NEREUS

Núcleo de Economia Regional e Urbana
da Universidade de São Paulo
The University of São Paulo
Regional and Urban Economics Lab

THERE IS TROUBLE WITH THE TREES: HOW TO AVOID TRADE-INDUCED DEFORESTATION?

Alan Leal
Maurício Bugarin

TD Nereus 05-2024
São Paulo
2024

There is Trouble with the Trees: How to Avoid Trade-Induced Deforestation?

Alan Leal*
Maurício Bugarin†

Abstract

Trade and environment are intertwined subjects. The literature on the impact of trade opening on environmental outcomes are vast. Lacking however is the literature in how trade can be used politically to induce better environmental outcomes. To model this properly, we develop a game theoretic model in which two countries engage in trade and choose their respective levels of deforestation and trade tariffs. We consider the scenarios of market and central equilibria and derive some useful insights into their relationship of these two variables. As an extension, we also propose different model specifications and develop a numeric generalization of the model, which allows testing our models prediction for several countries. As a result, we find that there is an incentive for free-riding from the countries less concerned with deforestation on the countries that suffer the most disutility of its own deforestation.

Keywords: trade; deforestation; game theory

Resumo

O comércio internacional e meio ambiente são assuntos profundamente relacionados. O impacto da abertura comercial sobre variáveis ambientais é longamente documentado. Como usar o comércio internacional politicamente para induzir melhores resultados ambientais é um assunto que a literatura explora de modo incipiente. Visando modelar essa relação, o presente artigo desenvolve um modelo de teoria dos jogos, no qual dois países engajam em comércio internacional e escolhem seus respectivos níveis de desmatamento e tarifa de comércio exterior. Consideram-se os cenários de equilíbrio de mercado e central e derivam-se resultados relevantes para a relação entre essas duas variáveis. Como extensão, também propõem-se generalizações do modelo teórico e um modelo numérico que permite testar as previsões teóricas do modelo para vários países. Como resultado, encontra-se que há um incentivo de "carona" para os países que se importam menos com o desmatamento sobre aqueles países que se importam mais com o desmatamento.

Palavras-chaves: comércio; desmatamento; teoria dos jogos

*Ph.D. candidate in Economics at Universidade of São Paulo
†Full Professor of Economics at University of Brasília

JEL Codes: C70; F18; Q23

1 Introduction

Trade and environment are deeply intertwined subjects. Given that international trade usually demands the production of goods intensive in factors related to the environment (e.g., land, water, among other materials), trade agreements can have an undesirable effect of increasing pollution, depletion of natural resources, and deforestation (Abman & Lundberg, 2019). However, recent studies have indicated that trade can be actually an inducer of environmental conservation, especially with regards to the deforestation, through common regulation on clean and green production (Balogh & Mizik, 2021). Trade agreements with a partner with stringent regulation can also decrease GHG emissions (Di Ubaldo, McGuire, & Shirodkar, 2022). In terms of this paper, although recent studies have been dedicated to understanding the relationship between trade and deforestation considering a game-theoretic approach (Harstad, 2022; Cunha, 2022), these studies focus on deriving a formal relationship among the levels of tariffs levied in the international trade and the deforestation. The rationale behind this approach consists of internalizing fully the cost of the deforestation by one country on its trade partner. On a regulatory note, trade agreements conditional on non-deforestation or green supply chains have been enabled recently explicitly in the trade agreements texts or by increasing of trade tariffs on non-compliers. Hence, trade agreements are one of the many instruments a country or bloc can use to enable non-deforestation on its trade partners (European-Union, 2023).

In physical terms, trade affect forests through several channels: (i) pressure for wood production by which forests are used as the main input and there may be or not any further used for this recently deforested land; (ii) forests cleared for the production of another good, as in international prices are attractive for a good produced in this recently deforested land and this motivates deforestation- this is called direct land use change, as land is cleared directly for some exports production; (iii) land used to produce non-tradable goods are now occupied by tradable goods and these non-tradable goods are then produced in recently deforested land- this is called indirect land use change. Hence, the interaction of domestic production, international demand, and land availability in terms of forests indicate how deforestation might occur in a country. These three channels might and probably do operate at the same time. They are also limited somehow or might be limited by foreign legislation such as EUDR and WTO new understandings regarding what is possible a country or trade bloc to do in applying their own non-deforestation laws (WTO (2022a) and WTO (2022b), regarding indirect land use change in Malasia and Indonesia in terms of palm oil production).

The questions regarding trade and deforestation are not easily modeled in terms of game theory, but there have been recent attempts to do so. Harstad (2022) analyze a multi-stage game, however finite, in which the Southern country (Brazil) choose its levels of deforestation, while the Northern country (EU, for concreteness) chooses its levels of trade tariffs. The author finds that conditioning free trade on non-deforestation effectively reduces deforestation, however not conditioning free trade to non-deforestation increases deforestation in the Southern country when it engages in a free trade agreement. On the other hand, Cunha (2022) builds upon Harstad (2022) by considering a dynamic game in which the Southern country produce agricultural goods for the Northern country, using land as the only factor in this production. Agricultural production uses land, especially newly deforested land. The author finds different results from Harstad (2022), which is free trade always causes larger deforetation in the Southern country.

