Appendices for "Deforestation: A Global and Dynamic Perspective"

Farid Farrokhi, Elliot Kang, Heitor S. Pellegrina, and Sebastian Sotelo*

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

*Email: farrokh@bc.edu, emkang@umich.edu, hpelleg3@nd.edu, ssotelo@umich.edu.

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: $d_A \to d_A + \mathrm{d}d_A$. 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: $(1+t_A) \to (1+t_A) + \mathrm{d}(1+t_A)$. 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

$$x_M = \beta_M x^F$$
$$x_A = \beta_A x^F,$$

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

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

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 $Q^W_M = \int_{i^*}^1 Z_{i,M} N_i di$ and $Q^W_A = \int_0^{i^*} \delta_L^{-1} Z_{i,A} Z_T N_i di$, 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

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

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

C.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 $\varepsilon^N_{i,s}$ from a Type-I extreme value distribution with dispersion parameter ν, and can choose to reallocate from its current sector s to another sector s', subject to moving cost $f^N_{i,ss'}$.

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, $v^N_{i,s}$, is the solution to:

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

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

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

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

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

C.3 Final and Intermediate Good Production

C.3.1 Technology

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

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

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

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

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:

$$E_i - T_i = (r_iU_i - q_iQ_{i,T}) \; + \; \Pi_{i,T} \; + \sum_{s=\{A,M,S,T\}} [w_{i,s}N_{i,s}]$$

In the right-hand of the first line, $(r_iU_i - q_iQ_{i,T})$ corresponds to (net) value added generated by land which equals gross payments to land, r_iU_i, net of purchases of new land, $q_iQ_{i,T}$. 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:

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

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 $w_{i,A}N_{i,A} = \gamma_{i,T}q_iQ_{i,T}$ and $\Pi_{i,T} = (1-\gamma_{i,T})q_iQ_{i,T}$ into equation C.47. Additionally, note that by replacing $q_iQ_i - \Pi_{i,T} = w_{i,A}N_{i,A}$, final expenditure can be equivalently expressed as:

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

where $r_iU_i - w_{i,T}N_{i,T}$ 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,

$$\begin{aligned} E_i - T_i &= r_iU_i + \sum\nolimits_{s=\{M,S,T\}} w_{i,s}N_{i,s} \\ &= \sum\nolimits_g \alpha_{i,g}(1-\gamma_{i,g})Y_{i,g} + \sum\nolimits_g \alpha_{i,g}\gamma_{i,g}Y_{i,g} \\ &= \sum\nolimits_g \alpha_{i,g}Y_{i,g} \end{aligned}$$

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, $\mathbf{N}_i\left(0\right)$, 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 $\tau_{ij,g}^{(\mathrm{T})}$—where $t_{ij,g}$ represents the effective ad valorem tariff rate—and non-tariff, iceberg component $\tau_{ij,g}^{(\mathrm{NT})}$,

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

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 $\tau_{ij,g}^{(\mathrm{T})} = (1 + t_{ij,g})$. 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

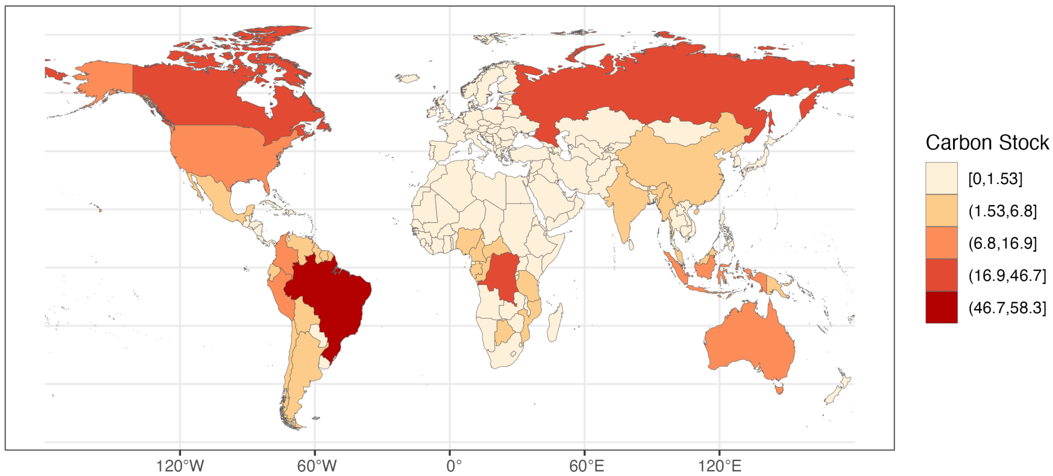
Notes: This table shows the cost and benefit analysis when we compute the welfare gains and environmental costs using different discounting schemes. Column (1) ignores any time period beyond the fifth year—i.e., we set the discount rate to 100 percent for any year after $t = 5$. Columns (2) to (5) shows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

