# North-South trade, property rights and the dynamics of environmental resources

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# North–South Trade, Property Rights, and the Dynamics of the Environment

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## 1. ENVIRONMENTAL RESOURCES AS A NORTH–SOUTH ISSUE

The global environment can be described by the physical dynamics and the economic use of the earth's resources. It has become, to a certain extent, a North–South issue.[1]

Developing countries tend to specialize in the production and the export of goods which deplete environmental resources such as rain forests, or resources such as petroleum and coal whose combustion leads to the emission of greenhouse gases. Currently two-thirds of the exports from Latin America are resources, and resources make an even higher proportion of Africa's exports. Most of these resources are imported and consumed by the industrial countries. For example, most of the world's production of wood pulp is consumed in the industrial countries, as is the petroleum exported by developing countries. The result is that industrial countries account for a large majority of $CO_2$ emissions. The U.S. alone consumes 25–30% of the world's oil production yearly. Because resources are traded intensively between the North and the South, when trying to define precisely the concept of sustainable development we are led therefore to question the role of international trade.[2]

[1]Wide debate focuses on acid rain, global warming and the preservation of rainforests. One hundred nations agreed to consider a treaty to reduce the threat of global warming at Rio de Janeiro, Brazil, June 1992. In Vancouver, February 1991 a pact was adopted that establishes a framework for a treaty linking environmental policy to economic issues of interest to industrial and developing countries, such as the remission of international sovereign debt and transfer of technology.

[2]W. Baumol and W. Oates (1975), I. Walter (1975), W. Oates (1991) J. A. Tobey (1990) and others have studied the effects that environmental control measures could have on patterns of international trade. Some of these studies have found measurable effects (d'Arge and Kneese (1971)). All these studies focus on the policy aspects of measures to control pollution rather than on our issue: how differences in property rights regimes can explain trade between countries in free markets, and the patterns of environmental use. The general concern that developing countries develop an advantage in pollution-intensive industries, known as the "pollution heaven hypothesis" has been studied by I. Walter and J. Ugelow (1979). The potential implication of policy measures to protect the environment on international trade was also studied by Krutilla (1976), Maler (1976, 1990a), Chichilnisky (1982, 1985, 1988b). On the other hand, Dasgupta (1990) points out that the literature on development economics and the environment is largely undeveloped. The international trade literature has not taken up the issue of property rights differentials affecting the pattern of trade, nor considered trade patterns in a general equilibrium model with common property inputs. To the extend that externalities have been studied in international trade, they refer to production externalities in a partial equilibrium framework, see, for example, Dixit and Norman (1980) within Hechscker–Ohlin models where endowments are fixed. Instead, we study a general equilibrium model with variable endowments of a common property resource which is an input to production, having supplies which depend on property rights.

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these conditions trade can lead to *private gains* but to *social losses*. We define here the concepts of private and public comparative advantage and of private and public gains from trade. The weaker are the property rights the larger is the difference between private and public comparative advantage and between private and public gains from trade. Private gains from trade in environmentally intensive goods may be acompanied by public losses from trade, and private comparative advantage may be accompanied by public comparative disadvantages. This leads us to question the extent to which traditional comparative advantages in the developing countries are a good foundation for North–South trade.

It seems worth noting that environmental overuse in the South does not occur solely because the locals over consume their resources, but because they export these resources to a rich international market at prices which are below social costs. This is why the global environmental issue is inextricably connected with North–South trade. The South overproduces, but mostly because the North over consumes. The international market transmits and enlarges the externalities of the global commons. No policy which ignores this connection can work.

Possible policy implications are discussed: they involve improving property rights of the local users of the common resource. Examples of innovative international property rights arrangements between U.S. industry and the localities near rain forests in Central and South America are discussed. In addition, it seems indicated to reconsider trade policies based on traditional comparative advantages in the South. These policies promote the export of environmentally intensive goods, such as wood products or cash crops. The World Bank has been for many years, and still is, a strong promoter for such policies. One ought to take into account the possible social losses in the South from following such policies, as well as the losses to the North. The overuse of resources in the South is tranmitted and enlarged by the international market and becomes a problem for the world economy. Under these conditions, either property rights in the South must be brought up to the level of the North's, or else trade policies based on traditional comparative advantages ought to be de-emphasized as much as possible. The production of agricultural products for the domestic market could be reasonably carried out in the South, but products based on agriculture seem a poor choice for their exports. Such products could be exported instead by the North, which has a comparative advantage in terms of agricultural productivity. The same holds for other environmentally intensive products. This could of course mean an increase in the market price of such products, but if so this would induce more efficient use of the world's resources, and as such it should be welcome.

