International trade and open-access renewable resources: the small open economy case

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Abstract. We examine a small open economy with an open-access renewable resource. Using a two-sector general equilibrium model, we characterize the autarkic steady state, and then show that trade reduces steady-state utility for a diversified resource exporter. Instantaneous gains occur as trade opens, but they are eroded by ongoing resource depletion. The present value of utility falls for appropriate discount rates, and terms of trade 'improvements' may be welfare reducing. We also show that autarky prices, the pattern of trade, and the structure of production all are linked to a simple ratio of the intrinsic resource growth rate to labour supply.

Commerce international et ressource renouvelable en propriété commune: le cas d'une petite économie ouverte. Les auteurs étudient le cas d'une petite économie ouverte dotée d'une ressource renouvelable en propriété commune. A l'aide d'un modèle d'équilibre général à deux secteurs, ils définissent le régime permanent autarcique, et puis montrent que le commerce international réduit l'utilité en régime permanent pour un exportateur de ressource diversifié. On obtient des gains instantanés quand le commerce commence, mais ils diminuent avec l'épuisement continu de la ressource. La valeur présente de l'utilité tombe quand on utilise des taux d'escompte appropriés, et des 'améliorations' des termes d'échange peuvent réduire le niveau de bien-être. On montre aussi que les prix en régime autarcique, le pattern de commerce, et la structure de production sont tous reliés à un ratio simple du taux de croissance intrinsèque de la ressource sur l'offre de travail.

I. INTRODUCTION

Concern over the sustainability of major renewable resource stocks has re-emerged as a significant international policy issue. For example, there have been widely

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publicized claims that forests in countries such as Brazil, Canada, and Indonesia are being harvested excessively rapidly. Other renewable resources, including fish and wildlife stocks, also are alleged to be under threat in many parts of the world.

Much of the concern over renewable resources arises from the 'open access' problem. It has been well established (starting with the classic paper by Gordon 1954) that resource over-exploitation may occur when a common property resource is subject to open access.[1] More generally, we can observe that over-exploitation may occur if property rights over a resource stock are hard to define, difficult to enforce, or costly to administer. Such problems are alleged to be very important. For example, Loayaza (1992, xi), after noting that the fishing industry provides direct employment to about 100 million people around the world, asserts: 'The most important characteristic of fisheries is the common property problem embodying open and free access to the resources ... Therefore, a large number of traditional fishing grounds, particularly in coastal waters, are being over exploited.'

In cases where renewable resource harvests are exported, there is often particular emphasis on the effect of international trade on renewable resource management. Furthermore, there is now considerable interest in incorporating trade rules focused on resource management into the World Trade Organization (WTO) and other international arrangements.[2]

Our objective in this paper is to examine the relationship between international trade and open-access renewable resources. Our most striking result is that trade may be welfare reducing for a small open economy with an open-access resource. In most real economies the tradeable renewable resource sector is not large enough to have more than a modest impact on aggregate economic performance. There are several cases, however, where the possible negative effects of trade liberalization on renewable resource management and economic development seem to be of first-order importance.

One such case is the Philippines, where the hardwood forest has been substantially depleted during the post-Second-World-War period. According to Bee (1987, 15), total harvesting of logs and lumber in the Philippines grew very dramatically in the early part of this period, rising from about 1 million cubic metres annually in the late 1940s to a peak of over 11 million cubic metres in 1969. Output then fell gradually to about 4 million cubic metres per year by the mid-1980s. Exports played an important role in this, as forest products rose from about 1 per cent of total exports in the late 1940s to a peak of about 40 per cent of total exports in 1969, before declining to about 4 per cent by the mid-1980s. It is also worth noting

1 In the early literature on renewable resources, the term 'common property' was often used as if it necessarily implied open access. It is now standard in resource economics to distinguish between 'common property,' which is simply property that is collectively owned, and 'open access,' which refers to an inability to restrict access to the resource. Common property may or may not be subject to open access. It is, of course, open access, not collective ownership per se, that gives rise to market failure.

2 The WTO does monitor resource management at present. The *GATT FOCUS Newsletter* of March-April 1994 (renamed the *WTO FOCUS* as of January 1995) reviews Iceland and observes that 'almost free-of-charge access to the fishing grounds ... had encouraged over-expansion of the fleet and over-fishing.'

that the share of exports in GDP itself rose from about 9 per cent in the late 1940s to about 15 per cent by 1970, reflecting the increasing openness of the Philippine economy and implying a truly remarkable growth of forest products exports. According to Kummer (1992, 75), between 1950 and the mid-1980s the forest stock was reduced by about 50 per cent and was continuing to decline rapidly.

As emphasized by Kummer (1992), the Philippine forest sector was very poorly regulated. The combination of forest exploitation by subsistence 'squatters' and illegal logging sponsored by senior military and government officials seeking private gain created the equivalent of an open-access environment. Also, even legal firms with legitimate timber licences had an incentive to exploit the forest rapidly because of the high level of political uncertainty they faced. Furthermore, a frequently expressed motivation for the excessive logging that occurred was a desire to 'earn foreign exchange,' which is consistent with the dramatic growth of forest-based exports in the 1960s and the continuing high level of exports in the 1970s and early 1980s. Finally, largely as a result of depletion, there was a significant decline in forest-based export earnings during the 1980s, which contributed to the decline in per capita real income that occurred over this decade. Thus the Philippine pattern appears to fit our model very well.

A similar and perhaps more extreme case is the Ivory Coast, as described by Brown (1995, 8–9). In the Ivory Coast, output and exports of hardwood rose rapidly in the 1960s and early 1970s, yielding export earnings of US$300 million per year, but substantially depleting the forests. By the early 1990s export earnings had dropped to about US$30 million per year, and the general decline in the forest sector was a significant factor in the approximate 50 per cent decline in per capita real income that occurred between 1980 and 1994. At the very least, the Philippines and Ivory Coast cases suggest a possible relationship between renewable resource mismanagement and increasing international openness.

A full characterization of the interaction between international openness and renewable resource management is beyond the scope of any one paper, but in this paper we take three significant steps forward. First, we construct a useful new model by combining the canonical renewable resource model of Schaefer (1957) with the standard Ricardian model of international trade. With this general equilibrium model in hand, we then characterize the determinants of comparative advantage and link autarky relative prices to a simple fundamental parameter reflecting both the biology of renewable resource growth and the scale of factor endowments. Finally, we consider the effects of trade on a small country with a nationally owned open-access renewable resource, and we provide necessary and sufficient conditions for trade to be welfare improving or welfare reducing.

Focusing on the small-country case and assuming that the resource is nationally owned rather than transboundary limit the scope of the analysis, but these assumptions seem like a natural starting point. We note in passing that most open-access renewable resources of current interest are nationally owned, including almost all forest stocks and pastureland and most inland and coastal fisheries.

One of the two goods is a resource good produced using labour and the resource stock. The other good is a generic 'manufactures' good produced using only labour.

The closed-economy version of the model is a natural general equilibrium extension of the canonical Schaefer (1957) renewable resource model, but it has not, to our knowledge, been previously studied. (There have been previous general equilibrium models of open access resources, including Weitzman 1974.) The closed-economy model is of some interest in itself and could potentially be used for a range of applications. We show, for example, that technical progress in resource harvesting can be welfare-reducing. Also, in Brander and Taylor (1997b), we combine the autarky resource model with population dynamics to explain economic cycles on Easter Island. Our main focus here, however, is on international trade. To trade theorists, the model will look much like a two-good Ricardian model, where at every point in time relative prices are determined solely by relative labour productivities. The evolution of these temporary Ricardian equilibria, however, is driven by factor endowment considerations.

As a necessary preliminary to our discussion of trade we use the closed-economy model to characterize the determinants of autarky relative prices or 'comparative advantage.' We then assume that the parameters of the model are such than a non-trivial autarkic steady state exists, and we allow the country to participate in world markets at fixed world prices.

Within this context we are able to prove several interesting results. First, we show that the ratio of a biological parameter, referred to as the 'intrinsic' resource growth rate (and denoted r), to labour (denoted L) determines autarky relative prices and hence indexes 'comparative advantage.' If we considered two hypothetical countries with the same ratio of r to L (and with identical homothetic preferences), then they would share the same autarky prices, independent of scale. For some sufficiently high ratio of r/L, a country would have an autarky price of the resource good less than the world price and can therefore be referred to as 'resource abundant' relative to the world as a whole.

