. Conversely, h_s denotes the fraction collected by governments in the form of tariffs from the expenditure on sector s,

$$h_s = \frac{t_s}{1+t_s}\left(1 - \pi_s^D\right) \tag{B.11}$$

We assume tariffs on non-agriculture to be zero, and so $h_M = 0$. Similarly, when agricultural tariffs are zero, $h_A = 0$ and farmers receive the entirety of payments to agriculture. However, when agricultural tariffs are positive, a fraction $\frac{t_A}{1+t_A}$ of import payments is collected by governments of importing countries (which is then rebated to households), and the remaining fraction, $\frac{1}{1+t_A}$, is received by farmers in exporting countries. Equation (B.11) follows by noting that *(i)* farmers receive all the domestic payments and *(ii)* imported share of expenditures equals $\left(1-\pi_s^D\right)$.

Next, note that we can rewrite the labor resource constraint, using the steady state law of motion, equation (B.1), as:

$$N_M = N - \frac{\delta}{Z_T} L. \tag{B.12}$$

Finally, divide equation (B.8) by (B.9), which yields

$$L = \left(\frac{1-h_A}{1-h_M}\right)\left(\frac{b_A}{b_M}\right)\left(\frac{Z_A}{Z_M}\right)^{\sigma-1}\left(\frac{\pi_A^D}{\pi_M^D}\right)^{\frac{1-\sigma}{\eta-1}}\left(\frac{r}{w}\right)^{-\sigma} \times N_M,$$

and substitute the rental rate of land using equation (B.2) and N_M from equation (B.12), to obtain:

$$L = \Phi \times \left(N - \frac{\delta}{Z_T} L\right), \qquad \Phi = \left(\frac{1-h_A}{1-h_M}\right)\left(\frac{b_A}{b_M}\right)\left(\frac{Z_A}{Z_M}\right)^{\sigma-1}\left(\frac{\pi_A^D}{\pi_M^D}\right)^{\frac{1-\sigma}{\eta-1}}\left(\frac{\rho+\delta}{Z_T}\right)^{-\sigma} \tag{B.13}$$

Equation (B.13) is the basis for our derivations leading to Propositions 2 and 3.

B.3.1 Proof of Proposition 2

Consider a worldwide uniform change in iceberg trade costs in agriculture, namely: $d_A \rightarrow d_A + \mathrm{d}d_A$. Based on equation (B.13), it is straightforward to show that[34]

$$\frac{\mathrm{d}\ln L}{\mathrm{d}\ln d_A} = \frac{N_M}{N}\frac{\mathrm{d}\ln \Phi}{\mathrm{d}\ln d_A}. \tag{B.14}$$

Supposing that tariffs are zero (and so $h_A = h_M = 0$), the only component in Φ that responds to a change in agricultural iceberg trade cost, d_A, is the domestic expenditure share in the agriculture sector, π_A^D, with the relationship governed by the following elasticity, derived from equation (B.10),

$$\frac{\partial \ln \pi_A^D}{\partial \ln d_A} = (\eta - 1)\left(1 - \pi_A^D\right). \tag{B.15}$$

Replacing (B.15) when taking the derivatives of equation (B.13), we obtain:

$$\frac{\mathrm{d}\ln \Phi}{\mathrm{d}\ln d_A} = \frac{1-\sigma}{\eta - 1} \times \frac{\partial \ln \pi_A^D}{\partial \ln d_A} = (1-\sigma)\left(1 - \pi_A^D\right)$$

Replacing the above expression into equation (B.14) delivers the steady-state elasticity of the stock of land with respect to agricultural iceberg trace cost:

$$\frac{\mathrm{d}\ln L}{\mathrm{d}\ln d_A} = \frac{N_M}{N}(1-\sigma)\left(1 - \pi_A^D\right). \tag{B.16}$$

which reproduces equation (16) in the main text.

B.3.2 Borlaug's hypothesis

The original Borlaug's hypothesis considers agricultural productivity growth in a closed economy. Dropping the country subscript, for a closed economy, note that $\pi_s^D = (1 - h_s) = 1$ in reference to equation (B.13). Now, for an increase in agricultural productivity Z_A, the same steps as the ones which we took above, leads us to the following proposition.

Proposition. *(Borlaug's hypothesis) An agricultural productivity growth in a closed economy is land-saving when the elasticity of substitution between agriculture and non-agriculture is*

[34] Taking the derivatives of Equation (B.13) with respect to d_A, we obtain: $\frac{\mathrm{d}L}{\mathrm{d}d_A} = \frac{\mathrm{d}\Phi}{\mathrm{d}d_A} \times \left(N - \frac{\delta}{Z_T}L\right) - \Phi\frac{\delta}{Z_T}\frac{\mathrm{d}L}{\mathrm{d}d_A}$, which can be organized as: $\frac{\mathrm{d}L}{\mathrm{d}d_A} = \frac{\mathrm{d}\Phi}{\mathrm{d}d_A} \times \frac{N - \frac{\delta}{Z_T}L}{1+\frac{\delta}{Z_T}\Phi}$. Considering that $\left(N - \frac{\delta}{Z_T}L\right) = N_M$ and $\left(1 + \frac{\delta}{Z_T}\Phi\right) = \Phi\frac{N}{L}$, the above can be expressed as: $\frac{\mathrm{d}\ln L}{\mathrm{d}\ln d_A} = \frac{\mathrm{d}\ln\Phi}{\mathrm{d}\ln d_A} \times \frac{N_M}{N}$

below one:

$$\frac{\mathrm{d}\log L}{\mathrm{d}\log Z_A} = \frac{N_M}{N}(\sigma - 1) < 0 \quad \textit{for} \quad \sigma < 1.$$

Note that another interpretation of Borlaug's hypothesis is the case of a uniform increase in agricultural productivities globally in all countries.

B.3.3 Proof of Proposition 3

Now, consider a worldwide uniform change in ad valorem import tariffs in the agriculture sector, that is: $(1 + t_A) \rightarrow (1 + t_A) + \mathrm{d}(1 + t_A)$. The same steps as in the derivations for the proof of Proposition 2 leads to the following expression:

$$\frac{\mathrm{d}\ln L}{\mathrm{d}\ln(1 + t_A)} = \frac{N_M}{N}\left(\frac{1-\sigma}{\eta - 1}\frac{\partial \ln \pi_A^D}{\partial \ln(1 + t_A)} + \frac{\mathrm{d}\ln(1 - h_A)}{\mathrm{d}\ln(1 + t_A)}\right)$$

Similar to Equation (B.15), $\frac{\partial \ln \pi_A^D}{\partial \ln(1+t_A)} = (\eta - 1)\left(1 - \pi_A^D\right)$. Consequently, we can rewrite the above equation as:

$$\frac{\mathrm{d}\ln L}{\mathrm{d}\ln(1 + t_A)} = \frac{N_M}{N}(1 - \sigma)\left(1 - \pi_A^D\right) + \frac{N_M}{N}\frac{\mathrm{d}\ln(1 - h_A)}{\mathrm{d}\ln(1 + t_A)} \tag{B.17}$$

The above expression introduces the second term on the right-hand side, $\frac{\mathrm{d}\ln(1-h_A)}{\mathrm{d}\ln(1+t_A)}$, to the elasticity of land with respect to iceberg trade costs, equation (B.16). Recall that, in the presence of tariffs, farmers do not collect all the payments for agricultural consumption. Accordingly, the second term appears indicating that an increase in tariffs changes the pass-through to farmers. We can unpack this effect by taking the derivatives of equation (B.11), $(1 - h_A) = 1 - \frac{t_A}{1+t_A}\left(1 - \pi_A^D\right)$, with respect to agricultural tariff, t_A,

$$\begin{aligned}\frac{\mathrm{d}\ln(1 - h_A)}{\mathrm{d}\ln(1 + t_A)} &= -\frac{1}{1 - h_A}\frac{t_A}{1 + t_A}\frac{\partial\left(1 - \pi_A^D\right)}{\partial \ln(1 + t_A)} - \frac{1 - \pi_A^D}{1 - h_A}\frac{\partial\left(\frac{t_A}{1+t_A}\right)}{\partial \ln(1 + t_A)} \\ &= \underbrace{\frac{h_A}{1 - h_A}(\eta - 1)\,\pi_A^D}_{(+)\text{ if }\eta > 1} + \underbrace{\frac{-1}{1 - h_A}\frac{1 - \pi_A^D}{1 + t_A}}_{(-)}.\end{aligned} \tag{B.18}$$

Inspecting the two terms on the right-hand side of the above equation:

- *(a)* Holding fixed $\frac{t_A}{1+t_A}$, an increase in tariff shifts the demand for agriculture from foreign varieties to the domestic variety in each country, which raises the pass-through to farmers. This effect equals $\frac{h_A}{1-h_A}(\eta - 1)\,\pi_A^D > 0$, which is positive under the empirically relevant case $\eta > 1$.

- *(b)* Holding fixed the imported expenditure share, $\left(1-\pi_A^D\right)$, an increase in tariff raises the fraction of payments received by farmers, which lowers the the pass-through to farmers. Specifically, this negative effect equals $\left(-\frac{1-\pi_A^D}{1-h_A}\frac{1}{1+t_A}\right)<0$.

Replacing for $\frac{\mathrm{d}\ln(1-h_A)}{\mathrm{d}\ln(1+t_A)}$ from equation (B.18) into equation (B.17), we obtain:

$$\frac{\mathrm{d}\ln L}{\mathrm{d}\ln(1+t_A)}=\underbrace{\frac{N_M}{N}(1-\sigma)\left(1-\pi_A^D\right)}_{(+)\text{ if }\sigma<1}+\underbrace{\frac{N_M}{N}\frac{h_A}{1-h_A}(\eta-1)\,\pi_A^D}_{(+)\text{ if }\eta>1}+\underbrace{\frac{N_M}{N}\frac{-1}{1-h_A}\frac{1-\pi_A^D}{1+t_A}}_{(-)},\quad\text{(B.19)}$$

which reproduces equation (17) in the first part of Proposition 3. To see this more clearly, note that:

$$\begin{cases}\frac{h_A}{1-h_A}\pi_A^D=s_A^D-\pi_A^D\\ \frac{1}{1-h_A}\frac{1-\pi_A^D}{1+t_A}=1-s_A^D\end{cases}$$

where $s_A^D=\frac{\pi_A^D}{1-h_A}$ denotes the share going to domestic farmers from the payments received by all farmers.

Next, by replacing $h_A=\frac{t_A}{1+t_A}\left(1-\pi_A^D\right)$ into equation (B.19), we can express the elasticity of the stock of land with respect to agricultural tariff, compactly, as:

$$\frac{\mathrm{d}\ln L}{\mathrm{d}\ln\left(1+t_A\right)}=\frac{N_M}{N}\left(1-\pi_A^D\right)\left[\frac{t_A\pi_A^D}{1+t_A\pi_A^D}\eta-\sigma\right]\quad\text{(B.20)}$$

To inspect whether an increase in agricultural tariff t_A raises the stock of land L, let us define the term in the brackets as a function of tariff rate t_A:

$$g\left(t_A\right)\equiv\frac{t_A\pi_A^D\left(t_A\right)}{1+t_A\pi_A^D\left(t_A\right)}\eta-\sigma,\qquad\text{where}\quad\pi_A^D\left(t_A\right)=\left[\left(I-1\right)\left(d_A\left(1+t_A\right)\right)^{1-\eta}+1\right]^{-1}$$

It is straightforward to check that: $g'(.)>0$, $g(0)=-\sigma$, $h(\infty)=\eta-\sigma$. Provided that $\eta>\sigma>0$, the Intermediate Value Theorem implies that $g(t_A)=0$ has a unique solution $t_A^*>0$ that satisfies:

$$t_A^*\pi_A\left(t_A^*\right)=\frac{\sigma}{\eta-\sigma}.$$

Moreover, it follows that $g\left(t_A\right)$ is negative when $t_A\in[0,t_A^*)$ and positive when $t_A\in(t_A^*,\infty)$. This observation, plus the fact that $\frac{N_M}{N}\left(1-\pi_A^D\right)>0$ in equation (B.20), imply that $\frac{\mathrm{d}\ln L}{\mathrm{d}\ln(1+t_A)}$ is negative when $t_A\in[0,t_A^*)$, positive when $t_A\in(t_A^*,\infty)$, and zero when $t_A=t_A^*$. This completes the proof of Proposition 3.

B.4 Model's Structure for Proof of Proposition 4

Let us reiterate the assumptions of the proposition. Within each sector, goods are homogenous ($\eta \to \infty$) and preferences take a Cobb-Douglas form with $\beta_A = \beta$ and $\beta_M = 1 - \beta$ denoting the fixed share of expenditure on agriculture and manufacturing respectively. The Cobb-Douglas form also implies $\sigma = 1$, which shuts down the structural change mechanism under Propositions 2 and 3. There is a continuum of countries $i \in [0, 1]$, that only differ in their productivity to produce agriculture and manufacturing, $Z_{i,A}$ and $Z_{i,M}$. With no loss of generality, we order countries in the decreasing order of comparative advantage in agriculture, i.e. $Z_{i,A}/Z_{i,M}$ decreases with i. In addition, we assume $Z_{i,A}/Z_{i,M}$ decreases continuously along the continuum of countries. Note that, because we assume that $Z_{i,T} = Z_T$ is the same across countries, the productivity of the land-producing sector is not a source of comparative or absolute advantage in agriculture. Likewise, because land δ_L is common across countries, reforestation capacity is not a source of comparative advantage either.

We proceed as follows. First we characterize the dynamic path and the steady state of an autarkic economy, with a focus on the allocation of labor across sectors and the corresponding stock of land and forest sustained in equilibrium. Second, we characterize equilibria for open economies, which will fully specialize either in manufacturing or in agriculture. Third, based on the previous results, we derive the statement in Proposition 4.

B.4.1 Autarky

Production. Because of our focus on a single economy, in this subsection we drop the country index i; we also drop the index t whenever it does not cause confusion. Take $p_A(t) = p_A$ as the numeraire at each time t.

Profit maximization in agricultural production yields a constant rental rate of land as a function of the agricultural price (i.e., the numeraire):

$$r = p_A Z_A,$$

noting that the agricultural sector always operates, whenever $L > 0$. Integrating forward the land asset pricing condition, equation (9), we also obtain a constant price of land as a function of the numeraire

$$q = \frac{p_A Z_A}{\rho + \delta}.$$

Before studying the manufacturing and land-clearing sectors, note that with linear technologies it is not obvious ex-ante that both sectors will operate. We proceed with the assumption that they are, which will happen if the initial stock of land is low enough.

Profit maximization in the land-clearing sector yields the wage of workers in terms of the numeraire:

$$w = Z_T \times \frac{p_A Z_A}{\rho + \delta},$$

i.e., the value of labor at the margin equates the present discounted value of returns of clearing $Z_{i,T}$ additional units of land.