In any case, the prices of environmentally intensive goods may not necessarily increase if these are exported by the North. Market prices reflect input prices as much as they reflect the productivity of these inputs. Expensive but productive inputs could lead to lower prices: indeed this is the experience of agricultural production in the industrial countries. The South could emphasize, instead, skilled-labour intensive products, such as consumer electronics or telecommunications and other manufactured products, following the example of the new industrialized nations in Asia.

The theory of trade based on differential property rights presented here initiated in Chichilnisky (1991), based on the North–South model introduced in Chichilnisky (1981, 1986). The model and the results in this paper differ however from the previous work in that the dynamics of the renewable resource is crucial to our arguments, while all the other pieces consider instead static economies. The distinctive feature of this paper is that we consider the dynamics of the renewable resource which is used as an input to production, and how this varies with different property rights regimes.



The chapter is organized as follows. Lemma 1 studies the connection between property rights regimes and the long run stock of the renewable resource as a function of prices. On the basis of this result, Theorem 1 establishes the patterns of trade implied by the difference in property rights in the two regions. It shows that different property rights alone explain international trade between countries, even when the countries are otherwise identical (same technologies, preferences and endowments). Corollary 1 explores the welfare implication of changes in property rights. Lemma 1, Theorem 1 and Corollary 1 apply to *unregulated and competitive markets*. Section 6 discusses property rights policies. Section 7 is a conclusion which summarizes the results. The Appendix formalizes the model of North–South trade with variable property rights for an environmental resource which is used as an input to production, and it proves the uniqueness of a market equilibrium.

The results provide a foundation for the desirability of improving property rights regimes, and, in this sense, support Coase's (1960) propositions within the context of international markets.[4] However, as pointed out in Chichilnisky (1991), in our case the pattern of ownership of property rights matters. Not only should property rights be well defined, but the owners of these rights should have appropriate economic characteristics and incentives, a point which Dasgupta and Heal (1979) also make within a different context.

## 2. GAINS FROM TRADE: PRIVATE VS. SOCIAL DIMENSIONS

Environmental issues are generally connected with externalities in production and consumption. Externalities have many forms. They occur for example when the output of traded goods by one firm affects the production by others. Here I shall address, instead, a class of environmental issues arising from *the use of environmental common property resources as inputs of production*. I shall concentrate on studying the behaviour of free markets in which the property rights for the common property resources vary across regions. Of particular interest is how property rights determine the patterns of trade in a free market (general) equilibrium, as well as the pattern of environmental use across the trading regions.

Consider, for example, a tropical forest which is a common property resource used as an input to production of timber, palm oil, fish, trapping, fishing, and pharmaceutical products based on its biodiversity. The fact that environmental resources are common property resources leads inevitably to a divergence between private and social costs (Dasgupta, 1990; Dasgupta and Heal, 1979. Many of these are renewable resources. They can be "produced" at a cost, up to a point, and used as crucial inputs to production. "Overgrazing, over fishing, the depletion of trees and shrubs from common land for use as fuel are familiar problems. They are traceable to the

[4]Cohen and Weitzman (1975) analyze a one-input model of an economy in which changes in property rights affect the general equilibrium, via changes in the supply conditions of a common property resource, land.

A, is the numeraire, i.e. $p_A = 1$. Since endowments, technologies and preferences are defined, all ingredients of a general equilibrium model have been provided.

*Demand* is formalized as usual. For each vector of prices[9] $p = (p_E, r, p_B)$ utility U(A, B) is maximized subject to a budget constraint: the value of consumption of A and B cannot exceed the value of initial endowments. Under appropriate (strict) concavity assumptions, this yields an *aggregate demand* vector for commodities denoted $(D_A, D_B)$, and a demand vector for inputs denoted $(D_K, D_E)$, for each price vector p. Formally:

$$(1) \quad (D_A, D_B, D_K, D_E) = D(p_B, r, p_E)$$

*Supply* is formalized as follows. At each price vector $p = (p_E, r, p_B)$ a quantity of inputs is supplied according to the supply functions $p_E = p_E(E)$ and $r = r(K)$. We shall assume that E is produced in the South from an input x which represents for example labour in the subsistence sector of the economy.