Second, we show that when a country is resource abundant in this sense, it exports the resource good on impact as trade opens, exports the resource good everywhere along the transition path towards its new steady state, and exports the resource good in steady state as well. Conversely, a sufficiently low ratio of r/L implies that the autarky relative price for the resource good exceeds the world price. Such a country will import the resource good on impact, along the transition path, and in steady state. Therefore, this simple fundamental ratio determines comparative advantage, and comparative advantage is a reliable predictor of trade flows both in and out of steady state.

Third, we show that, for a broad range of parameter values, the resource-exporting country will not specialize in producing the resource good in steady state, but will undertake diversified production in steady state. This occurs for moderate levels of ratio r/L. Very high levels of r/L lead to steady-state specialization in resource good production, and very low levels of r/L would lead to specialization in manufactures. A resource abundant country with a moderate r/L ratio will specialize in the resource good at the outset of trade and along the transition path, but it will eventually become diversified in production. We show that such an economy exhibits an interesting intertemporal pattern of early gains from international trade, followed by a period of declining utility levels. Instantaneous utility falls along the transition path because of resource depletion effects until it reaches a new steady-state level, which is unambiguously lower than autarkic steady-state utility. Consequently, for a resource-abundant country that cannot specialize in the resource good, steady-state utility is necessarily reduced by trade; moreover, for sufficiently small discount rates the overall welfare implications of trade are also negative.

Finally, we provide several counter-intuitive results regarding the welfare significance of terms-of-trade effects. For a resource-abundant country that cannot specialize in the resource good, we show that steady-state utility levels fall monotonically with 'improvements' in this country's terms of trade. In addition, for sufficiently small discount rates, the overall welfare implications of international trade will be less favourable for a resource exporter the more 'favourable' is the world relative price of the resource good! For a country that can specialize in the resource good, we find the unusual result that the small country's steady-state utility is U-shaped in the terms of trade. International trade at low or very high world relative prices for the resource good would raise steady-state utility, but trade at intermediate levels would reduce steady-state utility.

In this paper we draw on the literature on renewable-resource economics. This literature is too large to cite in any detailed fashion. Valuable overviews include Clark (1990), Munro and Scott (1985), and Neher (1990). The literature on trade in renewable resources seems comparatively modest in scope. The review article on trade and resources by Kemp and Long (1984) is devoted mostly to non-renewable resources and has relatively little coverage of trade in renewable resources. The early papers most closely related to ours are McRae (1978) and Scott and Southey (1969), both of which consider trade involving open-access renewable resources. In a companion paper, Brander and Taylor (1997a), we apply the structure developed in this paper to the case of two countries, where world relative prices become endogenous, and we analyse the effects of various trade policies in that context. In Brander and Taylor (1997c) we consider trade between an optimally regulated country and an otherwise identical open access country.

Our contribution differs from previous work in several significant ways. Most obviously, we focus on the open-access case, whereas much of the existing literature on renewable resources has focused on the optimal exploitation problem, implicitly (or explicitly) assuming that property rights are adequately enforced. While optimal exploitation is of interest, it also seems important to understand cases in which property rights are less than complete,[3] especially if we are considering trade flows involving low-income countries.

Chichilnisky (1994) considers the effects of trade between a country with incomplete property rights (the 'South') and a country with complete property rights

3 Among those papers that do consider incomplete property rights, almost all consider the open-access case (as we do), which is the other extreme. Papers in this category include Scott and Southey (1969), Markusen (1976), and McRae (1978). One recent exception that deals with effects of costly access under duopoly is Mason and Polansky (1994).

(the 'North'). In this context, she shows that the trading equilibrium is not Pareto efficient. However, as the autarky equilibrium is also Pareto inefficient, it is not established in the formal proofs in her paper that trade reduces welfare (relative to autarky) for the 'South.' Our paper does establish, in a quite different model incorporating depletion effects, that the resource-exporting country loses from trade in an important class of cases.

Finally, our model allows clear identification of the necessary and sufficient conditions for trade to be welfare improving or welfare reducing in the presence of open-access renewable resources. As such, our paper is a contribution to the large general category of papers dealing with the effects of trade in economies with existing distortions. In particular, some of our results bear a structural resemblance to those found in the trade and increasing returns literature.

In the remainder of this paper we proceed as follows. In section II the basic model of renewable resource growth is set out and the open access assumption is introduced. A closed economy model incorporating an open access renewable resource is developed in section III. The analysis of the small open economy case is contained in section IV. Concluding remarks are offered in section V.

II. THE OPEN-ACCESS RENEWABLE RESOURCE MODEL

Before proceeding to the general equilibrium setting, it is useful to describe the basic structure of renewable resource growth. We have in mind a renewable resource such as a forest or a fish species. The stock of the resource at time t is denoted $S(t)$. The natural growth rate of the resource, G, is taken to be 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, $H(t)$:

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

Perhaps the simplest empirically plausible form for G is the logistic function,[4] as given by (2):

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

The variable K is the maximum possible size for the resource stock and is referred to as the 'carrying capacity' of the resource. If stock S equals K, then the growth rate is zero and further additions to the stock cannot occur. The variable r is the 'intrinsic' or 'uncongested' growth rate. Note that the proportional growth rate

4 The logistic model has a long history in biology. First proposed early in the nineteenth century, the primary reason for its wide use is its apparent empirical success, including the widely cited work of Pearl (1930) on fruit fly populations. Feller (1940) discusses the general relevance of the logistic model for biological populations. Our analysis can be generalized (with some algebraic difficulty) to any compensatory growth function (i.e., one that starts at zero, rises, peaks, falls, and reaches zero at some finite level). Forest resources generally satisfy these properties.

$G(S)/S$ would be approximately equal to r if congestion effects were negligible in the sense that the carrying capacity was very large relative to the current stock.

The functional form for the harvest rate, H, would normally be derived from the economic incentives (or other decision rules) that control the behaviour of harvesters. As discussed in the introduction, we assume an open-access economic regime. The open-access case was first analysed by Gordon (1954). With open access, harvesting occurs up to the point at which the current return to a representative entrant is just equal to the entrant's current cost. Note that no harvester has any incentive to delay harvesting as long as positive current rents are available, because of the legitimate expectation that someone else will harvest the resource instead. While we might believe that incomplete property rights would often manifest themselves in a less extreme fashion than complete open access, the issues raised by poor resource management arise most starkly, and therefore most clearly, in this setting.

III. CLOSED-ECONOMY GENERAL EQUILIBRIUM WITH A RENEWABLE RESOURCE

We now introduce an explicit Ricardian general equilibrium setting for a country with a nationally owned open-access renewable resource. The country can potentially engage in trade, but first we examine the closed-economy or autarkic equilibrium. We use explicit functional forms that allow us to obtain closed-form solutions for various quantities of interest. Despite the use of specific functional forms, much of the analysis can be readily generalized, as discussed in section V, below.

1. Production and Supply

The country produces and consumes two goods. H is the harvest from a renewable resource. M is some other good, which might be thought of as manufactures. Good M is treated as the numeraire whose price is normalized to 1. Aside from the stock of the renewable resource, S, there is only one additional factor of production, labour, L. Manufactures are produced using labour as the only input. By choice of units, one unit of labour produces one unit of good M. As the price of good M is 1, it follows that labour's value of marginal product in manufacturing is 1. Therefore, given competitive labour markets, the wage must equal 1 if manufactures are produced.

We assume that harvesting of the resource is carried out according to the Schaefer harvesting production function,[5] which is written as follows,

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

5 The Schaefer harvesting function has been extensively applied to fishing, notably in Schaefer (1957), and is thought to be a good empirical description of fishing (holding capital and technology constant). Its use is perhaps more questionable in forestry. The important property of this function for our analysis is constant returns in labour input, and this is empirically reasonable. One supportive empirical test of this model is Paterson and Wilen (1977), who apply the Schaefer model to the North Pacific seal hunt.

where L_H is the amount of labour used in resource harvesting and α is a positive constant. (The superscript P stands for production.) We let $a_{LH}(S)$ represent unit labour requirements in the resource sector. From (3), unit labour requirements are

$$a_{LH}(S) = L_H/H^P = 1/(\alpha S). \tag{3a}$$

Note that $a'_{LH}(S) < 0$. As the resource stock falls, unit labour requirements rise.