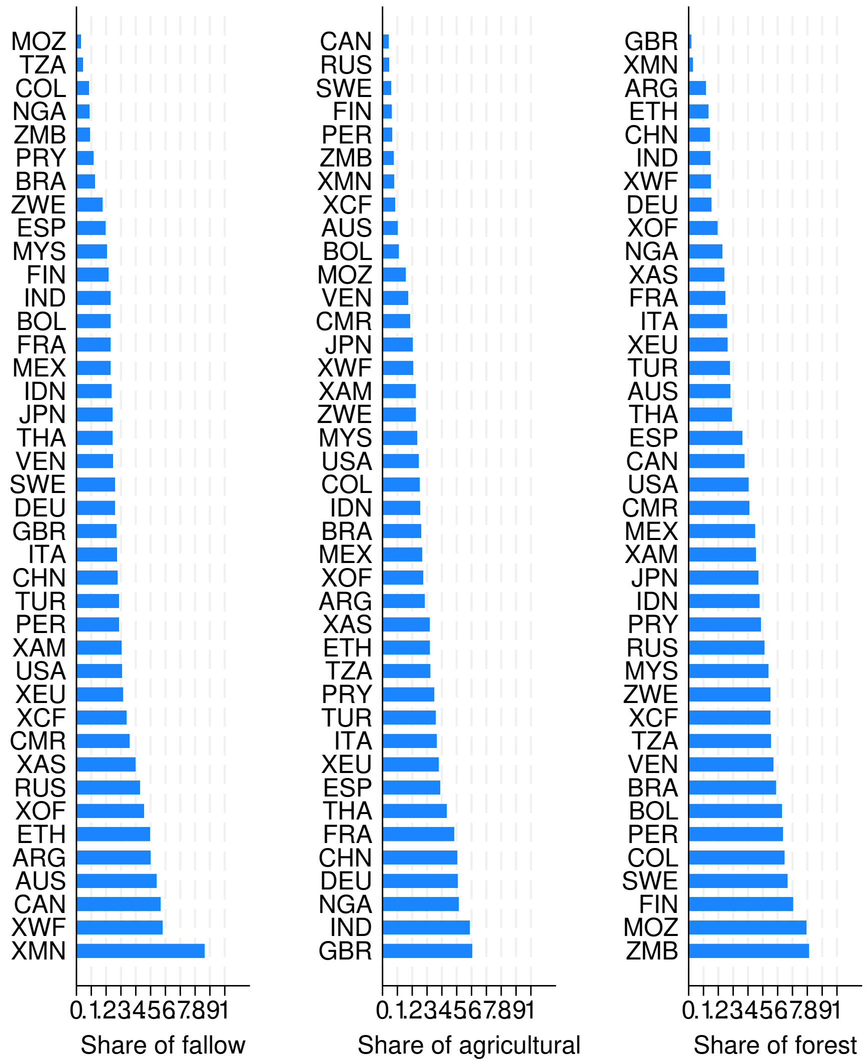
Notes: This table shows the changes in global deforestation when we consider non-homothetic preferences.

