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# new trade in renewable resources and consumer preferences for diversity

by Martin F. Quaas and Max T. Stöven

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# New trade in renewable resources and consumer preferences for diversity

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## Abstract

The literature on trade in renewable resources implicitly assumes that the traded resources are perfect substitutes. We model trade in renewable resources as stipulated not only by autarky price differences, but also by consumers' love of variety. We show that the love-of-variety effect enables welfare gains from trade even if total consumption decreases. Total consumption may decrease because the love of variety weakens the link between resource scarcity and demand. If consumers are willing to pay the rising prices for harvests from increasingly depleted stocks, trade liberalization may end in stock collapse. The love of variety may thus threaten variety.

*Keywords:* trade, environment, renewable resources, open access, love of variety

*JEL:* Q21, Q22, Q23, Q27, F18

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The question if trade liberalization threatens or benefits renewable resources and their users is at the center of a lively scientific debate (Bulte and Barbier, 2005; Fischer, 2010). Whilst country differences that stipulate trade and feedbacks to other economic sectors are modeled in diverse ways, all models for trade in renewable resources known to the authors implicitly assume that the traded resources are perfect substitutes (Bulte and Barbier, 2005; Fischer, 2010).

At the core of these models, trade liberalization balances two former autarky prices for resource harvests. If the countries have comparable management regimes and harvesting costs, the prices for resource harvest reflect the biological abundance and economic scarcity of the underlying resources. By aligning prices, trade liberalization works in the direction of balanced stock sizes. Modeling trade effects under the assumption that the resources are perfect substitutes might thus underestimate the risk of severe overexploitation and stock collapse. It is the aim of this paper to study the consequences of departing from this assumption. The term ‘New trade’ is used in the sense that we look at consumer preferences for diversity. Starting from the reference case of perfect substitutes, we show that increasing the love for diversity under free trade might lead to increasingly skewed exploitation patterns up to stock collapse under open access. At the same time, increasing the love for variety increases the potential welfare gains from trade liberalization that may offset the price-quantity welfare effects known from the literature.

The literature on trade in renewable resources<sup>1</sup> can be classified according to the country differences that stipulate trade:

In North-South models differences in resource management create trade between two otherwise identical countries. Chichilnisky (1994) shows that the country with weaker resource management appears to have an “apparent comparative advantage” as it ignores the opportunity costs of current harvesting. As a result, South exports to the country with better resource management (the North). North increases its consumption by imports while South loses. Brander and Taylor (1997b) show that South’s apparent advantage may become an apparent disadvantage if its harvesting sector has a backward-bending supply curve that enables severe over-harvesting at high autarky prices. In this case, South gains from trade as it becomes a resource importer. Karp et al. (2001) differentiate North and South more smoothly by varying the number of price-taking harvesters. Classified according to the intrinsic growth rate of the stocks, Karp et al. (2001) describe scenarios in which North drags down South (both lose) or North pulls up South (both gain). Copeland and Taylor

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<sup>1</sup>See Bulte and Barbier (2005) for a comprehensive review of the literature.

(2009) assume that management efficiency is endogenously determined by resource prices.

A second class of models assumes that both countries have open-access regimes but differ in factor proportions: The home country is labor abundant while the foreign country is resource abundant. Brander and Taylor (1997a, 1998) show that a move from autarky to trade benefits the resource importing home country as trade eases the local open-access problem and releases labor for the manufactures sector. The foreign country can only gain from trade if it is able to specialize in resource harvesting at very high resource prices. Hannesson (2000) shows that a diversified resource exporter may also gain from trade if the manufactures sector has decreasing returns to scale. In this case, the benefits of importing manufactures may offset the resource exporter's deteriorating open-access problem. Emami and Johnston (2000) show that if one of two Brander and Taylor (1997a) countries improves its resource management from open access to price-taking sole ownership, both countries gain if world price drops. If world price rises, the country with improved management gains while the other loses. If demand for resources is higher in the country that improves its resource management, that country may lose as well if consumer welfare losses outweigh the newly collected resource rent.

The welfare results in the trade literature are diverse, which is in part due to differences in the general equilibrium framework of these models.<sup>2</sup> For this reason, we concentrate on resource economics in a partial equilibrium setting and disregard spillovers to other economic sectors. In a related work, Quaas and Requate (2013) study how consumer preferences for diversity affect multi-species fishery management. The paper at hand can be interpreted as an extension of Quaas and Requate (2013) that focuses on trade-induced welfare effects in a two-country framework.

Trade liberalization can have two effects on renewable resources: First, opening up for trade increases the potential demand from domestic consumers to world demand. A second effect is that trade liberalization may enable demand to shift from depleted and hence expensive resources to more abundant and hence cheaper substitutes. The first effect is always present. While the literature assumes that the second effect works perfectly as well, we show that decreasing the elasticity of substitution weakens the demand reduction in reaction to increasing resource scarcity. In the limit, this may lead to a stock collapse or the sequential collapse of both stocks.

The rest of the paper is organized as follows. Section 1 presents the model. In Section 2, we study the move from autarky to free trade in a two country - two resources model.