Production in both sectors is carried out by competitive profit-maximizing firms under conditions of free entry. Thus, the price of the resource good must equal its unit cost of production. It follows that

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

where w is the wage. The condition that $p = wa_{LH}$ 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 resource stock S.

Labour is freely mobile, implying that both sectors must have the same wage. Therefore, if manufactures are produced, the wage in both sectors must be 1, and (4) becomes

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

2. Utility, consumption, and demand

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,

$$u = h^{\beta} m^{1-\beta}, \tag{5}$$

where h represents individual consumption of the resource good, m is individual consumption of manufactures, and taste parameter β is strictly between 0 and 1. The representative consumer maximizes utility at each moment, subject to the instantaneous budget constraint given by

$$ph + m = w. \tag{6}$$

As is well known, taking p and w as exogenous and maximizing (5) subject to (6) yields the demand functions $h = w\beta/p$ and $m = w(1-\beta)$. Noting that aggregate demands for H and M are given by $H^C = hL$ and $M^C = mL$, we find

$$H^C = w\beta L/p \qquad M^C = w(1-\beta)L, \tag{7}$$

where the C superscript stands for consumption. It is useful to rewrite the demand for H in inverse form:

$$p = w\beta L/H^C. \tag{8}$$

Note that with Cobb-Douglas preferences both goods are 'essential.' Since good M is essential and cannot be exhausted, it will always be consumed. Therefore, in autarky, M must be produced and the autarky wage must be 1.

3. Ricardian temporary equilibrium

At a given moment the resource stock S is fixed, and the economy is Ricardian. The full employment condition given by

$$H^P a_{LH}(S) + M = L \tag{9}$$

defines a standard Ricardian production possibility frontier. Substituting (3a) into (9) yields

$$H^P = \alpha LS - \alpha SM. \tag{10}$$

The temporary equilibrium can be solved algebraically by setting the supply price given by (4) equal to the demand price given by (8). Equating the two prices and solving for H yields

$$H = \alpha\beta LS. \tag{11}$$

We refer to expression (11) as the 'harvest schedule,' since it gives us the temporary equilibrium harvest for any given resource stock. The equilibrium output of M is simply $M = (1-\beta)L$, and hence a fraction β of the labour force is employed in the resource sector.

The temporary equilibrium just described is much like a standard Ricardian equilibrium, except that the vertical intercept of the production possibility frontier depends on the stock, S, as does the equilibrium value of H. At any temporary equilibrium there is no guarantee, of course, that the harvest will equal the underlying biological growth rate of the resource. The next step, therefore, is to consider the interaction between the temporary Ricardian equilibrium and the evolution of the resource stock.

4. Transition to the steady state

In figure 1 we combine our temporary equilibrium harvest schedule $H(S)$ (from (11)) with the logistic growth equation $G(S)$ (from (2)) to trace the evolution of the resource stock. (A characterization of the transition path and the conditions necessary for a steady state to exist are given in proposition 1.) Figure 1 illustrates a situation where the initial stock level, S_0, leads to a harvest, $H(S_0)$, in excess of the natural growth rate, $G(S_0)$. Accordingly, the stock shrinks toward the autarkic steady state level, S_A. The steady-state harvest is illustrated by the point at which the harvest schedule intersects the growth curve in figure 1. At the point of intersection, dS/dt (given by (1)) is zero. As drawn, this solution is to the right of the 'maximum sustainable yield' (MSY) given by the peak of the growth curve, but it could in principle also be to the left of MSY or at MSY.

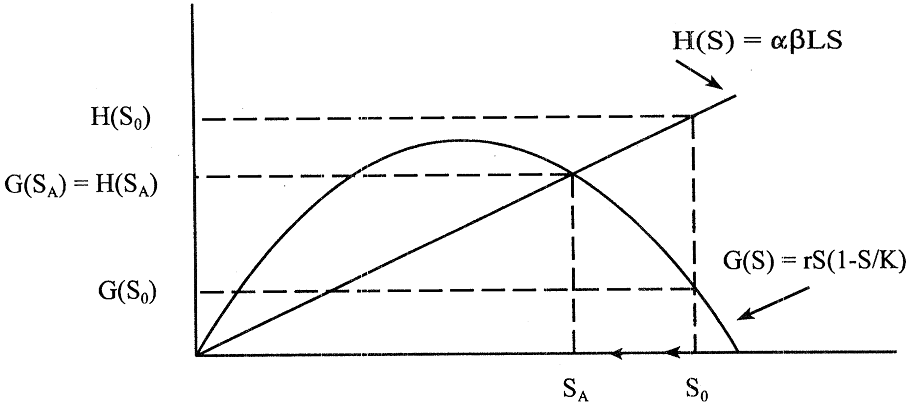

FIGURE 1 Resource dynamics

Figure 2 illustrates the corresponding transition of a Ricardian temporary equilibrium towards the steady state. At some initial resource stock, S_0, the associated harvest is $H(S_0)$. As the resource stock shrinks towards the autarky steady state level, S_A, production function (3) implies that the Ricardian production possibility frontier pivots inward, as shown, until the temporary equilibrium harvest falls to a level equal to the underlying natural growth of the resource.

Because utility is Cobb-Douglas, consumption of M is unaffected by the resource stock adjustment. More generally, consumption of both manufactures and the resource good would change as stock adjustment took place. To solve for the steady-state stock, we note that the temporary equilibrium condition (11) must be satisfied and, in addition, dS/dt as given by (1) must be zero. This implies that the harvest given by (11) must equal the resource growth rate given by (2), yielding

$$\alpha\beta LS = rS(1 - S/K). \tag{12}$$

Mechanically solving (12) for S yields $S = 0$ or $S = S_A$, as given by

$$S_A = K(1 - \alpha\beta L/r). \tag{13}$$

Provided that S_A as given in (13) is positive, S_A is the unique interior (i.e., positive) autarkic steady-state stock. Substituting the value of S_A given by (13) into condition (4a) allows us to solve for the corresponding steady-state autarky price, p^A. This solution is

$$p^A = 1/(\alpha K(1 - \alpha\beta L/r)) \tag{14}$$

Finally, to obtain the associated steady-state harvest,[6] we substitute S_A as given by (13) into (11) to find

$$H = \alpha\beta LK(1 - \alpha\beta L/r). \tag{15}$$

6 Implicit in this analysis is the fact that the steady-state supply curve for an open-access resource good is backward bending, as was demonstrated by Copes (1970). See also Scott and Southey (1969).

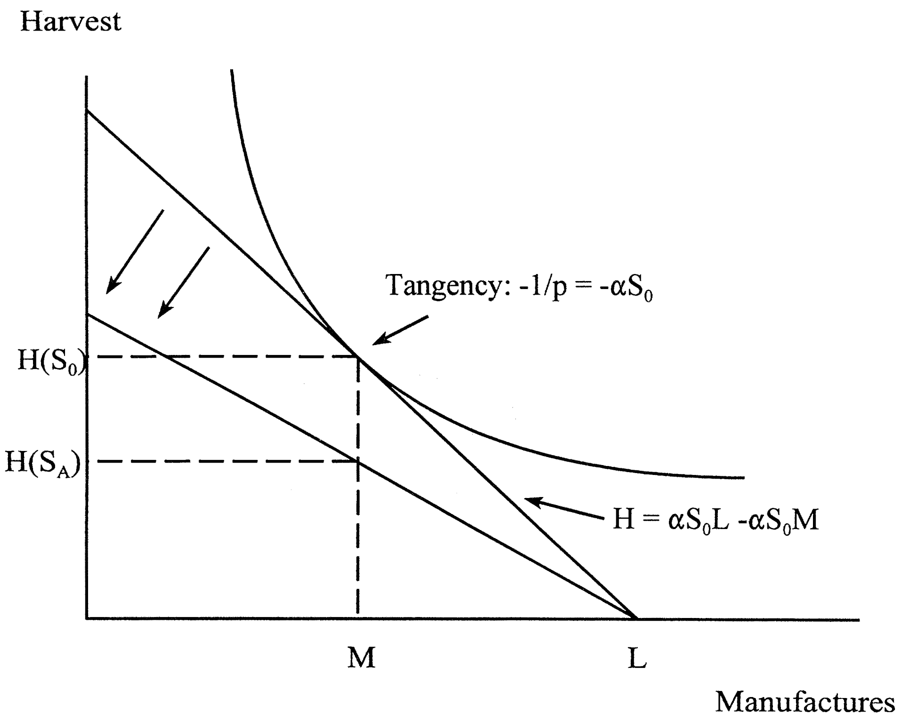

FIGURE 2 Temporary equilibrium dynamics

It is apparent from (13) and (15) that a steady state with positive stock and harvest levels will not exist for all parameter values. The main parameter restriction is given in part (ii) of proposition 1.

