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Open access renewable resources: Trade and trade policy in a two-country model

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Abstract

This paper develops a two-good, two-country model with national open access renewable resources. We derive an appropriate analog of "factor proportions" for the renewable resource case and link it to trade patterns and to the likelihood of diversified production. The resource importer gains from trade. However, a diversified resource exporting country necessarily suffers a decline in steady state utility resulting from trade, and may lose along the entire transition path. Thus the basic "gains from trade" presumption is substantially undermined by open access resources. Tariffs imposed by the resource importing country always benefit the resource exporter, and may be pareto-improving. © 1998 Elsevier Science B.V.

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1. Introduction

There are at least two important connections between international trade policy and renewable resource management. One connection is the concern that trade liberalization may lead some countries to excessively exploit their renewable

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resources, leading to long-run losses.[1] A second connection arises from suggestions that trade sanctions might reasonably be linked to resource management practices. Specifically, it has been suggested that weak resource management regimes confer the equivalent of an export subsidy on producers and should therefore be subject to countervailing duties under international trade law.[2]

There has, however, been relatively little formal economic analysis addressing such concerns. In an early step towards such analysis, Brander and Taylor (1997a) consider the case of a small open economy with an open access renewable resource. That paper obtains the striking result that if the small open economy has a comparative advantage in the resource good and remains diversified in production after trade, then its steady-state utility is necessarily reduced by trade.

In this paper we attempt to take another significant step forward in understanding the relationship between trade policy and renewable resource management. We wish to go beyond the small country case and allow the world price of the resource good to be endogenously determined within the model. This is important as it allows us to examine how one country's trade and resource management practices affect resource stocks and welfare elsewhere in the world. In this context, we examine the determinants of trade patterns, the welfare effects of opening trade, and the positive and normative consequences of tariffs and export taxes.

The simplest model for investigating these issues is a two-country model in which each country is similar to the small country considered in Brander and Taylor (1997a). Each country is endowed with a renewable resource stock and labour, and may produce the resource good and/or a numeraire good which we refer to as manufactures. The renewable resource is subject to domestic open access (i.e. foreigners cannot use the resource) and has a dynamic structure of the classic Schaefer (1957) type.

Using this model we are able to obtain several interesting results. First, we are able to find an analog of ''factor proportions'' for the case of a renewable resource model. We are then able to link trade patterns to relative factor service flows, deriving a result similar in structure to the Heckscher-Ohlin theorem. In addition, we show that sufficient similarity across countries in this ratio of factor proportions ensures diversified production and factor price equalization in steady state.

We also show that the resource abundant country necessarily suffers a reduction

[1] For example, Brown (1995) discusses the Ivory Coast and the Philippines, both of which dramatically increased harvesting and exporting of forest products in the 1970s, substantially depleted their forest stocks, and now have much lower levels of earnings from their forest resources. In the Ivory Coast, this was a major factor contributing to the approximate 50% decline in per capita real income that occurred between 1980 and 1994.

[2] There is an active literature in law and political science on the linkage between trade sanctions and environmental policies. Good examples include Reichert (1996) and Yechout (1996). These papers provide a balanced overview of how GATT and the WTO might seek to deal with issues related to resource management and environmental damage.

in its steady state utility as a result of trade if it is diversified in the trading steady state. Moreover, if the resource exporter is always diversified during the transition from autarky to the trading steady state, then it also loses at every point along the transition path. The basic intuition underlying these results arises from the negative externality associated with harvesting open access resources. An open access resource is one lacking property rights, so all producers can use the resource ‘‘freely’’, and do not face the full cost of stock depletion. The primary cost of stock depletion is that harvesting becomes more costly in the future (e.g. it is more costly to catch fish if the fish stock is largely depleted and more costly to harvest timber once the large trees have been cut). Because of this negative externality, there is over-harvesting even in autarky, and opening trade increases the cost of this externality for the resource good exporter.

The mechanism by which these welfare effects arise derives from the interaction of terms of trade effects and resource depletion. More specifically, under autarky, the resource abundant country has a larger resource stock and a lower relative price of the resource good. When trade opens, consumers in the resource poor country have an incentive to import the resource good, leading the resource abundant country to increase its harvesting (for export). This causes depletion of the resource stock in the resource abundant country and, as its resource stock falls, the labor cost of producing the resource good rises, causing a gradual increase in the price of the resource good. Because the resource stock is an open access resource, there are no direct factor returns to the resource stock and, in addition, potential profits are fully dissipated by entry. The only income is labour income, and the real value of this income falls as the price of the resource good rises.

Therefore, a resource abundant country may suffer long run losses from trade. This provides some rationale for concerns about the long run impact of trade liberalization on countries where renewable resources are an important part of the export sector but where property rights over the resources are incomplete. Our analysis of policy shows that an import tariff imposed by the country importing the resource good raises the steady state utility of the resource exporter, and may be pareto-improving. This result lends some support to the argument in favour of linking tariffs or other trade sanctions to resource management practices. In addition we show that export taxes on the resource good increase the steady state resource stock in the resource exporting country but reduce the importing country’s stock. The resource exporter necessarily gains from a small export tax, while the importer loses. In effect, tariffs or other trade restrictions can act as a ‘‘second-best’’ policy to reduce the negative consequences of the open access externality.

The assumption that resources are subject to open access may seem extreme. In practice, renewable resources often have partially controlled access. For example, many fisheries are regulated. However, excessive use and rent dissipation still occurs. In particular, restrictions on fishing time and numbers of boats have led to larger boats and more intensive fishing per unit of time, and direct catch limits have been hard to monitor and enforce. Rent dissipation and overuse in other renewable resources (such as forests, wildlife and soil) may be less severe than in fishing, but are still major problems in much of the world. As long as property rights are incomplete, even if they are not totally absent, the basic insights of our analysis will have relevance.

This work draws on traditional (Ricardian and factor proportions) trade theory, and on the theory of renewable resources. Suitable background for the trade theory component of our analysis is available in standard references such as Dixit and Norman (1980) or Ethier (1984). Papers focusing on trade and growth such as Srinivasan and Bhagwati (1980) and Deardorff (1973) also provide useful comparative background. As for the renewable resource component, our paper builds on the classic work of Schaefer (1957) and Gordon (1954), and much of the analytical background to our paper is set out in the comprehensive overview of ''bioeconomics'' provided by Clark (1990). Other valuable overviews include Munro and Scott (1985) and Neher (1990). The literature on trade in renewable resources is relatively modest in scope. The review article by Kemp and Long (1984) contains some material on renewable resources, and early papers dealing with trade and renewable resources include McRae (1978), Markusen (1976) and Scott and Southey (1969). A related recent paper is Lopez (1994).

There has been extensive recent analysis of the relationship between trade and the environment, including Barrett (1994), Copeland and Taylor (1994, 1995) and Rauscher (1993). Valuable overviews of international resource management problems are provided in books by Pearce and Warford (1993) and Cooper (1994). Overall, however, we view this paper, along with Brander and Taylor (1997a), as a substantial departure from existing themes in the literature. Also, in a tangentially related paper, (Brander and Taylor, 1997c) we combine closed-economy renewable resource dynamics with Malthusian population dynamics to explain the economic rise and fall of Easter Island.

An apparently closely related paper is Chichilnisky (1994), in which one country (the ''South'') has incomplete property rights and the other (the ''North'') has complete property rights. That paper demonstrates, using a static framework, that the free trade equilibrium is not pareto-efficient.[3] It is important to note, however, that the actual proofs of propositions do not provide a formal welfare comparison of autarky and free trade. In contrast, in this paper we do formally compare free trade and autarky, showing conditions under which the resource exporting country loses from trade in steady state and along the transition path.

The analysis in our paper has a connection to the literature on ''trade and distortions'' associated particularly with Bhagwati and Ramaswami (1963), and

[3] The same basic result is also reported in Chichilnisky (1991). Chichilnisky (1993) carries out a similar analysis for the dynamic case. In Brander and Taylor (1997b) we also consider a model in which one country has an open access resource and the other does not, but have a different specification and obtain different results from those of Chichilnisky (1991, 1993, 1994).

the formal structure of the second-best problems arising from trade liberalization is similar to the structure in the literature on ''immiserizing growth'' as represented by Bhagwati (1958); Johnson (1967) and Brecher and Choudri (1982). In the distortions literature, an ordering of policy interventions is provided for each type of distortion. In our model, the ''first-best'' policy is to eliminate the distortion of incomplete property rights at source, as in the distortions literature. However, the ordering of second-best policies does not carry over to our model, as our dynamic structure goes beyond the static models considered in the distortions literature.

