Running title: Trade, Species Diversity and Habitat Conservation.

International trade, species diversity, and habitat conservation

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Abstract:

Trade barriers may improve welfare if property rights with respect to renewable natural resources are lacking. Previous studies focus on the role of overharvesting, but we argue that trade–induced habitat destruction should also be taken into account. Habitat is one of the key factors determining the long–run viability of many natural resources, and economic activity oftentimes goes at the expense of habitat. While open access gives rise to within–industry externalities, habitat destruction creates across–industry externalities. We identify under what circumstances trade liberalization is welfare–enhancing as well as contributing to nature conservation, and analyze the consequences of trade policy.

Key words: Trade policy, trade liberalization, nature conservation, renewable resources, species diversity.

JEL codes: F18, Q20.

1. Introduction

Is trade liberalization detrimental to welfare and resource conservation, if property rights with respect to resource harvesting are not well enforced? The work by Brander and Taylor [4,5,6] suggests the answer to this question is affirmative for those countries that are relatively well-endowed with natural resources. Opening up to trade gives them the opportunity to exploit their comparative advantage in producing the resource good by exporting it, so that they harvest even more excessively (from a social welfare perspective) than in autarky. In such a second–best situation, trade policies that reduce foreign demand for the resource commodity mitigate the within–industry externality arising from the lack of well enforced property rights, and hence may improve welfare.

However, the argument that restricting trade in resources improves resource conservation, is not undisputed. Excessive harvesting pressure certainly provides a threat to the long–run survival of many species that are traded internationally. More than 50% of the mammals, reptiles, birds and amphibians that are currently threatened by extinction, are so because of overharvesting [12, p. 41]. But according to the same source, habitat destruction also threatens the long–run viability of more than 50% of those species (see also [3,14,15,16]). Habitat destruction compresses a species' population on a smaller piece of land. Competition for base resources such as food and water becomes more intense, resulting in a gradual decline of the resource population. This means that, by inducing a shift from resource harvesting towards a land–consuming economic activity, trade policies threaten rather than improve long–run species conservation if the habitat–destruction effect dominates the effect of reduced harvesting pressure.

In this paper, we extend Brander and Taylor's [6] two–country general equilibrium model to investigate the relationship between trade in a habitat–dependent natural resource, the size of its habitat, and a land–consuming economic activity, agriculture. We include the agricultural sector in the model, since it is one of the main causes of habitat destruction.[1] We assume that agricultural expansion necessarily goes at the expense of habitat conservation through land conversion. The lack of property rights with respect to resource harvesting does not only give rise to within–industry externalities (i.e., overharvesting of the resource). It also gives rise to across–industry externalities as incentives are lacking for farmers to take into account the negative impact of agricultural activity on resource conservation (via habitat destruction).

This paper is not the first to emphasize the relationship between habitat area and the long–run size of the resource stock in the economics literature. Swallow [14,15] analyzes socially optimal exploitation of (irreversible) habitat and a renewable resource, and Bulte and Horan [7] analyze the interaction between habitat and open–access resource harvesting in a single–country partial equilibrium framework. Our paper contributes to this literature by analyzing the interaction between resource harvesting and habitat destruction in a three–sector general equilibrium framework, and by allowing for the within– and across–industry externalities described above. We identify the conditions under which trade liberalization improves both domestic welfare as well as the conservation of a habitat–dependent natural resource.

Habitat size and international trade are linked through two main channels in our model. First, the abundance of the traded species depends positively on habitat size through its impact on the carrying capacity of the resource. Here, habitat can be thought of in a strict sense (a specific type of ecosystem) or, more loosely, as unclaimed land. Which interpretation is valid, depends on the species under consideration. Some species require a specific type of habitat for their survival. This holds for the tiger [9], but also for offshore marine fisheries (including shrimp) where individual species depend on the conservation of coastal estuarine wetland systems that serve as breeding grounds [2]. For these species, competition for space between nature and man is most obvious. But all species require base resources (such as water and fodder) to survive, and the availability of these resources ultimately depends on the area of land that is accessible to wildlife, which roughly coincides with uncultivated land. Here, elephants are an example in point [11]. Habitat destruction thus reduces the long–run viability of the natural resource, as well as its rate of growth: for a given population size, a decrease in habitat reduces the natural rate of regeneration.

The second link between habitat destruction and trade in our model operates through search costs, which affect the international competitiveness of resource harvesting industries. Reduction in habitat size does not result in the instantaneous demise of most terrestrial mammals, but their populations become compressed on a smaller area and hence individuals are easier to spot by hunters.

The reduced search costs increase the profitability of resource harvesting activity. Hence, if agriculture expands, it imposes externalities on the harvesting sector through habitat destruction. In the short run because it makes wildlife easier to catch (an economic across–industry externality), in the long run because it reduces the population of wildlife that can be caught (an ecological across–industry externality).

Conservation of *traded* species is not the only reason why the impact of trade and trade measures on habitat needs to be analyzed. Habitat also provides base resources for species that are not being traded internationally. These species may be valuable because of their genetic information or other types of use and non–use values. As is known from the island biogeography literature, the number of species living in a particular habitat is a positive function of the size of the habitat itself [10]. We take into account the role of habitat for biodiversity by analyzing the consequences of trade liberalization and trade policy on habitat size and long–run resource stocks in our model. These two variables serve as indicators of conservation, which matters from a global welfare perspective. We contrast conservation to consumer welfare derived from goods consumption.

The outline of the paper is as follows. In the second section, we introduce the model. In the third we study the autarky situation, which enables us to explore the consequences of free trade in the fourth section. The trade policy implications are derived in the fifth section, and section 6 concludes.

2. The model

There are two countries, Home and Foreign. There are three types of consumer commodities: agricultural products, a manufactured good, and a natural resource commodity. The production of each good requires labor as well as a sector–specific input. Agricultural production requires land, manufacturing requires capital, and resource harvesting depends on the resource stock. Labor earns a wage and capital a rent, but land and resources are not paid for. Rent dissipation occurs in the resource harvesting industry because of the lack of property rights. Land is assumed to be private property, but as we assume land *not* to be scarce in a strict economic sense, it is not paid for either. We assume the two countries to differ only with respect to input endowments; their technologies and preferences are identical. Therefore, we do not distinguish between the two countries until we describe trade (sections 4 and 5).

2.1 Supply side

Agricultural production, y_a, requires labor, l_a, and land, h_a, as perfectly complementary inputs. Land and labor are scaled such that efficient input use implies that one unit of agricultural output requires one unit of land and one unit of labor:

$$(2.1) \qquad y_a = \min\{l_a, h_a\}.$$

Each country's land endowment (h) is assumed to exceed its labor endowment (l), so that land is sufficiently abundant: it never becomes a limiting factor in agriculture. Therefore, land does not earn a rent. Unclaimed land can instantaneously be converted into agricultural land at zero conversion cost. Hence, unit production cost of agricultural goods equals the wage rate, w. In a competitive equilibrium with $l_a > 0$ the market price of agricultural products, p_a, equals the wage rate: $p_a = w$.

Manufactured commodities are produced using labor, l_m, and a fixed factor, k, for example capital or managerial labor, according to a Cobb–Douglas production function:

$$(2.2) \qquad y_m = k^{1-\eta} l_m^{\eta}, \quad \text{with } 0 < \eta < 1.$$

Profit maximization gives:

$$(2.3) \qquad l_m = (\eta p_m / w)^{1/(1-\eta)} k,$$

where p_m is the price of the manufactured commodity. Profits then equal $(1 - \eta)p_m y_m$.

We define habitat, h_r, as the area of land that is not used for agriculture: $h_r = h - h_a$.[2] Since in equilibrium one unit of labor employs one unit of land, $l_a = h_a$, it holds that:

(2.4) $$h_r = h - l_a .$$

The supply of resource commodities is given by an extended Schaefer harvesting production function. The productivity of harvesting effort, l_r, is determined by resource stock density (the ratio of the resource population size, s, to habitat area, h_r), and a 'catchability coefficient', α (> 0):

(2.5) $$y_r = (s / h_r)\alpha l_r .$$

The harvesting function extends the Schaefer function for spatial considerations. The size of habitat negatively affects harvest via its impact on search costs. One interpretation is that if agricultural activity expands (and hence habitat is smaller), a population of a given size lives on a smaller area and individuals are easier to spot; catch per unit of labor effort goes up. A second interpretation is that if agriculture expands, infrastructure is developed which may also be used to exploit natural resources. For example, roads facilitate access to previously inaccessible land areas and hence enhance open access [13].