PROPOSITION 1.

i) For all parameter values, a possible steady state exists at $S = H = 0$.

ii) A steady-state solution with a positive stock exists if and only if

$$r/L > \alpha\beta. \tag{16}$$

iii) If a positive autarkic steady-state stock, S_A*, exists, then it is the unique positive solution, it is globally stable, and convergence to this steady state from any initial positive stock is monotonic (i.e.,* $dS/dt > 0$ *for all positive stock levels less than* S_A *and* $dS/dt < 0$ *for all* $S > S_A$*).*

iv) If (16) is not satisfied, the resource will be extinguished and the unique steady state is $S = H = 0$.

Proof. (i) follows from inspection of equation (12). If $S = 0$, no resource growth is possible, so this must be a steady state. (ii) follows from the observation that S_A in expression (13) is positive if and only if (16) holds. (iii) follows from inspection of figure 1, but it is useful to characterize the evolution of $S(t)$ exactly. The dynamics of our autarky model are governed by equation (1). Substituting (2) and (11) into (1) implies that $dS/dt = rS(1 - S/K) - \alpha\beta LS$, subject to $S(t = 0) = S_0$. This non-linear differential equation can be transformed into a linear equation by the change of variables $S = 1/V$. Solving the transformed linear equation shows that

$$S(t) = 1/(b/a + ce^{-at}), \tag{17}$$

where $a = r - \alpha\beta L$, $b = r/K$, and $c = (1/S_0 - b/a)$. Taking the derivative of $S(t)$ with respect to t shows that $dS/dt > 0$ if $S_0 < S_A$ and $dS/dt < 0$ if $S_0 > S_A$. Provided (16) holds, the adjustment of the stock proceeds monotonically towards S_A, implying both stability and monotonicity. (iv) is implied by (i) and (ii). It can also be readily inferred from figure 1. ■

The slope of the harvest schedule is $\alpha\beta L$, while the slope of the growth curve at $S = 0$ is r. Proposition 1 therefore can be readily understood by noting that condition (16) means that the harvest schedule in figure 1 must lie inside the growth curve. If so, there is a unique, stable, positive solution. Note that there is a unique positive steady state despite the fact that a given harvest level can be achieved by either of two different stock levels. This follows because only one stock level is consistent with overall labour market equilibrium. If the parameter restriction given in proposition 1 is not met, the harvest line will lie above the growth curve, leading to extinction of the resource.

5. *Comparative steady states*

We can see from differentiation of equations (13)–(15) with respect to r and K that an increase in intrinsic growth rate r or carrying capacity K would increase steady-state stock and harvest levels, while reducing the price of the resource good. The comparative steady-state effects of changes in α, β, and L are slightly more subtle, as described in proposition 2.

PROPOSITION 2. *An increase in conditional labour-harvesting productivity α, taste parameter β, or labour supply L will*

- *i) increase the steady-state harvest if $r/L > 2\alpha\beta$ and decrease the steady-state harvest if $r/L < 2\alpha\beta$;*
- *ii) increase the relative price of the resource good if $r/L < 2\alpha\beta$ and descrease it if $r/L > 2\alpha\beta$; and*
- *iii) lower the steady-state resource stock.*
- *iv) A sufficiently large increase in α, β, or L will cause extinction of the resource.*

Proof. Results (i)–(iii) follow from differentiation of expressions (13)–(15). We report the algebra only for $dH/d\alpha$, since the other effects are derived in similar fashion. Differentiating (15) with respect to α yields

$$dH/d\alpha = \alpha\beta K - 2\alpha K(L\beta)^2/r = \beta LK(1 - 2\alpha\beta L/r). \tag{18}$$

From (18) it follows that whether $dH/d\alpha$ is positive or negative depends on the sign of $1 - 2\alpha\beta L/r$, which depends, in turn, on whether r/L exceeds or falls short of $2\alpha\beta$, as was to be shown. Result (iv) follows from the observation that if α, β, or L increases sufficiently, then eventually $\alpha\beta$ will exceed r/L, violating condition (16), which implies that extinction will occur. ■

These effects can be understood using figure 1. The condition that $r/L < 2\alpha\beta$ can be rewritten as $\alpha\beta L > r/2$, where $\alpha\beta L$ is the slope of the harvest schedule in figure 1. If slope $\alpha\beta L$ is less than $r/2$, then the harvest schedule must intersect the growth curve on its downward-sloping portion (i.e., $S > K/2$), as drawn. In this case, a small increase in α, β, or L causes the slope of the harvest schedule to increase, making the harvest schedule pivot upward slightly. The new intersection between the harvest schedule and the growth curve is therefore slightly higher on the growth curve, implying that the steady-state harvest will increase, while the steady-state stock diminishes. Alternatively, if $\alpha\beta L > r/2$, then the harvest schedule will intersect the growth curve on its upward-sloping part (i.e., $S < K/2$), implying that a small increase in α, β, or L would induce a steady-state decline in both the stock and the harvest. Sufficiently large increases in α, β, or L will cause $\alpha\beta L$ to exceed r, violating condition (16) and causing the harvest schedule to lie above the growth curve, leading to extinction of the resource.

It is perhaps not surprising that a sufficiently large increase in L (representing population increase) would cause extinction. After all, resource capacity is finite and will eventually be swamped by population growth. It is somewhat more striking that improvements in harvesting technology, reflected by increases in α, may be damaging or even catastrophic, given the underlying open-access market failure.[7]

6. *Factor proportions*

For a positive steady-state harvest to exist, the economy must be sufficiently 'resource abundant' in the sense that r/L must be sufficiently large. From (12) it is apparent that the flow of services from any positive resource stock, measured by the sustainable harvest it can support, is proportional to intrinsic growth rate r. In essence, r represents the flow of services available from the resource stock. Variable L is the flow of labour services. The ratio r/L can then be viewed as measuring the relative factor service flow.

From equation (14) we see that equiproportionate increases in the labour force and in the intrinsic rate of resource growth leave autarky relative prices unchanged.[8] Comparative advantage, as reflected by autarky prices, is determined by the composition of factor flows in that an increase in the relative resource abundance of

7 The U.S. passenger pigeon was hunted to extinction in the nineteenth century following improvement in hunting efficiency (better rifles). (We thank Gardner Brown for this example.) Similarly, the blue whale was hunted to near extinction during the period 1930–60 as a result of improved whaling technology. It is estimated that there were approximately 250,000 blue whales at the beginning of the twentieth century. Recent (mid-1994) estimates put the blue whale population at about 500.

8 The intuition is as follows. Starting from a steady state, consider a doubling of both L and r. On impact, since tastes are homothetic, the demand for both goods doubles because income, $wL =$

the economy, as measured by r/L, lowers the relative price of the resource good. A decrease in r/L raises this relative price. Therefore, the steady-state properties of the model are closely related to factor proportions.

IV. THE SMALL OPEN ECONOMY

1. The temporary equilibrium pattern of production and trade

We consider an economy that is small in the sense that the world relative price of the resource good can be taken as exogenous. We denote this world price as p^*. We assume that the small country is at an initial autarkic steady state, then becomes open to trade. When trade opens, the temporary pattern of production in the country is determined solely by the relative returns to labour in the two sectors. As trade opens, the resource stock is at its autarky level, S_A. Therefore, from (3), the marginal product of labour in the resource sector is αS_A. The new wage available in the resource sector is simply the value of marginal product, which is the world price times the marginal product: $p^*\alpha S_A$. If this wage exceeds 1 (the wage available in the manufacturing sector), then all workers move to the resource sector, and the economy will temporarily specialize in production of the resource good. Conversely, if $p^*\alpha S_A < 1$, then all workers will move to the manufacturing sector. If $p^*\alpha S_A = 1$, the initial temporary equilibrium pattern of production is indeterminate, since workers are indifferent between the two sectors. The production pattern can readily be linked to the comparison of autarky and world prices, as described in proposition 3.

PROPOSITION 3. *In the initial temporary equilibrium following the opening of trade, the small economy will*

i) specialize in and export the resource good if $p^* > p^A$;
ii) specialize in and export manufactures if $p^* < p^A$; *and*
iii) have an indeterminate pattern of trade and production if $p^* = p^A$.