Demand. Form our assumption on preferences, it follows that

$$\begin{aligned} x_M &= \beta_M x^F \\ x_A &= \beta_A x^F, \end{aligned}$$

where x^F is expenditure in final goods (agriculture and manufacturing) and x_k is expenditure in sector k. Note that in autarky, $x^F = rL + wN_M$ (expenditure in final goods).

Equilibrium. Using labor market clearing in the manufacturing sector yields the allocation of labor as a function of relative factor rewards

$$N_M = \frac{1-\beta}{\beta} \frac{r}{w} L,$$

and after substituting equilibrium wages and rental rates into this expression, we obtain the allocation of labor as a function of the stocks of land and labor at each period

$$\begin{aligned} N_M &= \frac{1-\beta}{\beta} \left(\frac{\rho + \delta}{Z_T} \right) L \\ N_T &= N - N_M \end{aligned}$$

Note that higher stocks of land L lead to more labor in manufacturing, as it scales demand for both goods up.

Finally using N_T in the law of motion of land, equation (10), we obtain the following differential equation for land accumulation

$$\dot{L} = Z_T N - KL,$$

with

$$K \equiv \frac{1-\beta}{\beta} (\rho + \delta) + \delta.$$

Because $K > 0$, the solution to this equation is stable, and given by

$$L(t) = L_{ss} + [L(0) - L_{ss}]\, e^{-Kt},$$

with $L_{ss} = Z_T N/K$ denoting the steady-state stock of land.

Note also that the ratio of prices that clears markets at each point is:[35]

$$\frac{p_A}{p_M} = \frac{1}{(w/Z_M)} = \frac{Z_M}{Z_T Z_A}(\rho + \delta).$$

Variation in this autarky price ratio across countries is determined entirely by the ratio of productivities in agriculture and manufacturing, $Z_{i,A}$ and $Z_{i,M}$, since the other terms are constant by assumption.

Steady state In the steady state, $\dot{L} = 0$, so

$$L = \frac{Z_T N}{K}$$

and all prices are constant (as they are outside of the steady state).

Using the equilibrium allocations of labor across manufacturing and land-clearing, and substituting the equilibrium land stock we obtain:

$$\frac{N_M}{N_T} = \frac{1-\beta}{\beta}\left[\frac{\rho+\delta}{\delta}\right] \tag{B.21}$$

This equation is important because it is the basis of the comparison of open and closed economies that allows us to establish the results in Proposition 4. Note the similarity with

[35] If the land-clearing sector is not open, then market clearing yields the following ratio of prices, which varies over time, as the stock of land changes.

$$\frac{p_M}{p_A} = \frac{1-\beta}{\beta}\frac{Z_A}{Z_M}\frac{L}{N}.$$

This is the case when $q < w/Z_M$, that is, when

$$\frac{L}{N} > \frac{1-\beta}{\beta}\frac{Z_T}{\rho+\delta}$$

so land is too abundant relative to demand of agricultural goods. If this initial condition is met, the law of motion of land boils down to

$$\dot{L} = -\delta.$$

Along the transition path, the relative price of manufacturing decreases, as agricultural production becomes more scarce, up to the point that land-clearing becomes profitable and the system evolves as described in the main body of the proof.

the standard Cobb-Douglas (that labor is allocated in accordance to expenditure shares), only the term in square brackets adjusts for the fact that a unit of labor in tree-cutting labor delivers a flow of agricultural goods.

B.4.2 International Trade – Specialization in Manufacturing

Now consider what happens when the economy opens up to a free trading system. Suppose country i starts with a stock of land given by $L_i(0) = L_{i,ss}$. Denote world prices by a star, so the price of agriculture is given by p_A^*.

Production. Country i will specialize in manufacturing when $p_A^*/p_M^* < p_{i,A}/p_{i,M}$. Because the economy specializes in manufacturing, we still have that profit maximization in that sector will pin down wages:

$$w_i = p_M^* Z_{i,M}.$$

At the same time, given the international prices, country i will not operate the land-clearing sector and there will be no entry into landowning.[36] Labor entirely specializes in manufacturing

$$Q_{iM} = Z_{i,M} N_i$$

and the law of motion of land in the transition to steady state is

$$\dot{L}_i = -\delta L_i.$$

Note, however, that during the transition $L_i > 0$, so land markets must clear, and $r_i = p_A^* Z_{i,A}$.

Demand. International trade decouples production and consumption. Total expenditure in final goods is given by

$$x_i^F = w_i N_i + r_i L$$

at each point in time. Expenditure in final goods reflects the Cobb-Douglas shares β and $1 - \beta$. Importantly, as the stock of land decreases, total expenditure in final goods in the economy decreases as well.

Steady state. In the steady state, the allocation of labor is still $N_{i,M} = N_i$, while no land is sustained in equilibrium, $L_i = 0$. Total expenditure is then $x_i^F = w_i N_i$.

[36] To see why, suppose the land-clearing sector is operational. Profit maximization implies $w_i = Z_{iT} q_i$, which implies the following relation between international prices and domestic productivities: $p_A^*/p_M^* = Z_{i,M}(\rho + \delta)/(Z_{i,A} Z_T)$. The right hand side of this expression, however, is the autarky relative price of country i. This contradicts the premise that $p_A^*/p_M^* < p_{i,A}/p_{i,M}$.

B.4.3 International Trade – Specialization in Agriculture.

Production. Country i will specialize in manufacturing when $p^*_A/p^*_M > p_{i,A}/p_{i,M}$. As before, given international prices, one can show that the manufacturing sector shuts down immediately, which means that all labor moves to land-clearing

$$N_{i,T} = N$$

and the law of motion of land at each time is given by

$$\dot{L}_{i,T} = Z_{i,T} N_i - \delta L_i.$$

Because the agricultural sector is operational, we must still have free-entry into land holding, as well as profit maximization in land-clearing and in agricultural production, which yields the following equilibrium prices

$$\begin{aligned} r_i &= p^*_A Z_{iA} \\ q_i &= \frac{p^*_A Z_{iA}}{r+\delta} \\ w_i &= \frac{Z_{iT} p^*_A Z_{iA}}{r+\delta} \end{aligned}$$

Demand. As before, international trade decouples production and consumption. Total expenditure in final goods now is given by

$$x_i^F = w_i N + r_i L_i,$$

which grows towards the new steady state.

Steady state. We impose $\dot{L} = 0$, which yields equilibrium land stocks:

$$L_i = \frac{Z_T}{\delta_L} N_i$$

(independent of preferences) and the steady state production of agriculture is

$$Q_{iA} = \frac{Z_{iA} Z_T}{\delta_L} N.$$

B.5 Proposition 4

We focus now on the steady state of the trading economy. Recall that, without loss of generality, we order countries such that $Z_{i,A}/Z_{i,M}$, decreases in $i \in [0,1]$, which, as we established above, translates into a ranking of autarky prices.

In the free trade equilibrium, the assumption that goods are homogeneous in each sector implies there is a single relative price of manufacturing relative to agriculture. We denote this price by $p^* = p_M^*/p_A^*$. Let country i^* be the the marginal country whose autarky price coincides with the free-trade price:

$$p^* = \frac{Z_{i^*,A} Z_T}{(\rho + \delta_L) Z_{i^*,M}} \tag{B.22}$$

All countries whose autarky relative price of manufacturing is higher than p^* completely specialize in agriculture, while the rest completely specialize in manufacturing. That is, all countries $i < i^*$ fully specialize in agriculture and all countries $i > i^*$ fully specialize in manufacturing. The marginal country $i = i^*$ may produce both goods, but has measure zero.

Next, note that with Cobb-Douglas preferences, the global expenditure share on agriculture is β, while that on manufacturing is $1 - \beta$. Therefore, market clearing requires:

$$\frac{p_M^*}{p_A^*} = \frac{\beta_M}{\beta_A} \frac{\int_0^{i^*} \frac{Z_{i,A} Z_T}{\delta} N_i di}{\int_{i^*}^1 Z_{i,M} N_i di} \tag{B.23}$$

since global production of each good is given by $Q_M^W = \int_{i^*}^1 Z_{i,M} N_i di$ and $Q_A^W = \int_0^{i^*} \delta_L^{-1} Z_{i,A} Z_T N_i di$, since in each country specialized in agriculture $Q_{i,A} = Z_{i,A} Z_T N_i / \delta_L$.

An equilibrium consists of a cutoff country i^* and an equilibrium relative price of agriculture p^*, such that equations (B.22) and (B.23) jointly hold. The right-hand side of equation (B.22) is decreasing in i^* by our choice of ordering. The right-hand side of equation (B.23) 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 4.

To determine the total demand for factors under free trade, we rearrange equation (B.23) as

$$\frac{1-n}{n} = \frac{\rho + \delta}{\delta} \frac{1-\beta}{\beta} \frac{\mathbb{E}\left[Z_{i,A} | i \le i\right] / Z_{i^*A}}{\mathbb{E}\left[Z_{i,M} | i > i\right] / Z_{i^*M}} \tag{B.24}$$

where $n \equiv \int_0^{i^*} N(i)\, di / \int_0^1 N_i(i)\, di$ is the share of countries specialized in agriculture and, since all countries have the same size, it is also the global share of labor in agriculture.

Recalling the allocation of labor in autarky, given in equation (B.21), we see that trade decreases the global amount of labor in agriculture relative to autarky if $n < \beta$, i.e., if the second term on the right-hand side of equation (B.24) is greater than one.

We now obtain sufficient conditions such that the second term on the right hand side of equation (B.24) 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 4.

- First, suppose $Z_{i,M}$ is decreasing in i. Given that by our ordering of countries, $Z_{i,A}/Z_{i,M}$ is decreasing in $i \in [0,1]$, this implies that $Z_{i,A}$ must be also decreasing in i—*i.e.,* comparative and absolute advantage are aligned in agriculture but reversely aligned in manufacturing. This ensures positive selection into agriculture and negative selection into manufacturing, so the right-hand side of equation (B.24) is greater than one. That is, $\mathbb{E}\left[Z_{i,A} | i \leq i^*\right] > Z_{i^*,A}$ and $\mathbb{E}\left[Z_{i,M} | i > i^*\right] < Z_{i^*,M}$. Under this case, global land use decreases, or equivalently, global forest area expands.

- Second, suppose that $Z_{i,A}$ is increasing in i. Given our ordering of countries, this implies that $Z_{i,M}$ must increase in i as well. This ensures that there is negative selection into agriculture and positive selection into manufacturing, so the right-hand side of equation (B.24) is smaller than one.

C The Quantitative Model

This section introduces in detail the model we use for quantification.

C.1 Time, Geography and Markets

The economy operates in continuous time $t \in [0, \infty)$, and divided into multiple countries, indexed by $i, j = 1, ..., I$. Each country i is endowed by a fixed, time-invariant amount of land, H_i, and an exogenous path of labor force, $N_i(t)$. Each country's land consists of agricultural land, $L_i(t)$, and forest area, $F_i(t)$, such that $H_i = L_i(t) + F_i(t)$, with the agricultural land itself being divided into *usable* land $U_i(t)$ and *fallow* land $O_i(t)$, such that $L_i(t) = U_i(t) + O_i(t)$.

There is a land-clearing sector, labelled as T, that converts forest and fallow land into new land to be used in the production of goods $g \in \mathcal{G}$, which span multiple industries, consisting of agricultural goods $(1,...,K)$, manufacturing (M), and services (S),

$$\mathcal{G} \equiv \left\{ \underbrace{1,...,K}_{\text{Agriculture}}, \underbrace{M}_{\text{Manufacturing}}, \underbrace{S}_{\text{Service}} \right\},$$

Each industry $g \in \mathcal{G}$ is further differentiated into varieties by country of origin. For each variety of industry g originated from supplying country i, there is a market in country j—corresponding to the international market for origin $i-$destination $j-$industry g. Shipping g from i to j entails trade costs $\tau_{ij,g} = (1 + t_{ij,g})\, d_{ij,g}$ where $t_{ij,g}$ denotes the ad valorem import tariff rate charged by importing country j, and $d_{ij,g} \geq 1$ represents the iceberg trade cost, with $t_{ii,g} = 0$ and $d_{ii,g} = 1$.

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.

C.2 Households

C.2.1 Preferences

Each country has a representative household with a three-tier demand system. The upper tier aggregates the composites of agriculture (A), manufacturing (M), and services (S) into final consumption with a sectoral substitution elasticity σ:

$$C_i = \left[\sum_{s \in \{A,M,S\}} b_{i,s} C_{i,s}^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}},$$

We also refer to C_i as "real consumption" which we use in our welfare evaluation of policies we consider. Here, $C_{i,s}$ represents the consumption of each sector. The middle tier defines $C_{i,s}$ for each sector. For agriculture $(s = A)$, the agricultural composite combines disaggregated agricultural industries with a substitution elasticity κ:

$$C_{i,A} = \left[\sum_{k=1}^{K} b_{i,k} C_{i,k}^{\frac{\kappa-1}{\kappa}} \right]^{\frac{\kappa}{\kappa-1}}.$$

For manufacturing $(s = M)$ and services $(s = S)$, the composites are simply $C_{i,M}$ and $C_{i,S}$, respectively. The lower tier aggregates national varieties of each industry $g \in \mathcal{G}$ with a substitution elasticity η:

$$C_{i,g} = \left[\sum_{j=1}^{I} b_{ji,g} C_{ji,g}^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}}, \qquad g \in \mathcal{G}.$$

C.2.2 Costs, Prices, and Expenditure Shares.

Country j's expenditure in good g produced by country i equals

$$\pi_{ij,g} = \frac{b_{ij,g} \left(c_{i,g} \tau_{ij,g} \right)^{1-\eta_g}}{p_{j,g}^{1-\eta_g}}, \tag{C.25}$$

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:

$$p_{j,g} = \left[\sum_{i=1}^{N} b_{ij,g} \left(c_{i,g} \tau_{ij,g} \right)^{1-\eta_g} \right]^{\frac{1}{1-\eta_g}}, \qquad g \in \mathcal{G} \equiv \{1, ..., K, M, S\}. \tag{C.26}$$

Note again that the trade shares, $\pi_{ij,g}$, and price indexes, $p_{j,g}$, are common to both consumers and intermediate input users in country i good g. Within-agriculture consumption expenditure shares equal:

$$\beta_{i,k} = b_{i,k} \left(\frac{p_{i,k}}{P_{i,A}} \right)^{1-\kappa}, \qquad k \in \{1, ..., K\} \tag{C.27}$$

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:

$$P_{i,A} = \left[\sum_{k=1}^{K} b_{i,k} p_{i,k}^{1-\kappa} \right]^{\frac{1}{1-\kappa}}, \qquad P_{i,M} = p_{i,M}, \qquad P_{i,S} = p_{i,S} \tag{C.28}$$

Lastly, the expenditure share on sector $s \in \{A, M, S\}$ equals:

$$\beta_{i,s} = b_{i,s} \left(\frac{P_{i,s}}{P_i} \right)^{1-\sigma}, \tag{C.29}$$

where the final consumer price is given by,

$$P_i = \left[\sum_{s \in \{A,M,S\}} b_{i,s} P_{i,s}^{1-\sigma} \right]^{\frac{1}{1-\sigma}}. \tag{C.30}$$

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

C.2.3 Worker Mobility and Sectoral Choices

Workers are forward looking and have perfect foresight. They are endowed with 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 $\varepsilon_{i,s}^N$ 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 $f_{i,ss'}^N$.