This paper moves in another direction, however. We want to characterize the equilibrium of deforestation levels and international trade tariffs based on how these two variables - deforestation and trade tariffs- affect the level of welfare of the representative individual of each country. In that way, we derive market and central-planner solutions in which country i does not and does internalize the externalities caused by the other country's trade tariffs and deforestation levels, respectively. We are then able to fully characterize the situations in which a trade arrangement is stable with regards to not getting higher tariffs given some preferences parametrization. Likewise, we are able to also explicitly declare when the equilibrium deforestation level will likely increase, in a analysis of heterogeneity of the representative individual of each country. We find as one of our results that countries more concerned with deforestation might suffer from free riding from less concerned countries. Moreover, deforestation seems to be increasing with leniency of a country with deforestation. On the other hand, trade tariffs tend to be small for countries less concerned with deforestation than for countries more concerned with deforestation.

More generally, international trade and deforestation displays several types of relationship. For instance, several studies indicates that higher international prices for trade goods affect deforestation positively (Robalino & Herrera, 2010; Assunção, Gandour, & Rocha, 2015; Lundberg & Abman, 2022; Berman, Couttenier, Leblois, & Soubeyran, 2023; Balboni, Berman, Burgess, & Olken, 2023). Other economic variables are also relevant in driving larger/smaller deforestation such as economic crises, with crises affecting negatively deforestation (Antonarakis, Pacca, & Antoniades, 2022). Deforestation also seems to occur more frequently in small exporting farms than in large exporting farms (Silva, Moran, Millington, Viña, & Liu, 2023), which indicates possibly that the incentives for farmers to deforest is not neutral in the size of their farmers. Hence, the relationship of trade and deforestation is not fully characterized in a macro and micro aspect and we aim to further this discussion in terms of incentives and effectiveness of trade arrangements to induce lower deforestation.

The text is divided, besides this Introduction, into a section detailing our Model Primitives, their Solution, Stability Scenarios, some Extensions to our original model, and a numeric exercise for N countries, ending the paper with some Concluding Remarks.

2 Model Primitives

The original game contains two players, i and j, in this case countries, that chooses their respective levels of deforestation and trade tariffs levied on the other country (its trade partner). The utility of country i depends on all deforestation levels and trade tariffs, despite the fact that in a non-cooperative fashion, they all are not to be defined by country i. Hence, there might be some gain of coordination or central planning or playing cooperatively. This section aims to characterize analytically these possible gains.

Country i optimizes its utility for the representative individual, given by:

$$u_i = u_i(\tau_i, d_i, \tau_j, d_j) \tag{1}$$

Country i chooses τ_i and d_i, her levels of tariffs and deforestation, respectively. The problem is then given by maximizing u_i, considering τ_i and d_i.

Consider that:

$$u_i(\tau_i,\tau_j,d_i,d_j) = u_{i0} + \tau_i - b\tau_i^2 + d_i - cd_i^2 - (\tau_i\tau_j) - (d_i + d_j)^2 \tag{2}$$

Likewise, u_j will be given by:

$$u_j(\tau_i,\tau_j,d_i,d_j) = u_{j0} + \tau_j - d\tau_j^2 + d_j - ed_j^2 - (\tau_i\tau_j) - (d_i + d_j)^2 \tag{3}$$

u_{i0} and u_{j0} are autonomous levels of utility of country i and j, respectively, that is, they are the utility that country attains that do not depend on deforestation and tariffs[1]. We also consider $b,c,d,e > 0$.

3 Solution

3.1 Market Solution

The First Order Conditions[2] of this problem for country i will be given by:

$[\tau_i]$

$$1 - 2b\tau_i - \tau_j = 0$$
$$\tau_i = \frac{1-\tau_j}{2b}$$

$[d_i]$

$$1 - 2cd_i - 2(d_i + d_j) = 0$$
$$d_i = \frac{1-2d_j}{2c+2}$$

The Nash Equilibrium will be given by b,c,d,e that solves the system formed by the FOCs for country i and j. These solution will be given by:

$$\tau_i = \frac{1-2d}{1-4bd} \tag{4}$$

$$\tau_j = \frac{1-2b}{1-4bd} \tag{5}$$

$$d_i = \frac{e}{2(ec+e+c)} \tag{6}$$

[1] Another interpretation is that this is level of utility when countries engage in a free trade arrangement and do not deforest.