Proof. (i) From (4a) we know that $p^A = 1/\alpha S_A$, or $p^A\alpha S_A = 1$. Therefore, if $p^* > p^A$, then $p^*\alpha S_A > 1$, implying that the value of marginal product (and the wage) available in the resource sector exceeds 1, which in turn implies that the small country specializes in the resource good. Since both goods are essential and prices are finite, both goods must be consumed, implying that the resource good must be exported so as to obtain imports of manufactures. Cases (ii) and (iii) follow by parallel reasoning. ■

Provided that the world price differs from the autarky price, the autarky resource stock, S_A, will not be consistent with a trading steady state. Following the opening

L, doubles. Also, both the temporary equilibrium harvest and the production of manufactures double. Thus the current demand and current supply of each good double, leaving relative prices unchanged. We can also see that this new temporary equilibrium is sustainable as a steady state, because doubling r also doubles the sustainable harvest for the given resource stock. It follows that this new temporary equilibrium is a new steady state as well.

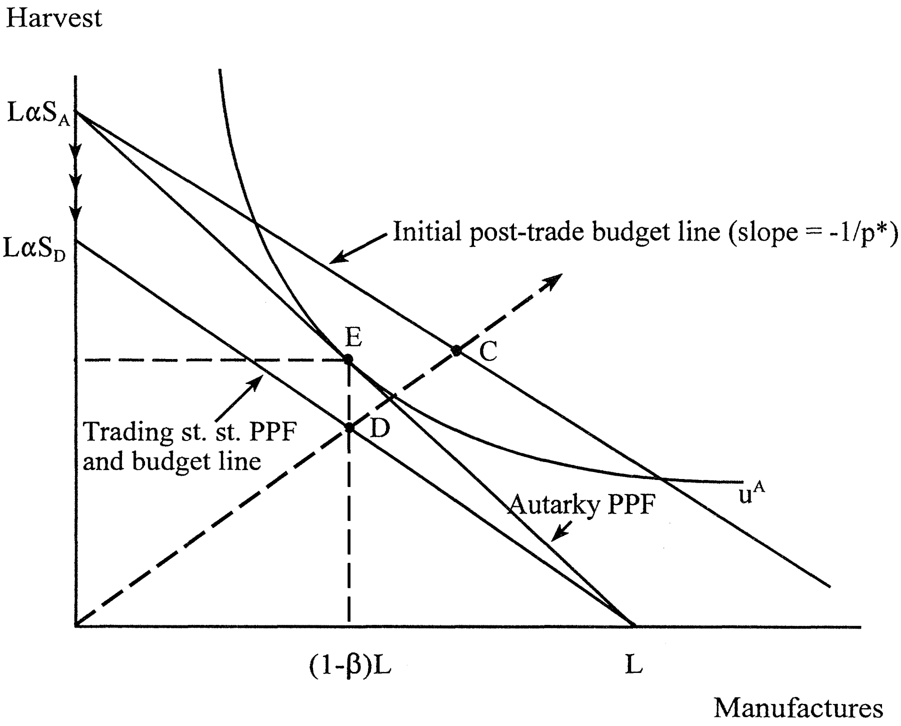

FIGURE 3 Transition to a diversified-trading steady state

of trade, the resource stock will evolve towards a new steady state. It is useful to consider the case of $p^* > p^A$ (comparative advantage in the resource sector) and $p^* < p^A$ (comparative advantage in the manufacturing sector) separately.

2. Transition to a steady state for a diversified resource abundant country ($p^* > p^A$)
The movement to a new steady state for the case $p^* > p^A$ can be readily understood using figure 3. The initial autarky production and consumption point is given by E. The production possibility frontier has a vertical intercept at $L/a_{LH}(S_A)$, which equals $L\alpha S_A$, and a horizontal intercept at L. When trade opens, if $p^* > p^A$, then, as described in proposition 3, the economy immediately specializes in the resource good and the temporary equilibrium production point moves to the vertical axis at $L\alpha S_A$. Hence, the economy's initial free-trade budget line has vertical intercept $L\alpha S_A$ and slope $-1/p^*$, and it lies outside the autarky production possibility frontier, as shown. The new temporary equilibrium consumption point, given by point C, must lie on the budget line above and to the right of E, the autarky consumption point. Thus, when trade opens, this economy exports the resource good, imports manufactures, and experiences temporary gains from trade.

At the initial trading temporary equilibrium, all labour has entered the resource sector, implying that the temporary harvest rate has risen above the steady-state autarky level. (Recall that in autarky only fraction β of the labour force was employed in the resource sector.) Thus, the harvest rate exceeds the growth rate of the resource and the resource stock diminishes. As the resource stock shrinks, labour productivity in the resource sector falls in accordance with equation (3), and the vertical intercept of the production possibility frontier moves down along the vertical axis as shown by the arrows. As production of the harvest falls along this transition path, so too does the economy's free-trade budget line. Exports of the resource good, imports of manufactures, and the economy's gains from trade shrink as time progresses.

The exact time pattern of stock adjustment and its consequent effect on production, utility, and trade flows can be worked out quite readily. The evolution of the stock dS/dt during the transition phase is, as before, governed by (1), which implies in this case that $dS/dt = rS(1 - S/K) - \alpha LS$. (This is as it is in autarky, with β replaced by 1, reflecting the fact that all of the labour force is now active in harvesting.) Also, the initial condition in this case is $S(0) = S_A$. The transition path is described by the following equation:[9]

$$S(t) = 1/(b/a + ce^{-at}), \tag{17a}$$

where $a = r - \alpha L$, $b = r/K$, and $c = (1/S_A - b/a)$. As implied by (17a), the stock declines monotonically over time, as does labour productivity in the resource sector (and output) until either the value of marginal product in the resource sector is driven to 1, allowing diversified production, or the resource stock stabilizes at a new (lower) level that can support the country's entire labour force at a wage exceeding 1. These two cases correspond to diversification and specialization, respectively. Either outcome is possible, depending on conditions to be specified in proposition 7.

Figure 3 illustrates the case of steady-state diversification. This diversification is reflected in the fact that the steady-state production possibility frontier and budget line are coincident. This can be understood by noting that the budget line and the PPF always have the same vertical intercept (given by $L\alpha S$). The budget line has slope $-1/p^*$, while the PPF will have this slope if both manufactures and resource products are produced (i.e., under diversification). Note that under diversification the steady-state post-trade budget line has horizontal intercept L. In this case the economy consumes at point D. Under the assumption of Cobb-Douglas utility (or homothetic utility more generally), the steady-state consumption point, D, must lie on the same ray from the origin as the initial post-trade temporary consumption point, C. Moreover, point D must also correspond to the same consumption of good M as in autarky (point E) because national income measured in terms of good M

9 Strictly speaking, this equation describes the transition path as long as the economy remains specialized in the resource good. The economy does remain specialized until the steady-state harvest is reached. In the case of diversification, some labour shifts out of the resource sector at this point.

is identical in the two cases and preferences are Cobb-Douglas. As a result, during the transition phase to the steady state, the economy's free-trade consumption point must lie along the same ray through D and C.

The steady-state stock supporting a diversified trading steady state is denoted S_D. In order for S_D to support diversified production, it must be the case (from (4a)) that

$$S_D = 1/(\alpha p^*) \tag{19}$$

or, equivalently, $p^* \alpha S_D = 1$. This implies that the value of marginal product is 1 in the resource sector and therefore is equal to the value of marginal product in the manufacturing sector. The temporary pattern of production is indeterminate, but there is only one division of labour across sectors that is consistent with a steady state. Labour has to be divided across sectors so that the current harvest is just equal to the natural growth rate. If more labour moved into the resource sector, the resource stock would fall and with it the value of labour's marginal product in resources. Workers would move into manufacturing, which would rebuild the stock and re-establish the previous equilibrium. Conversely, if labour moved out of resources and into manufacturing, then the stock of the resource would grow and the value of marginal product in the resource sector would rise, which would drive workers back into the resource sector. Consequently, the steady-state pattern of production is determinate, and the diversified steady state is stable.