Section 2 of the paper sets out the basic autarky model incorporating renewable resources, following the development in Brander and Taylor (1997a). Section 3 then extends the model to the two- country case and demonstrates the central normative and positive properties of trade in this setting. Section 4 and Section 5 consider possible trade policy interventions and Section 6 considers possible extensions and generalizations. Section 7 contains concluding remarks.

2. General equilibrium with a renewable resource: autarky

2.1. Renewable resource growth

As in Brander and Taylor (1997a) it is necessary to begin by describing the basic structure of renewable resource growth. Each country has a resource stock. Focusing on just one country for now, referred to as the ''domestic'' country, its resource stock at time t is denoted $S(t)$. The natural growth of the resource, denoted G, is a function of the existing stock. The change in the stock at time t is the natural growth rate $G(S(t))$, minus the harvest rate, $H(t)$. Dropping the time argument for convenience yields

$$\mathrm{d}S/\mathrm{d}t = G(S) - H. \tag{1}$$

We use a specific functional form for G, given by

$$G(S) = rS(1 - S/K). \tag{2}$$

This functional form for $G(S)$ is the logistic function. It is widely used in the analysis of renewable resources and is perhaps the simplest empirically plausible functional form for biological growth in a constrained environment. The variable K, referred to as the ''carrying capacity'', is the maximum possible size for the resource stock. If $S=K$, further growth cannot occur. The variable r is the ''intrinsic'' or ''uncongested'' growth rate. Proportional growth rate $G(S)/S$ would be approximately equal to r if congestion were negligible in the sense that carrying capacity were large relative to the current stock.

2.2. Production and supply

Each country produces and consumes two goods. H is the harvest of the renewable resource, and M is some other good which might be thought of as manufactures. Good M is treated as a numeraire whose price is normalized to 1. In addition to resource stock S, there is only one other factor of production, labour, L. Manufactures are produced with constant returns to scale using only labour. By choice of units, one unit of labour produces one unit of good M. As the price of M is 1, it follows that labour's value of marginal product in manufacturing is 1. We assume that labour markets are perfectly competitive, thus the wage in manufacturing is 1. We also assume that harvesting is carried out according to the Schaefer harvesting production function.

$$H^S = \alpha S L_H \tag{3}$$

where H^S is the harvest supplied by producers. (The superscript S stands for ''supply''.) L_H is the amount of labour used in resource harvesting and α is a positive constant. Letting $a_{LH}(S)$ represent the unit labour requirement in the resource sector, Eq. (3) implies that $a_{LH}(S) = L_H/H^S = 1/(\alpha S)$. Note that $a'_{LH}(S) < 0$: unit labour requirements rise as the resource stock falls. Production in both sectors is carried out by profit-maximizing firms operating under conditions of free entry. Thus the price, p, of the resource good must equal its unit cost of production.

$$p = w a_{LH} = w/(\alpha S) \tag{4}$$

where w is the wage. Condition Eq. (4) incorporates the open-access assumption, because it means that labour costs are the only explicit cost of production. There is no explicit rental cost for using S. Labour is mobile between the two sectors. Thus if manufactures are produced, the wage must be 1, and Eq. (4) becomes

$$p = 1/(\alpha S). \tag{4a}$$

2.3. Ricardian temporary equilibrium

A representative consumer is endowed with one unit of labour and is assumed to have instantaneous utility given by the following Cobb-Douglas utility function

$$u = h^{ß} m^{1-ß} \tag{5}$$

where h represents individual consumption of the resource good, m is individual consumption of manufactures, and taste parameter $ß$ is strictly between 0 and 1. The consumer maximizes utility at each moment in time subject to an instantaneous budget constraint $ph + m = w$. This maximization yields demand functions $h^D = wß/p$ and $m^D = w(1-ß)$, using superscript D to represent demand. Total domestic demand is just L times individual demand.

$$H^D = w\beta L/p \; ; M^D = w(1-\beta)L. \tag{6}$$

Rearranging the left hand expression in Eq. (6), the inverse demand for the resource good can be written as

$$p = w\beta L/H^D. \tag{7}$$

On the production side, at a moment in time the resource stock is fixed, and the economy is Ricardian. The full employment condition defines the temporary Ricardian production possibility frontier (PPF) and is given by $H^P\ a_{LH}(S)+M=L$. The temporary equilibrium harvest can be determined by setting the supply price given by Eq. (4) equal to the demand price given by Eq. (7) (i.e. by setting supply equal to demand). This yields

$$H = \alpha\beta LS. \tag{8}$$

Note that the temporary equilibrium harvest is an increasing linear function of the stock. The equilibrium output of M is $M=(1-ß)L$, hence fraction $ß$ of the labour force is employed in the resource sector.

2.4. An autarkic steady-state

The temporary equilibrium is like a standard Ricardian equilibrium. However, there is no guarantee that the harvest will equal the underlying biological growth rate of the resource. If, for example, the temporary equilibrium harvest, H, exceeds biological growth G, then the stock diminishes as time proceeds. As a result, labour productivity in the resource sector falls. (From Eq. (3)) the average and marginal product of labour is αS, which obviously falls as S falls.) The Ricardian PPF, which has harvest intercept αLS, then pivots inward, leading to a new temporary equilibrium, as illustrated in Fig. 1.

A steady state emerges when the stock has evolved to a level at which $H(S)$ as given by Eq. (8) is equal to $G(S)$ as given by Eq. (2). Setting these equal yields

$$\alpha\beta LS = rS(1-S/K) \tag{9}$$

One solution to Eq. (9) occurs when $S=0$. Thus $S=H=0$ is a possible (and miserable) steady state. If S is not zero, we obtain the solution

$$S_A = K(1-\alpha\beta L/r) \tag{10}$$

where S_A stands for the autarkic steady state resource stock. The resource dynamics associated with convergence to a steady state are illustrated in Fig. 2. This figure illustrates a situation in which the initial stock level, S_0, implies a harvest $H(S_0)$ in excess of natural growth $G(S_0)$. Thus the stock shrinks toward its autarkic steady state level S_A.

The autarkic steady state harvest, denoted H_A, is obtained by substituting Eq. (10) into Eq. (8).

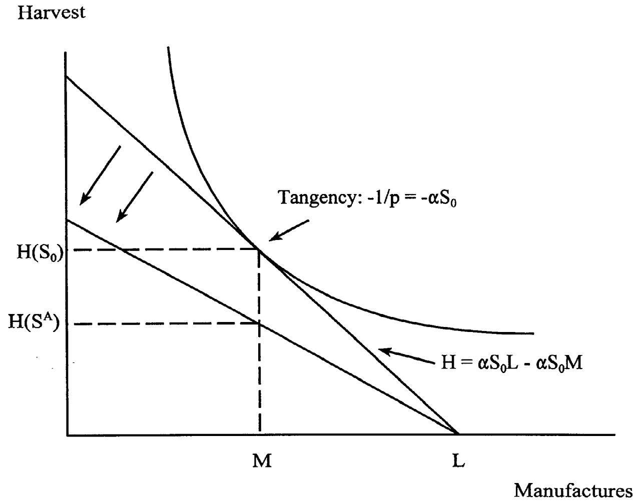

Fig. 1. Temporary equilibrium dynamics.

$$H_A = \alpha\beta LK(1 - \alpha\beta L/r) \tag{11}$$

As shown in Brander and Taylor (1997a), a positive steady state solution exists if and only if

$$r/L > \alpha\beta \tag{12}$$

in which case the solution is globally stable (for $S_0 > 0$). If Eq. (12) is not satisfied, the resource will be extinguished and the unique steady state is $S = H = 0$. To appreciate the meaning of Eq. (12) note (from Eq. (2)) that r is proportional to G, the instantaneous growth rate of the resource. Thus r is a measure of the service flow from the resource stock, and the ratio r/L measures the relative factor service

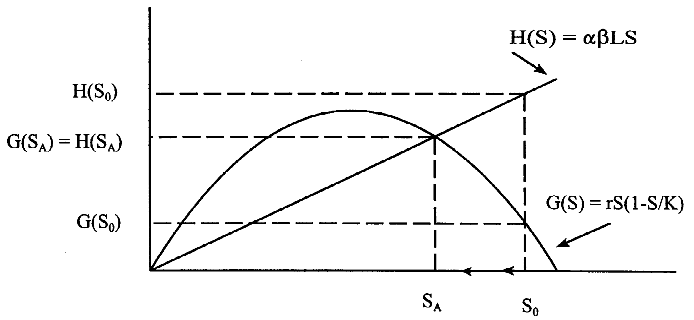

Fig. 2. Convergence to a steady state.

flow. Expression Eq. (12) can then be interpreted as saying that a positive steady state exists only if ''factor proportion'' r/L implies sufficient resource abundance.