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<sup>2</sup>Cf. for example the contrasting results of Brander and Taylor (1998) and Hannesson (2000).

As trade liberalization always entails a positive diversity effect if there is only one resource under autarky, a model extension in Section 3 analyzes trade between a species-rich and a species-poor country. Section 4 concludes.

## 1. The model

We consider two countries, each with a representative consumer and a renewable natural resource that is harvested under conditions of open access. We will compare two scenarios: In the first scenario, each resource is consumed only domestically. We refer to this situation as the ‘autarky’ case, although there may be trade between the countries in goods other than the natural resources. We use a superscript  $a$  to the variables to indicate this scenario. In the other scenario, the countries freely trade harvests of the two resources and all other goods without any costs. We refer this scenario as the ‘trade’ scenario, and indicate this scenario by a superscript  $t$  to the variables.

The two countries may differ from each other in two respects: (i) The consumers may value resource consumption to a different degree, and (ii) the biological productivity of the two resources may differ. To allow for a closed form solution, we assume symmetry between the two countries in all other parts of the model.

The representative household in country  $i = 1, 2$  has quasi-linear preferences over the consumption of a numeraire commodity ( $y_i$ ) and consumption of natural resources ( $v_i$ ) that are described by the utility function (Quaas and Requate, 2013)

$$u(v_i, y_i) = y_i + \gamma_i \ln v_i. \quad (1)$$

Due to unit elasticity of demand for resource products, the factor  $\gamma_i$  coincides with the expenditures on resources in country  $i$ . The sub-utility from resource consumption is described by a Dixit-Stiglitz utility function (Dixit and Stiglitz, 1977)

$$v_i = \left( \sum_{j \in \mathbb{S}_i} q_{ji}^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}}, \quad (2)$$

where  $q_{ji}$  is harvest produced in country  $j$  and consumed by the household in country  $i$ , and  $\mathbb{S}_i$  is the set of species available for consumption in country  $i$ . Under autarky, this is equal to the species richness available domestically; under free trade, this is the number of all resource species harvested globally. The parameter  $\sigma \geq 1$  measures the elasticity of substitution between different resources. The lower the value of  $\sigma$ , the stronger are the

representative household's preferences for diversity. The budget constraint is

$$m_i = y_i + \sum_{j \in \mathbb{S}_i} p_j q_{ji} \quad (3)$$

with exogenous income  $m_i$ . We assume that  $m_i > \gamma_i$  to assure an interior solution for the demand for natural resources.

In country  $i = 1, 2$ , the stock  $x_i$  grows according to the logistic function

$$g_i(x_i) = r_i x_i (1 - x_i) \quad (4)$$

with intrinsic growth rate  $r_i$  and carrying capacity normalized to one.

The representative resource harvester in country  $i$  has profits

$$\Pi_i = p_i h_i - \frac{c}{x_i} h_i = \left( p_i - \frac{c}{x_i} \right) h_i. \quad (5)$$

In (5)  $p_i$  denotes the price of harvest produced in country  $i$ . Under autarky,  $p_i$  is defined only for the domestic species. We assume that harvesting costs are the same for all resources, thus  $c$  carries no index. Everything that follows will depend on ratios of  $\gamma_i$  to the cost parameter  $c$ . To simplify notation, we normalize units of measurement for the numeraire commodity such that  $c = 1$ .

As resources are harvested under conditions of open access, resource rents are dissipated. Profits (5) are zero, and the price of species  $i$  is equal to marginal harvesting costs,

$$p_i = \frac{1}{x_i}. \quad (6)$$

Using the open-access condition (6), the price index for resource goods in country  $i$ ,  $P_i$ , can be expressed as a function of resource stocks,

$$P_i = \left( \sum_{j \in \mathbb{S}_i} p_j^{1-\sigma} \right)^{\frac{1}{1-\sigma}} = \left( \sum_{j \in \mathbb{S}_i} x_j^{\sigma-1} \right)^{\frac{1}{1-\sigma}}. \quad (7)$$

The Marshallian demand of consumer  $i$  for resource type  $j$  is obtained from the first-order conditions of utility maximization, i.e. the maximization of (1) with (2) subject to the

budget constraint (3),

$$q_{ji} = \gamma_i \frac{p_j^{-\sigma}}{\sum_{j \in \mathbb{S}_i} p_j^{1-\sigma}} = \gamma_i \frac{p_j^{-\sigma}}{P_i^{1-\sigma}}. \quad (8)$$

## 2. The two-species-two-country case

We first consider the case where each country has one resource stock each. The two countries may differ in the biological productivity of their resource  $r_i$  and in the consumer expenses for resource harvests,  $\gamma_i$ . We start the analysis by considering the autarky scenario and then proceed to the scenario of free trade.