Supposing 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 of agriculture (A), manufacturing (M), services (S) and the land-clearing sector (T). Given these assumptions, the expected present value of the stream of a worker's utility who is currently in sector s, $v_{i,s}^N$, is the solution to:

$$(\rho + \psi)\, v_{i,s}^N = u\left(\frac{w_{i,s}}{P_i}\right) + \psi W_{i,s} + \dot{v}_{i,s}^N, \tag{C.31}$$

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

$$W_{i,s} \equiv \mathbb{E}\left[\max_{s'}\left\{v_{i,s'}^N - f_{i,ss'}^N + \varepsilon_{i,s'}^N\right\}\right] = \nu \log \sum_{s' \in S} \exp\left(\frac{1}{\nu}\left(v_{i,s'}^N - f_{i,ss'}^N\right)\right). \tag{C.32}$$

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

$$\mu_{i,ss'} = \frac{\exp\left(\left(v_{i,s'}^N - f_{i,ss'}^N\right)/\nu\right)}{\sum_{l \in S} \exp\left(\left(v_{i,l}^N - f_{i,sl}^N\right)/\nu\right)}. \tag{C.33}$$

C.3 Final and Intermediate Good Production

C.3.1 Technology

Production technologies in country i, industry g takes a Cobb-Douglas form:

$$Q_{i,g} = Z_{i,g}\left(N_{i,g}^{\gamma_{i,g}} L_{i,g}^{1-\gamma_{i,g}}\right)^{\alpha_{i,g}} \left(M_{i,g}\right)^{1-\alpha_{i,g}}, \qquad g \in \mathcal{G};$$

where $Z_{i,g}$ is total factor productivity, $N_{i,g}$, $L_{i,g}$, and $M_{i,g}$ are, respectively, the use of labor, land, and intermediate inputs in industry g, and $\alpha_{i,g}$ is the value added share divided between land and labor with shares $\gamma_{i,g}$ and $(1-\gamma_{i,g})$. The intermediate input $M_{i,g}$ is an aggregate over all industries, which retains the same three-tier CES structure as final demand:

$$M_{i,g} = \left[\sum_{s\in\{A,M,S\}} b^I_{i,sg} M_{i,sg}^{\frac{\sigma^I-1}{\sigma^I}} \right]^{\frac{\sigma^I}{\sigma^I-1}}$$

$$M_{i,Ag} = \left[\sum_{k=1}^{K} b^I_{i,kg} M_{i,kg}^{\frac{\kappa^I-1}{\kappa^I}} \right]^{\frac{\kappa^I}{\kappa^I-1}}.$$

$$M_{i,g'g} = \left[\sum_{j=1}^{I} b_{ji,g} M_{ji,g'g}^{\frac{\eta^I-1}{\eta^I}} \right]^{\frac{\eta^I}{\eta^I-1}}, \qquad g \in \mathcal{G},$$

note that in the lowest tier, the shifters are shared with those of consumers. This implies that, in country i' market for each good g, households and industries have common international expenditure shares across supplying countries $j = 1..., I$.

Cost minimization implies that the marginal cost of producing good g in country i is given by:

$$c_{i,g} = \frac{1}{Z_{i,g}} \left(w_{i,g}^{\gamma_{i,g}} r_i^{1-\gamma_{i,g}} \right)^{\alpha_{i,g}} \left(P^I_{i,g} \right)^{1-\alpha_{i,g}}, \tag{C.34}$$

where $w_{i,g}$ is the wage rate in country $i-$industry g, r_i is the rental rate of land, and $P^I_{i,g}$ is the price of the composite intermediate input $M_{i,g}$.

C.3.2 Expenditure shares

Given our assumptions, the unit costs faced by producers in country i utilizing good $g \in \mathcal{G}$ as an intermediate input, $c_{i,g}$, coincide with those faced by final good consumers (equation (C.34)). So do the expenditure shares across sources within sector g, $\pi_{ij,g}$ (equation (C.25)) and goods prices, $p_{i,g}$ (equation (C.26)).

In turn, the CES input aggregators imply that intermediate input expenditure shares within agriculture equal

$$\beta^I_{i,kg} = b^I_{i,kg} \left(\frac{p_{i,k}}{P^I_{i,Ag}} \right) \qquad k \in \{1, ..., K\},$$

where

$$P^I_{i,Ag} = \left[\sum_{k=1}^{K} b^I_{i,kg} p^{1-\kappa}_{i,k}\right]^{\frac{1}{1-\kappa}}, \qquad P^I_{i,Mg} = p^I_{i,Mg}, \qquad P^I_{i,Sg} = p^I_{i,Sg} \forall g \in \mathcal{G}. \tag{C.35}$$

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

C.4 Land-Clearing and Landowners.

Land shares. Let z_i denote the share of agricultural land in total country area, z_i, and u_i represent the share of currently usable agricultural land:

$$z_i \equiv L_i/H_i, \qquad u_i \equiv U_i/L_i$$

Accordingly, the share of forest in total country area is given by $F_i/H_i = (1 - z_i)$, and the share of fallow land in total country area equals $O_i/H_i = z_i \times (1 - u_i)$.

Land-clearing sector. There are symmetric land-producing firms seeking to produce usable land by converting (i) forest or (ii) 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_i for new land regardless of its source.

The productivity in the land-clearing sector depends on the available stock of forest and fallow land. Usable land is generated by converting forest (F) and fallow land (O), which serve as specific factors, and employing labor as a variable input. The corresponding production technologies are expressed as:

$$Q^{FU}_{i,T} = \underbrace{\zeta_{i,F}\left(1 - z_i\right)^{\lambda_F}}_{J_i(z_i)} \left(N^{FU}_{i,T}\right)^{\gamma_F}, \qquad Q^{OU}_{i,T} = \underbrace{\zeta_{i,O}\left(z_i\left(1 - u_i\right)\right)^{\lambda_O}}_{\tilde{J}_i(z_i(1-u_i))} \left(N^{OU}_{i,T}\right)^{\gamma_O};$$

with total production and employment of the land-clearing sector given by:

$$Q_{i,T} = Q^{FU}_{i,T} + Q^{OU}_{i,T}$$

$$N_{i,T} = N^{FU}_{i,T} + N^{OU}_{i,T}. \tag{C.36}$$

In our specification, $J_i(.)$ and $\tilde{J}_i(.)$ represent the productivity of converting forest and fallow land into usable land, and $\{\gamma_F, \gamma_O\}$ denote the output elasticities with respect to labor —which are bounded between zero and one. Furthermore, $\{\zeta_{i,F}, \zeta_{i,O}\}$ are exogenous parameters, and $\{\lambda_F, \lambda_O\}$ are the elasticities of productivity $J_i(.)$ and $\tilde{J}_i(.)$ functions with respect to the available stock of forest and fallow land. The representative land-clearing producer treats these productivities as fixed and does not internalize the effects of its production decisions on them.

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 $w_{i,T}$

$$w_{i,T} = \gamma_O \zeta_{i,O} \times (z_i (1 - u_i))^{\lambda_O} \times \left(N_{i,T}^{OU}\right)^{\gamma_O - 1} \tag{C.37}$$

$$w_{i,T} = \gamma_F \zeta_{i,F} \times (1 - z_i)^{\lambda_F} \times \left(N_{i,T}^{FU}\right)^{\gamma_F - 1} \tag{C.38}$$

Moreover, since the two sub-sectors produce a homogenous usable land, they face the same price level q_i. Cost minimization implies that:

$$q_i = \frac{w_{i,T}}{\gamma_O \zeta_{i,O} \times (z_i (1 - u_i))^{\lambda_O}} \left(N_{i,T}^{OU}\right)^{1 - \gamma_O} \tag{C.39}$$

$$q_i = \frac{w_{i,T}}{\gamma_F \zeta_{i,F} \times (1 - z_i)^{\lambda_F}} \left(N_{i,T}^{FU}\right)^{1 - \gamma_F} \tag{C.40}$$

Free entry condition and value function of landowners. There is a continuum of landowners who are risk-neutral and have perfect foresight. Each of them owns one unit of usable land which can be rented out at a rate r_i. Landowners discount the future at a rate of ρ and, with arrival rates of δ_F and δ_O, each unit of usable land "depreciates", turning into forest and fallow land respectively. Let $v_{i,F}$ and $v_{i,O}$ 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, $v_{i,F} = v_{i,O} = v_i$, and the free entry condition requires:

$$v_i = q_i. \tag{C.41}$$

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

$$\rho v_i = r_i + \dot{v}_i - (\delta_O + \delta_F) \tag{C.42}$$

where r_i 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.

C.5 Sales, Expenditures and Market Clearing Conditions.

Country i's total sales in industry g equal:

$$Y_{i,g} = \sum_j \frac{\pi_{ij,g}}{1+t_{ij,g}} X_{j,g}, \qquad g \in \mathcal{G} \tag{C.43}$$

The expenditure, $X_{j,g}$,, is comprised of final and intermediate demand:[37]

$$X_{i,g} = \underbrace{\beta^F_{i,g} E_i}_{\text{final expenditure}} + \underbrace{\sum_{g' \in G} \beta^I_{i,g'g} \left(1-\alpha_{i,g'}\right) Y_{i,g'}}_{\text{intermediate expenditure}}. \tag{C.44}$$

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

$$w_{i,A} N_{i,A} = \sum_{k=1}^{K} \alpha_{i,k} \gamma_{i,k} Y_{i,k}, \quad w_{i,M} N_{i,M} = \alpha_{i,M} \gamma_{i,M} Y_{i,M}, \quad w_{i,S} N_{i,S} = \alpha_{i,S} \gamma_{i,S} Y_{i,S} \tag{C.45}$$

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

$$r_i U_i = \sum_{g \in \mathcal{G}} \alpha_{i,g} \left(1-\gamma_{i,g}\right) Y_{i,g} \tag{C.46}$$

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

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

$$E_i = r_i U_i + \sum_{s=\{A,M,S\}} w_{i,s} N_{i,s} + T_i, \tag{C.47}$$

where T_i is the country i's revenue from tariffs, which the government rebates to the con-

[37] In our framework, the service sector ($g = S$) also includes an international transportation industry, which uses the same production technology as other services and therefore has the same marginal cost and price. Demand for this industry comes from international trade, as a portion of trade costs are paid to the services it provides. Our specification and calibration of this feature are detailed in Appendix Section D.1. However, to avoid introducing burdensome notation, we present our quantitative model here without this component.

sumers as a lump sum:

$$T_i = \sum_{g\in\mathcal{G}} \sum_j \frac{t_{ji,g}}{1+t_{ji,g}} \pi_{ji,g} X_{i,g} \tag{C.48}$$

Accounting. Before we move on to the inter-temporal movement of flows, we demonstrate their accounting at any point in time. First, note that country i's national income, $E_i - T_i$, (from equation (C.47)), can be also expressed as:

$$E_i - T_i = (r_i U_i - q_i Q_{i,T}) \ + \ \Pi_{i,T} \ + \sum_{s=\{A,M,S,T\}} [w_{i,s} N_{i,s}]$$

In the right-hand of the first line, $(r_i U_i - q_i Q_{i,T})$ corresponds to (net) value added generated by land which equals gross payments to land, $r_i U_i$, net of purchases of new land, $q_i Q_{i,T}$. The second term, $\Pi_{i,T}$, corresponds to the value added generated by the specific factors employed in the land-clearing sector. The third term, which now includes $w_{i,A} N_{i,A}$ (as opposed to the comparable sum in equation (C.47)) is the value added generated by labor. This confirms that aggregate value added amounts to aggregate income.[38] Moreover, note that the market clearing conditions ensure that:[39]

$$E_i - T_i = \sum_g \alpha_{i,g} Y_{i,g} \tag{C.49}$$

Lastly, we show that the balance of trade holds. Let $X_{ij,g} = \frac{\pi_{ij,g}}{1+t_{ij,g}} X_{j,g}$denote country j's expenditure on country i's variety of good g. Then, country i's trade deficit can be expressed as:

$$\begin{aligned} D_i &= \textstyle\sum_{j\neq i,g} [X_{ij,g}] - \sum_{j\neq i,g} [X_{ji,g}] \\ &= \textstyle\sum_{j,g} [X_{ij,g}] - \sum_{j,g} [X_{ji,g}] \\ &= \textstyle\sum_g [Y_{i,g}] \ + \ T_i \ - \ \sum_g [X_{i,g}] \end{aligned}$$

where in the last line, $X_{i,g} = \sum_j [X_{ji,g}]$ denotes country i's total expenditure on g, and the

[38] To derive this expression replace $w_{i,A} N_{i,A} = \gamma_{i,T} q_i Q_{i,T}$ and $\Pi_{i,T} = (1-\gamma_{i,T}) q_i Q_{i,T}$ into equation C.47. Additionally, note that by replacing $q_i Q_i - \Pi_{i,T} = w_{i,A} N_{i,A}$, final expenditure can be equivalently expressed as:

$$E_i = (r_i U_i - w_{i,T} N_{i,T}) \ + \sum_{s=\{A,M,S,T\}} [w_{i,s} N_{i,s}] \ + \ T_i$$

where $r_i U_i - w_{i,T} N_{i,T}$ represents the net value added in land augmented with the specific factors that are used to generate land.

[39] Specifically, using equations C.45 and C.46,

$$\begin{aligned} E_i - T_i &= r_i U_i + \textstyle\sum_{s=\{M,S,T\}} w_{i,s} N_{i,s} \\ &= \textstyle\sum_g \alpha_{i,g} (1-\gamma_{i,g}) Y_{i,g} + \sum_g \alpha_{i,g} \gamma_{i,g} Y_{i,g} \\ &= \textstyle\sum_g \alpha_{i,g} Y_{i,g} \end{aligned}$$

entire line follows from the definition of sales, equation (C.43), and tariff revenues, equation (C.48),

$$\begin{aligned}\sum_{j,g} X_{ij,g} = &\sum_g \sum_j \tfrac{1}{1+t_{ij,g}} X_{ij,g} + \sum_g \sum_j \tfrac{t_{ji,g}}{1+t_{ji,g}} X_{ji,g} \\ &= \sum_g \left[Y_{i,g}\right] + T_i\end{aligned} \tag{C.50}$$

Using equation (C.50) and equation (C.44), trade deficits can be shown to be zero:

$$\begin{aligned} D_i &= \sum_g \left[\beta^F_{i,g} E_i + \sum_{g' \in G} \beta^I_{i,g'g} \left(1-\alpha_{i,g'}\right) Y_{i,g'}\right] - \left(\sum_g \left[Y_{i,g}\right] + T_i\right) \\ &= E_i + \sum_{g' \in G} \left(1-\alpha_{i,g'}\right) Y_{i,g'} - \sum_g Y_{i,g} - T_i \\ &= E_i - \sum_{g \in G} \left[\alpha_{i,g} Y_{i,g}\right] - T_i \\ &= 0 \end{aligned}$$

where the last line follows from equation (C.49).