It is apparent from figure 3 that if $p^* > p^A$ and a diversified steady state emerges, then the small country's steady state utility is reduced by international trade. This follows directly from the fact that the consumption possibility set in autarky dominates that in the diversified trading steady state. It is also apparent from figure 3 that the initial or impact effect of trade is to provide temporary gains from trade, as the economy moves from consumption at point E to consumption at point C. These gains are eroded over time, however, as the economy moves from point C towards point D. Given this time pattern of early gains followed by eventual losses, there is some positive discount rate such that if future utility is discounted at this rate or less, then the present discounted value of utility is reduced by trade.

This country exports the resource good and imports manufactures during the entire transition phase towards the steady state. Yet once the economy shifts to diversification as the steady-state stock is reached, it is no longer obvious from the diagram that the country still will export the resource good. It can, however, be shown algebraically. The simplest way to proceed is to compare the country's steady-state supply of the resource good with its steady-state demand. Steady-state supply must, by the definition of the steady state, equal the natural growth rate given by (2). Therefore, production, H^P, is $rS_D(1 - S_D/K)$, where S_D is given by (19). In addition, quantity demanded and consumed is given by (7) as $H^C = w\beta L/p^* = \beta L/p^*$ (noting that $w = 1$ whenever manufactures are produced). Taking the difference between H^P and H^C yields

$$H^P - H^C = (r/(\alpha p^*))(1 - 1/(\alpha p^* K)) - \beta L/p^*$$

$$= (r/(\alpha p^*))[1 - \alpha\beta L/r - 1/(K\alpha p^*)]$$

$$= r[1/p^A - 1/p^*]/(K\alpha^2 p^*), \tag{20}$$

where the transition between the second and third steps makes use of equation (14) for p^A. It follows that the sign of $H^P - H^C$ (resource good exports) is the same as the sign of $p^* - p^A$, leading to proposition 4.

PROPOSITION 4. *If $p^* > p^A$, and the trading steady state is diversified, then*
i) the small country exports the resource good and imports manufactures;
ii) the small country's steady-state utility is lower under free trade than in autarky; and
iii) for sufficiently small but positive discount rates, the present discounted value of utility is reduced by trade. ■

Proposition 4 is a strong result, since it shows that when the small country has a comparative advantage in production of the resource good (as defined by the condition that $p^* > p^A$) and remains diversified in production in the trading steady state, then its steady-state utility is driven below autarky levels. However, proposition 4 represents only one possibility. It is also possible that the small country may specialize in production of the resource good.

3. Transition to a specialized steady state for a resource-abundant country ($p^* > p^A$)

Specialization results if the resource stock stabilizes at a level that can sustain the entire labour force at a wage exceeding 1. Using figure 3, we can infer that in a specialized steady state, the small country's free-trade budget line would have a vertical intercept somewhere between $L\alpha S_A$ and $L\alpha S_D$ and a horizontal intercept at a point on the horizontal axis beyond L. In this case, steady-state consumption possibilities in trade are not necessarily dominated by those in autarky.

Several results follow immediately from diagrammatic reasoning. First, it is clear that the small country exports the resource good and imports manufactures, both in steady state and at every point along the transition path. Second, if the country's taste for the manufactured good is sufficiently strong, then free trade will yield higher utility in steady state (and along the transition path).

In addition, there always exists some p^* high enough to ensure that the small country gains from trade everywhere along the transition path and in steady state. To verify this last assertion, note that the utility of a representative consumer is given by (5), and that per capita values of h and m are obtained by dividing the expression in (7) by L. Under autarky, we know that $w = 1$ and $p = 1/(\alpha S_A)$. Substituting these values into (7) and substituting the result into (5) allow us to write the autarky utility of a representative consumer, denoted u^A, as

$$u^A = [\beta\alpha S_A]^\beta[1 - \beta]^{1-\beta}. \tag{21}$$

Denote the resource stock in a specialized equilibrium S_Z. From (4) it must be the case that

$$w = \alpha p^* S_Z, \tag{22}$$

which must exceed 1. Therefore, under free trade, $h = \beta w/p^* = \alpha\beta S_Z$ (using (22)) and $m = w(1-\beta) = p^*\alpha(1-\beta)S_Z$. Substituting these values for h and m into (5) yields

$$u^T = [\beta\alpha S_Z]^\beta [p^*(1-\beta)\alpha S_Z]^{1-\beta}. \tag{23}$$

From (21) and (23) it follows that

$$u^T < u^A \text{ if and only if } S_Z/(\alpha p^*)^{1-\beta} < (S_A)^\beta. \tag{24}$$

Note that S^A as given by (13) is independent of p^*. We can solve for S_Z by noting that in a specialized steady state, $H^P = \alpha L S_Z$ (from (3)). It must therefore be the case from (2) that $\alpha L S_Z = r S_Z(1 - S_Z/K)$. It follows that

$$S_Z = K(1 - \alpha L/r). \tag{25}$$

We can see from (25) that S_Z is also independent of p^*. It follows from (24) that steady-state utility under free trade can always be made to exceed autarky utility by making p^* sufficiently high. Furthermore, there is some critical value of p^*, which we denote p^r, such that u^T would just equal u^A. The key points from this discussion are summarized in proposition 5.

PROPOSITION 5. *If $p^* > p^A$, and a specialized steady state arises, then*
i) the small country exports the resource good and imports manufactures;
ii) if $p^* > p^r$, then both steady-state utility and the discounted value of utility are increased by trade;
iii) if $p^* < p^r$, then steady-state utility is reduced by trade; the present discounted value of utility may be increased or reduced by trade, depending on the discount rate. ■

We now consider the case in which the small country has a comparative advantage in manufactures (i.e., when $p^* < p^A$).

4. Transition to steady state for a resource-poor country ($p^* < p^A$)
Figure 4 depicts the movement of our economy towards a diversified steady state when $p^* < p^A$. When trade opens, the economy immediately specializes in manufactures, as stated in proposition 3. The initial temporary equilibrium production point moves to the horizontal axis at L. The temporary equilibrium consumption point will lie above the autarky consumption point on the free-trade budget line

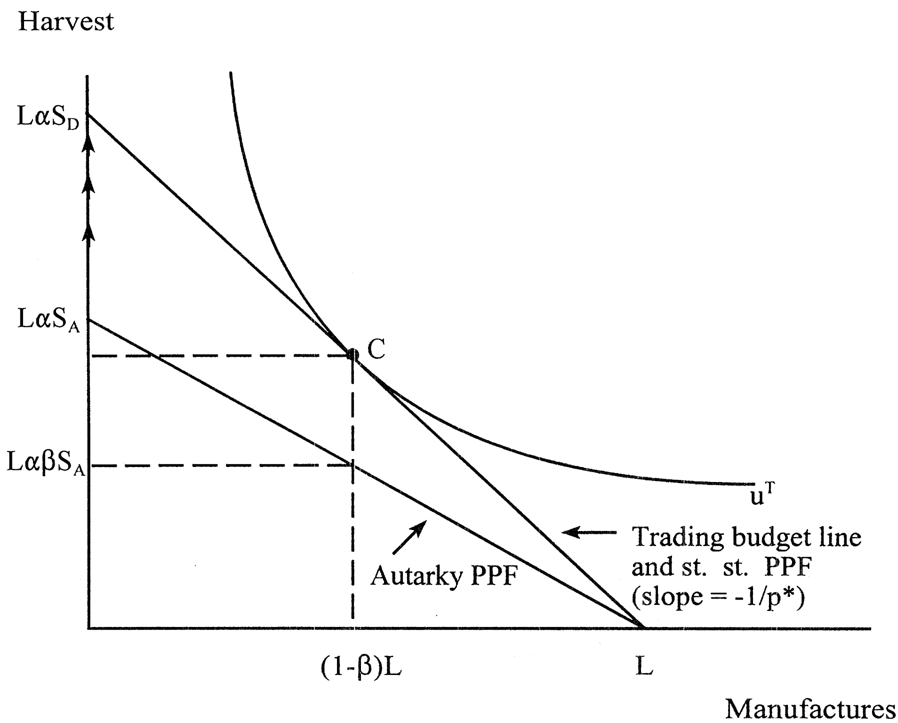

FIGURE 4 Transition to trade for a resource-poor economy

with horizontal intercept at L, as illustrated. When trade opens, the economy specializes in and exports manufactures, while it imports the resource good. From figure 4 we see that there are initial gains from trade. Because the economy's entire labour force is dedicated to manufacturing, the harvest is zero, and the resource stock grows in accordance with (2).