The natural resource is harvested under open access. The lack of property rights implies that producers only face labor cost and earn zero profits, so that (in case $l_r > 0$) the market price of the resource equals average labor costs:

(2.6) $$p_r = wh_r / s\alpha .$$

Note that the resource price is inversely related to stock density s / h_r.

The natural resource stock changes over time because of natural growth and harvesting. The natural growth of the total resource stock depends positively on habitat size. This is captured by:

$$(2.7) \quad \dot{s} = \rho s(1 - s/h_r) - y_r ,$$

where ρ is the maximum growth rate of the resource.[3] This equation implies that the maximum population size – the size it will obtain in the absence of harvesting – is proportional to habitat size.

Labor supply is inelastic at l, which implies the following in a full–employment equilibrium:

$$(2.8) \quad l_a + l_m + l_r = l .$$

2.2 Demand side

In each country there is a representative consumer whose welfare is given by

$$(2.9) \quad u(c_a, c_m, c_r) = c_a^{\gamma_a} c_m^{\gamma_m} c_r^{\gamma_r} ,$$

with c_i denoting consumption of commodity i ($i = a, m, r$ for the agricultural, manufactured and resource commodity, respectively) and $\gamma_a + \gamma_m + \gamma_r = 1$. The Cobb–Douglas structure implies that spending on each of the three goods is a fixed fraction of nominal national income, y:

$$(2.10) \quad p_i c_i = \gamma_i y , \qquad (i = a, m, r).$$

Nominal national income is the sum of labor income and profits in the manufacturing sector, $y = wl + (1-\eta) p_m y_m$. From (2.2)–(2.3), we have $wl_m = \eta p_m y_m$ so that we may write:

$$(2.11) \quad y = w[l + l_m (1-\eta)/\eta] .$$

Since rents to capital increase with employment in manufacturing, national income increases with l_m.

2.3 Main driving forces behind conservation and welfare

To identify how habitat destruction and resource harvesting affect conservation and welfare, we analyze how changes in labor allocation in general affect our main variables of interest, which are habitat, the size of the resource stock, and consumer welfare. Sections 4 and 5 will narrow down the analysis to two specific changes in labor allocation, viz. changes caused by trade liberalization and trade policy, respectively.

Due to competition for space, an expansion of agriculture reduces habitat size ($dh_r = -dl_a$). Habitat destruction and intensification of harvesting reduce resource stocks: in a steady state with constant labor allocation, the long–run resource stock is constant at level $s_\infty = h_{r\infty} - (\alpha/\rho) l_{r\infty}$, where the subscript ∞ refers to the steady state. Together with the labor market constraint, we can write:

(2.12) $$s_\infty = h - \frac{\alpha}{\rho} l - \left(1 - \frac{\alpha}{\rho}\right) l_{a\infty} + \frac{\alpha}{\rho} l_{m\infty},$$ and

(2.13) $$\frac{s_\infty}{h_{r\infty}} = 1 - \frac{\alpha}{\rho}\left(\frac{l_{r\infty}}{h_{r\infty}}\right) = 1 - \frac{\alpha}{\rho}\left(\frac{l - l_{a\infty} - l_{m\infty}}{h - l_{a\infty}}\right).$$

Based on (2.12) we can state

Proposition 2.1. (Conservation and labor allocation)

(i) $sign\ ds_\infty / dl_{a\infty}\,|_{dl_{m\infty}=0} = sign\ (\alpha - \rho)$.

(ii) $ds_\infty / dl_{m\infty}\,|_{dl_{a\infty}=0} > 0$.

For given l_a, an increase in manufacturing results in a larger steady–state resource stock since it comes at the cost of harvesting effort without affecting habitat. For given $l_{m\infty}$, expansion of agricultural activity reduces the stock through reducing habitat, but increases it through leaving less labor for harvesting. On balance, the stock rises with agricultural expansion if and only if the productivity of harvesting effort (α) is large relative to the sensitivity of natural growth to habitat (ρ). Then, the *within*–industry externality (the effect of excess harvesting on the long–run stock, as measured by α) is less severe than the *across*–industry externality (the effect of habitat destruction on the stock, as reflected by ρ).

Habitat and resource stocks affect consumer welfare through affecting the resource price. In equilibrium, consumer welfare depends on income and prices according to $u = y(\gamma_a / p_a)^{\gamma_a} (\gamma_r / p_r)^{\gamma_r} (\gamma_m / p_m)^{\gamma_m}$. Let us assume that labor is employed in all three sectors. In that case, we can substitute income and prices – using $p_a = w$, (2.3), (2.6), and (2.11) – to arrive at the following expression for welfare:

$$\text{(2.14)} \quad u = [(\eta\gamma_m)^{\gamma_m} \gamma_a^{\gamma_a} \gamma_r^{\gamma_r}][l + l_m(1-\eta)/\eta]\left(k / l_m\right)^{\gamma_m(1-\eta)} \left(\alpha s / h_r\right)^{\gamma_r} .$$

For a fixed labor input in manufacturing, national income, the price of agricultural products, and the price of manufactured commodities are fixed in terms of the agricultural good. Therefore in that case only the price of the harvested commodity matters. This observation allows us to characterize the relationship between welfare and conservation as follows:

Proposition 2.2 (Welfare and stock density)

$du / d(s / h_r)\big|_{dl_m = 0} > 0$ if $l_a > 0$ and $l_r > 0$.

Ceteris paribus, a larger resource stock is good for consumer welfare, but a larger habitat size hurts it. Net, a higher stock density (s/h_r) boosts welfare since it lowers the cost of supplying harvested goods.

Through this channel, within– and across–industry externalities link conservation and welfare. The absence of property rights with respect to resource harvesting implies that from a social welfare perspective, the steady–state resource stock is suboptimally small, which hurts consumer welfare through high harvesting costs.

The within–industry externality may be exacerbated by the across–industry externalities that agriculture imposes on harvesting. The lack of property rights with respect to the resource implies that land owners ignore the impact of their land allocation decisions on long–run resource stocks; they may allocate too much of their land to agriculture, which impairs resource growth and hence may result in smaller long–run resource stocks. This is the ecological across–industry externality. In the short run, however, an expansion of agriculture provides a positive externality on the resource sector because for given resource stocks, a decrease in habitat reduces search costs. This is the economic across–industry externality.

Although the two across–industry externalities work in opposite directions, in the long run agricultural expansion unambiguously raises consumer welfare[4] through increasing the long–run stock density (s/h_r), as follows from (2.13). Also, for a given labor input in agriculture, industrial expansion boosts welfare. This is stated in the following proposition:

Proposition 2.3 (Long–run welfare and labor allocation)

$du_\infty / dl_{a\infty}\big|_{dl_{m\infty}=0} > 0$ and $du_\infty / dl_{m\infty}\big|_{dl_{a\infty}=0} > 0$.

To clarify the role of habitat effects in our model, it is instructive to first take a look at a special two–sector version of the model in which habitat effects vanish, then introduce habitat effects in a two–sector setting, and finally introduce a third sector.

We start by omitting the agricultural sector – which implies that habitat is constant ($h_r = h$) – and by assuming constant returns to scale in manufacturing $(\eta = 1)$. This is the Brander and Taylor [6] model. Expression (2.14) for welfare then becomes $u = (\gamma_m)^{\gamma_m} (\gamma_r)^{\gamma_r} l (\alpha s / h)^{\gamma_r}$. Therefore, an increase in harvesting effort reduces the long–run resource stock, so that long–run welfare falls. The result is that resource depletion and welfare losses go together.

A key insight from introducing habitat effects is that the country that specializes in harvesting suffers a welfare loss, but not necessarily a loss in its long–run resource stock. We can introduce habitat effects by maintaining a two–sector structure, but replacing the manufacturing sector by the agricultural sector. This implies the special case of our model with $\gamma_m = 0$ so that $l_m = 0$. In this case, a resource producing country that increases harvesting effort reduces agriculture ($dl_r = -dl_a > 0$; see (2.8)). Therefore, habitat expands, which results in a decrease in stock density both immediately and in the long run (see (2.13)). Expression From (2.14) reduces to $u = (\gamma_a)^{\gamma_a} (\gamma_r)^{\gamma_r} l(\alpha s / h_r)^{\gamma_r}$ and we see that welfare must fall in the short and long run. Thus, the two–sector model with agriculture and habitat generates a similar welfare result as in Brander and Taylor's [6] model. The results with respect to the resource stock are different, though. If $\alpha < \rho$, an increase in harvesting comes at the cost of agriculture, which increases habitat and enhances conservation of the resource stock.