C.6 Law of Motion for Labor and Land.

To keep track of worker reallocation across sectors, we define the matrix, $\mathbf{M}_i$, with elements $\mathbf{M}_i\left[s,s'\right] = \psi \mu_{i,ss'}$ if $s \neq s'$, and $\mathbf{M}_i\left[s,s'\right] = -\psi\left(1-\mu_{i,ss}\right)$ if $s = s'$.[40] In country i, the mass of workers in each sector evolves according to:

$$\dot{\mathbf{N}}_i = \mathbf{M}_i^T \mathbf{N}_i, \tag{C.51}$$

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 follows from the definition of the share of agricultural land in total country area, $z_i \equiv L_i/H_i$, and the share of usable land within the agricultural land, $u_i \equiv U_i/L_i$. Accordingly, the fallow land evolves according to:

$$\dot{O}_i = -Q^{OU}_{i,T} - \delta_F \overbrace{(1-u_i) z_i H}^{O_i} + \delta_O \overbrace{u_i z_i H_i}^{U_i}, \tag{C.52}$$

where $Q^{OU}_{i,T}$ is the out-flow from fallow land to usable land, $\delta_F O_i$ is the outflow from fallow land to forest, and $\delta_O U_i$ is the in-flow from the usable land to fallow land. Similarly, the forest area evolves according to:

$$\dot{F}_i = -Q^{FU}_{i,T} + \delta_F z_i H_i \tag{C.53}$$

[40] When population growth is nonzero, we alter the on-diagonal elements to $\mathbf{M}_i\left[s,s'\right] = -\psi\left(1-\mu_{i,ss}\right) + \delta^N_i$, 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.

where $\delta_F z_i H_i$ is the inflow to forest from usable and fallow land. The above two equations, in turn, pin down the law of motion for usable land:

$$\dot{U} = Q_{i,T}^{FU} + Q_{i,T}^{OU} - (\delta_O + \delta_F) u_i z_i H_i \tag{C.54}$$

Here, in contrast to the Stylized Model of Section 4, generically $\dot{U}_i \neq -\dot{F}$. 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.

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

C.7 Equilibrium

We break down the definition of equilibrium into two parts: a static and a dynamic equilibrium. Let $\mathbf{Z}(t) \equiv \{Z_{i,g}(t)\}_{i,g}$, $\mathbf{B} \equiv \left\{ \{b_{ij,g}\}_{i,j,g}, \{b_{i,k}\}_{i,k}, \{b_{i,s}\}_{i,s}, \{b_{i,k}^I\}_{i,k}, \{b_{i,s}^I\}_{i,s} \right\}, \Upsilon \equiv \left\{ \sigma, \kappa, \{\eta_g\}, \sigma^I, \kappa^I, \{\eta_g^I\} \right\}$, $\mathbf{T}(t) = \{d_{ij,g}(t)\}_{ij,g}$

Static Equilibrium. At any time t, given (i) technologies, iceberg trade costs and tariffs, and preferences, $\mathbf{Z}_t, \mathbf{T}_t, \mathbf{B}, \Upsilon$ (ii) labor allocations across sectors $\{N_{i,s}(t)\}_{i,s}$ and land stocks $\{U_i(t), O_i(t), F_i(t)\}_i$, and (iii) the price of new land $\{q_i(t)\}_i$, a static equilibrium consists of (i) factor rewards $\{w_{i,s}(t)\}_{i,s}$ and $\{r_i(t)\}_i$, (ii) labor allocations across land-clearing technologies $\{N_{i,T}^{FU}(t), N_{i,T}^{OU}(t)\}_i$, such that land markets clear (equation (C.46)), labor markets clear in each sector (equations (C.45) and (C.36)), and new land is priced at marginal cost (equation (C.39)).

Dynamic Equilibrium. Given (i) exogenous paths of technologies, iceberg trade costs and tariffs, and preferences, $[\mathbf{Z}(t), \mathbf{T}(t)]_t, \mathbf{B}, \Upsilon$, (ii) exogenous paths of labor supplies $[\{N_i(t)\}_i]$, (iii) initial land stocks, $\{U_i(0), O_i(0), F_i(0)\}_i$, a dynamic equilibrium consists of (i) paths of land prices and for the stocks of land $[\{q_i(t), U_i(t), O_i(t), F_i(t)\}_i]$ and (ii) paths of labor allocations across sectors $\left[\{N_{i,s}(t)\}_{i,s}\right]$, such that the paths of labor supplies and land stocks satisfy the corresponding laws of motion (equations (C.51), (C.52), (C.53), and (C.54)) and land prices reflect future rents (equation (C.42)).

D Details of Calibration

This section describes the details of our calibration of trade costs and social cost of carbon.

D.1 Trade costs

We begin by noting that, by model inversion, we have already recovered the level of trade cost from country i to country j for good g ($\tau_{ij,g}$). Here, we distinguish between the policy-related and non-policy-related components that make up overall trade costs. To do this, we represent the log value of total trade cost, $\ln \tau_{ij,g}$, which we estimate via gravity equations with origin and destination fixed effects, as the sum of policy and non-policy components:

$$\ln \tau_{ij,g} = \ln \tau_{ij,g}^{(\text{policy})} + \ln \tau_{ij,g}^{(\text{non-policy})}.$$

We make this distinction to calibrate effective ad valorem tariff rates in agriculture. This is because, in agricultural, the use of specific tariffs (which are levied as a fixed amount per unit rather than as a percentage of value) is common, and standard data sources often have missing or incomplete tariff information. As a result, the ad valorem tariff rates that are typically reported do not provide an accurate measure of the effective ad valorem tariff levels faced by agricultural products.

In this specification, the policy component $\ln \tau_{ij,g}^{(\text{policy})}$ includes trade barriers that are influenced by government actions, including unweighted average tariff rates corresponding to origin $i-$destination $j-$sector g, $X_{ij,g}^{(\text{T})} = \ln(1 + \text{tariff}_{ij,g})$, and other non-tariff barriers such as an indicator for free trade agreements, import fees beyond tariffs, and days to import, which we include in $\boldsymbol{X}_{ij,g}^{(\text{NT})}$,

$$\ln \tau_{ij,g}^{(\text{policy})} = \beta^{(\text{T})} X_{ij,g}^{(\text{T})} + \beta^{(\text{NT})} \boldsymbol{X}_{ij,g}^{(\text{NT})}.$$

The non-policy component, $\tau_{ij,g}^{(\text{non-policy})}$, captures usual gravity variables such as geographic distance, language differences, and an indicator for sharing a common borders, which we incorporate in $\boldsymbol{X}_{ij,g}^{(\text{gravity})}$. Together with unobserved factors, $\epsilon_{ij,g}$, the non-policy component can be specified as:

$$\ln \tau_{ij,g}^{(\text{non-policy})} = \gamma^{(\text{gravity})} \boldsymbol{X}_{ij,g}^{(\text{gravity})} + \epsilon_{ij,g}$$

Putting together, we run a regression of $\ln \tau_{ij,g}$ against policy (tariff and non-tariff trade barriers) and non-policy variables (gravity measures). From that regression, we recover the component of trade costs predicted by policy, which we define as $\widehat{\ln \tau_{ij,g}^{(\text{policy})}}$ as well as the non-policy component $\widehat{\ln \tau_{ij,g}^{(\text{non-policy})}}$.

Next, we express our estimates of the policy-related component of trade costs as the sum of tariff component $\tau_{ij,g}^{(\text{T})}$—where $t_{ij,g}$ represents the effective ad valorem tariff rate—and non-tariff, iceberg component $\tau_{ij,g}^{(\text{NT})}$,

$$\ln \widehat{\tau_{ij,g}^{(\text{policy})}} = \ln \tau_{ij,g}^{(\text{policy T})} + \ln \tau_{ij,g}^{(\text{policy NT})}.$$

We proceed with an analogous decomposition of the non-policy term

$$\ln \widehat{\tau_{ij,g}^{(\text{non-policy})}} = \ln \tau_{ij,g}^{(\text{non-policy T})} + \ln \tau_{ij,g}^{(\text{non-policy NT})}.$$

where $\ln \tau_{ij,g}^{(\text{non-policy T})}$ captures a non ad-valorem, additive transportation term paid in terms of the service sector $p_{i,S}$ and an iceberg term $\ln \tau_{ij,g}^{(\text{non-policy NT})}$.

To pin down the level of $\tau_{ij,g}^{(\text{policy T})}$, we let the ratio of tariff to non-tariff component be common, $\kappa^{(\text{policy})} = \left(\tau_{ij,g}^{(\text{policy T})}/\tau_{ij,g}^{(\text{policy NT})}\right)$. Given our estimate of $\ln \widehat{\tau_{ij,g}^{(\text{policy})}}$, each choice of $\kappa^{(\text{policy})}$ gives a particular value of $\ln \tau_{ij,g}^{(\text{policy T})}$. We choose $\kappa^{(\text{policy})}$ such that the global tariff revenue from the resulting $\tau_{ij,g}^{(\text{policy T})}$ match the observed value of the sum of tariff revenue globally relative to the sum of total imports in the data, which equals 0.027. This calibration pins down $\tau_{ij,g}^{(\text{T})} = (1 + t_{ij,g})$. The median ad-valorem tariffs in agriculture that we find using this approach for $i \neq j$ is 10.4 percent.

To pin down the level of $\tau_{ij,g}^{(\text{non-policy T})}$, we set $\kappa^{(\text{non-policy})} = \left(\tau_{ij,g}^{(\text{non-policy T})}/\tau_{ij,g}^{(\text{non-policy NT})}\right)$ and choose $\kappa^{(\text{non-policy})}$ such that the model matches the ratio of the revenues from international transportation relative to total revenues of the service sector, which equals 0.006. We find that, in average, for every unit of agricultural good exported, 0.09 units of the service good have to be purchased.

D.2 Social Cost of Carbon

This section shows how we calibrate the social cost of carbon used in our analysis of Section 8.3. Using a simplified notation, we express the global climate-adjusted welfare as:

$$W(t) = C(t) - \varphi Z(t),$$

where $C(t)$ is the real consumption at the aggregate level of the world, φ is a parameter governing the global damage from emissions, and $Z(t)$ is the stock of accumulated emissions at time t.

We suppose the global climate-adjusted welfare is $C = \prod_i \left(\frac{C_i}{\alpha_i}\right)^{\alpha_i}$, with C_i denoting country i's real consumption and α_i its associated weight, which, in practice, we set to country i's share of global GDP. The globally-optimal carbon tax, which corresponds to the social cost of CO_2 (SC-CO_2), is equal to $P \times \varphi$ where $P = \prod_i P_i^{\alpha_i}$ denotes the global price index corresponding to C–see Appendix C in Farrokhi and Lashkaripour (2024).

Connecting the values in the model to those in data, and since we use the US GDP in the year 2010 as the numeraire, we can recover φ as follows:

$$\varphi = \frac{Y_{USA}}{Y_{USA}^{(data)}} \times (\text{SC-CO}_2) \times \frac{1}{P},$$

In our main specification, we set SC-CO_2 equal to 200 dollars per ton of CO_2 in line with the recent estimates in the literature and the EPA. Adding time indices and taking differences between the equilibrium path under a policy scenario relative to the BAU, we have:

$$\Delta W(t) = \Delta C(t) - \varphi \times \Delta Z(t).$$

Therefore, the change in present discounted value of the climate adjusted welfare at the global level is:

$$\int e^{-\rho t} \Delta W(t)\, \mathrm{d}t = \int e^{-\rho t} \Delta C(t)\, \mathrm{d}t - \varphi \int e^{-\rho t} \Delta Z(t)\, \mathrm{d}t,$$

where $\Delta Z\,(t)$ is the flow of emissions at time t. In our calculations we report the left-hand side of the expression above.

Our calibration requires an adjustment in scenarios with population growth. Specifically, as population $L(t)$ rises, per period aggregate real consumption and aggregate climate costs increase proportionally, but these future increases must be discounted when computing the present value of their corresponding gains and costs. With a population growth rate $n < \rho$,[41] the discounted climate cost, relative to the no-population-growth case, scales up by a ratio of $\rho/(\rho - n)$. We incorporate this adjustment in calculating climate-adjusted welfare in scenarios with population growth.

E The impact of a 30-percent reduction in iceberg trade costs

We contrast now two counterfactual scenarios, both of them involving 30-percent reductions in iceberg agricultural trade costs. In the first scenario, we only reduce the trade costs faced by Brazil; in the second, we reduce trade costs globally. These results allow us to highlight

[41] The condition $n < \rho$ empirically holds. While we set $\rho = 0.05$, according to the UN, world population is projected to grow from 7.8 billion to 10.2 billion between 2020 and 2100, implying an annual growth rate of 0.34% or 0.0034.

the importance of general equilibrium adjustments, in light of Propositions 1 and 2.

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 F.14 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.[42]

Counterfactual #1: Reduction in Brazil's export costs. We begin by considering a 30 percent reduction in iceberg trade costs of agricultural goods produced in Brazil.[43] As shown in Figure F.14, Panel (b) global forest area increases over time, but barely. Figure F.14, Panel (c) disaggregates this global trend into the experiences of selected individual countries, and Appendix Table F.4 presents the details. The reason global forest area grows is that, although Brazil's forest (as share of country area) drops by about 1 percentage points, regrowth in the rest of the world, dominates Brazil's response in the aggregate.

Counterfactual #2: Global trade cost reductions.

#2: Global trade cost reductions. Compare this outcome with that following a 30% reduction in trade costs of agricultural goods across all countries. In this case, the global forest share would grow by 2.5 percentage points in the steady state following the multilateral trade cost reduction.

The stark contrast between these two scenarios highlights a key message of our paper: global trade cost reductions can increase forest cover, which is the opposite of the impact of a trade cost reduction targeted to an individual country on its own forest. As highlighted in Propositions 1 and 2, this result follows because the elasticity of land demand at the country level is large—and driven by the trade elasticity—and that at the global level is small—and driven by the substitution between broad sectors of the economy.

Note also that in our counterfactual #2, there is wide dispersion in the responses across different countries (Figure F.14, Panel (d) and Appendix Table F.4). These responses reflect that in the aftermath of a global trade cost reduction, comparative advantage determines the specialization of countries across sectors. We return to this issue in more detail in our

[42] 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 8.2, we incorporate population growth into an alternative BAU scenario and evaluate how it affects our quantitative conclusions.

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

next exercise. Figure F.14, Panel (d) also shows that the average half-life of the shock across countries is 28 years: since (i) some countries tend to reforest and forest regrowth takes time, and (ii) the land use across countries is linked through international trade, deforestation cannot be too quick, resulting in a slow convergence to the steady state.