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

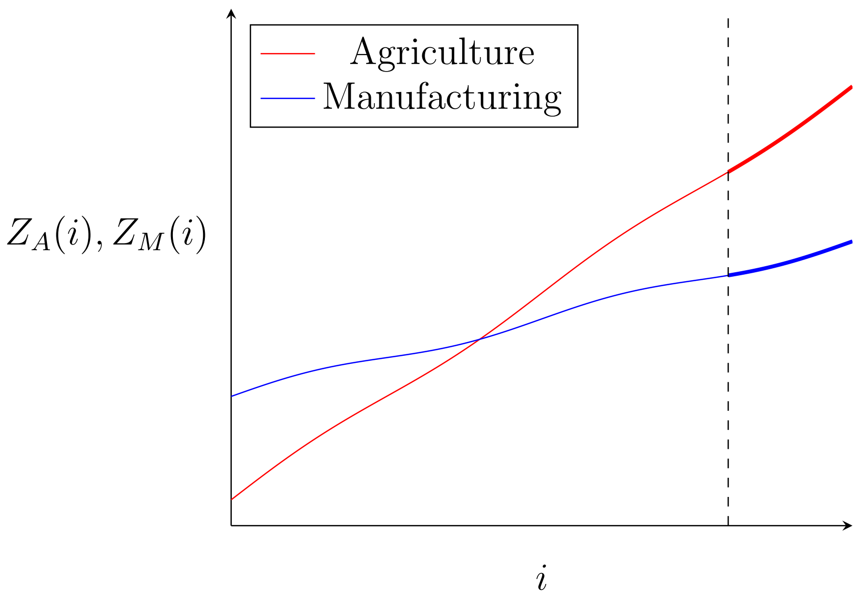
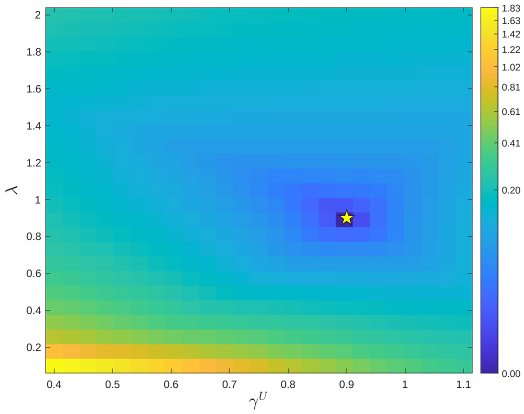
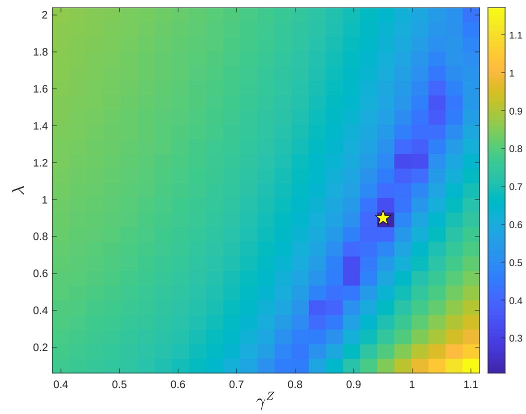