Finally, in the three–sectors case, we find that specialization in resource harvesting may even raise both consumer welfare and resource conservation. With three sectors, an increase in harvesting may produce either a decrease or an increase in agriculture – and hence an increase or decrease in habitat, respectively – depending on what happens to manufacturing labor. By the labor market constraint, we have $dl_a = -dl_r - dl_m$. If the increase in harvesting is accompanied by a decrease in manufacturing, agriculture may expand, which hurts habitat in contrast to what happens in the two two–sector models just discussed. In the long run, stock density s/h_r increases (see (2.13)), which *increases* welfare (provided it is not dominated by losses from reduced manufacturing). This is in contrast to what happens in the two–sector models.

So far we have studied conservation and welfare for given labor allocation. The next sections determine labor allocation endogenously under autarky, free trade and trade policy respectively.

3. Equilibrium in autarky

In autarky, all three goods are produced and consumed, $y_i = c_i > 0\ (i = a, m, r)$. We take the agricultural commodity as the numéraire ($p_a = 1$), which implies $w = 1$. The autarky labor allocation over the three sectors depends on preference parameters and on the labor cost share in manufacturing, η, according to the following expressions:[5]

$$(3.1)\qquad l_a^{AUT} = \tilde{\gamma}_a l,\ \ l_r^{AUT} = \tilde{\gamma}_r l\ ,\ \ l_m^{AUT} = \eta\tilde{\gamma}_m l,$$

where $\tilde{\gamma}_i \equiv \gamma_i / [1 - \gamma_m(1-\eta)]$ for $i = a,m,r$ and AUT denotes autarky.

Whereas labor allocation is constant over time, the resource stock may change over time. From (2.5), (2.7), and (3.1), we find that its steady state value in autarky is equal to:

$$(3.2)\qquad s_\infty^{AUT} = h - (\tilde{\gamma}_a + \tilde{\gamma}_r \alpha / \rho) l\ .$$

Hence, countries with a large endowment of land, h, relative to labor, l, sustain a large steady state resource stock in autarky. The autarky equilibrium prices are given by

$$(3.3)\qquad p_a^{AUT} = 1,\ \ p_m^{AUT} = \eta^{-\eta} (\tilde{\gamma}_m l / k)^{1-\eta}\text{, and }\ p_{r\infty}^{AUT} = \frac{1}{\alpha}\left(\frac{h/l - \tilde{\gamma}_a}{h/l - (\tilde{\gamma}_a + \tilde{\gamma}_r \alpha / \rho)}\right).$$

where the resource price follows from (2.13), (3.1) and (2.6). Comparing two countries that differ in endowments, the country with highest land to labor ratio sells the resource at the lowest relative price.

4. Free trade

We now study what happens if two similar countries, referred to as Home and Foreign, open up goods trade. We assume that when trade starts, say at time T, resource stocks are at their autarky steady–state equilibrium. The two countries differ only with respect to factor endowments k, h and l and therefore also with respect to their autarky steady–state resource stocks. All other parameters are identical across the countries. Without loss of generality, we furthermore assume that Foreign is relatively well endowed with land. Thus, using asterisks to denote parameters and variables that are specific to Foreign, we assume $1 < h/l < h^*/l^*$. As is clear from equation (3.3), this assumption implies that just before opening up to trade, the resource harvesting cost in Home exceeds the one in Foreign. Finally, we assume that both countries always engage in agriculture. This assumption facilitates the analysis, as it implies that wage rates are equal in the two countries. The simplest way to ensure this is to assume that aggregate demand for agricultural goods is too large to be produced by a single country: $\tilde{\gamma}_a > \max\{l/(l+l^*), l^*/(l+l^*)\}$.

From now on, the superscript *w* denotes aggregates over the two countries ($x^w \equiv x + x^*$ for any *x*). The superscript FT refers to free trade, which will be suppressed when there is no danger of confusion.

4.1. Determination of the free trade equilibrium

Since both countries produce the agricultural good, they charge the same price for this numeraire good and wages equalize, $w^{FT} = w^{FT*} = 1$. It follows that aggregate income equals:[6]

$$(4.1) \qquad y^{FTw} = \frac{w^{FT} l + w^{FT*} l^*}{1-(1-\eta)\gamma_m} = \frac{l^w}{1-(1-\eta)\gamma_m} = y^{AUTw}.$$

Aggregate income in terms of agricultural goods does not differ between autarky and free trade because of wage equalization and the Cobb–Douglas structure. With wage equalization, labor income in terms of agricultural goods remains constant ($wl^w / p_a = l^w$). The Cobb–Douglas specification of the utility and manufacturing production function implies constant value shares, so that rent income is a fixed fraction of labor income, and also remains constant in terms of agricultural goods.[7]

Equilibrium in the market for good i ($i = a, m, r$) requires that total revenue for producers in each market equals international consumer spending on the good $(p_i y_i^w = \gamma_i y^w = \tilde{\gamma}_i l^w)$. Since $p_a y_a^w = wl_a + w^* l_a^*$ and using $p_a = w = w^* = 1$, the labor allocation in agriculture satisfies:

(4.2) $\quad l_a^* = \tilde{\gamma}_a l^w - l_a$.

In free trade, both countries produce positive amounts of the manufactured good (since $0 < \eta < 1$). Wages are equalized and therefore profit maximization implies $l_m / l_m^* = k / k^*$. Together with (2.3) this implies that the manufactured goods market clears if $(l_m + l_m^*)/\eta = \gamma_m y^w = \tilde{\gamma}_m l^w$. Hence, in equilibrium, we have:

(4.3) $\quad l_m = \eta \tilde{\gamma}_m z l$; $l_m^* = \eta \tilde{\gamma}_m z^* l^*$,

where $z \equiv (k/l)/(k^w/l^w)$ and $z^* \equiv (k^*/l^*)/(k^w/l^w)$, which reflect relative abundance of capital per unit of labor in Home and Foreign, respectively. Hence, the country relatively well endowed with capital exports manufactured goods, that is Home (Foreign) exports if $z > 1 > z^*$ ($z^* > 1 > z$).[8]

Regarding harvesting there might occur a shared harvesting regime (SHR), where both countries harvest the resource, with equal unit harvest costs, or a concentrated harvesting regime (CHR), where only Foreign harvests, at lower unit costs than Home.[9] Harvest cost equalization implies that stock densities are equal across countries, see (2.6). Hence, in a shared harvest regime, $l_r > 0$, $l_r^* > 0$ and $h_r / h_r^* = s / s^*$. Substituting (2.4) and (2.8) to eliminate h_r and l_r respectively, we find for a shared harvest regime:

(4.4) $\quad \dfrac{h - l_a}{h^* - l_a^*} = \dfrac{s}{s^*}$, with $l_a < l - l_m$, $\quad l_a^* < l^* - l_m^*$.

Similarly, in a concentrated harvest regime, we have:

(4.5) $$\frac{h-l_a}{h^*-l_a^*} > \frac{s}{s^*}, \text{ with } l_a = l - l_m, \quad l_a^* < l^* - l_m^*.$$

From (4.2)–(4.5), we can solve for l_m^{FT}, l_m^{*FT}, l_a^{FT}, and l_a^{*FT} for given *s* and *s** to characterize the short–run free–trade equilibrium. Using the solution for long–run resource stocks, see (2.12), to eliminate *s* and *s**, we can solve for the same variables to characterize the long–run free–trade equilibrium. In the sequel we compare the short–run and long–run free–trade equilibria to the autarky equilibrium to characterize the effects of international trade on three key variables, namely habitat, the resource stock (only for the long run) and welfare.

4.2 The short–run consequences of trade liberalization

This section deals with the short–run effects of opening up to trade, starting from steady state autarky. The results depend on whether the short–run equilibrium is a shared or concentrated harvesting regime. The latter arises if autarky steady–state resource stocks imply that Home's producer price of the resource exceeds Foreign's producer price, even if Home allocates no labor to harvesting.