3. A two-country model of international trade

We now consider trade between two countries that are identical except for factor proportions. In particular, each country has a renewable resource that is subject to open access by residents of that country only. We therefore abstract from the international open access problem. The international aspect of open access is interesting and important, but the case of nationally controlled open access resources is much more empirically significant.[4] Both goods may be traded, but labour is immobile across countries.

As suggested earlier, a useful measure of comparative advantage is given by factor proportion ratio r/L. We refer to the countries as ''foreign'' and ''domestic'' and use asterisks to denote foreign variables. For concreteness, we take the foreign country to be relatively resource abundant and the domestic country to be labour abundant.[5]

$$r^*/L^* > r/L \tag{13}$$

We assume that the parameters are such that each country has a positive steady state resource stock in autarky (i.e. expression Eq. (12) holds for each country), and then consider trade.

3.1. The positive analysis of trade

A central feature of trade is that wages and resource stocks must be equalized (in or out of steady state) whenever each country produces both goods, as expressed in Proposition 1.

Proposition 1: *If each country remains diversified in production after trade, then*

(i) (factor price equalization, FPE) the wage must be equal to 1 in each country ($w = w^* = 1$), *and*

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[4]In a recent comprehensive review of international fisheries research conducted by the U.N. Development Program, the Commission of European Communities, the World Bank, and the Food and Agriculture Organization of the U.N, the authors conclude that ''Although states have largely ended international open access through the extension of jurisdiction, most still allow *free and open access* to their domestic fisheries.'' (original emphasis) World Bank (1992); (p14). Accordingly we take domestic open access as our working hypothesis.

[5]While we focus on cross-country differences in r/L as the central asymmetry between countries, differences in other parameters such as α (harvesting efficiency) and K (carrying capacity) would also have interesting consequences.

(ii) (resource stock equalization, RSE) each country will have the same resource stock ($S=S^*$).

Proof: (i) If each country is diversified, then each produces some manufactures, where the marginal value product of labour is 1, which implies that the wage is 1. (ii) From expression Eq. (4) and from (i), it follows that $p_T=a_{LH}=a^*_{LH}$, where p_T is the world price of the resource good. Then, as $a_{LH}=1/(\alpha S)$, while $a^*_{LH}=1/(\alpha S^*)$, it follows that $S=S^*$.

We now provide a brief heuristic description of the dynamic transition that occurs when trade opens using the relative supply and demand curves shown in Fig. 3. The demand for the harvest good relative to manufactures (H^D/M^D) is easily obtained from expression Eq. (6) as $\beta/((1-\beta)p)$. This relative demand is common to both countries and therefore to the world, and it applies both in and out of steady state. As shown by the line labelled RD in Fig. 3, this relative demand is a downward sloping function of relative price, p.

For each country, the relative supply curve at a point in time is a typical Ricardian relative supply curve, consisting of a horizontal segment and a vertical segment. Given a resource stock of size S, a country will specialize in manufactures if $p<1/(\alpha S)$, and the relative (and absolute) supply of the resource good would be zero. Thus the relative supply curve is vertical at zero for $p<1/(\alpha S)$. For $p>1/(\alpha S)$, a country would specialize in the resource good, implying an infinite relative supply, whereas the relative supply could be anything between 0 and infinity if $p=1/(\alpha S)$. The relative supply curve is therefore horizontal at $p=1/(\alpha S)$.

As trade opens, we assume each country is at its autarkic steady state. As the

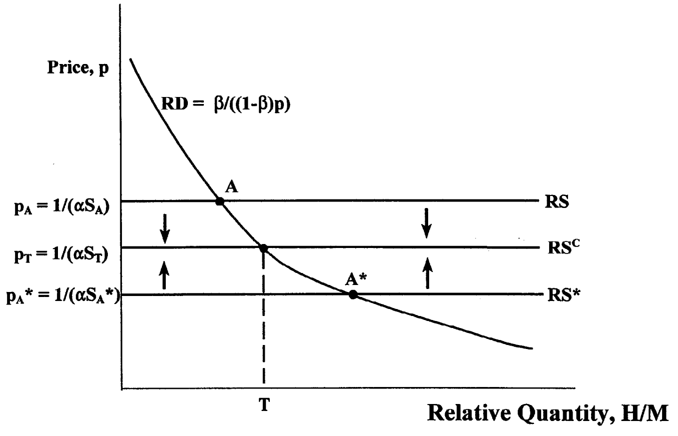

Fig. 3. Relative demand and supply under autarky and free trade.

foreign country has the higher autarky resource stock, the relative supply curves for the two countries are as shown in Fig. 3. RS is the initial relative supply curve for the domestic country and RS* is the relative supply curve for the foreign country. The autarky price and output are indicated by point A for the domestic country and point A^* for the foreign country. As trade opens, domestic consumers have access to lower prices from foreign resource good suppliers, implying that the foreign country will begin to export the resource good while the domestic country exports manufactures. Labour exits from the domestic resource sector, harvesting falls, and the domestic stock begins to rebuild, causing relative supply curve RS to shift down, as illustrated by the arrows in Fig. 3. The foreign country goes through the converse adjustment.

When trade opens, there are incipient profits available in the resource sector, inducing a shift of labour into that sector. Either all labour flows into the resource sector, or output rises sufficiently to bring the world price down to p_A^* at some production configuration short of full specialization. In either case, harvesting rises in the foreign country, the foreign stock starts to decline, and relative supply curve RS* starts to shift up, as indicated. These movements in the two relative supply schedules continue until a new steady state is reached (as shown more formally in Section 3.3).

At a diversified trading steady state, the two countries must have equal resource stocks, denoted S_T, and therefore have common relative supply curve RS^C, which has its horizontal segment at world price $p_T = 1/(\alpha S_T)$. At this world price, Fig. 3 implies that relative demand in each country is given by T. The foreign country produces to the right of T and exports the resource good, while the domestic country produces to the left of T and exports manufactures.

In Fig. 3 we have presumed that both countries remain diversified in steady state. However, if the world demand for the resource good is very high (i.e. if ß is large) or if countries differ substantially in factor proportions, then the foreign country might specialize in the resource good in steady state. The key difference in diagrammatic terms is that the adjustment in Fig. 3 ends before domestic and foreign supply curves become coincident. In the specialized case, the world price of the resource good lies above the relative supply curve of the foreign country and coincides with the horizontal portion of the domestic relative supply curve. The foreign country specializes in resource good production, while the domestic country is diversified. The configuration where the foreign country specializes in production of the resource good is the only possibility for specialization, as stated and proven in Proposition 4.

In this paper we focus on the diversified case. The specialized case is of some interest, but we view it as less empirically relevant and, given space constraints, we do not pursue it here. Proposition 4 states precisely when specialization and diversification will occur. We now demonstrate the properties of the trading state more formally, starting with our analog of the Heckscher-Ohlin theorem linking trade patterns to factor endowments.