### 2.1. Autarky

Without any trade in resources, only one type of resource harvest is available in each country. This reduces the model to the textbook case of an open-access resource. In particular, the demand function (8) simplifies to  $q_{ii} = \gamma_i/p_i$ , and domestic demand must equal domestic supply,  $q_{ii} = h_i$ . Consumer expenses for resource harvest must equal revenues from harvesting the domestically available species in country  $i$ ,

$$\gamma_i = p_i h_i. \quad (9)$$

Inserting (4) and (6) and solving yields the open-access steady-state stock of resource  $i$ ,

$$x_i^a = 1 - \frac{\gamma_i}{r_i}. \quad (10)$$

The open-access stock decreases with the expenditures for resources. It increases with the intrinsic growth rate  $r_i$  and the harvesting cost parameter  $c$ .

To study the consequences of trade liberalization, we assume that domestic demand cannot cause stock collapse:

**Assumption 1** (Positive autarky stocks). *Neither of the two stocks collapses under autarky,  $\gamma_i < r_i$ , for both countries  $i = 1, 2$ .*

Without loss of generality, we furthermore assume that the autarky price in country 1 is higher than in country 2:



**Assumption 2** (Ordered autarky prices). *The ratio of consumer expenses to growth rate is higher in country 1 than in country 2,*

$$\frac{\gamma_1}{r_1} > \frac{\gamma_2}{r_2}. \quad (11)$$

This implies a higher autarky price and a lower autarky stock in country 1,  $p_1^a > p_2^a$  and  $x_1^a < x_2^a$ .

For clarity of exposition, we treat the case  $\frac{\gamma_1}{r_1} = \frac{\gamma_2}{r_2}$  separately: The condition implies  $p_1^a = p_2^a$  such that both countries are indifferent to free trade in the case of perfect substitutes ( $\sigma \rightarrow +\infty$ ). For finite  $\sigma > 1$ , both countries gain from trade for any point on the isocost curve (16), cf. the following section.

## 2.2. Free Trade

With free trade, the prices for harvest from a specific resource are the same globally. Thus also the resource price indices are the same in both countries,

$$P_1 = P_2 \equiv P = (x_1^{\sigma-1} + x_2^{\sigma-1})^{-\frac{1}{\sigma-1}}. \quad (12)$$

The Equivalent/Compensating variation  $CV_i$  for country  $i$  of a move from autarky to free trade with price index  $P$  (cf. equation (7)) can be formulated as

$$CV_i = \gamma_i \ln \left( \frac{p_i^a}{P} \right) = \gamma_i \ln \left( \frac{(x_1^{\sigma-1} + x_2^{\sigma-1})^{\frac{1}{\sigma-1}}}{x_i^a} \right). \quad (13)$$

Indifference to autarky can be depicted by the following indifference curves in  $x_1 - x_2$  space:

$$x_2^{\text{indi}}(x_1) = x_1 \left[ \left( \frac{x_i^a}{x_1} \right)^{\sigma-1} - 1 \right]^{\frac{1}{\sigma-1}}, \quad i = 1, 2 \quad (14)$$

As the price index is strictly increasing in both stock sizes, all points above the indifference curve are preferred to autarky.

In free-trade equilibrium, surplus production from stock  $x_i$  must equal aggregate demand from both countries,

$$g_i(x_i) = \frac{p_i^{-\sigma}}{P^{1-\sigma}} (\gamma_1 + \gamma_2), \quad i = 1, 2 \quad (15)$$

Multiplying by the price of resource  $i$ , summing over  $i$  and rearranging yields the **isocost line** for an interior equilibrium as

$$x_2^{\text{ico}}(x_1) = \frac{r_1 + r_2 - \gamma_1 - \gamma_2}{r_2} - \frac{r_1}{r_2} x_1. \quad (16)$$

Using (4) and (6) in (15), and rearranging, we obtain the following conditions that implicitly determine the steady-state stock sizes  $(x_1^t, x_2^t)$ :

$$x_1 = 1 - \frac{x_1^{\sigma-1}}{x_1^{\sigma-1} + x_2^{\sigma-1}} \frac{\gamma_1 + \gamma_2}{r_1}, \quad (17a)$$

$$x_2 = 1 - \frac{x_2^{\sigma-1}}{x_1^{\sigma-1} + x_2^{\sigma-1}} \frac{\gamma_1 + \gamma_2}{r_2}. \quad (17b)$$

These conditions can be interpreted as the isoclines in  $x_1 - x_2$  space. Condition (17a) for example depicts all combinations of  $x_1, x_2$  for given  $\sigma, \gamma_1, \gamma_2, r_1, r_2$  for which demand for harvest from stock 1 equals stock growth such that  $\dot{x}_1 = 0$ . Rearranging the  $x_1$ -isocline (17a) yields

$$x_2^{\text{me1}}(x_1) = x_1 \left( \frac{\gamma_1 + \gamma_2}{r_1(1-x_1)} - 1 \right)^{\frac{1}{\sigma-1}}. \quad (18)$$

Inserting this condition in the isocost condition (16) gives the equilibrium stock size  $x_1^t$  as an implicit function of parameters only,

$$x_1^t \left( r_1 + r_2 \left( \frac{\gamma_1 + \gamma_2}{r_1(1-x_1^t)} - 1 \right)^{\frac{1}{\sigma-1}} \right) = r_1 + r_2 - (\gamma_1 + \gamma_2). \quad (19)$$