On the short–run consequences of trade liberalization for habitat, we can state the following:

Proposition 4.1 (Short–run habitat)

(*i*) $h_r^{FTw}(T) = h_r^{AUTw}(T)$.

(*ii*) $l_r^{FT}(T) > 0$ and $l_r^{FT*}(T) > 0$ implies $h_r^{FT}(T) < h_r^{AUT}(T)$ and $h_r^{FT*}(T) > h_r^{AUT*}(T)$.

(*iii*) $l_r^{FT}(T) = 0$ and $l_r^{FT*}(T) > 0$ implies $h_r^{FT}(T) > h_r^{AUT}(T)$ and $h_r^{FT*}(T) < h_r^{AUT*}(T)$ if and only if $\gamma_r < \eta\gamma_m(\mathrm{z}-1)$.

As aggregate income (measured in terms of agricultural goods) remains unchanged and a constant share of income is spent on agricultural goods, aggregate demand for agricultural goods does not change. Opening up to trade may affect the *allocation* of agricultural production over the two countries, but does not affect the total land area devoted to agriculture. Consequently total habitat remains unchanged.

The formal proof of the second and third part of the proposition is provided in the appendix. The intuition of the second part is as follows. In autarky, Home has higher unit harvest costs than Foreign. If trade liberalization makes both countries engage in harvesting and have equal unit harvesting costs, Home's harvest cost must fall, and, with a fixed short–run resource stock, this can only be accomplished through a fall in habitat since this lowers search costs.

The opposite, a decrease (increase) in Foreign (Home's) habitat, can only occur if Home stops harvesting after trade liberalization. Only if all labor previously allocated to harvesting shifts to the production of manufactured goods (rather than to agriculture), habitat destruction can be avoided. This requires that Home has a large comparative advantage in manufacturing (z large) and that there is a large market for these goods (γ_m large). In contrast, if there is no trade in manufactured goods or if home imports these goods ($z \leq 1$), free trade reduces home's habitat.

Next we consider the effect of opening up to trade on welfare.

Proposition 4.2 (Short run welfare).

(i) $u^{FT}(T) > u^{AUT}(T)$.

(ii) $sign[u^{FT*}(T) - u^{AUT*}(T)]$ is ambiguous, but

(iii) $u^{FT*}(T) > u^{AUT*}(T)$ if $h_r^{FT*}(T) < h_r^{AUT*}(T)$.

See the appendix for the proof. Home gains from trade in the short run since it imports harvested resources at a price lower than its autarky price. Moreover it gains from trade in manufactured goods, since the manufacturing sector is not riddled with externalities. The latter applies to Foreign, too, but the across–industry externality between agriculture and harvesting may make Foreign suffer. If its habitat falls through agricultural expansion, search costs in harvesting are lower, which boosts welfare. However, as stated in proposition 4.1, trade may instead raise habitat. If in this case the higher harvesting search costs are not completely offset by gains from trade in manufactured goods, Foreign welfare falls. Note that if there were no trade in manufacturing ($z = 1$)[10], foreign would always lose from opening up to trade.

4.3 The long–run effects of opening up to trade

Following the instantaneous reallocations as a result of opening up to trade, resource stocks start adjusting towards a new long–run level. This transition has an impact on harvest costs and trade patterns. In the long run, both countries harvest. Any country that does not harvest would end up with the highest possible stock density: $s/h_r = 1$ (see (2.13)). Therefore, its harvesting costs would be lower than those of the other country (which does harvest), and hence harvesting would be profitable.

We first show that aggregate habitat is not affected in the long run. We also derive a necessary and sufficient condition for per country habitats to increase or decrease.

Proposition 4.3 (Long–run habitat).

(i) $h_{r\infty}^{FTw} = h_{r\infty}^{AUTw}$.

(ii) $h_{r\infty}^{FT} < h_{r\infty}^{AUT}$ and $h_{r\infty}^{FT*} > h_{r\infty}^{AUT*}$ if and only if $\left[\dfrac{h^*/l^* - h^w/l^w}{h^w/l^w - \tilde{\gamma}_a}\right]\gamma_r > \eta\gamma_m(1 - z^*)$.

Result (i) has the same proof and intuition as proposition 4.1(i). The appendix gives the proof of (ii). In autarky, Home has higher harvesting costs, and hence will withdraw labor from resource harvesting when opening up to trade. This will shift labor into the agricultural sector, unless Home becomes a large exporter of manufactured goods. If Home is relatively abundant in capital (low z^*) and demand for manufacturing is relatively high (high γ_m), Home is likely to shift labor from agriculture to manufacturing so that habitat increases. In contrast, without trade in manufactured goods ($z^* = 1$), Home pays for resource imports by exporting agricultural goods, which comes at the cost of habitat.

Next we deal with the resource stock.

Proposition 4.4 (Long–run resource stocks).

(i) $s_\infty^{FTw} = s_\infty^{AUTw}$.

(ii) $s_\infty^{FT} < s_\infty^{AUT}$ and $s_\infty^{FT*} > s_\infty^{AUT*}$ if and only if $\left[\dfrac{h^*/l^* - h^w/l^w}{h^w/l^w - (\tilde{\gamma}_a + \tilde{\gamma}_r \alpha/\rho)}\right]\gamma_r\left(\dfrac{\rho-\alpha}{\rho}\right) > \eta\gamma_m(1-z^*)$.

The first part of the proposition follows from the result that trade only shifts employment in each of the sectors from one country to the other without affecting aggregate employment in each of the sectors. Aggregate harvesting employment remains unchanged as well as aggregate habitat. Since the aggregate steady–state resource stock depends on aggregate habitat and employment in harvesting, trade does not affect this stock in the long run.

The proof of the second part of the proposition is given in the appendix. The inequality condition allows us to separate the role of externalities (on the LHS) and that of manufacturing exports (on the RHS). We identify three cases in which, in contrast to the results obtained by Brander and Taylor [6], trade liberalization reduces the resource–exporter's resource stock.

First, if $z^* = 1$, manufactured goods are not traded and manufacturing employment is the same as in autarky. Hence, we can apply proposition 2.1 with $dl_m = 0$. Home imports the resource and destroys habitat to expand agriculture for exports, and the opposite happens in Foreign. The increase in Foreign's habitat raises its resource stock if $\rho > \alpha$, as explained in section 2.3.

Second, if $z^* < 1$, Foreign imports manufactured goods. Then, the sign of the RHS is positive, but since the term in square brackets is positive, the sign of the LHS is also positive if $\rho > \alpha$. Hence, if Foreign imports manufactured goods, Foreign's stock can only increase if across–industry externalities dominate within–industry externalities ($\rho > \alpha$) and if the market for harvested resources is large (γ_r large). In this case, Foreign reallocates labor from manufacturing and agriculture to resource harvesting, which boosts the stock through the effect of expanded habitat on natural growth.

Third, if $z^* > 1$, Foreign reduces agricultural activity mainly to expand manufacturing rather than harvesting activity, so that habitat increases substantially relative to harvesting effort. That means that even if $\rho < \alpha$ (that is, if the within–externality dominates), the net impact on the resource stock may be positive.

Finally we address the long–run welfare consequences of trade liberalization.[11]

Proposition 4.5 (Long–run welfare).

(i) $u_\infty^{FT} > u_\infty^{AUT}$.

(ii) $sign\,[u^{FT*} - u_\infty^{AUT*}]$ is ambiguous, but

(iii) $u_\infty^{FT*} < u_\infty^{AUT*}$ if $z^* = 1$.

Trade equalizes long–run harvest costs in the two countries. Hence, stock densities s / h_r are the same in both countries and equal to the world stock ratio, which is the same in free trade and autarky. In autarky, Home has high harvest cost and low stock density. As a result trade lowers its long–run harvest costs and Home gains. In contrast to the results obtained by Brander and Taylor [6], Foreign's welfare may increase, only if the gains from trade in manufacturing are large enough to offset the losses from the increases in harvesting costs (as shown numerically in the appendix).