[2] The proof that this solution characterizes a maximum is presented in the appendix.

$$d_j = \frac{c}{2(ec+e+c)} \tag{7}$$

3.2 Central Planner

The central planner finds the values τ_i, τ_j, d_i, and d_j that solve the optimization problem of $u_i + u_j$. Hence, he maximizes the following expression:

$$u_i + u_j = \tau_i - b\tau_i^2 + d_i - cd_i^2 + \tau_j - d\tau_i^2 + d_j - ed_j^2 - 2(\tau_i \tau_j) - 2(d_i + d_j)^2 \tag{8}$$

The FOCs[3] of this optimization problem will be given by:

$[\tau_i]$

$$1 - 2b\tau_i - 2\tau_j = 0$$
$$b\tau_i + \tau_j = 1/2$$

$[\tau_j]$

$$1 - 2d\tau_j - 2\tau_i = 0$$
$$d\tau_j + \tau_i = 1/2$$

$[d_i]$

$$1 - 2cd_i - 4(d_i + d_j) = 0$$
$$(2+c)d_i + 2d_j = 1/2$$

$[d_j]$

$$1 - 2ed_i - 4(d_i + d_j) = 0$$
$$(2+e)d_j + 2d_i = 1/2$$

The equilibrium is given by the values of τ_i, τ_j, d_i, and d_j that solve the previous four equations simultaneously. Hence, the solution is given by:

$$\tau_i = \frac{d-1}{2bd-2} \tag{9}$$

$$\tau_j = \frac{b-1}{2bd-2} \tag{10}$$

$$d_i = \frac{e}{2(2+e)c+4e} \tag{11}$$

$$d_j = \frac{c}{2(2+e)c+4e} \tag{12}$$

[3] The proof that this solution characterizes a maximum is presented in the appendix.

3.3 Market and Central Planner Comparison

The Central Planner solution outlined above is socially optimizing in the sense that externalities caused by tariffs and deforestation choice by one country are fully internalized in the analysis. The next important question is how these socially optimal solutions compare to the non-cooperative case (that is, the market solution). Given the symmetry of the problem, we might look directly into a single country. In that way, let's see how tariffs and deforestation of country i compare in the case of cooperation and in the case of non-cooperation.

Proposition 1 *Consider the previously derived market and central planner solutions, then tariffs of country i are larger in cooperation than in the market solution, whenever* $-1 \leq d(2b-3)$*. Moreover, deforestation of country i is always larger in the market solution than in the central-planner solution.*

Proof: Appendix.

The previous Proposition 1 asserts that deforestation is always larger in the non-cooperative solution. Hence, if countries aim to decrease deforestation, cooperating is the most straightforward way achieve to it. In other words, this Proposition 1 asserts that deforestation will always be higher in non-cooperation than in cooperation. This is caused by the fact that in the cooperation, there is a proper internalization of costs of deforestation and trade tariffs by all countries. On the other hand, trade tariffs are larger in the non-cooperative case than in the cooperative case, given $-1 \leq d(2b-3)$.

4 Stability of the Solution

Stability can be characterized as the situation in which the current equilibrium does not change. In the two subsections below, we suppose there is parametric change such that the equilibrium has changed. We aim to characterize the direction of this change.

4.1 Reduction of Trade Tariffs

By stability, suppose that initially we have $(\tau_{it}, \tau_{jt}) = (\tau_{i0}, \tau_{j0})$. We want to find the situations for which a new tariffs situation would arise, (τ_{i1}, τ_{j1}), such that $\tau_{i0} \leq \tau_{i1}$ and $\tau_{j0} \leq \tau_{j1}$, with a strict inequality for at least of one of these countries. We consider the scenario of a market economy, instead of cooperative solution.

Naturally, this change would occur with changes in the preferences, that is, parameters of our utility. So, if a country suffered more from a higher tariff or deforestation, this would affect the optimal level of tariffs in the non-cooperative case. We want to characterize this equilibrium properly.

How would the τ_i change in response to a change in the preference of country i for a higher level of deforestation. The following proposition explain this effect.

Proposition 2 *Whenever* $b > 1/2$*, tariffs are increasing in d; likewise, whenever* $d > 1/2$*, tariffs are increasing in b.*

Proof. Appendix.

Hence, for larger values of the disutility from tariffs, tariffs are increasing in the parameters b and d. Whenever b and d are high, that is, whenever a country representative consumer dislikes more trade tariffs, then trade tariffs are positive and increasing in these two parameters, b and d. In practical terms, the higher the discomfort with trade trariffs, more increasing are trade tariffs in this discomfort.

4.2 Reduction of Deforestation Levels

What are the situations in terms of preferences changes, that is, parameters changes, for which the level of deforestation of country i changes? Deforestation on the market equilibrium depends on the values of the preference parameters e and c. Hence, we enunciate the following Proposition:

Proposition 3 *The level of deforestation of country i is decreasing in its own disutility from deforestation and increasing in the disutility of other country's deforestation.*

Proof. Appendix

Proposition 3 implies that there is an incentive for free-riding in terms of deforestation on the country with the highest disutility from deforestation. This is a sound result, given that oftentimes countries will commit to different levels of deforestation and an inequality among them might create some incentives of free-riding.

5 Extensions

We propose some extensions to amplify the analytical power of our model. In a first moment, we consider that a country i will derive more utility in deforesting less. The second extension considers that the higher the deforestation of another country, the higher its own utility. We are particularly interested in analyzing the comparative statistics of the new parameters considered in the analysis.