Proposition 2: *In a diversified trading steady state, the resource abundant country must export the resource good. The labour abundant country must export manufactures (the labour intensive good).*

Proof: From expression Eq. (8) we have $H^D = L\alpha\beta S$ and $H^{D*} = L^*\alpha\beta S^*$. Recalling from Proposition 1 that $S = S^*$, it follows that $H^D/H^{D*} = L/L^*$. A steady state requires $H^S = G$ and $H^{S*} = G^*$. Therefore $H^S/H^{S*} = G/G^* = r/r^*$. We then obtain $(H^D/H^S)/(H^{D*}/H^{S*}) = (L/r)/(L^*/r^*) > 1$, or $H^D/H^S > H^{D*}/H^{S*}$. The material balance condition given by $H^D + H^{D*} = H^S + H^{S*}$ then implies that $H^D > H^S$. Thus the labour abundant country consumes more of the resource good than it produces and must import it. It follows that the resource abundant country must export the resource good.

Proposition 2 provides a formal statement and algebraic proof of the key point that follows from Fig. 3. Namely, as in standard factor proportions models, relative resource abundance determines autarky relative prices, which in turn predict the direction of trade. Unlike standard factor proportions models, however, the mechanism by which this occurs is that production reallocations across countries cause resource stocks to be equalized. Proposition 3 establishes the natural intuition about post-trade resource stock and price levels (as illustrated in Fig. 3).

Proposition 3: *In a diversified trading steady state, (i) the common post-trade resource stock in each country, denoted S_T, lies between the autarky and steady state stock sizes, and (ii) the post-trade world price of the resource good lies between the autarky prices.*

Proof: (i) By material balance, $H^D + H^{D*} = G(S_T) + G^*(S_T)$ or, using Eq. (8) and Eq. (2),

$$\alpha S_T(\beta(L + L^*)) = rS_T(1 - S_T/K) + r^*S_T(1 - S_T/K). \tag{14}$$

Rearrangement of Eq. (14) yields a solution for the diversified steady state stock in each country.

$$S_T = K[1 - (L + L^*)\alpha\beta/(r + r^*)] > 0. \tag{15}$$

Comparing expression Eq. (15) with expression Eq. (10) completes the proof.

(ii) Diversification of production implies (using Eq. (4a)) that $p = 1/(\alpha S)$ and $p^* = 1/(\alpha S^*)$ before trade, and also that $p_T = 1/(\alpha S_T)$ after trade. Using part i) then implies $p > p_T > p^*$, as was to be shown.

Propositions 1, 2, and 3, and Fig. 3 presume that both countries remain diversified in production after trade. Whether diversification occurs in steady state depends on the similarity across countries in factor proportions and the strength of tastes for the resource good, as follows from Proposition 4.

Proposition 4: *(i) Neither country can specialize in manufactures.*

(ii) A necessary and sufficient condition for the post-trade pattern of production to be diversified in both countries is

$$[(L^*/r^*)]/[(L+L^*)/(r+r^*)] > \beta. \tag{16}$$

(iii) If Eq. (16) fails to hold, then the foreign (resource abundant) country will specialize in production of the resource good and the domestic country will be diversified. This is the only specialization possibility.

Proof: See Appendix A.

The left hand side of expression Eq. (16) is a measure of the similarity of factor proportions across countries. If the countries are identical up to scalar multiples (i.e. $r=\delta r^*$ and $L=\delta L^*$ for some $\delta>0$) then $r/L=r^*/L^*$ and condition Eq. (16) reduces to $1>ß$, which is true by model construction. Thus, by continuity sufficient similarity in factor proportions implies that Eq. (16) must be satisfied, which in turn implies that diversification (and therefore FPE) follow.

We can increase the difference in factor proportions while maintaining our relative factor abundance ranking by increasing L/r or decreasing L^*/r^*. In either case, Eq. (16) is more likely to be violated. In addition, increases in $ß$ (reflecting the world taste for the resource good) make Eq. (16) more likely to be violated. If Eq. (16) is violated, then factor prices will not be equalized by trade and the foreign country will specialize in production of the resource good in steady state. In effect, Proposition 4 points out that the possibility of FPE depends both on relative resource endowments and on tastes, as in conventional factor proportions theory. (A standard reference on FPE is Dixit and Norman (1980), but see Deardorff (1994) for some new results and a recent perspective.)

Although the model is Ricardian at each point in time the positive steady state properties of the model are surprisingly similar to standard factor proportions models. A measure of relative resource abundance determines ‘‘comparative advantage’’, and trade flows are reliably predicted by this measure. Moreover, if the countries are sufficiently similar in factor proportions, then trade will bring about diversified production and FPE.

3.2. Normative steady state implications of trade

Despite the similarities between our renewable resource model and standard factor proportions models, we can now establish a result that contrasts sharply with the basic normative insight associated with the theory of comparative advantage.

Proposition 5: *Comparing a diversified trading steady state with autarky,*
(*i) trade causes steady state utility to fall in the resource-abundant country, and*
(ii) trade causes steady state utility to rise in the labour-abundant country.

Proposition 5 can be readily seen diagrammatically, as shown in Fig. 4. The foreign country has autarky consumption possibilities given by its PPF, $H^{D}*a^{*}_{LH}(S^{*}_{A})+M*=L*$ (noting that $H^{D}*=H^{S}*$ under autarky and letting S^{*}_{A} be the foreign autarky steady state resource stock). After trade, the foreign country must consume on a budget line running through the production point with slope equal to the world terms of trade. This is its post-trade steady state PPF. The equation of this line is $H^{D}*a^{*}_{LH}(S_{T})+M*=L*$. Because $S_{T}<S^{*}_{A}$ (from Proposition 3), it follows that the post-trade PPF lies inside the autarky consumption (and production) possibility frontier, except at the corner where $M*=L*$.

As autarky consumption lies outside the post-trade consumption possibility set, foreign steady state utility must be strictly lower in the trading steady state than under autarky. One way of seeing that foreign utility must fall in the move from autarky to a trading steady state is to observe that, relative to autarky, foreign nominal income stays constant (at $L*$), the price of manufactures stays constant (at 1), and the price of the resource good rises (from Proposition 3). Therefore, the representative foreign consumption bundle must shrink and foreign utility must fall. The home country undergoes a mirror-image change in its fortunes. The

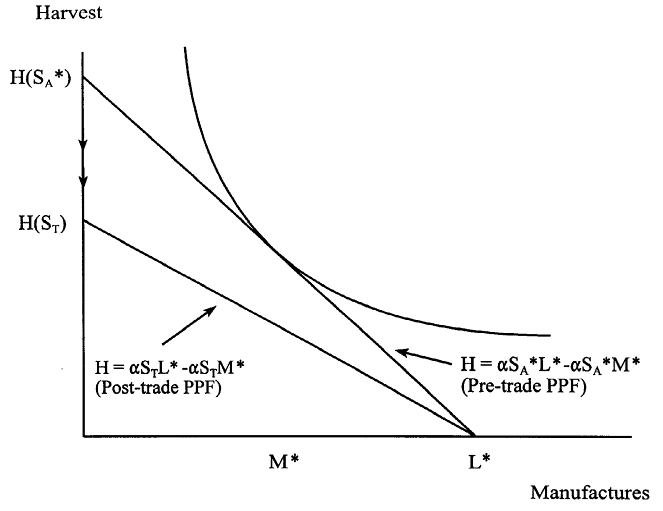

Fig. 4. Losses from trade for resource exporter.

reasoning is identical as for the foreign country, except that, as $S_T > S_A$, the home country experiences steady-state gains from trade. From its point of view, nominal (labour) income and the price of manufactures are the same as in autarky, while the price of the resource good is lower.

The only way the foreign country could take advantage of terms of trade effects and experience steady state gains from trade would be if it could specialise in the resource good and experience an increase in the wage. However, specialisation will only occur if Eq. (16) is violated (i.e. if the difference between foreign and domestic relative resource abundance is sufficiently great).

Proposition 5 is the analog to the result in Brander and Taylor (1997a) that a resource abundant small open economy that remains diversified after trade has a lower steady-state utility level after trade than in autarky. Taken together, Brander and Taylor (1997a) and Proposition 5 weaken the gains from trade presumption for trade based on the exploitation of a renewable resource under conditions of incomplete property rights. This can be seen as a ‘‘second-best’’ problem. Because open access creates a market failure, there is no presumption that removing another distortion (prohibitions on trade) will necessarily improve welfare.