5. Policy analysis: Taxation of the resource commodity imports by Home

In this section we explore how the key variables habitat, the resource stock and welfare are affected when Home levies a tariff on its resource imports. The tariff reduces profitability of resource harvesting in Foreign. This has two consequences. First, it mitigates the within–industry externalities arising from the absence of property rights (cf. Brander and Taylor [6]). Second, it shifts labor away from resource harvesting and hence may stimulate the land–consuming economic activity, agriculture. Therefore, it may exacerbate the across–industry externality that operates through habitat destruction.

We assume that Home introduces an ad–valorem tariff on its resource commodity imports in the long–run free–trade equilibrium and that the tariff is positive but close enough to zero, so that we can analyze marginal deviations from the free–trade equilibrium. For expositional purposes, we also assume that Foreign has no manufacturing production and that rents to capital can be ignored. We arrive at this situation by assuming $k^* = 0$ and $\eta \to 1$. We finally assume that Home is a net resource importer in the steady–state free–trade equilibrium (that is $\Gamma \equiv \gamma_r y / p_r - y_r = \gamma_r l - l_r > 0$); otherwise, the tariff would not be effective. One way to guarantee this result is by assuming that $\gamma_m < (h^* / l^* - h / l)(l / l^w)$.

Let τ denote the ad–valorem tariff on resource imports in Home and let p_r (p_r^*) denote the resource price paid by a consumer in Home (Foreign). Cross–border arbitrage implies:

(5.1) $\quad p_r = (1+\tau) p_r^*.$

In Home, national income is equal to the sum of its labor income and the import revenues, $y = wl + \tau p_r^* \Gamma = wl + \tau p_r^* \left(\gamma_r y / p_r - y_r \right)$. Taking into account that $w = 1$, $p_r y_r = l_r$ (zero-profit condition) and using (5.1), Home's income is $y = l + \tau(\gamma_r l - l_r)/(1+\tau(1-\gamma_r))$. Because Foreign's income equals labor income ($y^* = l^*$), aggregate income (in terms of agricultural goods) equals:

(5.2) $\quad y^w = l^w + \tau(\gamma_r l - l_r)/(1+\tau(1-\gamma_r))$.

Aggregate income decreases with l_r: the more of the resource commodity is produced by Home, the smaller the imports from Foreign and hence the smaller the import tariff revenues.

Together with (5.1) and (5.2), our assumptions that $k^* = 0$ and $\eta \to 1$ imply that in equilibrium $l_a + l_a^* = \gamma_a y^w$ (cf. (4.2)), and $l_m = \gamma_m y^w$, $l_m^* = 0$ (cf. (4.3)). Zero profits in the harvest sector imply that domestic prices equal domestic unit harvest costs $wh_r / s\alpha$. Together with $w = 1$, this allows us to write (5.1) as:

(5.3) $$\frac{h-l_a}{s}=(1+\tau)\frac{h^*-l_a^*}{s^*}.$$

5.1 The short–run consequences of Home levying a resource import tax

In this subsection we derive the immediate effects of the tariff on habitat and welfare, that is keeping the resource stocks at their free–trade steady–state level. The symbol Δx will denote the instantaneous change in variable *x* as a result of the marginal tariff τ. We first deal with habitat.

Proposition 5.1 (Tariff's short–run impact on habitat).

(i) $\Delta h_r^w < 0$.

(ii) $\Delta h_r > 0, \Delta h_r^* < 0$.

The import tariff has two direct consequences. First, it shifts Home's demand from imported resources to domestically harvested resources. Therefore Home's harvesting activity expands whereas Foreign harvesting falls $(\Delta l_r > 0, \Delta l_r^* < 0)$. Second, the tariff raises the price of harvested commodities relative to manufactured goods, so that demand for Home's manufactured goods increases (from (5.2), $l_m = \gamma_m y^w$, and evaluating at τ = 0, we have $\Delta l_m = \gamma_m \Gamma > 0$). Therefore, producers in Home reallocate labor from agriculture to harvesting and manufacturing, which boosts Home's habitat. The higher resource price also shifts relative demand to agriculture and aggregate land use expands at the cost of aggregate habitat (from (5.2) and $l_a + l_a^* = \gamma_a y^w$ we have $-\Delta h_r^w = \Delta l_a^w = \gamma_a \Gamma > 0$).

Next we state the welfare consequences.

Proposition 5.2 (Tariff's short–run impact on welfare).

(i) $sign \Delta u$ is ambiguous.

(ii) $\Delta u^* > 0$.

The increase (decrease) in habitat in Home (foreign) reduces per unit harvest costs in Foreign relative to Home. Therefore, while imported resource commodities become relatively more expensive in Home because of the tariff, they become relatively less expensive due to lower search costs. In the new equilibrium, Foreign remains an exporter of harvested resources. The increased stock density in Foreign results in a welfare improvement. Home receives the tariff revenues, but also experiences an increase in the costs of resource harvesting and hence its net welfare change is undetermined.

5.2 The long–run consequences of Home levying a resource import tax

In the long run, the resource stocks have adjusted to their steady state level. The consequences of the tariff on habitat can now be formalized (Δx_∞ denotes the long–run change in variable x).

Proposition 5.3 (Tariff's impact on long–run habitat).

(i) $\Delta h_{r\infty}^{w} < 0$.

(ii) $sign\,\Delta h_{r\infty}$ is ambiguous, $\Delta h_{r\infty}^{*} < 0$.

Thus, as compared to the steady state free trade equilibrium, agriculture in Foreign increases and harvesting activity falls, since the tariff reduces exports of harvested goods to Home. In the latter country, the tariff has an ambiguous impact on agriculture. On the one hand, as was the case in the short run, it reallocates labor to the harvesting and manufacturing sectors, at the cost of agriculture. On the other hand, the resource stock changes in the long run, which affects the allocation of labor.

Next, we can determine the circumstances under which Foreign's resource stock increases.

Proposition 5.4 (Tariff's impact on long–run resource conservation).

(i) $\Delta s_\infty^{w} > 0 \Leftrightarrow \gamma_m > \gamma_a(\rho - \alpha)/\alpha$.

(ii) $\Delta s_\infty^{*} > 0 \Leftrightarrow \rho < \alpha$.

The tariff only results in unambiguously larger resource stocks in Foreign if the within–industry externality (reflected by a higher productivity parameter α) is more severe than the across–industry externalities (associated with habitat destruction, the importance of which depends on ρ). The tariff is effective in reducing harvesting in Foreign, but since it also destroys habitat through agricultural expansion, the stock only increases if habitat destruction has relatively small effects on natural growth. A similar trade–off exists in Home where harvesting activities are increased, but this impact is mitigated because of the increase in demand for manufactured goods. At the aggregate level, the bigger the shift to manufacturing relative to the shift to agriculture, the more the aggregate resource stock is boosted since expansions of manufacturing do not come at the cost of habitat. The strength of this second effect depends on the size of γ_m relative to γ_a.

Finally, we address the long–run welfare consequences.

Proposition 5.5 (Tariff's long–run impact on welfare).

(i) $\Delta u_{\infty}^{*} > 0$.

(ii) $sign\,\Delta u_{\infty}$ is ambiguous.

Although the impact of the tariff on s^{*} is ambiguous, s^{*}/h_{r}^{*} increases. This means that search costs in Foreign fall, and hence the tariff mitigates the search externality. For Home, the long–run welfare consequences are less clear–cut, as it faces increased harvesting costs which may or may not be compensated by the inflow of tariff revenues.

6. Conclusions

Many renewable natural resources are harvested under de facto open access. This implies that in autarky harvesting levels exceed their socially optimal levels. Absent well-enforced property rights, trade liberalization may not be welfare–improving. It enhances the profitability of resource harvesting in countries with a comparative advantage in that activity, and hence exacerbates the within–industry externality arising from the lack of property rights. Indeed, in their seminal paper, Brander and Taylor [6] conclude that (i) trade liberalization does not enhance welfare in all countries involved, and (ii) trade barriers imposed by countries with a comparative disadvantage in resource harvesting are welfare–improving.

In this paper, we have extended Brander and Taylor's model by introducing economic and ecological interdependencies between the renewable natural resource and one type of economic activity, agriculture. The ecological interdependency is a negative one; habitat, be it defined in terms of quality or in terms of quantity, is one of the main determinants of the long–run viability of many renewable natural resources, including fauna and flora, and agriculture takes place at the expense of habitat through claims on land or by degrading its quality (e.g., via pesticide use or, more general, pollution). The economic interdependency concerns the impact of habitat on harvesting costs: spreading the resource stock over a larger habitat means that resource harvesting costs increase due to, for example, increased search costs. That means that we should not only consider the within–industry externality arising from the lack of effective property rights, but also the (positive and negative) externalities between agriculture and harvesting activity.