5.1 Utility from preserving forests

Consider that the representative utility of country i is given by:

$$u_i(\tau_i, \tau_j, d_i, d_j) = u_{i0} + \tau_i - b\tau_i^2 + d_i - cd_i^2 - (\tau_i \tau_j) - (d_i + d_j)^2 + \phi_i(1 - d_i) \tag{13}$$

ϕ_i measures how much the representative individual of country i values keeping the forests of its own country intact. Likewise, the representative utility of country j will be given by:

$$u_j(\tau_i, \tau_j, d_i, d_j) = u_{j0} + \tau_j - d\tau_j^2 + d_j - ed_j^2 - (\tau_i \tau_j) - (d_i + d_j)^2 + \phi_j(1 - d_j) \tag{14}$$

The First Order Conditions of the market equilibrium will be given by:

$[\tau_i]$

$$1 - 2b\tau_i - \tau_j = 0$$

$[d_i]$

$$1 - 2cd_i - 2(d_i + d_j) - \phi_i = 0$$

$[\tau_j]$

$$1 - 2d\tau_j - \tau_i = 0$$

$[d_j]$

$$1 - 2ed_j - 2(d_i + d_j) - \phi_j = 0$$

The market solution of this extension will then be given by:

$$\tau_i = \frac{2d - 1}{4bd - 1} \tag{15}$$

$$\tau_j = \frac{2b - 1}{4bd - 1} \tag{16}$$

$$d_i = \frac{e - \phi_i + \phi_j - e\phi_i}{2(e + c + ec)} \tag{17}$$

$$d_j = \frac{c + \phi_i - \phi_j - c\phi_j}{2(e + c + ec)} \tag{18}$$

The trade tariffs does not change in this scenario in comparison to the standard model. However, the level of deforestation changes. Even more so, the deforestation changes in response to both parameters ϕ_i and ϕ_j. The following proposition can thus be enunciated.

Proposition 4 *The level of deforestation decreases how much the representative individual values keeping your own forests intact, however it increases with the importance given by country j's representative individual values his own intact forests.*

Proof. Observe that $\frac{\partial d_i}{\partial \phi_i} = -\frac{1+e}{2(c+e+ec)} < 0$ and $\frac{\partial d_i}{\partial \phi_j} = \frac{1}{2(e+c+ec)} > 0$.

Proposition 4 asserts the public opinion on forests affect the level of deforestation that a country has. There is a positive relationship between a country's public opinion care for its own forests and non-deforestation, while there is a negative relationship between a country's public opinion care for its own forests and the non-deforestation of other countries. This selfish behavior is in line with out findings of free riding incentives displayed previously.

5.2 Forest-related tariffs on trade

Consider now the utility of a representative individual in country i is given by the following expression:

$$u_i = u_{i0} + \tau_i - b\tau_i^2 + d_i - cd_i^2 - (\tau_i\tau_j) - (d_i + d_j)^2 - \tau_i(d_j - d_{ji})I\{d_j > d_{ji}\}$$

Where $I\{\}$ is the indicator function. d_{ji} can be understood as the level of deforestation by country j that country i supports. Levels above this threshold imply a disutility for country i. Assume that $d_j > d_{ji}$ also. Otherwise, this extension produces the same results as our standard model. Considering this scenario, we have that the FOCs for the country i market problem will be given by:

$[\tau_i]$

$$1 - 2b\tau_i - \tau_j - d_j + d_{ji} = 0$$

$[d_i]$

$$1 - 2cd_i - 2(di + dj) = 0$$

$[\tau_j]$

$$1 - 2d\tau_j - \tau_i - d_i + d_{ij} = 0$$

$[d_j]$

$$1 - 2ed_j - 2(d_i + d_j) = 0$$

The solutions to this system will be given by:

$$\tau_i = -\frac{2c + e - 2cd + 2cd_{ij} + 2ce - 4de + 2ed_{ij} - 4cdd_{ji}}{2(4bd-1)(c+e+ec)} - \frac{4cde + 2ced_{ij} - 4ded_{ji} - 4cded_{ji}}{2(4bd-1)(c+e+ec)} \tag{19}$$

$$\tau_j = -\frac{c + 2e - 4bc - 2be - 2cd_{ji} + 2ce_2ed_{ji} - 4bcd_i - 4bce}{2(4bd-1)(c+e+ec)} - \frac{4bed_{ij} + 2ced_{ji} - 4bced_{ij}}{2(4bd-1)(c+e+ec)} \tag{20}$$

$$d_i = \frac{e}{2(c+e+ec)} \tag{21}$$

$$d_j = \frac{c}{2(c+e+ec)} \tag{22}$$

In this case, we might make the following assertion.

Proposition 5 *The higher the tolerance of a country with regards to other country's deforestation, the lower its tariffs, given that* $4bd - 1 < 0$.

Proof. Appendix.