F Additional Tables and Figures

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

Country	% of Global Forest (1)	% area in 1990 Forest (2)	% area in 1990 Utilized (3)	Change in Forest % (4)	Change in Forest p.p. (5).	Change in Forest Total (6)	% of Global Deforestation (7)
Russia	19.50	51	61	0.02	0.01	0.13	-0.05
Brazil	14.33	68	99	-17.07	-11.68	-99.94	34.32
Canada	8.41	39	45	-4.33	-1.68	-14.89	5.11
Central Africa	7.54	60	70	-13.44	-8.01	-41.36	14.21
USA	6.97	41	73	-0.79	-0.32	-2.24	0.77
Rest of Asia	4.54	26	68	-9.58	-2.45	-17.76	6.10
Australia	3.25	29	62	-0.94	-0.27	-1.24	0.43
Indonesia	2.90	59	91	-26.01	-15.43	-30.79	10.58
China	2.77	13	69	19.73	2.52	22.29	-7.66
Other Africa	2.62	22	54	-17.41	-3.87	-18.61	6.39
Rest of America	2.55	47	72	-5.16	-2.45	-5.38	1.85
Rest of West Africa	1.91	18	41	-21.50	-3.86	-16.78	5.76
Peru	1.87	66	75	-6.49	-4.29	-4.94	1.70
Rest of Europe	1.79	25	77	5.56	1.41	4.07	-1.40
Mexico	1.73	47	87	-7.03	-3.33	-4.96	1.70
Colombia	1.59	69	99	-9.48	-6.58	-6.15	2.11
India	1.43	15	87	1.15	0.17	0.67	-0.23
Bolivia	1.41	68	82	-12.14	-8.31	-7.01	2.41
Tanzania	1.39	64	100	-20.49	-13.06	-11.65	4.00
Venezuela	1.26	63	82	-13.04	-8.27	-6.73	2.31
Zambia	1.16	82	89	-5.48	-4.51	-2.59	0.89
Mozambique	1.06	89	100	-15.39	-13.62	-6.67	2.29
Argentina	0.84	14	56	-21.20	-2.92	-7.30	2.51
Sweden	0.69	67	78	-0.30	-0.20	-0.08	0.03
Nigeria	0.64	26	97	-18.47	-4.76	-4.85	1.67
Paraguay	0.63	64	100	-37.55	-23.93	-9.59	3.29
Rest of Mena	0.57	3	11	6.88	0.18	1.60	-0.55
Cameroon	0.55	44	69	-9.80	-4.32	-2.20	0.76
Finland	0.54	69	80	2.44	1.69	0.53	-0.18
Turkey	0.47	26	76	11.78	3.07	2.27	-0.78
Ethiopia	0.46	15	74	-16.14	-2.40	-3.05	1.05
Malaysia	0.46	57	83	-6.78	-3.87	-1.27	0.44
Zimbabwe	0.46	58	79	-7.16	-4.13	-1.34	0.46
Thailand	0.43	30	82	-7.40	-2.25	-1.31	0.45
Japan	0.36	47	81	0.60	0.28	0.09	-0.03
France	0.32	22	83	14.69	3.26	1.92	-0.66
Spain	0.29	27	87	33.64	9.13	4.02	-1.38
Italy	0.17	22	85	26.34	5.75	1.86	-0.64
Germany	0.14	15	85	1.05	0.16	0.06	-0.02
United Kingdom	0.01	2	84	0.00	0.00	0.00	0.00
World	100.00	36	65	-7.13	-2.59	-291.17	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 a country's share of forest area and Column 3 a country's share of utilized land—that is, share of land that is not fallow. Column 4 shows the change in forest area in percent, in percentage points, and in total area (millions of hectares) . The last column shows the share of global deforestation coming from that country.

Table F.3: Summary Statistics by Country (1990-2020) - First Part

	% of Global	% area in 1990		Change in Forest			% of Global
	Forest	Forest	Utilized	%	p.p.	Total	Deforestation
Country	(1)	(2)	(3)	(4)	(5).	(6)	(7)
Russia	19.50	51	61	0.02	0.01	0.13	-0.05
Brazil	14.33	68	99	-17.07	-11.68	-99.94	34.32
Canada	8.41	39	45	-4.33	-1.68	-14.89	5.11
USA	6.97	41	73	-0.79	-0.32	-2.24	0.77
DRC	3.69	70	77	-16.26	-11.40	-24.48	8.41
Australia	3.25	29	62	-0.94	-0.27	-1.24	0.43
Indonesia	2.90	59	91	-26.01	-15.43	-30.79	10.58
China	2.77	13	69	19.73	2.52	22.29	-7.66
Angola	1.92	92	100	-15.97	-14.76	-12.50	4.29
Peru	1.87	66	75	-6.49	-4.29	-4.94	1.70
Mexico	1.73	47	87	-7.03	-3.33	-4.96	1.70
Colombia	1.59	69	99	-9.48	-6.58	-6.15	2.11
India	1.43	15	87	1.15	0.17	0.67	-0.23
Bolivia	1.41	68	82	-12.14	-8.31	-7.01	2.41
Tanzania	1.39	64	100	-20.49	-13.06	-11.65	4.00
Venezuela	1.26	63	82	-13.04	-8.27	-6.73	2.31
Zambia	1.16	82	89	-5.48	-4.51	-2.59	0.89
Mozambique	1.06	89	100	-15.39	-13.62	-6.67	2.29
Myanmar	0.96	47	81	-28.25	-13.17	-11.07	3.80
Papua New Guinea	0.89	79	83	-1.50	-1.19	-0.54	0.19
Argentina	0.84	14	56	-21.20	-2.92	-7.30	2.51
Central Africa	0.81	28	47	-3.71	-1.06	-1.22	0.42
Sweden	0.69	67	78	-0.30	-0.20	-0.08	0.03
Nigeria	0.64	26	97	-18.47	-4.76	-4.85	1.67
Paraguay	0.63	64	100	-37.55	-23.93	-9.59	3.29
Gabon	0.58	98	100	-0.97	-0.95	-0.23	0.08
Sudan	0.57	14	48	-22.26	-3.20	-5.22	1.79
Cameroon	0.55	44	69	-9.80	-4.32	-2.20	0.76
Republic of Congo	0.54	91	95	-1.66	-1.51	-0.37	0.13
Finland	0.54	69	80	2.44	1.69	0.53	-0.18
Turkey	0.47	26	76	11.78	3.07	2.27	-0.78
Ethiopia	0.46	15	74	-16.14	-2.40	-3.05	1.05
Botswana	0.46	57	64	-18.87	-10.69	-3.55	1.22
Malaysia	0.46	57	83	-6.78	-3.87	-1.27	0.44
Zimbabwe	0.46	58	79	-7.16	-4.13	-1.34	0.46
Guyana	0.46	97	100	-1.00	-0.97	-0.19	0.06
Thailand	0.43	30	82	-7.40	-2.25	-1.31	0.45
South Africa	0.40	7	17	-6.04	-0.40	-0.99	0.34
Laos	0.40	71	84	-8.70	-6.16	-1.41	0.49
Suriname	0.38	97	99	-1.19	-1.15	-0.18	0.06
Japan	0.36	47	81	0.60	0.28	0.09	-0.03
Ecuador	0.36	56	80	-15.09	-8.43	-2.20	0.76
Mongolia	0.35	30	69	-1.27	-0.38	-0.18	0.06
Chile	0.33	22	31	10.49	2.28	1.43	-0.49
Madagascar	0.33	42	75	-9.99	-4.16	-1.34	0.46
Mali	0.33	13	23	-4.24	-0.57	-0.56	0.19
France	0.32	22	83	14.80	3.27	1.91	-0.66
Norway	0.30	32	38	-0.49	-0.16	-0.06	0.02
Spain	0.29	27	87	33.64	9.13	4.02	-1.38
Mena	0.29	3	14	11.47	0.38	1.34	-0.46
Cambodia	0.27	58	88	-31.75	-18.57	-3.47	1.19
Ghana	0.24	49	99	-22.13	-10.94	-2.19	0.75
Senegal	0.23	53	94	-13.32	-7.06	-1.23	0.42
Poland	0.22	27	91	6.77	1.86	0.60	-0.21
Namibia	0.21	19	26	-24.29	-4.54	-2.13	0.73
Vietnam	0.21	21	60	19.27	4.05	1.66	-0.57
Liberia	0.21	95	100	-10.95	-10.42	-0.93	0.32
Somalia	0.20	34	56	-27.81	-9.51	-2.30	0.79
Other South America	0.20	96	98	-1.50	-1.44	-0.12	0.04
Cote Divoire	0.19	30	81	-64.01	-19.41	-5.02	1.72
New Zealand	0.19	35	97	-0.42	-0.15	-0.03	0.01
Burkina Faso	0.19	24	68	-21.59	-5.24	-1.66	0.57
Phillipines	0.18	22	68	-9.08	-2.00	-0.68	0.23
Guinea	0.18	33	86	-15.26	-4.98	-1.10	0.38
Italy	0.17	22	85	26.34	5.75	1.86	-0.64
Honduras	0.17	60	92	-8.99	-5.44	-0.63	0.22
Chad	0.16	6	32	-36.11	-2.31	-2.43	0.83
Belarus	0.16	36	84	-0.32	-0.11	-0.02	0.01
Nicaragua	0.16	50	87	-47.78	-23.90	-3.06	1.05
Romania	0.14	28	91	3.27	0.91	0.19	-0.07
North Korea	0.14	47	79	-12.79	-5.98	-0.74	0.25
Germany	0.14	15	85	1.05	0.16	0.06	-0.02
Nepal	0.14	27	78	2.82	0.76	0.16	-0.05
Morocco	0.13	20	67	-1.15	-0.22	-0.06	0.02
Oceania	0.13	61	74	1.35	0.83	0.07	-0.02

Table F.4: 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	0.08	-0.33	-1.33	0.07	-0.26	39.3
AUS	Australia	-0.00	0.31	-1.65	-7.91	0.28	-1.58	94.6
BOL	Bolivia	-0.00	0.14	0.52	-7.25	0.13	0.56	73.1
BRA	Brazil	-0.00	-3.53	-1.12	0.08	-3.74	-1.20	-7.7
CAN	Canada	-0.00	0.37	-2.08	-6.44	0.28	-1.62	67.5
CHN	China	-0.00	0.28	1.96	1.57	0.26	1.99	-20.4
CMR	Cameroon	-0.00	0.10	-0.06	-18.08	0.05	0.08	343.6
COL	Colombia	-0.00	0.14	0.42	-0.31	0.14	0.22	-0.0
DEU	Germany	-0.00	0.15	-0.37	-0.55	0.14	-0.38	-8.6
ESP	Spain	-0.00	0.23	-0.92	1.33	0.27	-1.23	-28.7
ETH	Ethiopia	-0.00	0.02	-0.01	-5.40	0.01	-0.04	235.9
FIN	Finland	-0.00	0.32	-0.87	-0.18	0.30	-0.94	-2.0
FRA	France	-0.00	0.23	-0.41	-1.71	0.22	-0.83	3.0
GBR	United Kingdom	0.02	0.01	-0.06	-0.11	0.01	-0.06	24.4
IDN	Indonesia	-0.00	0.29	3.03	-2.95	0.25	3.05	32.6
IND	India	-0.00	0.05	1.57	-0.91	0.05	1.61	17.2
ITA	Italy	-0.00	0.19	-0.31	2.08	0.20	-0.65	-32.5
JPN	Japan	-0.00	0.19	1.19	6.89	0.26	0.98	-41.5
MEX	Mexico	-0.00	0.17	0.14	-2.43	0.15	0.14	24.0
MOZ	Mozambique	-0.00	0.84	5.33	-22.73	0.47	3.86	425.5
MYS	Malaysia	-0.00	0.20	0.32	-3.78	0.17	0.35	42.1
NGA	Nigeria	-0.00	0.00	0.07	-10.83	0.00	0.04	362.4
PER	Peru	-0.00	0.06	1.32	-3.43	0.06	1.39	34.9
PRY	Paraguay	-0.00	0.15	-1.05	-4.46	0.16	-0.82	39.8
RUS	Russia	-0.00	0.29	1.13	-0.32	0.30	0.44	-11.7
SWE	Sweden	-0.00	0.34	-2.43	-4.68	0.38	-2.54	38.9
THA	Thailand	-0.00	0.36	0.70	3.85	0.33	0.54	-31.5
TUR	Turkey	-0.00	0.21	0.56	-2.00	0.20	0.34	19.1
TZA	Tanzania	-0.00	0.04	1.45	-23.94	0.03	0.93	544.1
USA	USA	-0.00	0.31	-1.01	-2.82	0.23	-0.87	40.3
VEN	Venezuela	-0.00	0.26	1.02	-2.29	0.23	1.01	20.4
XAM	Rest of America	-0.00	0.21	-0.16	-2.69	0.18	-0.13	29.3
XAS	Rest of Asia	-0.00	0.16	1.63	-2.39	0.14	1.64	49.6
XCF	Central Africa	-0.00	0.43	4.25	-21.05	0.28	3.04	468.1
XEU	Rest of Europe	-0.00	0.16	0.05	0.94	0.18	-0.37	-26.0
XMN	Rest of Mena	-0.00	0.09	1.21	-2.39	0.07	0.91	98.7
XOF	Other Africa	-0.00	0.07	1.31	-6.29	0.04	0.76	249.8
XWF	Rest of West Africa	-0.00	0.07	0.17	-9.64	0.03	0.12	405.5
ZMB	Zambia	-0.00	0.05	-0.31	-25.61	0.04	-0.47	499.3
ZWE	Zimbabwe	-0.00	0.12	0.94	-11.67	0.12	0.81	143.9
World		-0.00	-0.07	0.55	-3.97	-0.12	0.35	40.0