These across–industry externalities imply that the clear–cut results obtained by Brander and Taylor [6] no longer hold. First, whereas Brander and Taylor find that trade liberalization unambiguously reduces welfare in the relatively resource–rich country (labeled Foreign), we observe that the results crucially depend on the role of habitat in our model. Trade may shift labor into or out of agriculture, depending on whether the country starts exporting agricultural goods or not. A shift towards agriculture reduces habitat, and yields short–run gains to the extent that smaller habitat means lower search costs, which is welfare–improving for the resource exporter. There are long–run costs, too. Smaller habitats impair carrying capacity and long–run resource stocks. Reduced habitat may also impose costs in terms of loss of biodiversity if species diversity is indeed positively correlated with habitat size as is implied by the literature on the species area curve.

Second, the consequences of Home introducing a marginal tariff on resource imports from Foreign are not unambiguously beneficial, neither from an environmental perspective, nor from a goods consumption perspective. In Foreign, labor shifts from resource harvesting to agriculture. The resulting reduction in harvesting pressure favors resource conservation. But this positive effect may be overtaken by the decrease in habitat (which negatively affects resource regeneration), so that the net impact on resource conservation is ambiguous. Because of the same considerations, the change in the aggregate resource stock in Home and Foreign is also ambiguous, but their total habitat unambiguously declines.

In short, we find that Brander and Taylor's policy recommendations may be appropriate for natural resources such as high–sea fisheries, for which competition for space is absent, but not necessarily for terrestrial resources. Trade measures may not enhance conservation of terrestrial resources in countries that are still endowed with substantial areas of habitat, that are rich in terms of biodiversity, and where agriculture is an important source of income.

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Appendix: Proofs

In this appendix we only use the superscript *FT* when a variable is compared with its value in autarky.

Free–trade regime conditions

(i) $l_r = 0, l_r^* > 0$ (CHR) is an equilibrium if and only if $\frac{s^*}{s} \geq \frac{h^* - (1-\eta\tilde{\gamma}_m z^*)l^* + \tilde{\gamma}_r l^w}{h - (1-\eta\tilde{\gamma}_m z)l}$.

(ii) $l_r > 0,\ l_r^* = 0$ (CHR) is an equilibrium if and only if $\frac{s^*}{s} \leq \frac{h^* - (1-\eta\tilde{\gamma}_m z^*)l^*}{h - (1-\eta\tilde{\gamma}_m z)l + \tilde{\gamma}_r l^w}$.

(iii) With free trade, $l_r > 0,\ l_r^* > 0$ (SHR) is an equilibrium if and only if $\frac{h^* - (1-\eta\tilde{\gamma}_m z^*)l^*}{h - (1-\eta\tilde{\gamma}_m z)l + \tilde{\gamma}_r l^w} < \frac{s^*}{s} < \frac{h^* - (1-\eta\tilde{\gamma}_m z^*)l^* + \tilde{\gamma}_r l^w}{h - (1-\eta\tilde{\gamma}_m z)l}$.

Proof

$l_r = 0, l_r^* > 0$ is an equilibrium if and only if Home and Foreign make nonzero and zero profits, respectively. Hence $h_r^* / s^* = p_r / \alpha \leq h_r / s$. Hence, from (2.4) and (2.8), we may write $\frac{s^*}{s} \geq \frac{h_r^*}{h_r} = \frac{h^* - l^* + l_m^* + l_r^*}{h - l + l_m}$, in which we can substitute (4.3) and $l_r^* = l_r^w = \tilde{\gamma}_r l^w$. This proves (i). The proof of (ii) is analogous, and (iii) is an immediate implication of (i) and (ii).

Proof of proposition 4.1 ii and iii (Short–run habitat)

$p_r^{AUT}(T) = \frac{1}{\alpha}\frac{h_{r\infty}^{AUT}}{s_\infty^{AUT}} > p_r^{AUT*}(T) = \frac{1}{\alpha}\frac{h_{r\infty}^{AUT*}}{s_\infty^{AUT*}}$. If $y_r^{FT}(T) > 0$ and $y_r^{FT*}(T) > 0$ (SHR) then $p_r^{FT}(T) = h_{r\infty}^{FT} / s_\infty^{AUT}\alpha = h_{r\infty}^{FT*} / s_\infty^{AUT*}\alpha$. Also $p_r^{AUT}(T) > p_r^{FT}(T) > p_r^{AUT*}(T)$. This proves *(ii)*.

If $y_r^{FT}(T) = 0$ and $y_r^{FT*}(T) > 0$ (CHR) then $l_a^{FT} = l - \eta\tilde{\gamma}_m zl$. $h_r^{FT} = h - l_a^{FT} < h_r^{AUT} = h - l_a^{AUT} \Leftrightarrow \tilde{\gamma}_a < 1 - \eta\tilde{\gamma}_m z \Leftrightarrow \gamma_r > \eta\gamma_m(z-1)$. This proves *(iii)*.

Proof of proposition 4.2 (Short–run welfare)

By substituting (2.3), (2.10), (2.11), and p_a = 1 into (2.9), we find an expression for welfare, from which we calculate welfare in autarky and free trade by substituting (3.3) and (4.3), respectively. We find (we omit T because there is no danger of confusion):

$$\frac{u^{FT}}{u^{AUT}} = \frac{1+(1-\eta)\tilde{\gamma}_m z}{1+(1-\eta)\tilde{\gamma}_m}\left(\frac{1}{z}\right)^{\gamma_m(1-\eta)}\left(\frac{p_r^{AUT}}{p_r^{FT}}\right)^{\gamma_r} = \left[\{1-(1-\eta)\gamma_m(1-z)\}\left(\frac{1}{z}\right)^{\gamma_m(1-\eta)}\right]\left(\frac{p_r^{AUT}}{p_r^{FT}}\right)^{\gamma_r}.$$

The term in square brackets reaches a minimum equal to unity for $z = 1$.

To prove (i), we show that $p_r^{AUT}(T) > p_r^{FT}(T)$ so that $u^{FT}(T) > u^{AUT}(T)$. In autarky, zero profits in harvesting in Home and Foreign requires $p_r^{AUT}s^{AUT} = h_r^{AUT}/\alpha$ and $p_r^{AUT*}s^{AUT*} = h_r^{AUT*}/\alpha$, respectively. Combining, we find $p_r^{AUT}(s^{AUT}+s^{AUT*})-(p_r^{AUT}-p_r^{AUT*})s^{AUT*} = h_r^{AUTw}/\alpha$ for the aggregate. In free trade, non–positive profits in Home and zero profits in Foreign requires $p_r^{FT}s^{FT} \le h_r^{FT}/\alpha$ and $p_r^{FT*}s^{FT*} = h_r^{FT*}/\alpha$, respectively. Combining, we find for the aggregate $p_r^{FT}(s^{FT}+s^{FT*}) \le h_r^{FTw}/\alpha$. We write the aggregate conditions for autarky and free trade, together with proposition 4.1(i), as $[p_r^{AUT}(T)-p_r^{FT}(T)]s^w(T) \ge [p_r^{AUT}(T)-p_r^{AUT*}(T)]s^{AUT*}(T) = [p_{r\infty}^{AUT}-p_{r\infty}^{AUT*}]s_\infty^{AUT*}$. Since (2.6) and $h/l < h^*/l^*$ imply $p_{r\infty}^{AUT} > p_{r\infty}^{AUT*}$, we have $p_r^{AUT}(T) > p_r^{FT}(T)$.