Proposition 5 implies that, when conditions are met, a larger tolerance for deforestation by another country tends to lead to reduction of trade tariffs as understood in this paper. In other words, the highest the tolerance of country for deforestation of the other country, more unlikely is the use of trade tariffs as a deterrence to deforestation.

6 The case of finite number of countries: a numerical exercise

In this section, we expand this paper model in its simplest version to a case of a finite number of countries and/or regions. Given the complexity of the problem, we are able to derive the solutions of the model, but not in explicit form. Hence, this is a good case for using numerical methods to check whether these derivations are effective in predicting tariffs and deforestation based in different settings of the utility.

6.1 Set-up

The setup is not very different from the two countries scenario, however we opt to use matrix notation as a way to keep the model compact and easier to understand. In that way, define u_i as the utility of country i, u is a $n \times 1$ vector containing the utilities from countries $1, \ldots, N$. Moreover, we define $\otimes$ as the Kronecker product and $\odot$ as the Hadamard product. Then, the utility of $1, \ldots, N$ countries might be defined in the following fashion:

$$u = u_0 + \tau + d - W_1 \tau \otimes \tau' \mathbf{1}_N - W_2 d \otimes d' \mathbf{1}_N$$

u_0 is a $n \times 1$ vector and can be understood again as an autonomous level utility, that countries enjoy with free trade and zero deforestation. τ is a vector $n \times 1$ containing the tariffs levied by one country on all its trade partners. We assume for simplicity that there is only one trade tariff being levied by one country on all its partners[4]. d is a vector $n \times 1$ containing the level of deforestation of all countries. W_1 is a $n \times n$ matrix measuring the impact tariffs of other countries tariffs on one another. Likewise, W_2 measures the impact of each country's levels of deforestation on each other. All elements of W_1 and W_2 are strictly non-negative. These matrix are not null either. These two matrix are very generic and can be calibrated considering different variables and determinants, that is, we only impose non-negativity as a restriction on the values of these two matrix. $\mathbf{1}_N$ is a column vector of size N, filled with 1s.

We enunciate the following proposition:

Proposition 6 *The market solution for N countries is characterized by the following expressions:*
Tariffs

$$I_N = W_1 \tau \otimes \mathbf{1}'_N I_N + W_1 \odot \tau'$$

Deforestation

$$I_N = W_2 d \otimes \mathbf{1}'_N I_N + W_2 \odot d'$$

[4] This hypothesis might seem restrictive, however this is not the case. The argument for restriction is valid in the sense that we do not allow for different trade tariffs within the context of a free or preferential trade agreement, which postulates lower tariffs for members of this FTA or PTA. However, if we assume the world of this numeric exercise is one of no FTA or PTA, then the tariffs have the appropriate interpretation of the Most Favourable Nation (MFN) tariffs, that is, the tariffs that a country must apply to all its trade partners.

I_N is the identity matrix of size N.

Proof. Appendix.

The Central Planner solution, on the other hand, will be given by the following proposition.

Proposition 7 *The central planner solution for N countries is characterized by the following expressions:*
Tariffs

$$\mathbf{1}_N = 2(\mathbf{1}_N \otimes (\mathbf{1}_N'\tau))(\mathbf{1}_N' W_1)'$$

Deforestation

$$\mathbf{1}_N = 2(\mathbf{1}_N \otimes (\mathbf{1}_N' d))(\mathbf{1}_N' W_2)'$$

Proof. Appendix.

6.2 Calibration

We simulate two scenarios for W_1, with W_2 being the same for both scenarios. W_2 is defined as $W_2[,j] = forests_j / \sum_{i=1}^{N} forests_i$, in which $forests_j$ is the forest cover of country j in km^2. . We use the forest cover as in 2021, provided by the World Bank Development Indicators. W_1, on the other hand, considers either GDP per capita in 2021 (constant 2015 US$) or Trade (% GDP) in 2021, both provided by the World Bank Development Indicators. In that way, we have that $W_1[i,j] = inv\_dist[i,j] * gdp\_percapita[i] * gdp\_percapita[j]'$ or $W_1[i,j] = inv\_dist_{i,j} * trade\_gdp[i] * trade\_gdp[j]'$,
in which $inv\_dist[i,j] = 1/dist[i,j]$, with $dist[i,j]$ being the distance between countries i and j. The inverse of distance among the countries is used to weight W_1, as a way to account for gravity relations in the trade among them. In Table 1 below, we present the results in the case of market and central planner for both variables in our model and considering different specifications for the Top 5 countries in terms of absolute forest cover.

Table 1: Results for N countries game of trade and deforestations (N=218) for selected countries

	GDP per capita				Trade (% of GDP)			
	τ_M	τ_C	d_M	d_C	τ_M	τ_C	d_M	d_C
Russia	0.79	0.91	0.79	0.73	0.58	0.98	0.82	0.36
Brazil	0.84	1.42	0.85	0.43	0.17	0.35	0.66	0.11
Canada	0.60	0.85	0.20	0.20	0.30	0.55	0.06	0.06
United States of America	0.56	1.01	0.70	0.70	0.14	0.64	0.53	0.14
China	0.64	0.76	0.18	0.03	0.80	1.67	0.99	0.30

Source: Authors' elaboration.