3.3. Normative analysis of transitional dynamics

We now consider the welfare properties of the dynamic transition from autarky to the new post-trade steady state. Even when trade leads to diversified production and lower steady state utility for the foreign country, it may provide utility gains during the transition period. This seems an important qualification to our analysis, but we show that there are reasonable conditions under which the foreign country loses at every point on the transition path as well as in steady state.

The key to understanding this possibility follows from the intuition regarding terms of trade and resource depletion effects. If the foreign country remains diversified throughout the transition process then utility would be lower at each point in time in trade than in autarky, because of ongoing resource depletion effects. The aggregate present value of foreign welfare would then necessarily be reduced by trade, regardless of the discounting rule used.

One condition underlying transitional losses from trade for the foreign country is

$$L^* > \beta(L + L^*) \tag{17}$$

Rearranging Eq. (17) yields $(1-ß)(L+L^*)>L$. Wage rates w and w^* cannot be less than 1. Therefore,

$$(1 - \beta)(wL + w^*L^*) > L \tag{17a}$$

However, it follows from the right hand expression in Eq. (6) that world demand for manufactures is precisely the left hand side of expression Eq. (17a). Therefore, world demand exceeds L. But L is the maximum amount of manufactures that can be produced in the domestic country even if all domestic labour is devoted to manufactures. It follows that the foreign country must in this case (i.e. if Eq. (17) holds) produce some manufactures and have a wage equal to 1 at every point on the transition path. Condition Eq. (17) also implies that Eq. (16) holds and therefore insures convergence to a diversified steady state.

Now consider what happens when trade opens. As established in Section 3, expression Eq. (10) implies that the initial resource stock is higher in the foreign country than in the domestic country. Furthermore, foreign and domestic wages equal 1. We can then infer from Eq. (4a) that the supply price of the resource good in the foreign country must be less than the supply price in the domestic country. Therefore, the domestic country cannot sell the resource good, as it will be undercut by foreign producers, so it must specialize in manufactures and produce a harvest of zero. The foreign country remains diversified, and the wage remains at 1 in both countries. As long as $S^* > S$, the domestic harvest remains zero, and the evolution of the domestic stock (from Eq. (1)) is given by

$$\mathrm{d}S/\mathrm{d}t = rS(1 - S/K) > 0 \tag{18}$$

To obtain the corresponding equation for the foreign country, we need to determine its harvest. This can be done by finding the labour allocated to harvesting. With the (specialised) domestic country producing amount L of manufactures, and with world demand for manufactures given by $(1-ß)(L+L^*)$ (from Eq. (17a) with $w = w^* = 1$), it follows that foreign production of manufactures is $(1-ß)(L+L^*)-L$. This must also be the amount of foreign labour devoted to manufacturing, so the amount of foreign labour left over for harvesting is $L^* - [(1-ß)(L+L^*)-L] = ß(L+L^*)$. Using Eq. (3), we can then observe that the foreign harvest is $H^* = \alpha ß(L+L^*)S^*$. Therefore, from Eq. (1), the differential equation governing the evolution of the foreign stock (for $S^* > S$) is

$$\mathrm{d}S^*/\mathrm{d}t = r^*S^*(1 - S^*/K) - \alpha ß(L + L^*)S^* \tag{19}$$

We could integrate Eq. (18) and Eq. (19) to provide explicit solutions for the trajectory of foreign and domestic stocks. It is easier, however, to draw inferences directly from Eq. (18) and Eq. (19). From Eq. (18), recalling that $S < K$ as trade opens, we can infer that S approaches and gets arbitrarily close to K as time proceeds. To interpret Eq. (19) recall (from Eq. (8)) that under autarky $r^*S^*(1 - S^*/K) = \alpha ß L^* S^*$. Therefore Eq. (19) must be negative as trade opens. Thus, immediately upon the opening of trade, S starts to grow and S^* starts to fall.

As S grows, eventually one of two things must happen. Either S must get arbitrarily close to K (as implied by Eq. (18)), or it must equalize with S^*. Meanwhile, S^* would continue to fall either until it reached the stabilizing value implied by Eq. (19), which is $K[1-\alpha ß(L+L^*)/r^*] < K$, or until it equalized with S. Given that $S^* > S$ initially, S and S^* must equalize at some finite time. When S

and S^* do equalize, differential Eq. (18) and Eq. (19) cease to govern the further evolution of the stocks. We denote this time when S and S^* equalize as t_e.

Throughout this entire time up to t_e foreign utility is falling. To see this recall that the foreign country remains diversified throughout the process. (This is ensured by condition Eq. (17).) Therefore its wage remains at 1 and its total income is L^*. The price of manufactures remains stable at 1. The world price of the resource good is determined by the foreign supply price, as only the foreign country produces the resource good. This price starts at the foreign autarky level then rises as the foreign stock declines. Therefore, the foreign country has a stable nominal income and a steadily increasing real cost of consumption, implying that its utility falls at each point along the transition until $S=S^*$ at time t_e.

Once the two resource stocks equalize, they can never differ from each other again. Any incipient deviation of S from S^* would lead to an instantaneous flood of labour into the resource sector of the country with the marginally higher stock. The speed of this production ‘‘correction’’ is instantaneous, whereas stock adjustment occurs in real time (i.e. comparatively slowly). Thus stock deviations can never get started because they are instantaneously swamped by production adjustments.

The two stocks evolve in tandem toward the steady state value S_T given by Eq. (17). The dynamic behaviour of the stocks after time t_e (i.e. when $S=S^*$) is given by

$$\mathrm{d}S/\mathrm{d}t = rS(1-S/K) - \alpha L_{HS} = \mathrm{d}S^*/\mathrm{d}t = r^*S^*(1-S^*/K) - \alpha L_H^*S^* \tag{20}$$

Given condition Eq. (17), the two countries must both be diversified when stocks are equalized. Therefore wages are equal to 1 and (from Eq. (17a)) world demand for manufactures is $(1-ß)(L+L^*)$. Total labour devoted to manufactures must be precisely the same quantity. The remaining amount of labour, $ß(L+L^*)$, must equal $L_H+L_H^*$. Using Eq. (20) and this market-clearing condition allows us to solve for the labour allocations in each country during this phase of the transition. These are given by

$$L_H = (1/2)[[(r-r^*)/\alpha](1-S/K) + \beta(L+L^*)] \tag{21}$$

$$L_H^* = (1/2)[[(r^*-r)/\alpha](1-S^*/K) + \beta(L+L^*)] \tag{22}$$

where $S=S^*$. These allocations apply at each point in time from t_e forward along the transition path.

We can now solve for the transition path of either country’s resource stock over the remaining interval of the transition period. Substituting Eq. (21) into Eq. (20) and rearranging shows that the evolution of the domestic resource stock from its position at $t=t_e$ is given by:

$$\mathrm{d}S/\mathrm{d}t = \tfrac{1}{2}[(r+r^*)S(1-S/K) - \alpha\beta(L+L^*)S] \tag{23}$$

The solution to Eq. (23) shows that the domestic stock converges monotonically to steady state stock S_T (given in Eq. (17)), as does the foreign stock (substituting Eq. (22) into Eq. (20)). We have already determined that the foreign country has a declining instantaneous utility everywhere along the first part of its transition path towards the trading steady state (i.e. for $t<t_e$). We have now shown that over the rest of the transition the foreign stock must move monotonically toward $S_T<S_A^*$. Therefore, the foreign stock is less than its autarky level throughout the entire transition period, and the world price of the resource good, which equals $1/(\alpha S^*)$ must always exceed the foreign autarky price. Foreign nominal income is steady at L^*, and the price of manufactures is steady at 1. Thus foreign utility must be lower at every point along the transition path. Parallel reasoning implies that the home country gains during the transition. Proposition 6 summarizes this discussion.