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

	% of Global	% area in 1990		Change in Forest			% of Global
	Forest	Forest	Utilized	%	p.p.	Total	Deforestation
Country	(1)	(2)	(3)	(4)	(5).	(6)	(7)
Benin	0.12	35	70	-35.47	-12.35	-1.71	0.59
Guatemala	0.12	38	87	-29.04	-10.97	-1.38	0.47
Pakistan	0.12	4	68	-26.64	-1.09	-1.26	0.43
Ukraine	0.12	9	87	2.87	0.27	0.13	-0.05
South Korea	0.11	44	91	-13.32	-5.85	-0.62	0.21
Panama	0.11	65	90	-9.75	-6.31	-0.45	0.15
Turkmenistan	0.10	24	57	0.00	0.00	0.00	0.00
Balkans	0.10	33	84	26.07	8.64	1.06	-0.36
Kenya	0.09	7	50	-6.68	-0.47	-0.25	0.08
Uganda	0.08	13	82	-45.01	-6.04	-1.53	0.53
Portugal	0.08	39	79	-2.56	-1.01	-0.09	0.03
Malawi	0.08	32	84	-35.59	-11.45	-1.20	0.41
Greece	0.08	30	97	18.30	5.48	0.58	-0.20
Sierra Leone	0.08	52	79	-19.44	-10.13	-0.61	0.21
Costa Rica	0.07	57	100	2.34	1.33	0.07	-0.02
Latvia	0.07	51	91	3.03	1.53	0.09	-0.03
Georgia	0.07	44	84	1.93	0.86	0.05	-0.02
Kazakhstan	0.06	3	49	14.69	0.43	0.39	-0.13
Czech Republic	0.06	26	87	1.81	0.48	0.05	-0.02
Bhutan	0.06	53	63	8.72	4.66	0.22	-0.07
Serbia	0.06	24	89	14.64	3.45	0.33	-0.11
Guinea-Bissau	0.05	69	100	-11.37	-7.89	-0.25	0.09
Bosnia	0.05	49	84	-1.00	-0.49	-0.02	0.01
Sri Lanka	0.05	29	78	-11.00	-3.21	-0.23	0.08
Austria	0.05	29	79	9.37	2.72	0.19	-0.07
Estonia	0.05	47	85	10.54	4.92	0.21	-0.07
Niger	0.05	2	20	-49.54	-0.82	-0.94	0.32
Bangladesh	0.05	5	98	-6.49	-0.30	-0.12	0.04
Hungary	0.04	20	92	13.18	2.64	0.24	-0.08
Croatia	0.04	31	77	6.42	1.97	0.11	-0.04
Cuba	0.04	17	81	58.35	9.65	1.00	-0.34
Belize	0.04	68	76	-20.23	-13.80	-0.32	0.11
Dominican Republic	0.04	27	88	24.16	6.46	0.38	-0.13
Lithuania	0.04	26	84	3.65	0.95	0.06	-0.02
Uzbekistan	0.03	4	61	4.92	0.22	0.07	-0.02
Togo	0.03	27	82	-14.34	-3.86	-0.19	0.07
West Africa	0.03	2	6	-16.68	-0.30	-0.20	0.07
Afghanistan	0.03	3	34	0.00	0.00	0.00	0.00
Slovakia	0.03	29	88	1.17	0.34	0.01	-0.00
Eritrea	0.03	16	78	-11.25	-1.84	-0.13	0.04
West Europe	0.03	23	71	14.38	3.36	0.15	-0.05
Kyrgyzstan	0.02	9	29	11.12	0.97	0.11	-0.04
Timor Leste	0.02	63	86	-4.36	-2.76	-0.04	0.01
Caribbean	0.02	42	61	-1.89	-0.79	-0.02	0.01
Macedonia	0.02	41	86	9.81	4.05	0.09	-0.03
Albania	0.02	28	70	0.01	0.00	0.00	-0.00
El Salvador	0.02	25	100	-20.13	-5.08	-0.14	0.05
Azerbaijan	0.02	10	57	26.74	2.59	0.17	-0.06
Uruguay	0.01	4	87	42.21	1.81	0.25	-0.09
Denmark	0.01	10	87	18.25	1.89	0.10	-0.03
Jamaica	0.01	45	92	14.83	6.68	0.08	-0.03
Tunisia	0.01	4	49	-0.57	-0.03	-0.00	0.00
Gambia	0.01	31	99	-41.66	-13.02	-0.17	0.06
Brunei	0.01	76	81	-9.04	-6.90	-0.04	0.01
Haiti	0.01	10	80	-15.00	-1.44	-0.06	0.02
Netherlands	0.01	6	81	7.00	0.42	0.02	-0.01
United Kingdom	0.01	2	84	0.00	0.00	0.00	0.00
Armenia	0.01	13	44	-3.43	-0.46	-0.01	0.00
Puerto Rico	0.01	27	89	54.94	14.91	0.18	-0.06
Swaziland	0.01	27	98	33.06	9.06	0.10	-0.03
Tajikistan	0.01	3	22	3.77	0.10	0.01	-0.00
Belgium	0.01	5	77	8.70	0.44	0.02	-0.01
Libya	0.01	0	2	0.00	0.00	0.00	0.00
Rwanda	0.00	5	93	-38.24	-1.96	-0.08	0.03
East Africa	0.00	25	76	-4.87	-1.23	-0.01	0.00
Moldova	0.00	6	87	-6.31	-0.38	-0.01	0.00
Ireland	0.00	1	90	32.68	0.34	0.03	-0.01
Egypt	0.00	0	9	2.67	0.00	0.00	-0.00
Central America	0.00	36	76	-3.32	-1.19	-0.00	0.00
Lesotho	0.00	2	57	0.00	0.00	0.00	0.00
Singapore	0.00	15	48	5.01	0.77	0.00	-0.00
Iceland	0.00	0	4	12.18	0.02	0.00	-0.00
Djibouti	0.00	0	15	0.00	0.00	0.00	0.00
Maldives	0.00	3	30	0.00	0.00	0.00	0.00
Other Northern Europe	0.00	0	5	0.00	0.00	0.00	0.00
World	100.00	36	65	-7.13	-2.58	-291.17	100.00

Table F.6: The Relationship between Population Growth and Forest Area (30 years interval)

	OLS (1)	OLS (2)	OLS (3)	IV (4)	IV (5)	IV (6)
a. DV is the log of forest area						
$s^{\text{Own}} \times \Delta$ Log(Own Pop)	-0.428***	-0.450***	-0.349***	-0.516***	-0.523***	-0.391***
	(0.061)	(0.064)	(0.071)	(0.061)	(0.063)	(0.076)
$s^{\text{Partner}} \times \Delta$ Log(Partner Pop)	-0.655***	-0.849***	-0.624***	-0.850***	-0.982***	-0.694***
	(0.223)	(0.209)	(0.220)	(0.237)	(0.216)	(0.251)
R2 or K-P	0.290	0.329	0.361	67.828	69.616	49.170
Obs	150	150	150	150	150	150
b. DV is the log of agricultural area						
$s^{\text{Own}} \times \Delta$ Log(Own Pop)	1.124***	1.096***	0.818***	1.211***	1.172***	0.647***
	(0.099)	(0.105)	(0.114)	(0.098)	(0.102)	(0.125)
$s^{\text{Partner}} \times \Delta$ Log(Partner Pop)	1.626***	1.575***	0.843	1.960***	1.883***	0.629
	(0.530)	(0.532)	(0.569)	(0.605)	(0.607)	(0.609)
R2 or K-P	0.464	0.474	0.542	67.828	69.616	49.170
Obs	150	150	150	150	150	150
Controls (Initial period value in logs)						
- Share of Agricultural area	-	Y	Y	-	Y	Y
- Share of Forest area	-	Y	Y	-	Y	Y
- Natural reserve area	-	-	Y	-	-	Y
- GDP p.c.	-	-	Y	-	-	Y

Notes: * / ** / *** denotes significance at the 10 / 5 / 1 percent level. Robust standard errors clustered at the country level in parenthesis. Instrument in columns (4) to (6) are (1) the log of the median age of the population, (2) the birth rate, and (3) the average age of child bearing in the baseline year. Kleinberg-Paap weak instrument statistic is reported in columns (4) to (6) instead of R2.

Table F.7: The Relationship between Population Growth and Fallow Land (30 years interval)

	OLS (1)	OLS (2)	OLS (3)	IV (4)	IV (5)	IV (6)
a. DV is the log of fallow land						
$s^{\text{Own}} \times \Delta$ Log(Own Pop)	0.551	0.757**	0.613	0.505	0.646**	0.150
	(0.407)	(0.368)	(0.591)	(0.348)	(0.304)	(0.702)
$s^{\text{Partner}} \times \Delta$ Log(Partner Pop)	8.973**	9.366***	9.114***	8.521**	9.054***	8.429***
	(3.628)	(3.251)	(3.175)	(3.339)	(2.847)	(2.958)
R2 or K-P	0.167	0.332	0.336	34.995	32.726	12.313
Obs	40	40	40	40	40	40
Controls (Initial period value in logs)						
- Share of Agricultural area	-	Y	Y	-	Y	Y
- Share of Forest area	-	Y	Y	-	Y	Y
- Natural reserve area	-	-	Y	-	-	Y
- GDP p.c.	-	-	Y	-	-	Y

Notes: * / ** / *** denotes significance at the 10 / 5 / 1 percent level. Robust standard errors clustered at the country level in parenthesis. Instrument in columns (4) to (6) are (1) the log of the median age of the population, (2) the birth rate, and (3) the average age of child bearing in the baseline year. Kleinberg-Paap weak instrument statistic is reported in columns (4) to (6) instead of R2.

Table F.8: Domestic vs Foreign Pop Shock

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

Notes: * / ** / *** denotes significance at the 10 / 5 / 1 percent level. Robust standard errors clustered at the country level in parenthesis. Column (1) shows the reduced-form impact of population growth in the actual data, as reported in our Empirical Fact 4. Column (2) presents the reduced-form impact of population growth using the data generated by our model when we introduce the population growth projected by United Nations.

Table F.9: Costs and Benefits of A 10x Hike in Agricultural Tariffs

	(1)	(2)	(3)	(4)
Panel A: Brazil				
Climate Costs (as fraction of US GDP)	0.000	0.816	1.427	-2.456
Welfare gains (percentual change)	-0.127	-0.129	-0.130	-0.015
Panel B: All countries				
Climate Costs (as fraction of US GDP)	0.000	7.514	13.150	3.194
Welfare gains (percentual change)	-0.198	-0.217	-0.231	-0.226
Panel C: All countries ($\sigma = 1.5$)				
Climate Costs (as fraction of US GDP)	0.000	-4.948	-8.659	-30.818
Welfare gains (percentual change)	0.831	0.843	0.851	0.881
Economic Assumptions				
- SCC = 0	Y	-	-	-
- SCC = 200	-	Y	-	-
- SCC = 350	-	-	Y	Y
- Population Growth	-	-	-	Y

Table F.10: SSC - Tariff to 0 - No sequestration

	(1)	(2)	(3)	(4)
Panel A: Brazil				
Climate Costs (as fraction of US GDP)	0.000	1.977	3.460	4.827
Welfare gains (percentual change)	-0.090	-0.100	-0.107	-0.009
Panel B: All countries				
Climate Costs (as fraction of US GDP)	0.000	8.788	15.380	4.535
Welfare gains (percentual change)	0.131	0.086	0.053	0.159
Panel C: All countries ($\sigma = 1.5$)				
Climate Costs (as fraction of US GDP)	0.000	37.456	65.548	67.763
Welfare gains (percentual change)	1.267	1.144	1.052	-0.171
Economic Assumptions				
- SCC = 0	Y	-	-	-
- SCC = 200	-	Y	-	-
- SCC = 350	-	-	Y	Y
- Population Growth	-	-	-	Y

Table F.11: Costs and Benefits of Eliminating Agricultural Tariffs with Low Persistence

	(1)	(2)	(3)	(4)
Panel A: Brazil				
Environmental Costs (as fraction of US GDP)	0.000	1.067	1.155	5.776
Welfare gains (percentual change)	0.014	0.008	0.007	-0.014
Panel B: All countries ($\sigma = 0.5$)				
Environmental Costs (as fraction of US GDP)	0.000	7.055	0.743	3.713
Welfare gains (percentual change)	0.125	0.089	0.171	0.160
Panel C: All countries ($\sigma = 1.5$)				
Environmental Costs (as fraction of US GDP)	0.000	42.163	47.381	236.907
Welfare gains (percentual change)	0.016	-0.124	-0.109	-0.674
Economic Assumptions				
- SCC = 0	Y	-	-	-
- SCC = 200	-	Y	Y	-
- SCC = 1000	-	-	-	Y
- Population Growth	-	-	Y	Y

Notes: This table replicates results from Table 3 using a low value for λ of 0.2, which translate into weaker persistence in the costs of producing cleared land in the model.

Table F.12: Exploring Dynamics Considerations

	Consider only periods t and below				
	5	10	20	50	200
	(1)	(2)	(3)	(4)	(5)
Panel A: Brazil					
Environmental Costs (as fraction of US GDP)	0.067	0.639	1.413	1.941	1.977
Welfare gains (percentual change)	-0.083	-0.094	-0.100	-0.100	-0.100
Panel B: All countries ($\sigma = 0.5$)					
Environmental Costs (as fraction of US GDP)	1.011	4.076	6.992	8.674	8.788
Welfare gains (percentual change)	0.112	0.081	0.075	0.083	0.086
Economic Assumptions					
- SCC = 200	Y	Y	Y	Y	Y

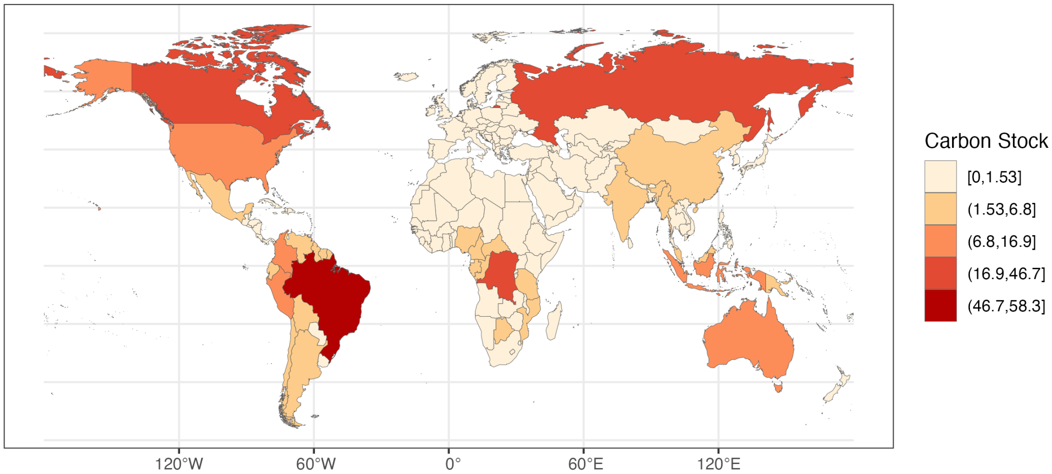
Notes: This table shows the cost and benefit analysis when we compute the welfare gains and environmental costs using different discounting schemes. Column (1) ignores any time period beyond the fifth year—i.e., we set the discount rate to 100 percent for any year after $t = 5$. Columns (2) to (5) shows how our conclusions change as we add additional time periods.