The previous Table 1 indicates that our predictions in the two-country model is transposed to the solution of the model for the five countries with the largest forest cover - we display only five of 218 countries due to space constraints. These conclusions are that trade tariffs in the central planner solution are larger than their market solution. On the other hand, deforestation in the market economy is larger than the central planned economy for all five economies considered in this analysis. This solution pattern is consistent across different specifications for W_1, whether this matrix is built using GDP per capita or trade (% of GDP).

7 Concluding Remarks

This paper provides some relevant insights into the preferences of the public for tariffs and deforestation and impacts on the stability of trade arrangements and deforestation levels.

The market solution for deforestation levels is always worse than the cooperative solution. This is an expected result of a good model and it informs that deforestation levels seem to decrease with higher cooperation amongst the parties.

On the other hand, the relationship between the optimal level of tariffs in the market and central planner solutions is not easily predicted. There are some preferences by a country that might direct the inequality of the Nash and the cooperative equilibria toward a different relationship. This adds realism to the model considered here in which countries can change their preferences over tariffs and deforestation and this changes the levels of tariffs that are found to be the highest.

The model also indicates there is an incentive for free-riding from the countries less concerned with deforestation on the countries that suffer the most disutility of its own deforestation. This is an interesting dynamic that relates to how the countries will define their own level of disutility and how that might compromise the countries in reaching a lower and more interesting levels of deforestation.

Finally, a global campaign for the change of public perception on deforestation seems to be the more sounding way to reduce deforestation in all countries and avert the phenomenon of free riding of unconcerned countries with those more committed with deforestation reduction.

References

Abman, R., & Lundberg, C. (2019). Does free trade increase deforestation? the effects of regional trade agreements.

Antonarakis, A. S., Pacca, L., & Antoniades, A. (2022, 5). The effect of financial crises on deforestation: a global and regional panel data analysis. *Sustainability Science*, *17*, 1037–1057. doi: 10.1007/s11625-021-01086-8

Assunção, J., Gandour, C., & Rocha, R. (2015, 12). Deforestation slowdown in the brazilian amazon: prices or policies? *Environment and Development Economics*, *20*, 697–722. doi: 10.1017/S1355770X15000078

Balboni, C., Berman, A., Burgess, R., & Olken, B. A. (2023, 9). The economics of tropical deforestation. *Annual Review of Economics*, *15*, 723–754. doi: 10.1146/annurev-economics-090622-024705

Balogh, J. M., & Mizik, T. (2021, June). Trade–Climate nexus: A systematic review of the literature. *Econ. Soc.*, *9*(3), 99.

Berman, N., Couttenier, M., Leblois, A., & Soubeyran, R. (2023, 5). Crop prices and deforestation in the tropics. *Journal of Environmental Economics and Management*, *119*, 102819. doi: 10.1016/j.jeem.2023.102819

Cunha, J. V. (2022). *A strategic analysis of trade and public environmental goods* (Unpublished doctoral dissertation).

Di Ubaldo, M., McGuire, S., & Shirodkar, V. (2022, December). Voluntary programs and emissions revisited: What is the effect of EU trade agreements with environmental provisions? *Journal of International Business Policy*, *5*(4), 467–489.

European-Union. (2023). Regulation (eu) 2023/1115 of the european parliament and of the council of 31 may 2023 on the making available on the union market and the export from the union of certain commodities and products associated with deforestation and forest degradation and repealing regulation (eu) no 995/2010.

Harstad, B. (2022). Trade, trees, and contingent trade agreements.

Lundberg, C., & Abman, R. (2022, 3). Maize price volatility and deforestation. *American Journal of Agricultural Economics*, *104*, 693–716. doi: 10.1111/ajae.12246

Robalino, J., & Herrera, L. D. (2010). *Staff working paper ersd-2010-04 trade and deforestation: A literature review trade and deforestation: A literature review **. doi: https://doi.org/10.30875/a6679776-en

Silva, R. F. B. d., Moran, E. F., Millington, J. D. A., Viña, A., & Liu, J. (2023, 7). Complex relationships between soybean trade destination and tropical deforestation. *Scientific Reports*, *13*, 11254. doi: 10.1038/s41598-023-38405-1

WTO. (2022a). *Ds593: European union — certain measures concerning palm oil and oil palm crop-based biofuels.* `https://www.wto.org/english/tratop_e/dispu_e/cases_e/ds593_e.htm`. (Accessed: 2024-06-20)

WTO. (2022b). *European union and certain member states — certain measures concerning palm oil and oil palm crop-based biofuels.* `https://www.wto.org/english/tratop_e/dispu_e/cases_e/ds600_e.htm`. (Accessed: 2024-06-20)

APPENDIX

A Maximum of the Market Solution: Characterization

In order for our solution to characterize properly a maximum, it is necessary that the objective function to be quasi-concave. A formal test to see whether the function is quasi-concave consists of testing whether the Hessian of the maximization problem is negative definite. Consider that the Hessian in this problem is given by:

$$H_1 = \begin{bmatrix} -2b & 0 \\ 0 & -2(c+1) \end{bmatrix}$$

Given that this square matrix is a diagonal one, then its eigenvalues are its non-null elements in the main diagonal. Moreover, as $-2b < 0$ and $-2(c+1) < 0$, given $b, c > 0$. Then, we have that our problem is fully characterized for country i. Given the symmetry of the utilities of country i and country j, then we can affirm that FOCs characterize fully a maximum, hence the utility is majored in the points we have found.