For general values of the elasticity of substitution  $\sigma$ , it is obviously not possible to solve for the steady-state stock sizes in closed form. It is however possible to prove the existence of a unique free-trade equilibrium:

**Proposition 1.** *1a) For  $\sigma > 1$ , there exists a unique free-trade equilibrium with positive stock sizes for both resources,  $x_1^t, x_2^t > 0$ .*

*1b) Resource stocks under free trade and in autarky are ordered as follows*

$$x_1^t \underset{\leq}{\overset{\geq}{\cong}} x_1^a \quad \text{and} \quad x_2^t \underset{\geq}{\overset{\leq}{\cong}} x_2^a \quad \text{for} \quad x_1^a \left( \frac{\gamma_2}{\gamma_1} \right)^{\frac{1}{\sigma-1}} \underset{\geq}{\overset{\leq}{\cong}} x_2^a. \quad (20)$$

*Proof.* Prerequisite: The stock size  $x_1^{\text{co}} = 1 - \frac{\gamma_1}{r_1} - \frac{r_2}{r_1}$  is a corner solution after the collapse of

stock 2 such that all consumer expenses are directed at stock 1, cf. (28). For inner solutions, stock 1 receives less than the total consumer expenses, such that it holds that  $x_1^t > x_1^{\text{co}}$  for all  $\sigma > 1$ . It also holds that  $x_1^a > x_1^{\text{co}}$  as  $x_1^{\text{co}} = x_1^a - \frac{r_2}{r_1}$ .

1a) The right-hand side (RHS) of (19) is independent of  $x_1$  and positive. Define the left-hand side (LHS) of (19) as

$$\Omega(x) \equiv x \left( r_1 + r_2 \left( \frac{\gamma_1 + \gamma_2}{r_1(1-x)} - 1 \right)^{\frac{1}{\sigma-1}} \right). \quad (21)$$

We further consider two cases. In case 1,  $\gamma_1 + \gamma_2 > r_1$ ,  $\Omega(x)$  is defined and positive for all  $x \in [0, 1)$ . In case 2,  $\gamma_1 + \gamma_2 \leq r_1$ ,  $\Omega(x)$  is defined and positive for all  $x \in (x_1^{\text{co}}, 1)$ .

Case 1.  $\Omega(0) = 0 < r_1 + r_2 - (\gamma_1 + \gamma_2)$ ;  $\lim_{x \rightarrow 1} \Omega(x) \rightarrow +\infty$ . For all  $x \in (0, 1)$ ,  $\Omega'(x) > 0$ . Hence, there exists a unique  $x > 0$  such that (19) holds with equality.

Case 2.  $\Omega(x_1^{\text{co}}) = r_1 - (\gamma_1 + \gamma_2) < r_1 + r_2 - (\gamma_1 + \gamma_2)$ ;  $\lim_{x \rightarrow 1} \Omega(x) \rightarrow +\infty$ . For all  $x \in (x_1^{\text{co}}, 1)$ ,  $\Omega'(x) > 0$ . Hence, there exists a unique  $x > x_1^{\text{co}}$  such that (19) holds with equality.

1b) The intersection of the  $x_1$ -isocline (18) and the isocost line (16) determine the market equilibrium with equilibrium stock size  $x_1^t$ :  $x_2^{\text{me1}}(x_1^t) = x_2^{\text{ico}}(x_1^t)$ . It is straightforward to verify that  $x_2^{\text{ico}'}(x_1) < 0$  and that  $x_2^{\text{me1}'}(x_1) > 0$  for  $x_1 > x_1^{\text{co}}$ . Thus,  $x_1^t \underset{\geq}{\leq} x_1^a$  if  $x_2^{\text{me1}}(x_1^a) \underset{\geq}{\leq} x_2^{\text{ico}}(x_1^a)$ . Evaluating both expressions at  $x_1^a$ , we obtain

$$\begin{aligned} x_2^{\text{me1}}(x_1^a) &= x_1^a \left( \frac{\gamma_2}{\gamma_1} \right)^{\frac{1}{\sigma-1}} \\ x_2^{\text{ico}}(x_1^a) &= x_2^a. \end{aligned}$$

□

Condition (20) is always fulfilled if  $\gamma_2 < \gamma_1$ . If  $\gamma_2 > \gamma_1$  there is some threshold value  $\sigma' > 1$  such that for all  $\sigma < \sigma'$   $x_1^t < x_1^a$  and for all  $\sigma > \sigma'$   $x_1^t > x_1^a$ .

If the countries differ in their expenses for resource products or in the biological productivity of their stocks, explicit expressions for the free-trade equilibrium can be calculated for the two limit cases of the CES utility function, the case of perfect substitutes ( $\sigma \rightarrow +\infty$ ) and Cobb-Douglas preferences ( $\sigma \rightarrow 1$ ).