Table F.13: Deforestation over Time with Non-homothetic Preferences

	(1)	(2)
Panel A: t = 10		
Brazil only reduction	-0.004	-0.003
Global reduction	0.148	0.150
Panel B: t = 50		
Brazil only reduction	-0.144	-0.140
Global reduction	0.288	0.294
Panel C: t = SS		
Brazil only reduction	-0.267	-0.262
Global reduction	0.489	0.501
Preference		
- Non-homothetic CES	-	Y

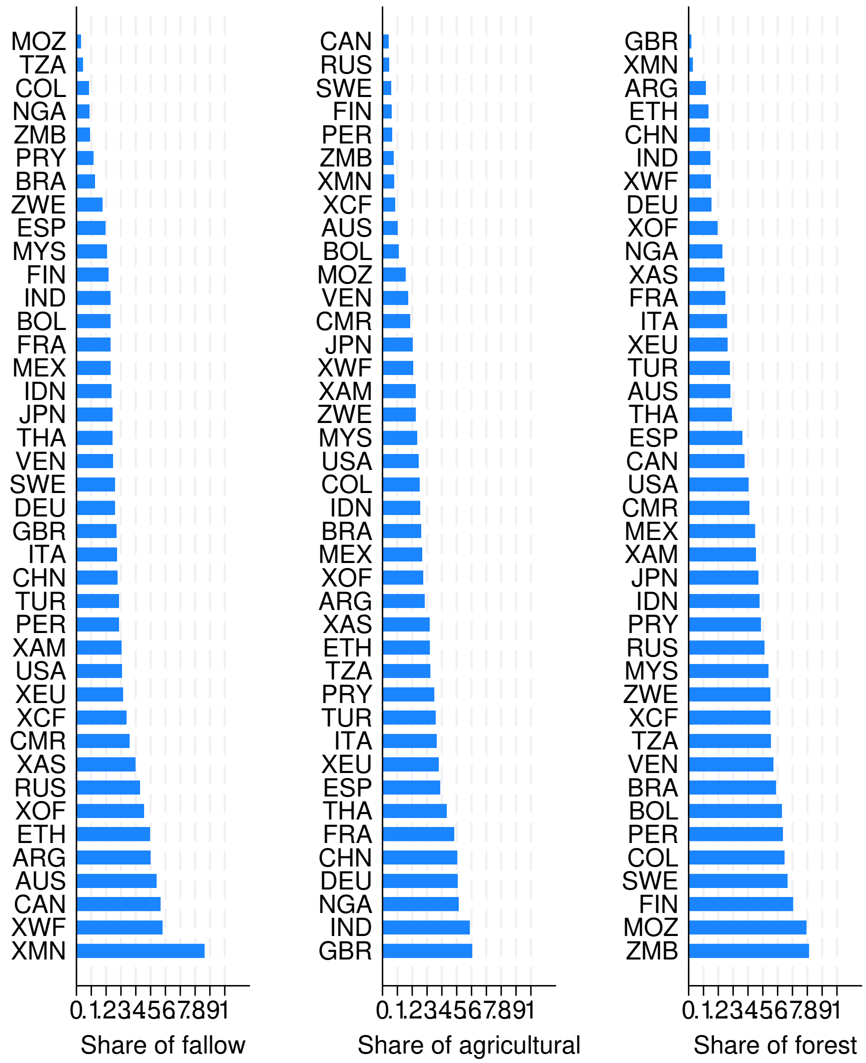
Notes: This table shows the changes in global deforestation when we consider non-homothetic preferences.

Figure F.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. Data come from FRA-FAO.

Figure F.2: Share of Land Allocated to each broad Category



Notes: This figure shows the share of land allocated to different types of uses in the 40 regions included in our data. Agricultural land includes both pasture and crop land. Fallow land is the total area of the country minus area under forest and agriculture. Total area of a country excludes water surface or other non-productive.

Figure F.3: Graphical Representation of Proposition 4 when Countries are Ranked based on their CA in Agriculture

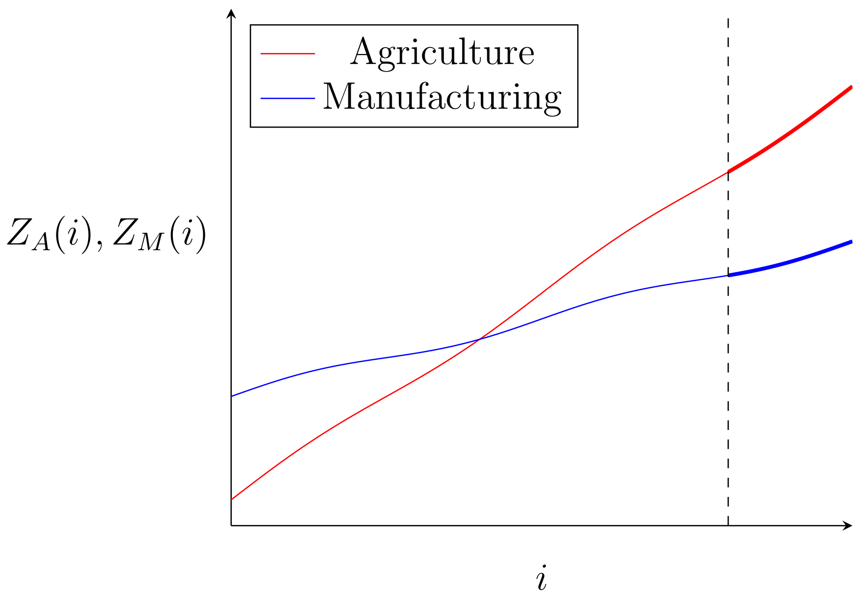
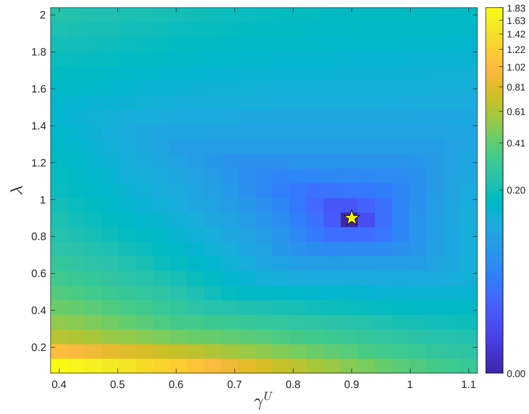
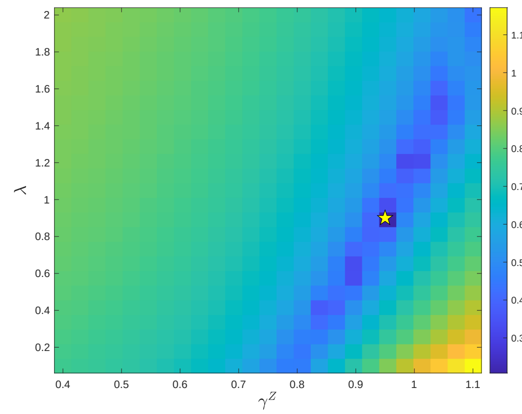


Figure F.4: Identification — Local Minimum — holding either γ_O, γ_F or λ fixed

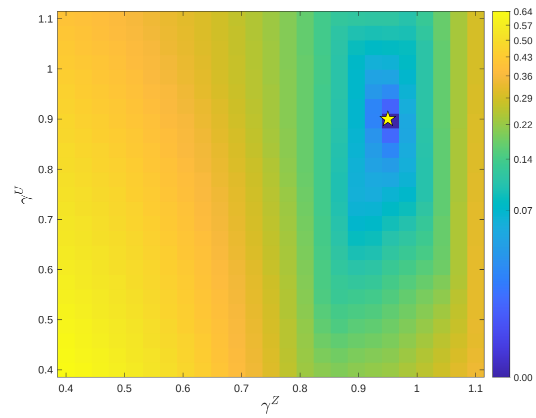
(a) Given γ_F



(b) Given γ_O



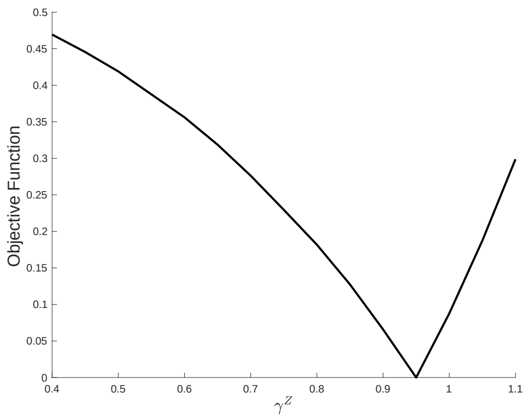
(c) Given λ



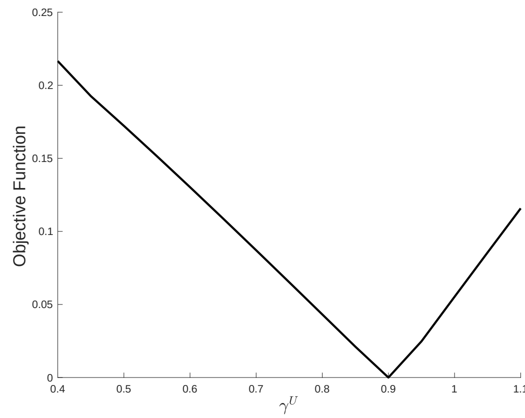
Notes:This figure checks whether the parameters that we estimate provide a local minimum in our grid search for γ_O, γ_F and λ.

Figure F.5: Identification — Local Minimum —Parameter by Parameter

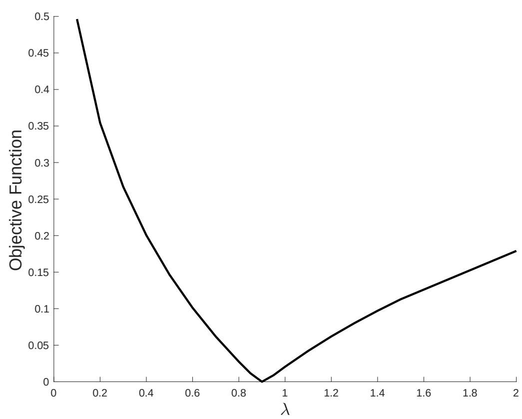
(a) γ_F



(b) γ_O



(c) λ



Notes:This figure checks whether the parameters that we estimate provide a local minimum in our grid search for γ_O, γ_F and λ.