B Maximum of the Central Planner Solution: Characterization

In the case of the central planner, we must also guarantee that function is quasi-concave. As a way to assess this is to test the Hessian of this problem, which will be given by the following 4x4 square matrix $(\tau_i, \tau_j, d_i, d_j)$:

$$H_2 = \begin{bmatrix} -2b & -2 & 0 & 0 \\ -2 & -2d & 0 & 0 \\ 0 & 0 & -2(c+2) & -4 \\ 0 & 0 & -4 & -2(e+2) \end{bmatrix}$$

Its characteristic equation will be given by:

$$(-2b-\lambda)[(-2d-\lambda)(-2(c+2)-\lambda)(-2(e+2)-\lambda)+ \\ 16(2d+\lambda)] + +2[-2(2(c+2)+\lambda)(2(e+2)+\lambda)+32] = 0$$

The roots of this system will be given by:
$\lambda_1 = -b-d-\sqrt{4+b^2-2bd+d^2}$
$\lambda_2 = -e-c-4-\sqrt{c^2+e^2-2ec+16}$
$\lambda_3 = -b-d+\sqrt{4+b^2-2bd+d^2}$
$\lambda_4 = -e-c-4+\sqrt{c^2+e^2-2ec+16}$.

We must have that $\lambda_k < 0, \forall k = 1,2,3,4$. Given that we previously assumed that $b, c, d, e > 0$, then $\lambda_1, \lambda_2 < 0$ always. For $\lambda_3 < 0$, we must have $\sqrt{4+b^2-2bd+d^2} < b+d$. Likewise, for $\lambda_4 < 0$, we must have $\sqrt{c^2+e^2-2ec+16} < e+c+4$, which happens whenever $c > -1.15223$[5].

[5] We have assumed that $c > 0$, hence this condition is always met.

Whenever these conditions are met, our FOCs characterizes a maximum.

C Comparative Statics

This section aims to analyze how the Nash Equilibrium in the market equilibrium changes with parameter variation. It is a simple comparative statistics analysis.

Looking more directly at country i, we have the τ_i changes with the parameter b in the following manner:

$$\frac{\partial \tau_i}{\partial b} = \frac{4d(1-2d)}{(1-4bd)^2} \begin{array}{l} \geq 0, d \leq 1/2 \\ < 0, d > 1/2 \end{array}$$

Now, looking at comparative statistics of the level of deforestation of country i, with regards to the parameter c:

$$\frac{\partial d_i}{\partial c} = \frac{-2e(e+1)}{(2(ec+e+c))^2} < 0, e > 0$$

Hence, the impact of c on the deforestation of country i is always negative.

D Proofs

D.1 Market and Central Planner Comparison

1. Tariffs (τ_i)

$$\begin{gathered} \tau_i^{NASH} \leq \tau_i^{COOP} \\ \frac{1-2d}{1-4bd} \leq \frac{d-1}{2bd-2} \\ (1-2d)(2bd-2) \leq (1-4bd)(d-1) \\ -1 \leq 2bd-3d \\ -1 \leq d(2b-3) \end{gathered}$$

Hence, whenever $-1 \leq d(2b-3)$, tariffs in the cooperative case will be higher than in the non-cooperative case.

2. Deforestation (d_i)

$$\begin{gathered} d_i^{NASH} \geq d_i^{COOP} \\ \frac{e}{2(ec+c+e)} \geq \frac{e}{2(2+e)c+4e} \\ 2(ec+c+e) \leq 2(2+e)c+4e \\ 0 < 2c+2e \end{gathered}$$

$$0 < 2(c+e)$$

This always happens, given that $c, e > 0$. Hence, the market equilibrium levels for deforestation is always higher than the cooperative equilibrium levels of these variables.

D.2 Stability of Trade Arrangements

Tariffs of country i change with regard to d in the following manner:

$$\frac{\partial \tau_i}{\partial d} = \frac{-2(1-4bd)+4b(1-2d)}{(1-4bd)^2}$$

When will $\frac{\partial \tau_i}{\partial d}$ be positive? Whenever we have:

$$-2(1-4bd)+4b(1-2d) > 0$$

$$-2+8bd+4b-8bd > 0$$

$$4b > 2$$

$$b > 1/2$$

Whenever $b > 1/2$, increasing d leads to an increase of the tariffs of country i on goods of country j. Likewise, whenever $d > 1/2$, the impact of b on the tariffs for country i is positive.