Figure F.4: Identification — Local Minimum — holding either γ_O, γ_F or λ fixed

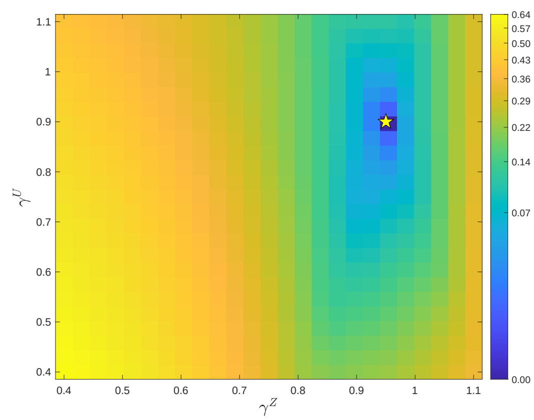
(a) Given γ_F



(b) Given γ_O



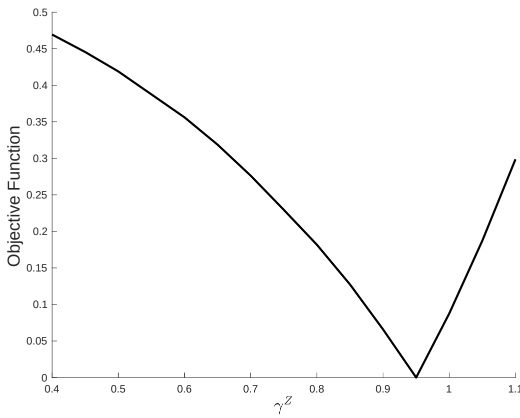
(c) Given λ



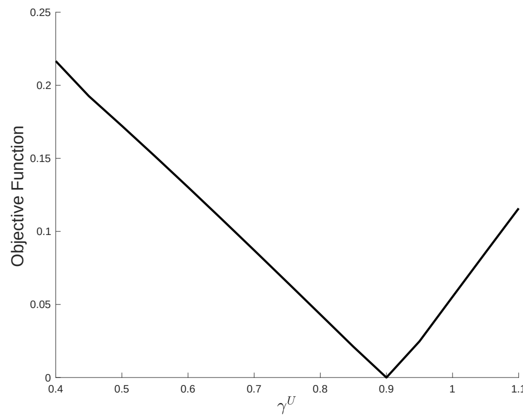
Notes:This figure checks whether the parameters that we estimate provide a local minimum in our grid search for γ_O, γ_F and λ.