Proposition 6: *If condition Eq. (17) holds ($L^*>ß(L+L^*)$), then foreign utility is lower at every point along the transition from autarky to free trade than in autarky. Conversely, domestic utility is higher at every point along the transition than in autarky. Therefore, for any plausible discounting procedure, foreign welfare is reduced by trade and domestic welfare is increased by trade.*

If condition Eq. (17) does not hold, then the foreign country may gain, depending on parameter values, along some interval of the transition path, even if the steady state is ultimately diversified. In such a case discount rates and adjustment speeds would be important in determining an overall welfare result. Specifically, a high discount rate would tend to reduce the present discounted value of losses from trade and could even cause net discounted benefits from trade for the country exporting the resource good. What happens is that this country may specialize in the resource good as trade opens, driving wages above 1, and earn gains from trade in the early stages of adjustment (i.e. until its resource stock has depleted sufficiently). Similarly, slow adjustment speeds improve the prospects for a resource exporting country to experience increases in the discounted value of welfare arising from the opening of trade.

Furthermore, if the steady state is specialized, the foreign country may gain from trade along the transition and in steady state. Nevertheless, Propositions 5 and 6 taken together do provide a serious caveat to the ‘‘trade lifts all boats’’ hypothesis when open access renewable resources are present.

4. Trade policy

We now consider possible interventions. There are many policies that might be considered. Rather obviously, the ‘‘first-best’’ policy would be to solve the open access market failure by establishing some system of appropriate property rights or by using an appropriate harvesting tax. By hypothesis, however, this is either impossible or very costly, leading to a search for alternative policy instruments. Given the policy-level debate over resource management and trade policy, the natural first step is to consider a small import tariff on resource good imports by the domestic country. In addition, as many resource exporting countries argue that export taxes are really tools of resource management, we will also consider a small export tax by the resource exporter.

We restrict attention to comparative steady state analysis with diversified production. As we introduce policy, we need to distinguish between steady state domestic and foreign stock levels. We now use S and S^* to refer to the post-trade steady state resource stocks. Similarly, p and p^* will refer to post-trade steady state prices in the two countries.

We are interested in how a domestic tariff on the resource good will affect steady state stocks, harvests, prices, and utility levels. The basic methodology is that we imagine an initial tariff of 0, then consider the introduction of a marginal specific tariff, τ. To carry out the associated comparative analysis we need to see how various endogenous magnitudes must change so as to maintain the steady state material balance requirement, while also maintaining temporary equilibrium requirements for profit-maximization under free entry. In addition, perfect competition implies that domestic and foreign prices differ only by the amount of the tariff, implying that $p=p^*+\tau$.

The steady state material balance requirement is based on based on setting expression Eq. (1) to 0 for each country. Thus harvesting in each country must equal that country's resource growth in steady state. As world demand of the resource good $(H+H^*)$ must equal the world harvest, expression Eq. (24) follows from Eq. (6) and Eq. (2).

$$\beta I/p + \beta I^*/p^* = rS(1 - S/K) + r^*S^*(1 - S^*/K) \tag{24}$$

With $w=w^*=1$, domestic nominal income I is simply $L+\tau Z$, where Z is imports, and foreign nominal income is L^*. Noting that production is diversified in both countries, we have $p=1/(\alpha S)$ and $p^*=1/(\alpha S^*)$. Making these substitutions, Eq. (24) can be rewritten as

$$\begin{aligned} A(S, S^*; \tau) &= \beta(L + \tau Z)\alpha S + \beta L^*\alpha S^* - rS(1 - S/K) - r^*S^*(1 - S^*/K) \\ &= 0 \end{aligned} \tag{25}$$

Also, the condition $p=p^*+\tau$ becomes $1/(\alpha S)=1/(\alpha S^*)+\tau$, or

$$B(S, S^*; \tau) = 1/(\alpha S) - 1/(\alpha S^*) - \tau = 0 \tag{26}$$

Expressions Eq. (25) and Eq. (26) form a two-equation simultaneous system that must be maintained across comparative steady states. We can solve for the comparative steady state effects $\mathrm{d}S/\mathrm{d}\tau$ and $\mathrm{d}S^*/\mathrm{d}\tau$ by totally differentiating this two equation system and using Cramer's rule to find:

$$\mathrm{d}S/\mathrm{d}\tau = (-A_\tau B_{S*} + A_{S*}B_\tau)/D \tag{27}$$

$$\mathrm{d}S^*/\mathrm{d}\tau = (-A_S B_\tau + A_\tau B_S)/D \tag{28}$$

where subscripts represent partial derivatives, and $D = A_S B_{S*} - A_{S*} B_S. > 0$. Proposition 7 follows.

Proposition 7: *Starting from free trade ($\tau=0$), a marginal import tariff imposed by the domestic (labour abundant) country on imports of the resource good will have the following effects.*

(i) The domestic steady state resource stock will fall and the foreign steady state resource stock will rise ($\mathrm{d}S/\mathrm{d}\tau<0$ *and* $\mathrm{d}S^*/\mathrm{d}\tau>0$).

(ii) The domestic steady state price of the resource will rise and the foreign steady state price of the resource good will fall ($\mathrm{d}p/\mathrm{d}\tau>0$ *and* $\mathrm{d}p^*/\mathrm{d}\tau<0$).

(iii) Foreign steady state utility rises and domestic steady state utility may either rise or fall.

Proof: See Appendix A.

There are two surprising results given in Proposition 7. First, even though the world price of the resource good falls and the resource exporter suffers a terms of trade loss, the resource exporter gains (in steady state). The exporter gains because, when the world price falls, the foreign stock rebuilds to make harvesting a break-even activity again, and this has the effect of expanding its consumption possibilities set. Second, the home country may lose from the tariff even though it ''benefits'' from a terms of trade improvement. The potential domestic loss stems from the fact that the domestic relative price of the resource good rises. A higher domestic price for the resource leads to additional harvesting and to a lower steady state resource stock. The domestic PPF pivots in from this effect. The domestic country could still gain, however, because it also receives tariff revenue. Thus it is quite possible that both countries may gain (in steady state) from such a tariff, and this possibility can be verified using specific numerical examples.

5. An export tax

We now consider the imposition of an export tax by the exporter of the resource good (i.e. by the foreign country). Let the export tax be denoted by τ^*. As before, the domestic and foreign prices must differ by the amount of the tax; that is, $p=p^*+\tau^*$. Expression Eq. (24) applies here as well: total consumption of the resource good must equal total production of the resource good. In this case, however, domestic income is simply L, while foreign income is $L^*+\tau^*Z$, because the foreign government collects the revenue associated with an export tax. Our two-equation system becomes:

$$A(S, S^*; \tau^*) = \beta L \alpha S + \beta(L^* + \tau^* Z)\alpha S^* - rS(1 - S/K) - r^* S^*(1 - S^*/K) = 0 \tag{29}$$

$$B(S, S^*; \tau^*) = 1/\alpha S - 1/\alpha S^* - \tau^* = 0 \tag{30}$$

Totally differentiating this two equation system with respect to S, S^*, and τ^* yields

$$\mathrm{d}S/\mathrm{d}\tau^* = (-A_{\tau^*}B_{S^*} + A_{S^*}B_{\tau^*})/D \tag{31}$$

$$\mathrm{d}S^*/\mathrm{d}\tau^* = (-A_s B_{\tau^*} + A_{\tau^*}B_S)/D \tag{32}$$

Proposition 8: *Starting from a position of free trade, a marginal export tax has the following steady state effects.*

(i) The domestic resource stock falls and the foreign resource stock rises ($\mathrm{d}S/\mathrm{d}\tau^* < 0$ *and* $\mathrm{d}S^*/\mathrm{d}\tau^* > 0$).

(ii) The domestic price of the resource good rises while the foreign price falls ($\mathrm{d}p/\mathrm{d}\tau^* > 0$ and $\mathrm{d}p^*/\mathrm{d}\tau^* < 0$).

(iii) Domestic steady state utility falls and foreign steady state utility rises.

Proof: See Appendix A.

The domestic country loses from the export tax because the tax raises the world relative price of the resource good and this leads to further stock depletion at home. The foreign country gains from the export tax because the tax depresses its relative producer price of the resource good and this leads to stock rebuilding.