For Foreign, we have $\dfrac{p_r^{AUT*}(T)}{p_r^{FT}(T)} = \dfrac{h_r^{AUT*}(T)}{h_r^{FT*}(T)}\dfrac{s^{FT*}(T)}{s^{AUT*}(T)} = \dfrac{h_r^{AUT*}(T)}{h_r^{FT*}(T)}$. Proposition 4.1 establishes that this ratio may either fall short of or exceed unity. If it exceeds unity, the whole above expression for $u^{FT*}(T)/u^{AUT*}(T)$ exceeds unity. This proves (iii). We calculate numerical examples, in which we fix the following parameters $h^* = 4$, $l^* = k^* = l = 1$, $k = h = 1.5$, $\alpha/\rho = 1$, $\eta = 0.9$, $\gamma_a = 0.6$ and in which we set $\gamma_r = 1 - \gamma_a - \gamma_m$. For $\gamma_m = 0.2$, we find a SHR and $u^{FT*}(T) < u^{AUT*}(T)$. For $\gamma_m = 0.35$, we find a CHR and $u^{FT*}(T) > u^{AUT*}(T)$. This proves (ii).

Proof of Proposition 4.3.ii (Long–run habitat)

The steady–state free trade equilibrium is a shared harvest regime, so we have $s_\infty^{FT}/h_{r\infty}^{FT} = s_\infty^{FT*}/h_{r\infty}^{FT*}$.

Then, from (2.13), we have $\frac{l_{r\infty}^{FT}}{h_{r\infty}^{FT}} = \frac{l_{r\infty}^{FT*}}{h_{r\infty}^{FT*}}$. Hence $\frac{h_{r\infty}^{FT} - l_{r\infty}^{FT}}{h_{r\infty}^{FT}} = \frac{h_{r\infty}^{FT*} - l_{r\infty}^{FT*}}{h_{r\infty}^{FT*}}$. Combining these results, and using (2.4), (2.8), and (4.3), we find: $\frac{s_{r\infty}^{FT}}{s_{r\infty}^{FT*}} = \frac{l_{r\infty}^{FT}}{l_{r\infty}^{FT*}} = \frac{h_{r\infty}^{FT}}{h_{r\infty}^{FT*}} = \frac{h - l + l_m}{h^* - l^* + l_m^*} = \frac{h - l + \eta\tilde{\gamma}_m z l}{h^* - l^* + \eta\tilde{\gamma}_m z^* l^*}$.

Hence, in the long–run shared harvest regime, we have: $\frac{h_{r\infty}^{FT*}}{h_r^w} = \frac{1}{1 + h_{r\infty}^{FT} / h_{r\infty}^{FT*}} = \frac{h^* - l^* + \eta\tilde{\gamma}_m z^* l^*}{h^w - l^w + \eta\tilde{\gamma}_m l^w}$.

From (2.4) and (3.1), we have: $\frac{h_{r\infty}^{AUT*}}{h_r^w} = \frac{h^* - \tilde{\gamma}_a l^*}{h^w - \tilde{\gamma}_a l^w}$. Solving for $h_{r\infty}^{FT*} / h_r^w > h_{r\infty}^{AUT*} / h_r^w$, we find $(1 - \tilde{\gamma}_a - \eta\tilde{\gamma}_m)(h^* / l^* - h^w / l^w) - \eta\tilde{\gamma}_m (1 - z^*)(h^w / l^w - \tilde{\gamma}_a) < 0$, which we can simplify by substituting $1 - \tilde{\gamma}_a - \eta\tilde{\gamma}_m = \tilde{\gamma}_r$ and $\tilde{\gamma}_m / \tilde{\gamma}_r = \gamma_m / \gamma_r$.

Proof of proposition 4.4 ii (Long–run resource stocks)

Using (3.2) and results from the previous proof, we may write

$$\frac{s_\infty^{FT*}}{s_\infty^{AUT*}} = \frac{s_\infty^{FT*}}{s_\infty^{FTw}} \frac{s_\infty^{FTw}}{s_\infty^{AUT*}} = \frac{h_{r\infty}^{FT*}}{h_{r\infty}^{FTw}} \frac{s_\infty^{AUTw}}{s_\infty^{AUT*}} = \left(\frac{h^* - l^* + l_m^{FT*}}{h^w - l^w + l_m^{FTw}} \right) \frac{s_\infty^{AUTw}}{s_\infty^{AUT*}} = \left(\frac{h^* - l^* + \eta\tilde{\gamma}_m z^* l^*}{h^w - l^w + \eta\tilde{\gamma}_m l^w} \right) \left(\frac{h^w - (\tilde{\gamma}_a + \tilde{\gamma}_r \alpha / \rho) l^w}{h^* - (\tilde{\gamma}_a + \tilde{\gamma}_r \alpha / \rho) l^*} \right).$$

For the inequality in proposition 4.4.ii, the latter expression exceeds unity.

Proof of Proposition 4.5 (Long–run welfare)

The expression for u^{FT} / u^{AUT} from the proof of proposition 4.2 applies to the long run. Since a SHR applies in the long run, we may substitute (2.6). This gives:

$$\frac{u^{FT}}{u^{AUT}} = \left[\{1 - (1-\eta)\gamma_m (1-z)\} \left(\frac{1}{z} \right)^{\gamma_m (1-\eta)} \right] \left(\frac{s^{FT} / h_r^{FT}}{s^{AUT} / h_r^{AUT}} \right)^{\gamma_r}.$$

We prove that the RHS of this expression is the product of two terms bigger than one, so that $u_\infty^{FT} / u_\infty^{AUT} > 1$. First, the term in square brackets reaches a minimum equal to unity for $z = 1$. Second, from (3.3) and $h / l < h^* / l^*$, we have $\alpha / p_r^{AUT} = s_\infty^{AUT} / h_{r\infty}^{AUT} < s_\infty^{AUT*} / h_{r\infty}^{AUT*} = \alpha / p_r^{AUT*}$. From proposition 4.3.i and 4.4.i, we write this as $s_\infty^{AUT} / h_{r\infty}^{AUT} < s_\infty^{AUTw} / h_{r\infty}^{AUTw} = s_\infty^{FTw} / h_{r\infty}^{FTw} < s_\infty^{AUT*} / h_{r\infty}^{AUT*}$.

In the long run, we have a SHR with $\alpha / p_r^{FT} = s_\infty^{FT} / h_{r\infty}^{FT} = s_\infty^{FT*} / h_{r\infty}^{FT*} = s_\infty^{FTw} / h_{r\infty}^{FTw}$. Combining the last two conditions, we find $s_\infty^{FT} / h_{r\infty}^{FT} > s_\infty^{AUT} / h_{r\infty}^{AUT}$. This proves (i). Similarly, we find $s_\infty^{FT*} / h_{r\infty}^{FT*} < s_\infty^{AUT*} / h_{r\infty}^{AUT*}$. This proves (iii). For Foreign, we calculate numerical examples. With the first (second) set of parameter values used in the proof of proposition 4.3, Foreign loses (gains) in the long run. This proves (ii).

Proof of proposition 5.1 (Tariff's short–run impact on habitat)

Totally differentiating (5.2) and $l_a + l_a^* = \gamma_a y^w$, and evaluating the resulting equations at the free trade equilibrium by setting $\tau = 0$, we find $\Delta h_r + \Delta h_r^* = -(\Delta l_a + \Delta l_a^*) = -\gamma_a \mathit{\Gamma} < 0$. This proves (i). Differentiating (5.3) and using (2.4) and (2.8), we find $\Delta h_r^* = -\Delta l_a^* = -(s^* / s^w)[\gamma_a \mathit{\Gamma} + h_r] < 0$ and $\Delta h_r = -\Delta l_a = -(s / s^w)[\gamma_a \mathit{\Gamma} - h_r^*] = (s / s^w)[h^* - l^* + (1-\gamma_a) l_r^* + \gamma_a \gamma_r l^*] > 0$. This proves (ii).

Proof of proposition 5.2 (Tariff's short–run impact on welfare)

Welfare (2.9) can be written as $u=y/p_c$, with $y = l + \tau(\gamma_r l - l_r)/(1+\tau(1-\gamma_r))$ and $p_c = \prod_{i=a,m,r} (p_i / \gamma_i)^{\gamma_i}$. Noting that $\Delta y = \mathit{\Gamma}$, $\Delta y^* = 0$ and $\Delta p_c / p_c = \gamma_r \Delta h_r / h_r$ (and similar for $\Delta p_c^* / p_c^*$), we find $p_c^* \Delta u^* = \Delta y^* - l^* \Delta p_c^* / p_c^* = -l^* \gamma_r \Delta h_r^* / h_r^* > 0$ because $\Delta h_r^* < 0$; see proposition 5.1. This proves (i).