Figure F.6: Comparing Fallow with no Fallow

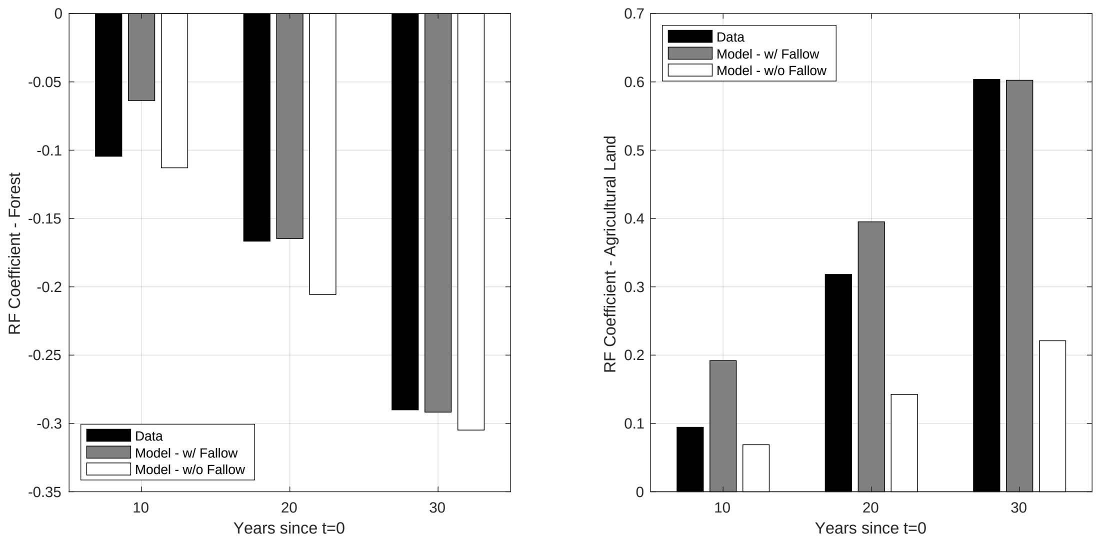


Figure F.7: Correlation between Forest Protection and ζ_F

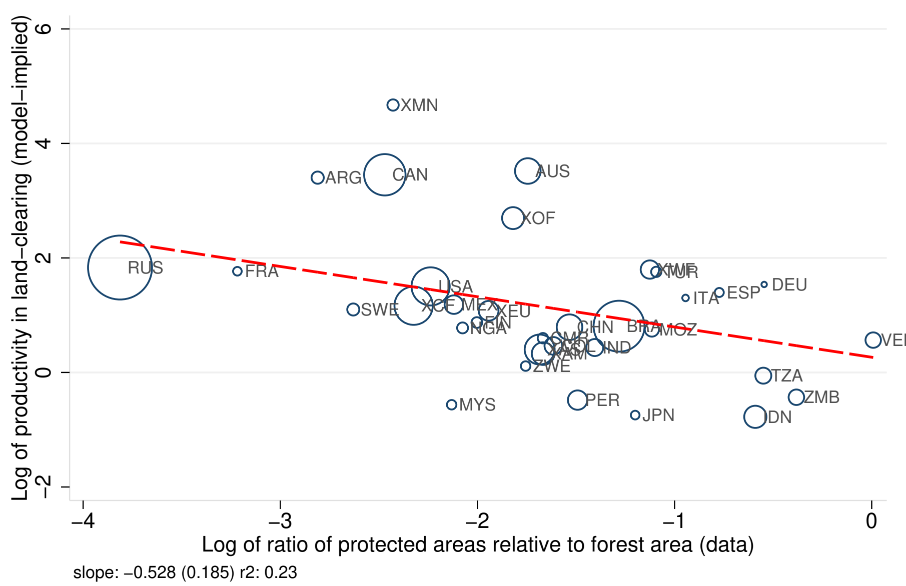


Figure F.8: Correlation between Physical Yields in the Model and in the Data

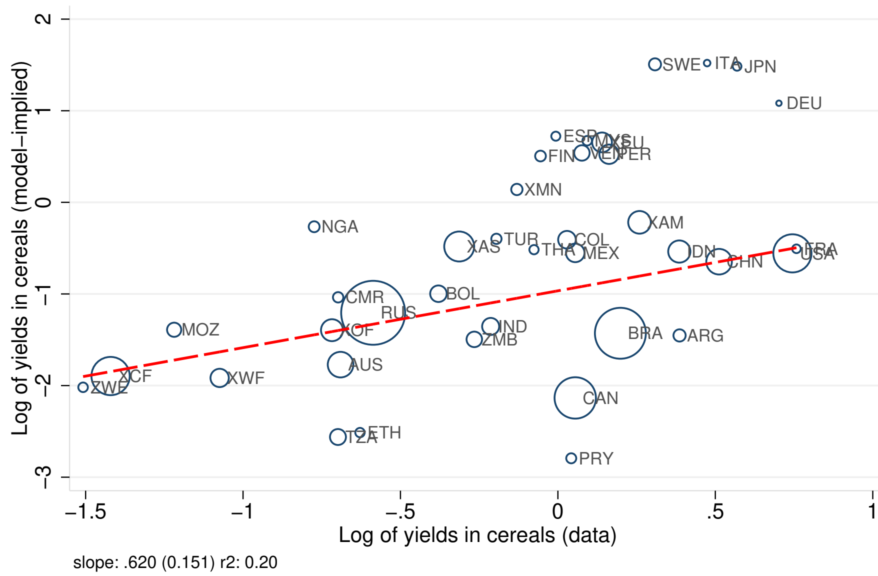


Figure F.9: Evolution of Workers

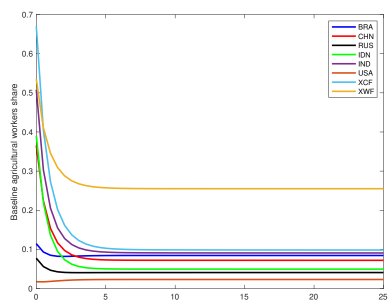


Figure F.10: Role of Persistence

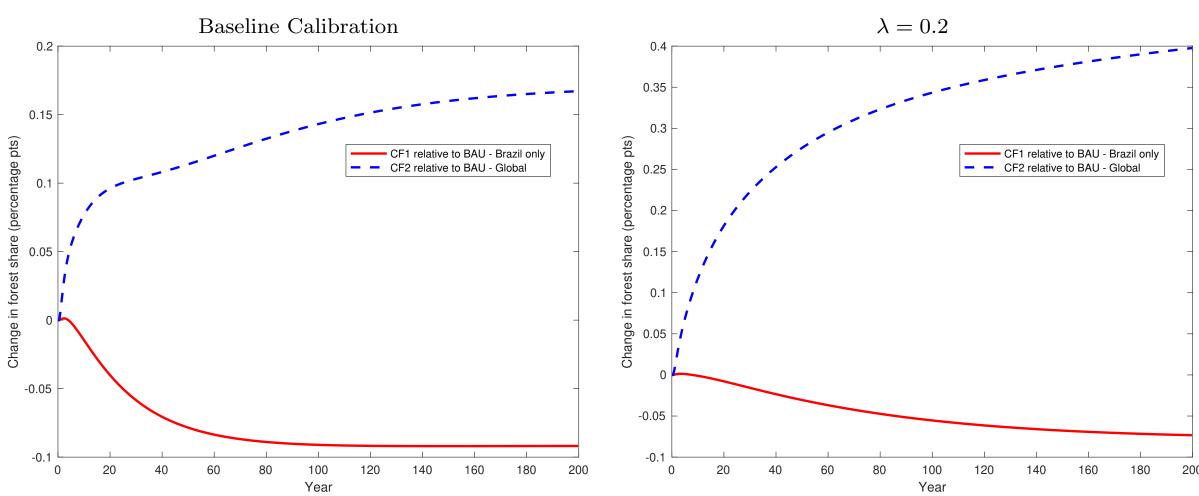
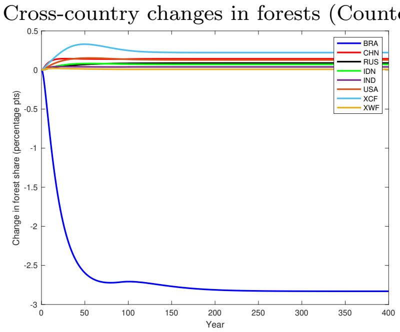


Figure F.11: Multilateral vs Unilateral Tariff Elimination: Change in Forest Area Relative to Population Growth Baseline Baseline (Global and Selected Countries)

Panel (c): Cross-country changes in forests (Counterfactual 1)



Panel (d): Cross-country changes in forests (Counterfactual 2)

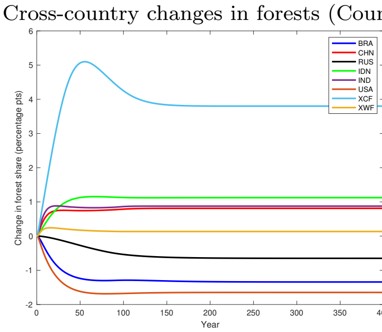
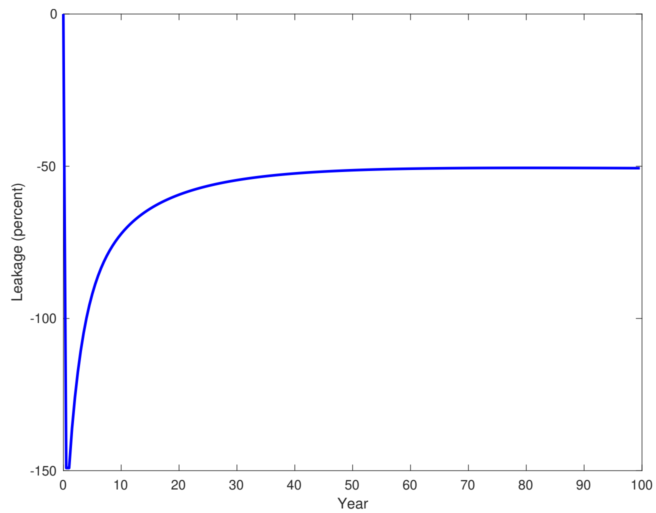
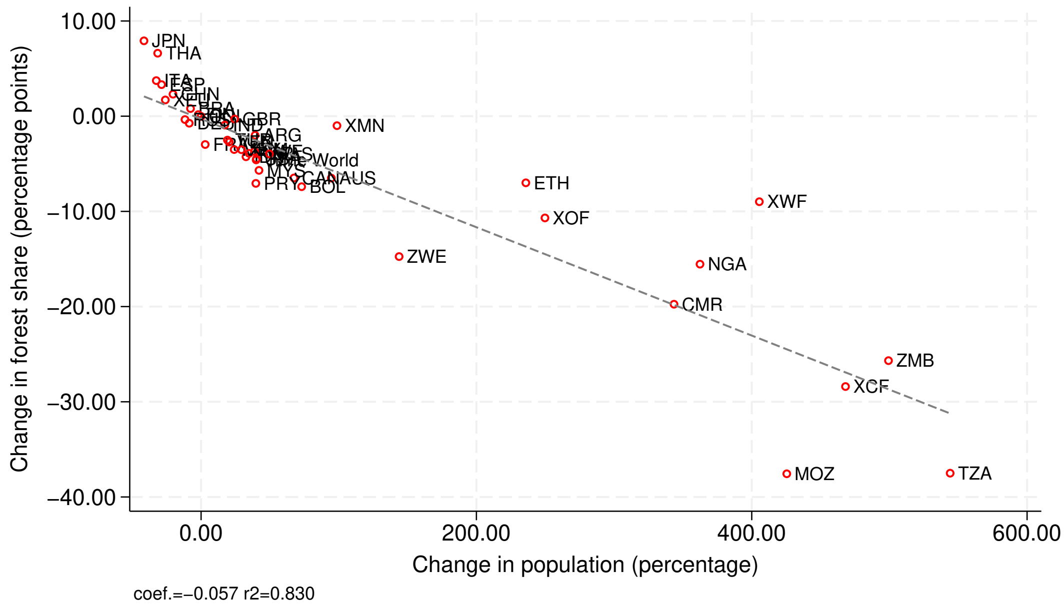


Figure F.12: Leakage from a Reduction in Import Tariff from Brazil



Notes: This figure shows the dynamics of the leakage from reducing tariffs for Brazil over time.

Figure F.13: Change in Forest Share versus Population



Notes:This figure shows the relationship between changes in forest area and changes in population in steady-state relative to the initial period.

Figure F.14: Multilateral vs Unilateral Trade Cost Reduction: Change in Forest Area Relative to Baseline (Global and Selected Countries)

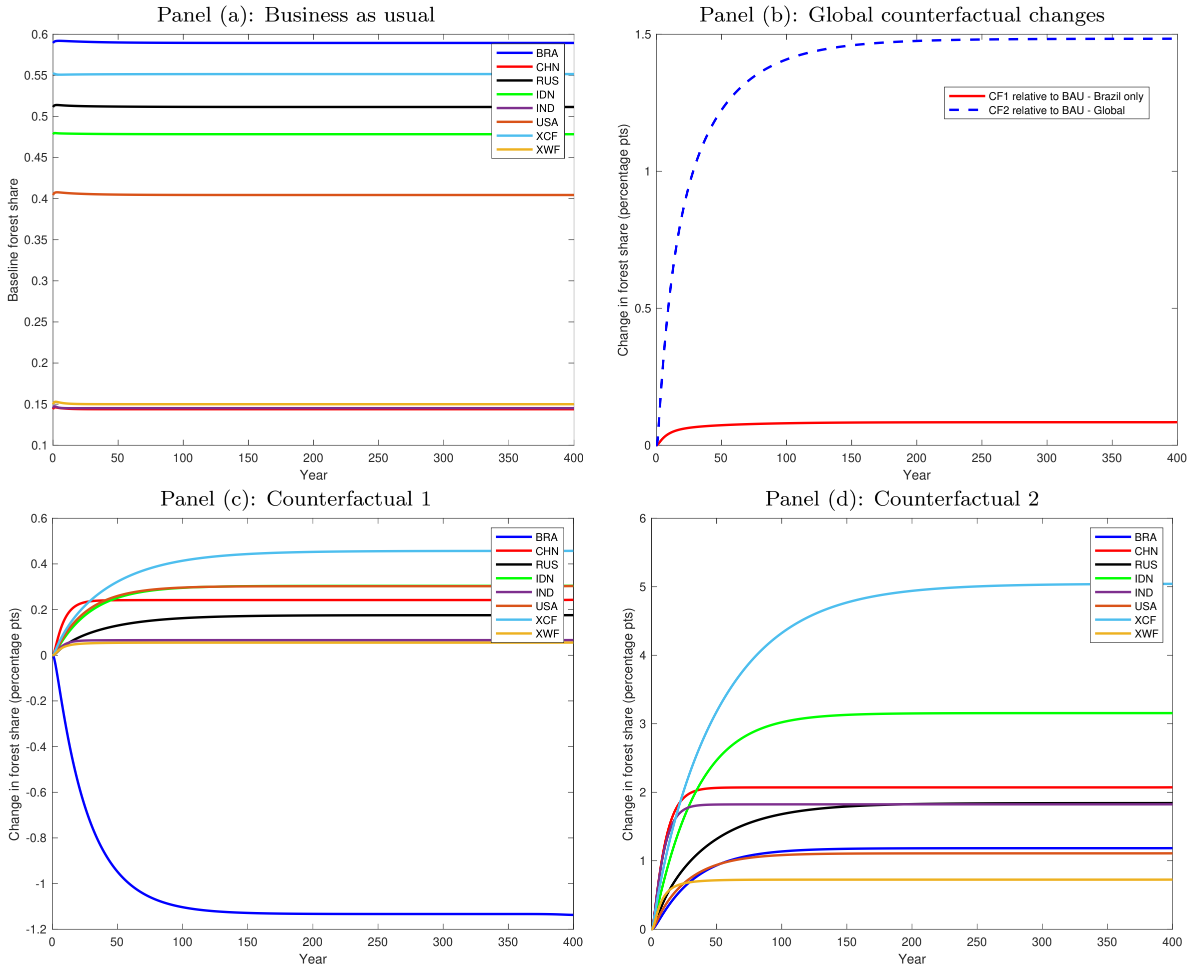
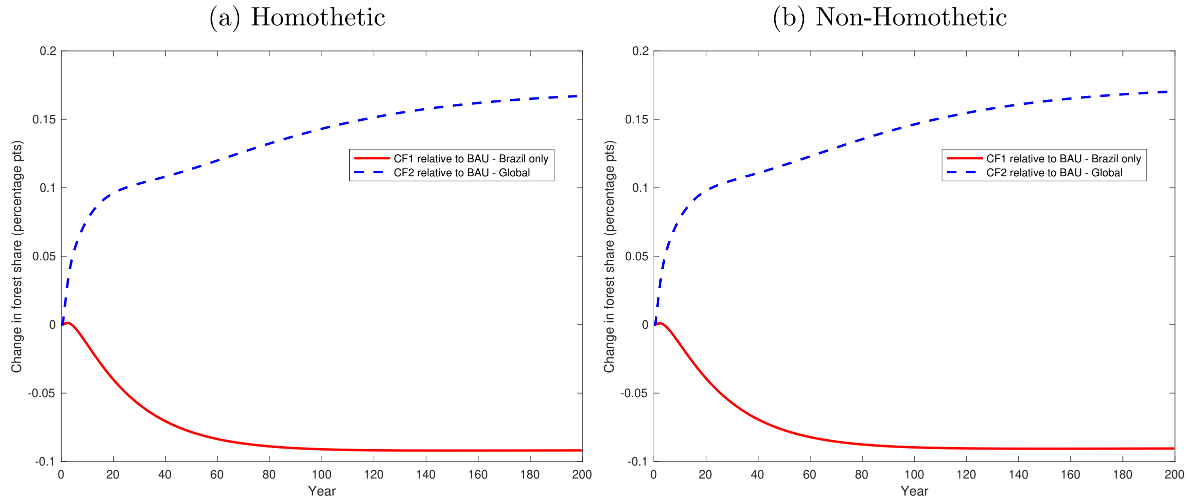


Figure F.15: Comparing Homothethic and Non-Homothetic Preferences



Notes: Panel (a) replicates the results from the main body of the paper. Panel (b) shows the effects when we allow for non-homothetic preferences, using the Comin et al. (2021) formulation. Specifically, we let the consumption shares depend on real income in a country, using an income elasticity parameter of 0.7 for agriculture, 1 for manufacturing, and 1.6 for services.

Appendix References

Alvarez, F. and Lucas, R. J. (2007). General equilibrium analysis of the eaton-kortum model of international trade. *Journal of Monetary Economics*, 54(6):1726–1768.

Comin, D., Lashkari, D., and Mestieri, M. (2021). Structural change with long-run income and price effects. *Econometrica*, 89(1):311–374.

Curtis, P. G., Slay, C. M., Harris, N. L., Tyukavina, A., and Hansen, M. C. (2018). Classifying drivers of global forest loss. *Science*, 361(6407):1108–1111.

Farrokhi, F. and Lashkaripour, A. (2024). Can trade policy mitigate climate change? *Working Paper*.

Federici, S., Tubiello, F. N., Salvatore, M., Jacobs, H., and Schmidhuber, J. (2015). New estimates of co2 forest emissions and removals: 1990–2015. *Forest Ecology and Management*, 352:89–98.

Hansen, M. C., Potapov, P. V., Moore, R., Hancher, M., Turubanova, S. A., Tyukavina, A., Thau, D., Stehman, S. V., Goetz, S. J., Loveland, T. R., Kommareddy, A., Egorov, A., Chini, L., Justice, C. O., and Townshend, J. R. G. (2013b). High-resolution global maps of 21st-century forest cover change. *Science*, 342(6160):850–853.

IPCC (2006). 2006 ipcc guidelines for national greenhouse gas inventories.

Keenan, R. J., Reams, G. A., Achard, F., de Freitas, J. V., Grainger, A., and Lindquist, E. (2015). Dynamics of global forest area: Results from the fao global forest resources assessment 2015. *Forest Ecology and Management*, 352:9–20.

MacDicken, K. G. (2015). Global forest resources assessment 2015: what, why and how? *Forest Ecology and Management*, 352:3–8.