As the literature on trade in renewable resources implicitly assumes that the traded harvests are perfect substitutes, we start with this case. If consumers do not differentiate between the two types of harvest, prices must be equal in equilibrium. As prices depend on

stock sizes only (cf. equation 6), stock sizes must be the same. From (18) we thus obtain

$$x^{ps} = 1 - \frac{\gamma_1 + \gamma_2}{r_1 + r_2}. \quad (22)$$

The intuition is that the global expenditures for resources,  $\gamma_1 + \gamma_2$  are spent over the two resources according to their productivities, as measured by the intrinsic growth rates, such that in equilibrium both stocks are of equal size. As it holds that  $\lim_{\sigma \rightarrow \infty} P = \frac{1}{\max(x_1, x_2)}$ , the indifference curves (14) simplify to rectangles in the limit case of perfect substitutes,

$$x_i^a = \max(x_1, x_2). \quad (23)$$

As

$$x^{ps} = \frac{r_1}{r_1 + r_2} x_1^a + \frac{r_2}{r_1 + r_2} x_2^a,$$

and  $x_1^a > x_2^a$  it follows that  $x_2^a > x^{ps}$  and  $x_1^a < x^{ps}$ , such that country 1 wins and country 2 loses from trade.

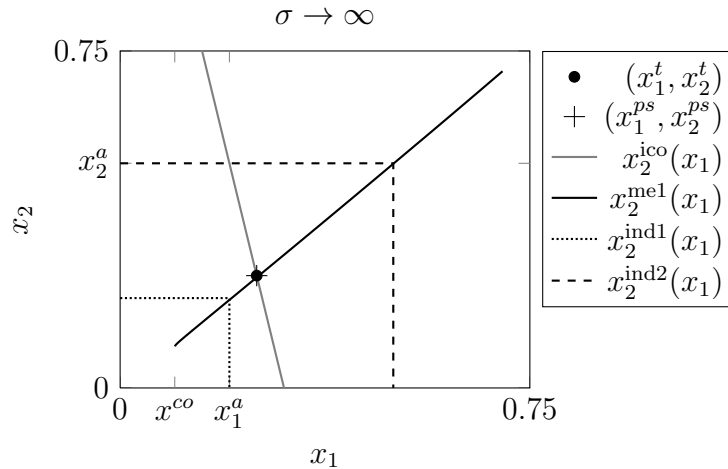


Figure 1: Trade in perfect substitutes: Country 1 with its lower autarky stock and higher autarky price gains while country 2 loses. Equilibrium at  $x_1^t = x_2^t = x^{ps} = 0.25$  ( $r_1 = 0.5$ ,  $r_2 = 0.1$ ,  $\gamma_1 = 0.4$ ,  $\gamma_2 = 0.05$ ).

Figure 1 depicts this standard case: The intersection point of the isocost line (16) and the  $x_1$ -isocline (18) determines the trade equilibrium, here also given in closed form by (22). Country 1 has a higher autarky price than country 2, such that trade liberalization leads to a price decrease in country 1 and a price increase in country 2. It follows that the country with the smaller autarky stock gains from the trade while the one with the larger autarky

stock loses.

If both stocks have the same biological productivity, the trade equilibrium in case of perfect substitutes holds for all elasticities of substitution:

**Proposition 2.** *If  $r_1 = r_2$ , the unique free-trade equilibrium for all  $\sigma \geq 1$  is*

$$x_i^t = x^{ps}, i = 1, 2. \quad (24)$$

*Proof.* A unique trade equilibrium exists for  $\sigma > 1$  (cf. Proposition 1). For  $r_1 = r_2$ , (22) solves (19) for all  $\sigma > 1$ . In the limit case  $\sigma = 1$ , (27) equals (22).  $\square$

For  $r_1 = r_2$ , the stock sizes and hence total biomass are independent of the preferences for diversity and equal to aggregate autarky levels,  $x_1^t + x_2^t = x_1^a + x_2^a$ . In this case, trade liberalization leads to balanced stock sizes for all  $\sigma \geq 1$ .

For  $r_1 \neq r_2$ , the effect of decreasing the elasticity of substitution from the limit case of perfect substitutes towards the second limit case of Cobb-Douglas preferences is depicted in Figure 2:

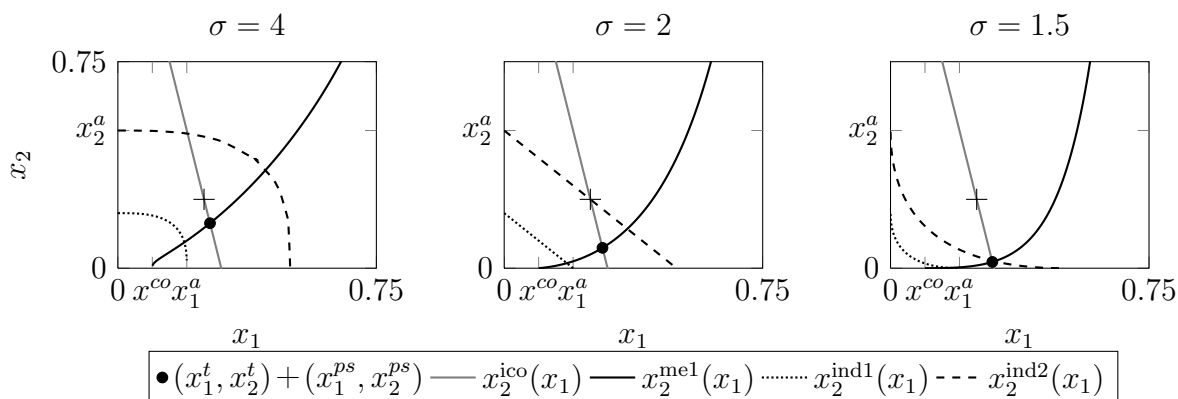


Figure 2: Trade equilibria at intersection of the isocost line (16) and the  $x_1$ -isocline (18). Decreasing  $\sigma$  moves the equilibrium on the isocost line (16) towards the biologically more productive stock ( $r_1 = 0.5, r_2 = 0.1, \gamma_1 = 0.4, \gamma_2 = 0.05$ ). In the Cobb-Douglas limit case, stock 2 collapses.

The indifference curves become strictly concave for  $\sigma > 2$ , linear for  $\sigma = 2$  and strictly convex for  $\sigma < 2$  while keeping their symmetric intercepts at  $x_i^a$  on both axes. The indifference curves bending towards the origin with decreasing  $\sigma$  reflects the increasing importance of the love of variety to consumer welfare. The lower the elasticity of substitution, the larger the area of  $x_1 - x_2$  combinations above the indifference curves that are preferred to autarky.

At the same time, decreasing the elasticity of substitution weakens the reaction of consumer demand towards resource scarcity such that the equilibrium size of the biologically less productive stock decreases while the other one faces reduced demand and increases. This can be seen in Figure 2 by the movement of the intersection point of the  $x_1$ -isocline (18) on the isocost line (16). The equilibrium moves southeastwards, implying a decrease in stock 2 and an increase in stock 1. Decreasing  $\sigma$  hence has two effects: It moves the symmetric indifference curves towards the axes while it also moves the equilibrium on the isocost line (16) towards the axis of the biologically more productive stock, cf. Figure 2. For country 2 to gain from trade for  $\sigma > 1$ , the trade equilibrium has to approach the axis slower than the country's indifference curve. The following proposition shows that this is always the case.

**Proposition 3.** *There exists a  $\sigma^* > 1$  such that both countries gain from trade for  $\sigma \in (1, \sigma^*]$ .*

*Proof.* It is a sufficient condition for country 1 to gain from trade that country 2 does, cf. (14). The indifference-to-autarky curve of country 2 (14) can be written as

$$x_2^{\text{ind2}}(x_1) = x_1 \left[ \left( \frac{x_2^A}{x_1} \right)^{\sigma-1} - 1 \right]^{\frac{1}{\sigma-1}}, \quad (25)$$

and the  $x_1$ -isocline (18) as

$$x_2^{\text{me1}}(x_1) = x_1 \left[ \frac{\gamma_1 + \gamma_2}{r_1(1-x_1)} - 1 \right]^{\frac{1}{\sigma-1}}. \quad (26)$$

A unique trade equilibrium with positive stock sizes exists for  $\sigma > 1$  (cf. Proposition 1). The equilibrium stock sizes fulfill (26). Country 2 gains from trade if the term in brackets on the right-hand side of (25) is smaller than the term in bracket on the right-hand side of (26).

Now consider the two cases  $\gamma_2 > \gamma_1$  and  $\gamma_2 < \gamma_1$ . For the case  $\gamma_2 > \gamma_1$ , the proof of the proposition is simple: Let  $\sigma^* = \sigma'$ , where  $\sigma' > 1$  is the threshold value characterized in Proposition 1b). For  $\sigma < \sigma'$  it follows that  $x_2^t > x_2^a$ . This implies that the trade equilibrium  $(x_1^t, x_2^t)$  lies to the northwest of  $x_2^{\text{ind2}}(x_1)$  (convex for sufficiently small  $\sigma < 2$ ), such that country 2 gains from trade, which proves the proposition for the case  $\gamma_2 > \gamma_1$ .

For the case  $\gamma_2 < \gamma_1$  it follows from Proposition 1b) that  $x_1^t > x_1^a$ . Thus,

$$\left(\frac{x_2^a}{x_1^t}\right)^{\sigma-1} - 1 < \left(\frac{x_2^a}{x_1^a}\right)^{\sigma-1} - 1 \quad \text{and} \\ \frac{\gamma_1 + \gamma_2}{r_1(1-x_1^t)} - 1 > \frac{\gamma_1 + \gamma_2}{r_1(1-x_1^a)} - 1$$