As the resource stock grows, the potential productivity of labour in the resource sector also grows, and the economy's production possibility frontier pivots up as shown by the arrows. Production of the resource is still zero during the transition phase and manufacturing output is constant (and equal to L). Therefore, exports of manufactures, imports of the resource good, and instantaneous utility are constant over time. This process continues until either the value of marginal product in the resource sector rises to 1 and the economy becomes diversified, or the stock grows until it reaches its carrying capacity, K. The stock will reach K if the world price of the resource good is so low that the potential wage in the resource sector remains less than 1 even at $S = K$. In the latter case, the economy remains specialized in steady state.

Figure 4 illustrates the case in which the economy becomes diversified. In this case, the steady-state production possibility frontier is coincident with initial trading budget line. If, on the other hand, the world price of the resource good was sufficiently low, then the budget line drawn through L would intersect the vertical axis at a point above $L\alpha K$. In this case, the economy would remain specialized in manufactures even in steady state, and the steady-state production possibility frontier would be below the budget line, sharing only the same horizontal intercept.

It can be inferred from figure 4 that steady-state utility is higher in trade than in autarky whether the steady state is diversified or specialized. In both cases, the steady-state consumption possibilities set under trade dominates the autarky consumption possibilities set. It is also apparent that there are gains from trade everywhere along the transition path; hence, the overall present discounted value of utility must be higher under trade than in autarky. Finally, the economy must export manufactures in steady state, even if its steady-state production is diversified (and certainly if it is specialized in manufactures). The fact that even a diversified economy exports manufactures if $p^* < p^A$ follows from (20), where it is shown that exports of the resource good have the same sign as $p^* - p^A$. Thus $p^* - p^A < 0$ implies that imports of the resource good are positive and the country must export manufactures.

PROPOSITION 6. *If $p^* < p^A$, then*
i) the small country exports manufactures and imports the resource good; and
ii) steady state and present discounted utility are increased by trade.

5. The steady-state pattern of production

We have pointed out that specialized or diversified steady states may arise, but we have not yet specified the precise conditions that lead to one outcome or the other. Proposition 7 gives these conditions.

PROPOSITION 7.

i) The small open economy will specialize in manufactures if (and only if)

$$p^* \leqq 1/(K\alpha). \qquad (26)$$

ii) The small open economy will produce both goods if (and only if)

$$p^* > 1/(K\alpha) \text{ and } L/r > (1/\alpha)[1 - 1/(p^*K\alpha)]. \qquad (27)$$

iii) The small open economy will specialize in the resource good if (and only if)

$$L/r \leqq (1/\alpha)[1 - 1/(p^*K\alpha)]. \qquad (28)$$

Proof. (i) To specialize in manufactures, labour's value of marginal product in the resource sector must be less than 1 even at the maximum stock. Therefore, if $p^*\alpha K < 1$, then the resource sector will attract no labour. Furthermore, even if $p^*\alpha K = 1$, the harvest will be 0. Inequality (26) follows immediately. (ii) This follows by implication from (i) and (iii). We can therefore proceed directly to the proof of (iii). (iii) Specialization in the resource good requires that the wage in the resource sector be greater than 1 at S_Z. Therefore we require $p^*\alpha S_Z \geqq 1$, where S_Z is given by (25), yielding the requirement

$$p^*\alpha K(1 - \alpha L/r) \geqq 1 \tag{29}$$

for specialization in the resource good. Statement (iii) follows by rearrangement of (29). ■

Proposition 7 covers all possible cases and implies the following corollary.

COROLLARY 7.1
If $r/L > \alpha$, the steady-state pattern of production can be characterized as a function of world price, p^*.

$p^* \leqq 1/(K\alpha)$ => *specialization in manufactures*
$1/(K\alpha) < p^* < 1/[(1 - \alpha L/r)K\alpha]$ => *diversified production*
$p^* \geqq 1/[(1 - \alpha L/r)K\alpha]$ => *specialization in the resource good.*

If $r/L < \alpha$, then the country cannot specialize in the resource good, regardless of the world price. ■

Putting Propositions (4)–(7) together allows an interesting characterization of the consequences of trade as a function of the world price, p^*.

In figure 5, the flat line labelled u^A represents the steady-state level of per capita utility under autarky. The other line represents steady-state utility under free trade as a function of the world price of the resource good for a country with $r/L > \alpha$. The prices $p1^*, \ldots, p3^*$ marked on the horizontal axis are pivotal prices for this case. There is some possible world price $p1^*$, such that world prices less than $p1^*$ would lead the small country to specialization in manufactures. At $p1^*$, the domestic economy moves from specialization to diversification, but still exports manufactures. If the world price happened to equal the small country's autarky price, p^A, its trading utility would equal its autarky utility, as illustrated. At all prices below p^A, the domestic economy would export manufactures and would experience steady-state gains from trade. At world prices just above p^A, the domestic economy would be an exporter of the resource good but would be diversified in production. In this range, steady-state utility under free trade would be less than it would be in autarky.

Provided that $r/L > \alpha$, there exists a price such as $p2^*$ that would be just high enough to induce the domestic economy to specialize in production of the resource good. This world price actually minimizes steady-state utility. Beyond price $p2^*$, further increases in the world price are beneficial to the domestic economy, and there is some price, $p3^*$, that yields trading steady-state utility equal to autarky

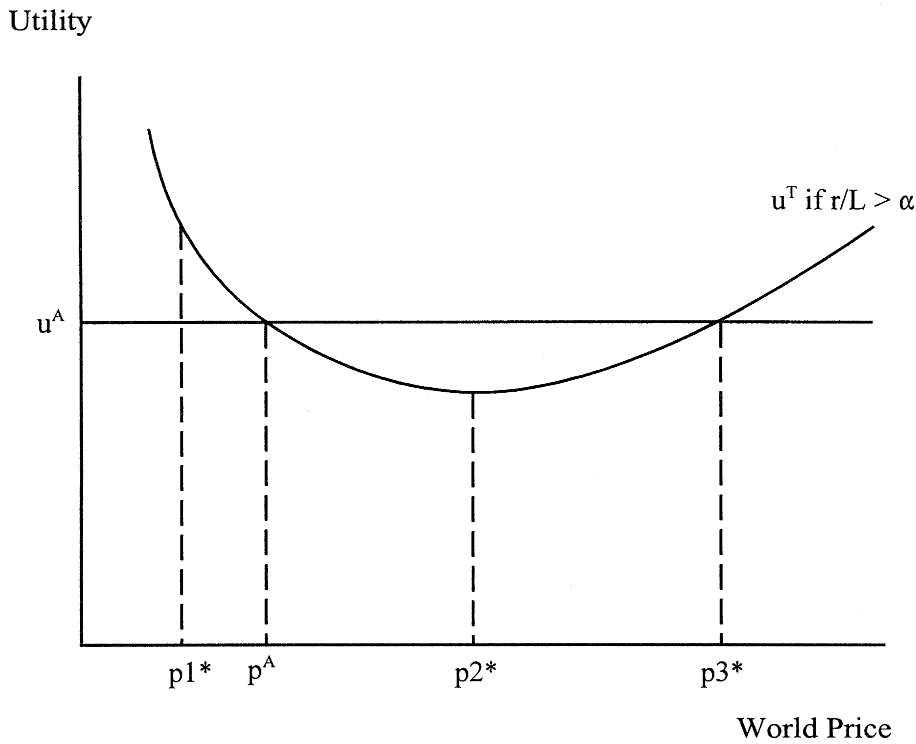

FIGURE 5 Steady-state utility and the terms of trade

utility. Still higher world prices would imply steady-state utility gains relative to autarky.

If, on the other hand, $r/L < \alpha$, then the small country cannot specialize in the resource good in steady state because employing its full labour force in harvesting would lead to extinction of the resource. Before the resource is physically exhausted, however, the value of marginal product in harvesting declines to 1, and thus economic forces will ensure that this economy must diversify its production and reduce its harvest rate. Per capita steady-state utility is monotonically falling in the world price of the resource good. The stronger this country's apparent 'comparative advantage' in the resource good, the lower its steady-state utility. In addition, since steady-state utility falls with improvements in the terms of trade, for sufficiently low discount rates international trade at more favourable world prices can lead to lower overall welfare for this resource-abundant country. Although a more favourable terms of trade is beneficial during the specialization period leading up to diversification, the eventual steady-state utility level in trade is lower the higher is the world price of the resource good. As a consequence, for some discount rates the transitional benefits of a higher terms of trade will be more than offset by steady-state losses.