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

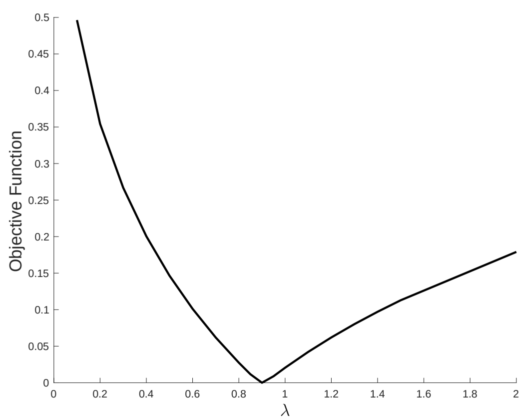
(a) γ_F



(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

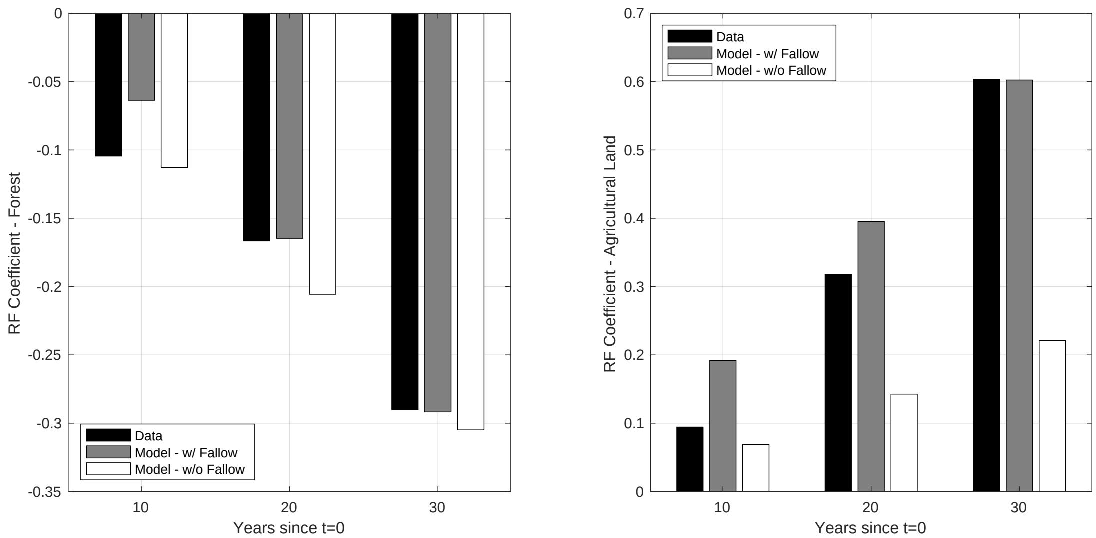


Figure F.7: Correlation between Forest Protection and ζ_F

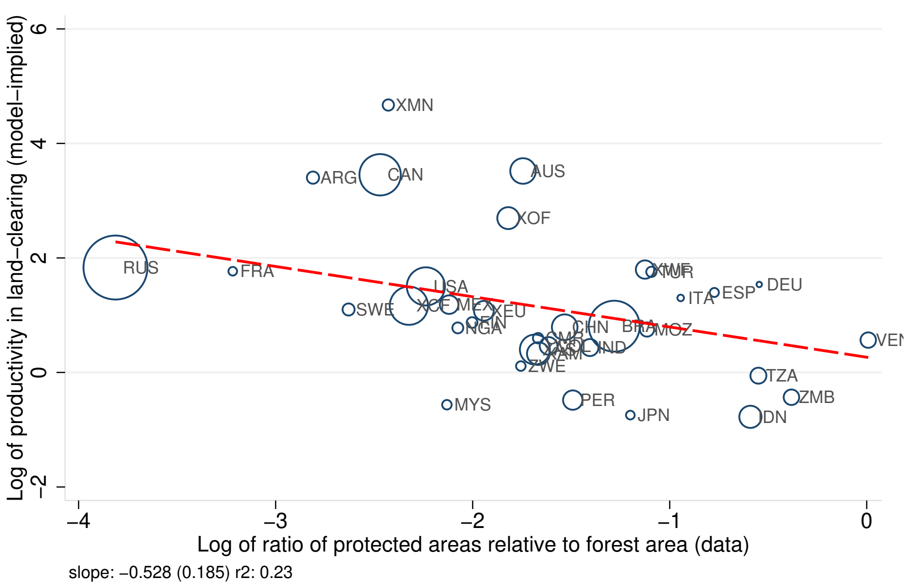


Figure F.8: Correlation between Physical Yields in the Model and in the Data

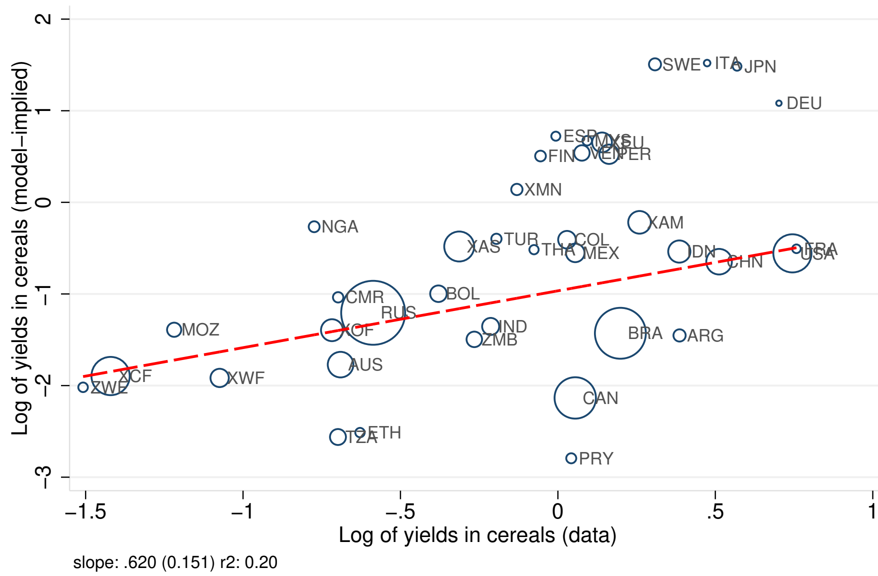