The producers of goods A and B use these inputs efficiently, and so that all available capital and environmental resources are employed. This determines the quantity of A and B produced,[10] denoted $(S_A, S_B) = S(p_E, r, p_B)$.

The *excess demand function* of the economy is therefore $\Phi(p_B, r, p_E) = D(p_B, r, p_E) - S(p_B, r, p_E)$. Because the budget constraint is satisfied, at all prices Walras Law is too: the value of excess demand equals zero:

$$(2) \quad (D_A - f(K, E)) + p_B(D_B - g(K, E)) + r.(D_K - K(r)) + p_E.(D_E - E(p_E)) = 0$$

A *one region equilibrium* is a price vector p* at which each of the four markets clears[11] i.e. $p^* = \Phi^{-1}(0)$ (or $p^* \pi \{\Phi^{-1}(0)\}$. This is a standard definition of a market equilibrium in a competitive market economy.

The *two-region model (North–South) general equilibrium model* is constructed as usual by considering two one-region models together, and relaxing the hypothesis that each commodity market (for goods A and B) clears in each region, so as to allow international trade. Input markets clear in each country because factors (K and E) are immobile, i.e. not traded internationally. For the same reason, in a world equilibrium the prices of these inputs may in principle be different in the two countries.[12]

The two regions are assumed to be identical in most respects: same technologies, same inputs and produced goods, same utilities and the same supply function for capital. The only difference between the regions is in the property rights which will

[9]In an equilibrium the prices of the inputs, $p_E$ and r, are related to those of the outputs, $p_B$.

[10]This gives the quantities of goods A and B produced by profit maximizing producers, when both factor markets clear. Note that as is standard in constant returns economies there may be no well defined partial equilibrium supply function for each producer without the additional assumption of full employment of factors.

[11]Because Walras' Law is satisfied, it suffices that all but one markets clear, with non-zero prices, the last market will clear automatically.

[12]Effectively the factor markets in each country are different markets under this assumption, and achieve different prices in an equilibrium. This is a standard specification. Under certain conditions, discussed in the last section, factor prices will equalize across the two regions even though the factors, K and E, are not traded.



lead in turn to different supply functions[13] for the environmental common property resource E, to which we now turn.

We shall consider two types of supply curves for the environmental common property resource: one is the *private supply curve*, derived from the private marginal cost curve of using or extracting the resource, the other the *social supply curve* derived from the social marginal costs of use or extraction, and which takes account of the negative externalities that one user has on others. This is formalized in the following section, where we show that *at each market price* the private[14] supply curve $E^{\pi}(p_E)$ provides more E than the social supply curve $E^{\sigma}(p_E)$. In the model we shall consider one supply curve for the North, its social supply curve, and two for the South, both the social and the private supply curves. This is because we assume that property rights for environmental common resources in the North are sufficiently good that most social costs are internalized. The North's social and private curves are therefore very close, and we assume they are equal. On the other hand, we shall argue that in the South such property rights are not well defined, so that the private and social curves are quite different. This derives from the lack of property rights in the South, and is substantiated in the next section. Using the two different curves in the South, private and social, leads to different concepts of comparative advantages and of gains from trade.

A new concept of comparative advantage must now be defined. Neither the Ricardian nor Heckscher–Ohlin concepts can be utilized here: since technologies are the same, Ricardian comparative advantage does not exist in our model, and since the endowments of factors vary with their prices, the Heckscher–Ohlin concept of comparative advantage is not well defined here. We adopt the following definition: Region S is said to have a *comparative advantage* in the production of good B, which is intensive in the use of the input E, when for each price $p_E$ the supply of E relative to that of K in region S is larger than the corresponding relative supply in region N at the same price. Obviously this definition requires that we specify which supply curve is used: we shall differentiate between public and private comparative advantages as follows. *Private comparative advantage* in region S is defined by using the private supply curve for E in the South; *public comparative advantage* is defined by using the social supply curve for E. As we shall prove in the following section, when property rights are less developed in the South, the South will exhibit a private comparative advantage in the production of B, even though it has no public comparative advantage.

Different supply curves will also give rise to different *production possibility sets*. Consider at each price vector p the quantity of E supplied according to the private supply curve $E = E^{\pi}(p_E)$, and the corresponding quantity of $K = K(r)$. With these two quantities of E and K we may compute the set of all possible combinations of outputs A and B which are feasible using the production functions f and g. This set is denoted $PP^{\pi}(p)$. Taking the union for all p, we obtain the *private production possibility set* $PPS^{\pi} = \cup p \; PP^{\pi}(p)$, which we assume to be convex. Performing the same procedure, but using the social supply curve $E = E^{\sigma}(p_E)$, yields the *public production possibility set* $PPS^{\sigma} = \cup p \; PP^{\sigma}(p)$, which is also convex.