The central insight in both Propositions 7 and 8 is that any marginal policy intervention away from ‘‘laissez faire’’ that raises the relative price of the resource good in a particular country will, taken by itself, tend to create losses for that country via resource depletion effects. If that country is the recipient of revenues from the policy instrument, these losses may be partially or even more than offset by those revenues. Conversely, a country where the relative price of the resource good is depressed by a policy instrument will tend to gain from the resulting resource accumulation, and these gains may be augmented by any revenues flowing directly from the policy instrument itself.

It is difficult to rank alternative policies, but some rankings can be inferred. For the resource abundant or ‘‘foreign’’ country, tax instruments can be ranked as follows. The first-best policy would be a production tax that offsets the externality, and an export tax that allows it to optimize with respect to terms of trade effects. (However, if one country sought to use its market power, the other country might be expected to object or to retaliate.) The second best policy for this country is an export tax alone, and the third best policy is an import tariff imposed by the other country. For the domestic country, rankings are more difficult to establish, but it certainly prefers to levy its own import tariff rather than have the foreign country tax exports.

6. Extensions and generalizations

The model and analysis in this paper contain a number of limitations. First, the analysis is based on specific functional forms for utility, production, and for resource growth. While the functional forms are not unreasonable, obviously the generality of the analysis is limited. If we attempt to replace these specific forms with general functions, then we can no longer carry out the analysis using explicit closed-form solutions and must adopt a different approach. The easiest approach is to use diagrams that exploit whatever properties are imposed on the three basic functional relationships in the model. It is possible to develop an understanding of how the generalized case would work by building up the generalization in steps.

The easiest generalization is the harvest function $G(S)$. The natural approach is to replace the logistic form given by expression Eq. (2) with a general compensatory (i.e. bent-over) growth function with the properties that $G(0)=0$, $G(K)=0$ for some $K>0$, and $G''(S)<0$ for S between 0 and K. This generalization does not affect the Ricardian temporary equilibrium (shown in Fig. 1) in any way. The autarkic steady state is very similar to the situation illustrated in Fig. 2, except that growth function $G(S)$ need not have such a regular shape. It must, however, be concave and single-peaked and would have an interior steady state provided that r exceeds $\alpha\beta L$, where r is defined as the limit of $G(S)/S$ as S approaches 0.

Now consider two countries which have the same growth functions but different levels of L (causing r/L to differ across the countries). The country with the higher L will have the steeper harvest function, and will therefore have the lower autarky steady state stock, and the higher price. Opening trade will cause the resource abundant country to export the resource good, depleting its resource stock, until resource stocks in the two countries equalize. The main positive and normative properties of the model are unchanged by this generalization. If the growth function were not compensatory (bent-over) then the model could behave very differently, but the compensatory assumption is very plausible for renewable resources.

The next step is to generalize the harvest production function given by Eq. (3). A natural generalization would be to allow the harvest production function to show constant returns to labour, but variable (and probably decreasing) returns to S. This harvesting production function would be written as $H^P=Lf(S)$ where $f'(S)>0$ and $f''(S)<0$. In this case, the temporary equilibrium remains Ricardian, as in Fig. 1. In Fig. 2 the only change is that the harvest function becomes a concave increasing function, rather than a linear increasing function. We can compare two countries with different values of L, draw the two harvest functions, and proceed as before. The algebraic analysis becomes much more cumbersome (and less instructive) than with specific forms, but the basic structure of the analysis remains unchanged.

The third line of generalization concerns utility. The natural step here is to replace the Cobb-Douglas form with a general homothetic utility function. The harvest function is again an increasing function of the resource stock and the analysis proceeds much as before, although the possibility of multiple steady states arises. Some restrictions would be required to obtain a unique steady state. For non-homothetic utility the analysis becomes quite intractable as income effects can have a major impact on the pattern of trade. Countries at different levels of real income may have different relative demands for the two products and this may muddy the link between cost-based comparative advantage and trade patterns.

Overall, we feel comfortable in asserting that the basic structure of our model is not an artifact of particular functional forms, as the basic results hold given fairly standard (but still strong) ''regularity'' conditions on the three central functional relationships. This should not be a surprise as both the intuition and the diagrammatic structure of the analysis seem to follow from relatively general economic principles. However, we do not wish to overstate the case, as the formal analysis using general forms is very awkward and we acknowledge that our paper might be viewed only as an example at this stage.

There are other extensions and generalization that would be natural to consider. For example, we have not considered capital markets. If private agents (or governments) could take the proceeds from temporary resource rents earned in trade and invest these proceeds in an alternative asset such as physical capital or claims on future consumption, then the consumption path of private agents would be smoother than predicted here. However, the absence of capital markets is not critical for our results. The key problem is the externality created by open access. Opening capital markets does not reduce a marginal agent's incentive to move into harvesting when presented with a higher price for the product, nor does it eliminate the negative production externality created when this agent's harvesting lowers the common stock of the resource.

7. Concluding remarks

This paper examines trade flows, gains and losses from trade, and the effects of trade policy in a two-good, two-country model in which one of the goods derives from harvesting an open access renewable resource. We are able to define an appropriate notion of factor proportions based on the ratio of the intrinsic growth rate of the resource to labour. We show that this ratio determines comparative advantage and the direction of the trade flow. The country with the higher ratio is effectively ''resource abundant'' and exports the resource good. Sufficient similarity across countries in factor proportions ensures diversified production in steady state and factor price equalization.

To the extent that the model captures an element of real trade flows, it suggests that incomplete property rights in renewable resource sectors undermine the presumption that trade liberalization is necessarily welfare-improving. Thus the claim that some countries are induced to over-exploit their renewable resources because of trade liberalization appears to have some merit. We find that the resource exporter must have lower steady state utility in a diversified trading steady state than in autarky, and in some cases will have lower instantaneous utility at every point along the transition path as well. Conversely, the resource importer always gains from trade. Furthermore, we have shown that diversified production is necessarily the result of trade if countries are sufficiently similar.

Our analysis stands as a marked counterpoint to the recent literature on trade and growth. In, for example, Baldwin (1992); Grossman and Helpman (1991) and Taylor (1994), trade liberalization may enhance welfare through dynamic effects on capital accumulation or on research and development. We abstract from such considerations, but clearly they are important, and we have no wish to understate them. However, renewable resource dynamics are also important and abstracting from them may lead to a rather optimistic assessment of the dynamic effects of trade liberalization.

As for our analysis of trade policy, we found that an import tariff that acts as a ‘‘countervail’’ to inadequate resource management practices may improve the steady state utility of both trade partners. Export taxes by resource exporters raise resource stocks in the exporting country and serve a conservationist end, but they reduce resource stocks elsewhere and lower utility in the importing country. Overall, while there are various modifications to the paper that could be carried out, we believe that our structure provides a simple and flexible framework for examining some of the important policy issues associated with resource management and international trade. Here we have focused on one important concern that has received relatively little attention in the formal literature on international trade despite its significant practical importance: incomplete property rights in renewable resource sectors. While we are convinced that none of our results is sufficient reason to abandon ongoing trade liberalizations around the world, we are equally convinced that trade liberalization is a two-edged sword for a country with a comparative advantage in renewable resources and weak property rights in those sectors.

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Appendix A

Proofs of Propositions

Proof of Proposition 4

(i) Consider the possibility that the labour abundant country specializes in manufactures. In this case its wage is 1. Over time, its resource stock grows to K. Thus the implicit cost of producing the resource good is $a_{LK}(K)$. In the other (foreign) country the resource good is being produced. The foreign wage must be at least 1 (depending on whether manufactures are also being produced) and the stock must be less than K. Therefore the cost of production (and world relative price) must be $w^*a^*_{LK}(S_T)>a_{LK}(K)$. This implies that the (domestic) labour abundant country would certainly produce the resource good, contradicting the initial hypothesis. By similar reasoning, the resource abundant country cannot specialize in the manufacturing good either.