Figure F.9: Evolution of Workers

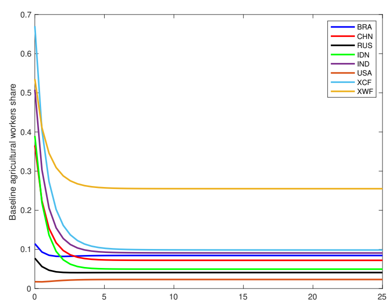


Figure F.10: Role of Persistence

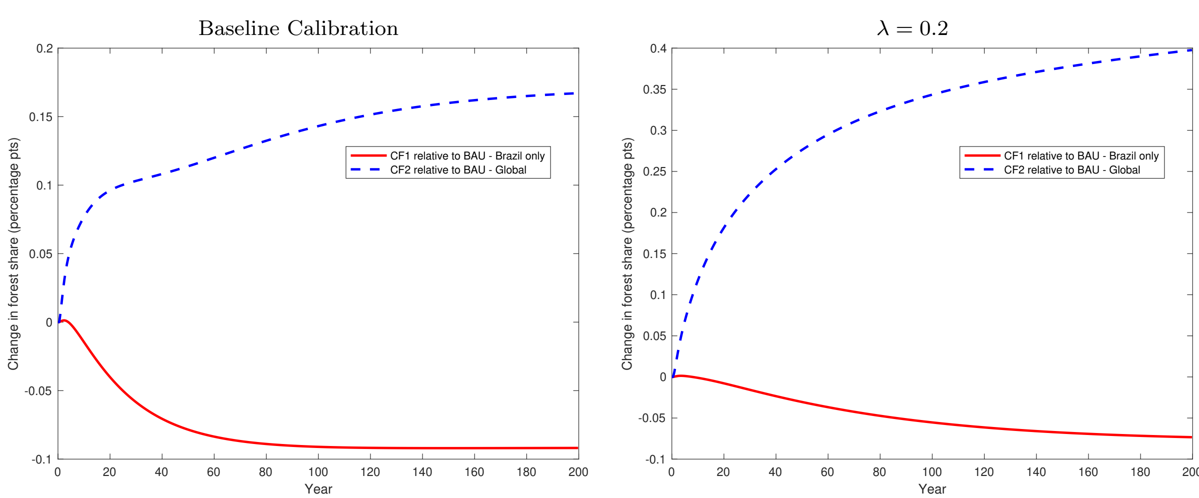


Figure F.11: Multilateral vs Unilateral Tariff Elimination: Change in Forest Area Relative to Population Growth Baseline Baseline (Global and Selected Countries)

Panel (c): Cross-country changes in forests (Counterfactual 1) Panel (d): Cross-country changes in forests (Counterfactual 2)