Now fixing  $x_1$  at  $x_1^a$  it holds that  $\lim_{\sigma \rightarrow 1} \frac{\gamma_1 + \gamma_2}{r_1(1-x_1^a)} - 1 > 0$  while  $\lim_{\sigma \rightarrow 1} \left(\frac{x_2^a}{x_1^a}\right)^{\sigma-1} - 1 = 0$ . Thus, there must be some threshold value  $\sigma^* > 1$  such that  $\frac{\gamma_1 + \gamma_2}{r_1(1-x_1^a)} - 1 > \left(\frac{x_2^a}{x_1^a}\right)^{\sigma-1} - 1$  for all  $\sigma < \sigma^*$ . It follows that

$$\frac{\gamma_1 + \gamma_2}{r_1(1-x_1^t)} - 1 > \frac{\gamma_1 + \gamma_2}{r_1(1-x_1^a)} - 1 > \left(\frac{x_2^a}{x_1^a}\right)^{\sigma-1} - 1 > \left(\frac{x_2^a}{x_1^t}\right)^{\sigma-1} - 1$$

for all  $\sigma < \sigma^*$ . □

Without loss of generality, we defined country 2 to be the country with the lower autarky price (cf. 2). For the standard case of perfect substitutes, trade liberalization leads to a welfare decrease in country 2 as the country experiences a price increase relative to autarky. The love-of-variety effect outweighs the negative price-quantity effect for all  $\sigma \in (1, \sigma^*]$ . In the example of Figure 2, country 2 gains from trade for all  $\sigma \in (1, 1.46]$ .

In the limit case of Cobb-Douglas preferences, the link that increasing resource scarcity leads to a price increase and hence a demand reduction is disabled. Because of their intense love of variety, both consumers spend half their expenses on each type of harvest, irrespective of the individual prices and hence stock sizes. As there is no longer a substitution mechanism that works in the direction of balanced stock sizes, a stock collapse or a sequential collapse of both stocks may occur:

**Proposition 4.** *Let  $r_a$  ( $r_b$ ) denote the stock with the higher (lower) intrinsic growth rate.*

*If  $\sigma = 1$  and  $\gamma_1 + \gamma_2 < 2r_b$ , no stock collapses and the trade equilibrium follows as*

$$x_i^t = x_i^{cd} = 1 - \frac{\gamma_1 + \gamma_2}{2r_i}, \quad i = 1, 2. \quad (27)$$

*If  $\sigma = 1$  and  $\gamma_1 + \gamma_2 \geq 2r_b$  and  $\gamma_1 + \gamma_2 < r_a$ , the less productive stock collapses and the trade equilibrium follows as*

$$x_a^t = x_a^{co} = 1 - \frac{\gamma_1 + \gamma_2}{r_a}, \quad x_b^t = x_b^{cd} = 0. \quad (28)$$

If  $\sigma = 1$  and  $\gamma_1 + \gamma_2 \geq 2r_b$  and  $\gamma_1 + \gamma_2 \geq r_a$ , a sequential collapse of both stocks occurs,

$$x_i^t = x_i^{cos} = 0, \quad i = 1, 2. \quad (29)$$

The limit case of free trade with Cobb-Douglas preferences can be understood as an autarky case with consumer expenses per stock adjusted to half the total expenses of both consumers,  $x_i^{cd} = 1 - \frac{\gamma_1 + \gamma_2}{r_i}$ . If the less productive stock cannot sustain these expenses and collapses, the remaining stock has to sustain the total consumer expenses, hence  $x_a^{cd} = 1 - \frac{\gamma_1 + \gamma_2}{r_a}$  in this case.

In the example of Figure 2, we have that  $\gamma_1 + \gamma_2 = 0.45 > 2r_2 = 0.2$  and  $\gamma_1 + \gamma_2 = 0.45 < r_1 = 0.5$  such that stock 2 collapses for  $\sigma = 1$ . The trade equilibrium follows as  $x_1^t = x_1^{co} = 0.1$ ,  $x_2^t = x_2^{co} = 0$ .

As corner solutions cannot be compared to inner solutions in the case of Cobb-Douglas preferences, a welfare comparison of autarky and free trade is limited to  $\sigma > 1$ .

### 3. Trade between a species-rich and a species-poor country

In the previous section, trade liberalization resulted in a price increase for country 2. Trading harvest from its formerly larger autarky stock always entailed a reduced total consumption of resource harvests in country 2. This negative quantity effect on consumer welfare was counterbalanced by a positive love-of-variety effect.

As the positive diversity effect was a result of modeling only one resource per country, we modify our model in this section by making country 1 a species-rich country with  $n \geq 2$  species. Country 1 with its small autarky stock was the unambiguous beneficiary of trade in the previous section because trade led to an increase in domestic resource consumption. By a short model extension that introduces species-richness in country 1, we want to show that the diversity effect of trade may also be negative, bringing a country an increase in consumption and a decrease in welfare.