The intuition behind these results is straightforward. If a country exports the manufactured good, then trade creates conventional 'consumption' and 'production' gains. In addition, it partially corrects for the open-access problem by shifting the economy's production mix away from the open-access (resource) sector. Consequently, gains from trade are ensured.

If a country exports the resource good, there are two offsetting forces at work: resource depletion effects that arise when trade raises a country's harvest rate and lowers its production possibilities over time; and terms-of-trade effects that work in just the opposite direction by raising a country's consumption possibilities in trade. From proposition 7 we know that when a country cannot specialize in trade, it continues to harvest the resource until the value of marginal product in harvesting is driven to 1. As a consequence, national income (measured in terms of the numeraire) is now once again at its autarky level. Consumers' income measured in terms of the numeraire is now the same as it is in autarky, but the resource good has a higher relative price than before. Consequently, both production and consumption possibilities are reduced by trade, steady-state utility is thereby reduced, and the overall welfare comparisons given in proposition 4 follow as well.

If the resource good exporter specializes in production, however, then the value of national income falls in terms of the resource good but rises in terms of manufactures. Steady-state losses from trade may occur, but this depends quite sensitively on tastes and the level of world relative prices. Unlike the case of diversified production, there are some combinations of taste parameter β and price p^* that will allow gains from trade.

V. CONCLUDING REMARKS

This paper examines the trade flows, production patterns, and welfare outcomes for a small open economy endowed with an open-access renewable resource. The pattern of production and trade follows in a very natural way from the small open economy version of comparative advantage. Specifically, whether the country exports or imports the resource good depends on whether the world price of the resource good exceeds or is less than the autarky price of the resource good in the small country. Autarky prices, in turn, are determined by a measure of relative resource abundance, r/L, where r is the intrinsic resource growth rate and L is labour supply.

Despite the similarities to standard factor endowment models, the welfare effects of trade are notably different. Given the market failure created by open access, it is perhaps not too surprising to find that international trade may provide lower steady-state utility than autarky, and the overall welfare consequences of free trade may well be negative. Our other major results are less easily anticipated. We show that for any resource-abundant economy that has a labour force too large to allow specialization in production, steady-state utility is necessarily reduced as a result of trade; overall welfare is also reduced if future utility is discounted at some small but positive discount rate; and there does not exist any sufficiently favourable world relative price of the resource good that will lead to greater consumption possibilities in the trading steady state. Moreover, we find that 'improvements' in this country's terms of trade (i.e., increases in the world price of the resource good) may well be immiserizering because they necessarily reduce steady-state consumption possibilities and can reduce overall welfare as well.

When a small country exports the resource good under free trade but specializes in production, then its steady-state consumption possibilities may or may not increase with trade. A country that specializes in the resource good can have lower steady-state utility in trade and suffer a reduction in overall welfare as a result of trade, but gains must occur if the world relative price of the resource good is sufficiently high or consumers' taste for the resource good is sufficiently weak. A small country that exports manufactures always gains from trade.

We have used explicit functional forms for utility, resource growth, and the harvesting production function. Using these specific and relatively simple functional forms allows calculation of closed-form solutions for variables of interest and allows a clear understanding of the underlying economic principles at work in our analysis. We have not reported the effects of generalizing these assumptions, primarily because of space considerations. We have found, however, that the basic pattern of our analysis is robust to natural generalization of these functional forms. For example, we can replace the Cobb-Douglas utility function with general homothetic utility or we can replace the Schaefer production function with a general homogenous production function and obtain similar results, although with some loss of clarity and some expansion of algebra.

There are many additional lines of research that could be pursued. We have focused on the small open economy as a useful starting point. Arguably, this is an empirically plausible representation for some low-income countries producing renewable resource products. A natural extension is to consider a simple two-country model with endogenous world prices, which is done in Brander and Taylor (1997a).

Throughout our analysis we have excluded any discussion of optimal policy. It should be understood that the losses from trade and the inefficiencies arising under autarky could be prevented by introducing an efficient resource management policy. In addition to simply establishing property rights, alternative first-best policies could take the form of either quantity restrictions or taxes. By assumption, however, such solutions are not possible, or at least not complete. If they were possible, the open-access problem would not be relevant. Even if first-best solutions cannot be undertaken, there are possible second-best approaches, such as trade restrictions. Another second-best possibility would be to impose a modified 'Hartwick's rule' (see Hartwick 1977) under which an exporting country that experienced temporary gains from selling a resource good on world markets might re-invest those proceeds in an alternative asset. Exploration of these possibilities would require extensions of our basic model, and we see considerable scope for further investigation.

The main contribution of this paper is a demonstration that when a renewable resource is subject to open access, or something approaching it, then free trade may not be the tide that raises all boats. Improved management of renewable resources may be a necessary precondition for gains from trade.

REFERENCES

Bee, O.J. (1987) 'Depletion of the forest resources in the Philippines.' Field Report Series No. 18, Institute of Southeast Asian Studies

Brander, J.A., and M.S. Taylor (1997a) 'Open access renewable resources: trade and trade policy in a two-country model.' *Journal of International Economics* (forthcoming)

— (1997b) 'The simple economics of Easter Island.' *American Economic Review* (forthcoming)

— (1997c) 'International trade between consumer and conservationist societies.' *Resource and Energy Economics* (forthcoming)

Brown, L.R. (1995) 'Nature's limits.' In *State of the World 1995*, ed. L.R. Brown et al. (New York: Norton)

Chichilnisky, G. (1994) 'North-south trade and the global environment.' *American Economic Review* 84, 851–74

Clark, C.W. (1990) *Mathematical Bioeconomics: The Optimal Management of Renewable Resources.* 2nd ed. (New York: Wiley)

Copes, P. (1970) 'The backward-bending supply curve of the fishing industry.' *Scottish Journal of Political Economy* 17, 69–77

Feller, W. (1940) 'On the logistic law of growth and its empirical verification in biology.' *Acta Biotheoretica* 5, 51–66

Gordon, H.S. (1954) 'The economic theory of a common property resource: the fishery.' *Journal of Political Economy* 62, 124–42

Hartwick, J. (1977) 'Intergenerational equity and the investing of rents from exhaustible resources.' *American Economic Review* 67, 972–74

Kemp, M.C., and N.V. Long (1984) 'The role of natural resources in trade models.' In *Handbook of International Economics*, vol. I, ed. R.W. Jones and P.B. Kenen (Amsterdam: North-Holland)

Kummer, D.M. (1992) *Deforestation in the Postwar Philippines* (Chicago: University of Chicago Press)

Loayaza, E.A (1992) (with collaboration of L.M. Sprague), 'A strategy for fisheries development.' World Bank Discussion Paper, Fisheries Series, No. 135

Markusen, J.R. (1976) 'Production and trade from international common property resources.' This *Journal* 9, 309–19

Mason, C.F., and S. Polasky (1994) 'Entry deterrence in the commons.' *International Economic Review* 35, 507–26

McRae, J. (1978) 'Optimal and competitive use of replenishable natural resources by open economies.' *Journal of International Economics* 8, 29–54

Munro, G.R., and A.D. Scott (1985) 'The economics of fisheries management.' In *Handbook of Natural Resource and Energy Economics*, vol. II, ed. A.V. Kneese and J.L. Sweeney (Amsterdam: North-Holland)

Neher, P. (1990) *Natural Resource Economics: Conservation and Exploitation* (Cambridge: Cambridge University Press)

Paterson D.G., and J.E. Wilen (1977) 'Depletion and diplomacy: the North-Pacific seal hunt, 1880–1910.' In *Research in Economic History*, vol. 2, ed. P. Uselding (Connecticut: JAI Press)

Pearl, R. (1930) *The Biology of Population Growth* (New York: Knopf)

Schaefer, M.B. (1957) 'Some considerations of population dynamics and economics in relation to the management of marine fisheries.' *Journal of the Fisheries Research Board of Canada* 14, 669–81

Scott, A.D., and C. Southey (1969) 'The problem of achieving efficient regulation of a fishery.' In *Economics of Fishery Management: A Symposium*, ed. A.D. Scott (Vancouver, BC: Institute of Animal Resource Ecology, University of British Columbia)

Weitzman, M.L. (1974) 'Free access vs. private ownership as alternative systems for managing common property.' *Journal of Economic Theory* 8, 225–34