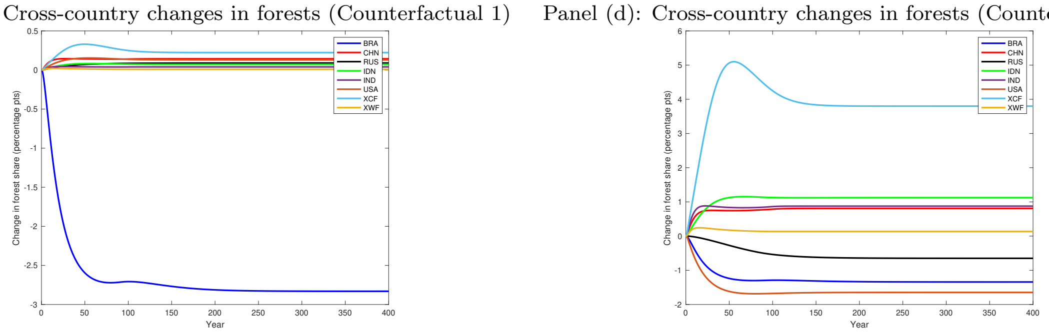
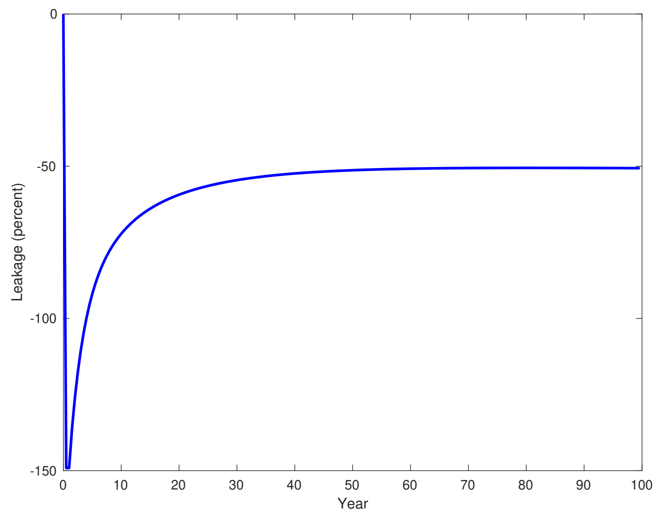
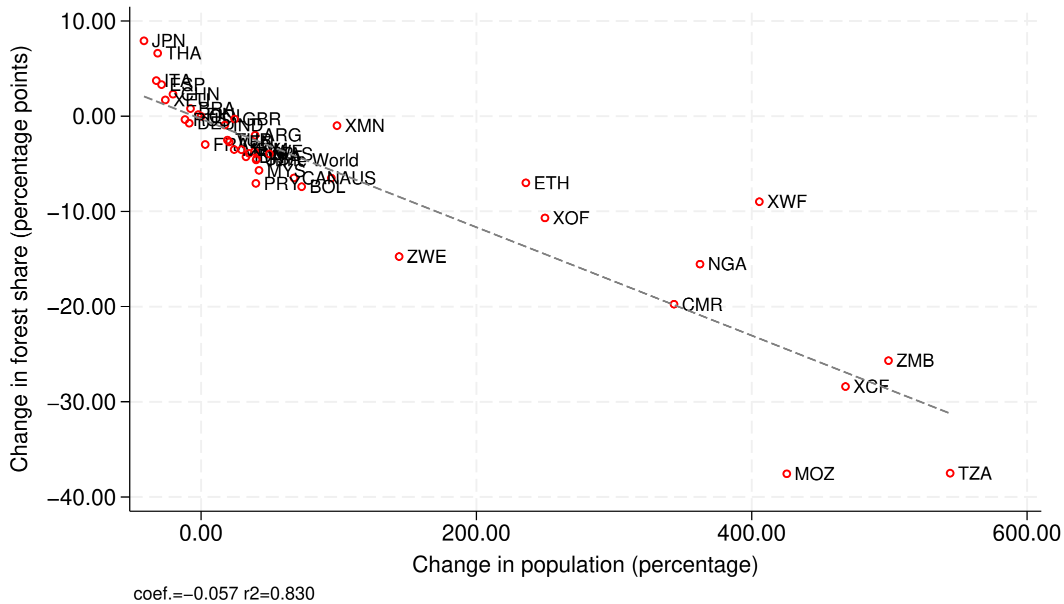


Figure F.12: Leakage from a Reduction in Import Tariff from Brazil



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)