Analogously, we find $p_c \Delta u = \Delta y - l \Delta p_c / p_c = \mathit{\Gamma} - l \gamma_r \Delta h_r / h_r$, which cannot be directly signed as $\Delta h_r > 0$. We consider numerical examples, in which we fix the following parameters: $h^* = 4$, $h = l^* = l = 1$, $\alpha / \rho = 2.5$, and $\gamma_a = 0.6$ and in which we set $\gamma_r = 1 - \gamma_a - \gamma_m$. For $\gamma_m \in (0.0735, 1-\gamma_a)$, we find $\Delta u < 0$. For $\gamma_m \in (0, 0.0735)$ we find $\Delta u > 0$. This proves (ii).

Proof of proposition 5.3 (Tariff's impact on long–run habitat)

Linearizing (5.2)–(5.3), (2.8), $l_a + l_a^* = \gamma_a y^w$, $l_m = \gamma_m y^w$, and $l_m^* = 0$ around the free–trade steady state and using $s_\infty = h_{r\infty} - (\alpha/\rho) l_{r\infty}$ to eliminate the resource stocks in (5.3), we find $\Delta h_{r\infty} + \Delta h^*_{r\infty} = -(\Delta l_{a\infty} + \Delta l^*_{a\infty}) = -\gamma_a \Gamma < 0$. This proves (i).

Similarly, we find $\Delta h^*_{r\infty} = -\Delta l^*_{a\infty} = -\dfrac{[\gamma_a(h^*_r - l^*_r) + \gamma_m h^*_r]\Gamma + (\rho/\alpha) h^*_r s}{h^w_r - l^w_r} < 0$. For habitat at Home, we calculate numerical examples, in which we fix the following parameters: $h = 1.1$, $h^* = 1.2$, $l = l^* = 1$, $\alpha/\rho = 1.5$, and $\gamma_a = 0.6$, and in which we set $\gamma_r = 1 - \gamma_a - \gamma_m$. For $\gamma_m \in (0.0371, 1-\gamma_a)$, we find $\Delta h_{r\infty} > 0$; for $\gamma_m \in (0, 0.0371)$, we find $\Delta h_{r\infty} < 0$. This proves (ii).

Proof of proposition 5.4 (Tariff's impact on long–run resource conservation)

From (2.4)–(2.8), we have $\rho s^w_\infty = \rho(h^w - l^w_{a\infty}) - \alpha(l - l^w_{a\infty} - l^w_{m\infty})$. Substituting $l^w_m = \gamma_m y^w$, and $l^w_a = \gamma_a y^w$, and taking the first derivative of the resulting equation, we find $\Delta s^w_\infty = (\alpha/\rho)\Delta l_{m\infty} - (1 - \alpha/\rho)\Delta l^w_{a\infty} = [(\alpha/\rho)(\gamma_a + \gamma_m) - \gamma_a]\Gamma$. This expression is positive if and only if the term in brackets is positive. This proves (i). From $\rho s_\infty = \rho(h - l_{a\infty}) - \alpha(l - l_{a\infty} - l_{m\infty})$ (see (2.4)–(2.8), (2.4) and $l^*_m = 0$, we have $\Delta s^*_\infty = \Delta l^*_{a\infty}(\alpha - \rho)/\rho = -\Delta h^*_{r\infty}(\alpha - \rho)/\rho$. From proposition 5.3, we see that the sign of this expression equals the sign of $\alpha - \rho$. This proves (ii).

Proof of proposition 5.5 (Tariff's long–run impact on welfare)

The proof is similar to the one in Proposition 5.2, but here $\Delta p_r / p_r = \gamma_r \left(\Delta h_r / h_r - \Delta s / s\right)$ and analogous for Δp^*_r. We have $p^*_r \Delta u^*_\infty = -l^* \gamma_r \left(\dfrac{\Delta h^*_{r\infty}}{h^*_r} - \dfrac{\Delta s^*_\infty}{s^*}\right) = -\Delta h^*_{r\infty} l^* \gamma_r \left(\dfrac{1}{h^*_r} - \dfrac{1}{s^*}\left(1 - \dfrac{\alpha}{\rho}\right)\right) > 0$ because of proposition 5.3 and $\dfrac{s^*}{h^*_r} = \dfrac{s^w}{h^w_r} = \dfrac{h^w - (\gamma_a + \gamma_r \alpha/\rho) l^w}{h^w - \gamma_a l^w} = 1 - \dfrac{(\alpha/\rho)\gamma_r l^w}{h^w - \gamma_a l^w} > 1 - \dfrac{\alpha}{\rho}$. This proves (i). Analogously, we find $p_c \Delta u_\infty = \Delta y_\infty - l \Delta p_{c\infty}/p_c = \Gamma - l\gamma_r(\Delta h_{r\infty}/h_r - \Delta s_\infty / s)$ = $\Gamma\left(1 + \dfrac{\alpha/\rho}{s} l \gamma_r \gamma_m\right) + l\gamma_r\left[\dfrac{1}{h_r} - \dfrac{1}{s}\left(1 - \dfrac{\alpha}{\rho}\right)\right]\Delta h_{r\infty}$. Since $\Delta h_{r\infty}$ is ambiguous, we study numerical examples. We fix the following parameters: $h^* = 4$, $h = l^* = l = 1$, $\alpha / \rho = 2.5$, and $\gamma_a = 0.6$. We set $\gamma_r = 1 - \gamma_a - \gamma_m$. For $\gamma_m \in (0.1855, 1 - \gamma_a)$, we find $\Delta u_\infty < 0$; for $\gamma_m \in (0, 0.1855)$, we find $\Delta u_\infty > 0$. This proves (ii).

Notes:

[1] Agriculture is the direct cause of 80% of annual tropical forest loss [1, p. 69], while these forests provide habitat for about half of the species on earth [12, p. 41].

[2] We assume that conversion of habitat to agricultural land is reversible. This is consistent with the broader definition of habitat (i.e., unclaimed land), but less so with the stricter definition (i.e., a specific type of ecosystem). Irreversibility is left for future research.

[3] This specification can be derived from a logistic specification of natural resource growth *per unit of land*, $g(s_v) = \rho(1 - s_v / \kappa)$ where s_v is the density of the resource (s/h_r), $\kappa > 0$ denotes the carrying capacity per unit of habitat area, and $\rho > 0$ is the maximum growth rate. Normalizing $\kappa = 1$, and multiplying natural growth per unit of land, $g(s_v)$, by habitat size, h_r, yields natural growth of the total resource stock. Subtracting harvest, y_r, from this expression, we obtain (2.7).

[4]If one type of economic activity negatively affects the net returns to another, trade may enhance welfare by spatially separating the two activities [8]. Here, in contrast, we find that spatial separation (of harvesting and agriculture in particular) may be detrimental to welfare due to the search cost externality: the economy that specializes in harvesting by letting agriculture move abroad, finds its resource stock spread over more habitat, faces higher search costs, and lower welfare.

[5] We can write the sum of labor and capital income as $y = wl + (1 - \eta)p_m y_m = l + (1 - \eta)\gamma_m y$, since $w = 1$ and $p_m y_m = p_m c_m = \gamma_m y$. Hence, $y = l/[1 - (1 - \eta)\gamma_m]$. Labor demand in each sector then follows from profit maximization and (2.10) with $p_a y_a = l_a = \gamma_a y$, $p_m y_m = l_m / \eta = \gamma_m y$, and $p_r y_r = l_r = \gamma_r y$.

[6] This follows from the procedure in footnote 5, but now for aggregate values.

[7] Defining rent income as $\pi = kp_m \partial y_m / \partial k$, we may write from profit maximization and utility maximization: $\pi^w = (1-\eta) p_m y_m^w = (1-\eta)\gamma_m (wl^w + \pi^w)$. Hence, π^w / wl^w is a constant.

[8] Home exports if $p_m c_m = \gamma_m y < p_m y_m = l_m/\eta$. After substitution of (2.11) and (4.3), this boils down to $1 < z$.

[9] The situation with zero harvesting in Foreign is ruled out by our assumption that $h^*/l^* > h/l$.

[10] With $z = 1$ (which implies $z^* = 1$), the manufacturing sector is not relevant for the effects of trade on labor allocation. The trade effects are then similar as in a model without manufacturing sector ($\gamma_m = 0$).

[11] Note that we ignore welfare changes along the transition path; we only compare steady–state results.