To keep the analysis tractable, we assume that country 1 has  $j = 1, \dots, n$  domestic stocks whose growth functions

$$g_{1j}(x_{1j}) = r_1 x_{1j} (1 - x_{1j}) \quad (30)$$

have identical intrinsic growth rates  $r_{1j} = r_1$ . Country 2 continues to have only one stock  $x_2$  that grows according to (4). Due to the assumption that the stocks in country 1 are equally



productive, the utility function (1) of the consumers in country  $i$  can be represented as

$$u_i = y_i + \gamma_i \ln \left[ \left( n h_{i1}^{\frac{\rho-1}{\rho}} + h_{i2}^{\frac{\rho-1}{\rho}} \right)^{\frac{\rho}{\rho-1}} \right]. \quad (31)$$

The term in square brackets in (31) can be rearranged as the quantity consumed in country  $i$ ,  $H_i$ ,

$$H_i = n h_{i1} + h_{i2} \quad (32)$$

times a diversity factor  $D_i$ ,

$$D_i = \left( n \left( \frac{h_{i1}}{H_i} \right)^{\frac{\rho-1}{\rho}} + \left( \frac{h_{i2}}{H_i} \right)^{\frac{\rho-1}{\rho}} \right)^{\frac{\rho}{\rho-1}}. \quad (33)$$

Under autarky, consumption in country 1 comprises its  $n$  domestic stocks. The diversity factor of country 1 under autarky follows as

$$D_1^a = n^{\frac{1}{\rho-1}}. \quad (34)$$

After trade liberalization, harvest from  $x_2$  becomes available in country 1. The consumption bundle in country 1 increases to  $n + 1$  species and the diversity factor of country 1 under free trade follows as

$$D_1^{ft} = \left( n \left( h_{11}^{ft}/H_1^{ft} \right)^{\frac{\rho-1}{\rho}} + \left( 1 - n h_{11}^{ft}/H_1^{ft} \right)^{\frac{\rho-1}{\rho}} \right)^{\frac{\rho}{\rho-1}}. \quad (35)$$

The species-rich country 1 gains (loses) from free trade if  $U_1^a = n h_{11}^a D_1^a$  is larger (smaller) than  $U_1^{ft} = \left( n h_{11}^{ft} + h_{12}^{ft} \right) D_1^{ft}$ . Even if trading  $n + 1$  species with country 2 increases the quantity consumed in country 1, the country might be worse off due to a negative diversity effect:

**Proposition 5.** *For all  $h_{11}^{ft}/H_1^{ft} < h^*$  with  $0 < h^* < 1/(n + 1)$  it follows that*

$$D_1^{ft} < D_1^a. \quad (36)$$

*Proof.*

$$D_1^a = D_1^{ft} \quad (37)$$

$$\Leftrightarrow n^{\frac{1}{\sigma}} = n \left( \frac{h_{11}^{ft}}{H_1^{ft}} \right)^{\frac{\rho-1}{\rho}} + \left( 1 - n \frac{h_{11}^{ft}}{H_1^{ft}} \right)^{\frac{\rho-1}{\rho}} \quad (38)$$

has a unique solution  $h^* = h_{11}^{ft}/H_1^{ft}$  with  $0 < h^* < 1/(n+1)$ , as for  $h_{11}^{ft}/H_1^{ft} = 0$ , the left-hand-side (LHS) is larger than the right-hand-side (RHS), the RHS is monotone and strictly convex in  $h_{11}^{ft}/H_1^{ft}$ , and assumes a unique maximum  $(1+n)^{1/\sigma}$  at  $h_{11}^{ft}/H_1^{ft} = 1/(n+1)$ , which is larger than the LHS.  $\square$

For  $\sigma = 2$ , the solution is

$$h^* = \frac{1}{n} \left( \frac{n-1}{n+1} \right)^2. \quad (39)$$

If the share of domestic species in domestic consumption drops below  $n h^* = \left( \frac{n-1}{n+1} \right)^2$ , diversity in country 1 decreases. This might happen if the  $n$  species of country 1 are not resilient to the additional demand from country 2 following trade liberalization. In the new steady-state with trade, the species-poor country 2 might dominate consumption in country 1.

This scenario is even easier to model in a North-South model such as Chichilnisky (1994): Country 1 might be a species-rich Southern country that begins trading with a Northern country 2, for example Norway with its well-managed cod or herring fisheries. In such a modeling framework, the open-access stocks of the Southern country would be overused and imports from the well-managed Northern stock would dominate consumption in the South. Even if total consumption in the South increases, South might be worse off due to decreased diversity.

#### 4. Conclusion

Departing from the assumption that traded resources are perfect substitutes yields two important insights: First, the welfare effect of trade liberalization becomes more ambiguous as the price/quantity effect is expanded by a diversity effect that may outweigh increases or decreases in domestic consumption.

Second, increasing the consumers' love of variety weakens the link between resource scarcity and demand. Harvesting overexploited resources is expensive. If consumers are willing to pay the rising prices for harvests from increasingly depleted stocks, trade liberalization may enable higher levels of overexploitation than under autarky. In the limit case

of Cobb-Douglas preferences, free trade may result in stock collapses. This consequence of the love of variety contrasts results from models which implicitly assume that the traded resources are perfect substitutes. In the limit case of perfect substitutes, trade liberalization decreases the demand for the most depleted resources such that it works in the direction of balanced stock sizes. Modeling trade in renewable resources as trade in perfect substitutes thus assumes the best-case scenario concerning the risk of trade-induced overexploitation and stock collapse. Integrating a love-of-variety effect in a trade model shows that trade liberalization may enable the love of variety to threaten variety.

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