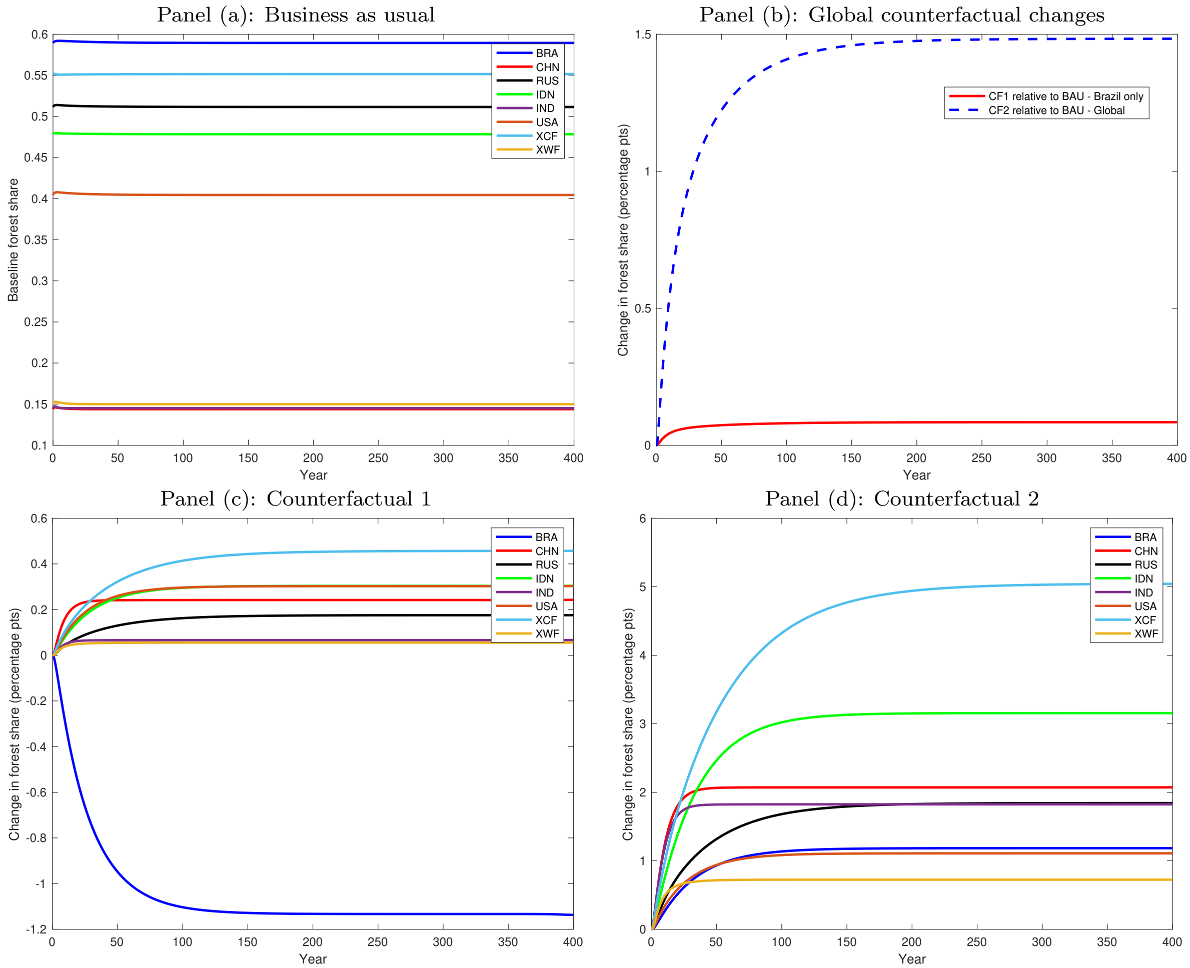
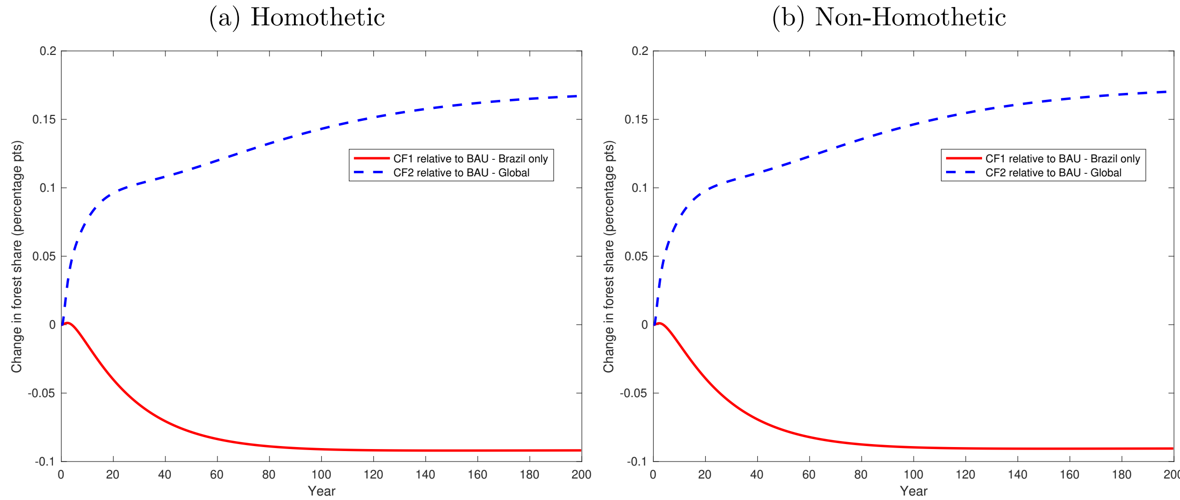


Figure F.15: Comparing Homothethic and Non-Homothetic Preferences



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.