(ii) To demonstrate (ii) precisely requires a substantial amount of detailed algebra that we judge to be a poor use of space, so we report only the basic method of proof here. It is necessary to show that Eq. (16) is necessary and sufficient for diversification. To show necessity, assume diversification. Foreign demand for labour in the resource sector is given by $L^*_H=H^{P*}a^*_{LH}=G^*(S_T)a^*_{LH}=r^*S_T(1-S_T/K)(1/\alpha S_T)$, where S_T, the common steady state stock, is given by Eq. (15). Simplifying this expression and imposing the condition that labour used in the resource sector cannot exceed total labour in the country yields expression Eq. (16). To show sufficiency, we assume that specialization occurs, note that $S^*=K(1-L^*\alpha/r^*)$ in this case, invoke overall material balance, and show that the inequality in Eq. (16) must run the other way. Thus, if Eq. (16) is satisfied, diversification is the only possibility.

(iii) The proof of part (ii) implies that if inequality Eq. (16) is not satisfied, then the resource abundant country specializes in the production of the resource good. Together with (i) this proves (iii).

Proof of Proposition 7

(i) First we calculate the various components in comparative steady state expressions Eq. (27) and Eq. (28).

$$A_S = \beta L\alpha - r(1-2S/K),\ A_{S*} = \beta L^*\alpha - r^*(1-2S^*/K),$$
$$A_\tau = \beta\alpha SZ,\ B_S = -1/(\alpha S^2),\ B_{S*} = 1/(\alpha S^{*2})$$

and $B_\tau = -1$.

Substituting the necessary partial derivative expressions into D yields

$$D = A_S B_{S*} - A_{S*} B_S$$
$$= (\beta L\alpha - r(1-2S/K))/\alpha S^2 + (\beta L^*\alpha - r^*(1-2S^*/K))/(\alpha S^{*2}) \quad \text{(A1)}$$

$$= [\beta L\alpha - r(1-S/K) + \beta L^*\alpha - r^*(1-S^*/K)]/\alpha S^2 + r + r^*)/(\alpha KS) \quad \text{(A2)}$$

$$= (r + r^*)/(\alpha KS) > 0 \quad \text{(A3)}$$

In moving from Eq. (A1) to Eq. (A2) we have made use of the fact that $S = S^*$ at $\tau = 0$. In moving from Eq. (A2) to Eq. (A3) we have used expression Eq. (25).

With $D > 0$, we can sign comparative steady state effects $dS/d\tau$ and $dS^*/d\tau$ by evaluating the numerators in expressions Eq. (27) and Eq. (28). Define N as the numerator of expression Eq. (27) and N^* as the numerator of expression Eq. (28). The sign of comparative static effect $dS/d\tau$ is therefore given by the signs of N. $N = A_{S*}B_\tau - A_\tau B_{S*} = -(ßL^*\alpha - r^*(1 - S^*/K) + r^*S^*/K) - ß\alpha SZ/(\alpha S^{*2})$.

In order to simplify N we note that $S = S^*$ at $\tau = 0$. We can also use the fact that domestic imports, Z, must be the difference between foreign production and foreign consumption, implying that $Z = r^*S^*(1 - S^*/K) - ß\alpha L^*S^*$. Substituting Z into our expression for N and rearranging yields $N = [ß^2\alpha L^* - ß\alpha L^*] + r^*(1 - 2S^*/K) - ßr^*(1 - S^*/K)$. The term in square brackets is obviously negative, since $ß < 1$. The remaining terms can be written as $r^*[(1 - 2S^*/K) - ß(1 - S^*/K)]$. We therefore need to show that the expression inside the square brackets is negative. Recalling that $S^* = S_T$ at $\tau = 0$, we can use Eq. (15) to substitute for S^* in this expression in square brackets. We can think of this expression as a function of $ß$ and write it as follows: $\phi(ß) = (L + L^*)\alpha ß/(r + r^*) - 1/(2 - ß)$. We wish to show that $\phi(ß) < 0$ for all relevant values of $ß$.

To see this, note that $\phi(0) = -1/2 < 0$ and $\phi(1) = \alpha(L + L^*)/(r + r^*) \ -1 < 0$ (using Eq. (12) for both countries with $ß = 1$). Thus ϕ must be negative at the endpoints of the region $ß \in [0,1]$. It can then be shown that $\phi'(ß) > 0$ if $\phi(ß) > 0$. To see this note that $\phi'(ß) = \alpha(L + L^*)/(r + r^*) - 1/(2 - ß)^2$. We then observe that $\phi'(ß)$ must have the same sign as $ß\phi'(ß) = \alpha ß(L + L^*)/(r + r^*) - ß/(2 - ß)^2$. But, if $\phi(ß) \geq 0$, then $ß\phi'(ß)$ must be positive also, as $ß/(2 - ß)^2 < 1/(2 - ß)$ for all $ß \in (0,1)$. Therefore, if $\phi(ß)$ is non-negative, then $\phi'(ß)$ is positive. It follows that if $\phi(ß)$ were zero or positive for any $ß < 1$, then it would be impossible for $\phi(1)$ to be negative. This is a contradiction, as $\phi(1)$ must be negative. It follows that $\phi(ß)$ must be negative for all permissible values of $ß$, which proves the result.

We now show that $dS^*/d\tau > 0$. Sign $(dS^*/d\tau) =$ sign $[A_\tau B_S - A_S B_\tau] =$ sign

$[-ßSZ/S^2+ßL\alpha-r(1-2S/K)]=\text{sign } [(1-ß)Z/S+rS/K]>0$. In moving to the last equality we have used the fact that $ßL\alpha-r(1-S/K)=Z/S$, as domestic imports, Z, equal the difference between domestic consumption (given by $\alpha ßLS$) and domestic production (given by $rS(1-S/K)$).

(ii) follows immediately from (i).

(iii) Since all individuals are identical, we can examine the welfare effects on a representative consumer with an endowment equal to that of the whole economy. Straightforward substitution of the foreign counterpart to Eq. (6) into the aggregate version of utility function Eq. (5) yields the aggregate indirect utility function for the foreign country:

$$U^* = \gamma I^* p^{*^{-ß}} \tag{A4}$$

where $\gamma=ß^{ß}(1-ß)^{1-ß}$ and $I^*=L^*$. Taking the derivative of U^* with respect to τ yields

$$\mathrm{d}U^*/\mathrm{d}\tau = -\gamma p^{*^{-\beta}}\beta(L^*/p^*)\mathrm{d}p^*/\mathrm{d}\tau > 0 \tag{A5}$$

It is easily seen that expression Eq. (A5) is positive, as $\mathrm{d}p^*/\mathrm{d}\tau<0$ from part (ii) of the proposition.

Domestic indirect utility can be written as $U=\gamma Ip^{-ß}$ where $I=L+\tau Z$. Differentiating U with respect to τ then yields

$$\mathrm{d}U/\mathrm{d}\tau = \gamma p^{-\beta}(Z - (\beta I/p)\mathrm{d}p/\mathrm{d}\tau) \tag{A6}$$

There are two effects of a tariff on domestic utility. There is a positive effect arising from tariff revenue, but a negative effect associated with the increase in the domestic price of the resource good. We have established by simulation that either of these effects may dominate. Therefore, there are cases in which both countries experience steady state gains from trade.

Proof of Proposition 8

(i) The proof is almost identical to the proof of part (i) of Proposition 7.

(ii) This follows from (i), since $p=1/(\alpha S)$ and $p^*=1/(\alpha S^*)$.

(iii) Domestic welfare is given by $U=\gamma p^{-ß}I$ where $I=L$. Hence

$$\mathrm{d}U/\mathrm{d}\tau^* = \gamma p^{-\beta}\beta(L/p)(\mathrm{d}p/\mathrm{d}\tau^*) < 0 \tag{A7}$$

using the fact that $\mathrm{d}p/\mathrm{d}\tau^*>0$ from part (ii). Foreign welfare is given by Eq. (A4) where $I^*=L^*+\tau^*Z$. Substituting this for I^*, differentiating with respect to τ^*, and rearranging yields

$$\mathrm{d}U^*/\mathrm{d}\tau^* = \gamma p^{*^{-\beta}}(Z - I^*\beta/p^*)(\mathrm{d}p^*/\mathrm{d}\tau^*) > 0. \tag{A8}$$

The fact that $\mathrm{d}U^*/\mathrm{d}\tau^*>0$ follows from the result of part (ii) that $\mathrm{d}p^*/\mathrm{d}\tau^*<0$.

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