D.3 Reduction of Deforestation Levels

In the case of e, we have the following partial effect:

$$\frac{\partial d_i}{\partial e} = \frac{2(ec+e+c)-e(c+1)}{[2(ec+e+c)]^2}$$

This implies that a positive change in the parameter e will increase deforestation levels in the equilibrium for country i.

The impact of the parameter c on the deforestation levels of country i will be given by the following expression:

$$\frac{\partial d_i}{\partial c} = \frac{-e(e+1)}{2(ec+c+e)^2}$$

Which is negative whenever $e > 0$.

D.4 Forest-tariffs on trade

We need to prove that tariffs will move in a different direction than a preference by country i with regards to the deforestation of country j. Consider the τ_i in this scenario. Then, $\frac{\partial \tau_i}{\partial d_{ji}}$ will be given by:

$$\frac{\partial \tau_i}{\partial d_{ji}} = -\frac{-4cd - 4de - 4cde}{2(4bd-1)(c+e+ec)}$$

$\frac{\partial \tau_i}{\partial d_{ji}} < 0$ whenever $4bd - 1 < 0$.

D.5 Market equilibrium for N countries

The derivation for the case of deforestation is identical to the case of tariffs. Hence, we only present the derivation for the case of tariffs. Consider that W_1 is nxn square matrix, with generic element given by w_{ij}, with $i = 1,\dots,N$ and $j = 1,\dots,N$. Hence, the first order conditions will be given by:

$$\frac{\partial u}{\partial \tau} = \underbrace{\frac{\partial \tau}{\partial \tau}}_{A} - \underbrace{\frac{\partial W_1 \tau \otimes \tau' \mathbf{1}_N}{\partial \tau}}_{B}$$

A is given by the following expression:

$$\text{A=}\begin{bmatrix} \frac{\partial \tau_1}{\partial \tau_1} & \frac{\partial \tau_1}{\partial \tau_2} & \cdots & \frac{\partial \tau_1}{\partial \tau_N} \\ \frac{\partial \tau_2}{\partial \tau_1} & \frac{\partial \tau_2}{\partial \tau_2} & \cdots & \frac{\partial \tau_2}{\partial \tau_N} \\ \vdots & \vdots & \cdots & \vdots \\ \frac{\partial \tau_n}{\partial \tau_1} & \frac{\partial \tau_n}{\partial \tau_2} & \cdots & \frac{\partial \tau_n}{\partial \tau_N} \end{bmatrix}$$

Which can be simplified into: $A = I_N$. **B**, on the other hand, will be given by the following expression:

$$\text{B=}\begin{bmatrix} w_{11}2\tau_1 + \cdots + w_{1n}\tau_n & \cdots & w_{1n}\tau_n \\ \vdots & & \vdots \\ w_{n1}\tau_1 & \cdots & w_{n1}\tau_1 + w_{n2}\tau_2 + \cdots + 2w_{nn}\tau_n \end{bmatrix}$$

Which can be simplified in the following expression:

$$B = W_1 \tau \otimes \mathbf{1}'_N I_N + W_1 \odot \tau'$$

Hence, the Fist Order Conditions imply that in the maximum:

$$I_N = W_1 \tau \otimes \mathbf{1}'_N I_N + W_1 \odot \tau'$$

D.6 Central Planner equilibrium for N countries

Considering that if u is the $nx1$ vector with each country's representative individual, then $\mathbf{1}'_N u$ is the utility the central planner optimizes with regards to τ or d. Solving for τ, given its similarity with the problem with d, we must calculate the following expression:

$$\frac{\partial \mathbf{1}'_N u}{\partial \tau} = \underbrace{\frac{\partial \mathbf{1}'_N \tau}{\partial \tau}}_{A} - \underbrace{\frac{\partial \mathbf{1}'_N (W_1 \tau \otimes \tau' \mathbf{1}_N)}{\partial \tau}}_{B}$$

A is given by the following expression:

$$A = \frac{\partial \mathbf{1}'_N \tau}{\partial \tau} = \mathbf{1}_N$$

Before displaying the value of **B**, let's explore the expression: $\mathbf{1}'_N(W_1\tau \otimes \tau' \mathbf{1}_N)$. This expression can be written as:

$$\sum_{k=1}^{N} \sum_{j=1}^{N} \tau_j \tau_k \sum_{i=1}^{N} w_{ij}$$

The derivative B will create a $nx1$ vector, with the following terms: B=2 $\begin{bmatrix} \sum_{j=1}^{N} \tau_j \sum_{i=1}^{N} w_{i1} \\ \sum_{j=1}^{N} \tau_j \sum_{i=1}^{N} w_{i2} \\ \vdots \\ \sum_{j=1}^{N} \tau_j \sum_{i=1}^{N} w_{in} \end{bmatrix}$

Which can be simplified into the following matrix:

$$B = 2(\mathbf{1}_N \otimes (\mathbf{1}'_N \tau))(\mathbf{1}'_N W_1)'$$