[13]This assumption is made to emphasize the patterns of trade which are due to differences in property rights between the two regions. This assumption can be relaxed or weakened to consider different technologies and preferences across the regions, see Chichilnisky (1988a).

[14]$E^{\pi}(p_E)$ is the inverse function of $p_E = p_E(E)$, i.e. $p_E = p_E(E^{\pi}(p_E))$.

and optimal behaviour under a private property regime implies that

(9) $F' = \partial/\partial x(F) = q/p_E$

from which the problem is reduced to analyzing a single first order differential equation. To fix ideas, consider for example the case where

(10) $F(z,x) = z^a x^b,\ 0 < a,\ b < 1,$

which implies that

(11) $\dot{z}_t = H(z_t) - (p_E b/q)^{b/(1-b)}\, z_t\, a/(1-b)$

The long run or steady state solution to this problem requires analyzing a single first order differential equation

(12) $H(z_t) - (p_E b/q)^{b/(1-b)}\, z_t\, a/(1-b) = 0$

To study the stability of the steady state solution we postulate that the adjustment mechanism for the input x is that the quantity of the input applied to harvesting the resource increases with profits as defined in (8) (see Dasgupta and Heal (1979), p. 122.) i.e.

(13) $\dot{x}_t = \mu\pi$, where $\mu > 0$.

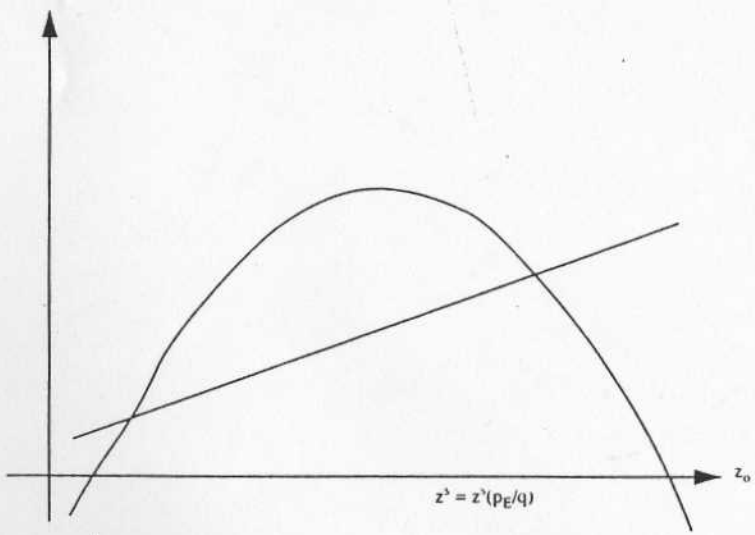



**Figure 15.2**

Typically (i.e. when a <1–b)) there will be two steady states, given by the intersection of the curves H(t), a quadratic equation, and $E(z) = (p_E/qb)^{b/(1-b)}\, z_t a/(1-b))$. The larger steady state (denoted $z^s$ in Figure 15.2) is stable under (13) when the



slope of E(z) nears zero, which we now assume. The solution path of the adjustment process defined by (13) depends on its initial value; the natural initial value is the long run population size in its natural environment, i.e. the long-run stock without economic encroachment, $z_0$ in Figure 15.2. In this event, the population size tends in the long run to the steady state $z^s$ as illustrated in Figure 15.2, where $z^s$ is a function of $p_E$ and q, $z^s = z^s(p_E/q)$. The corresponding harvest or extraction is $E^s = E^s(p_E/q)$.

## Resource Supplies and Property Rights

The solution $z^s(p_E/q)$ describes the long run behaviour of the stock of the renewable resource E under private property regimes (equations 7 to 9). Note that $E^s = z^s(p_E/q)$ is an increasing function of the relative market value of the resource, $p_E$. This is because a larger value $p_E$ leads to an upwards vertical shift of the curve $E(z) = (p_E b/q)^{b/(1-b)}\, z_t a/(1-b)$ in Figure 15.2 which in turn implies a larger steady state harvest and a correspondingly smaller steady state stock $z^s$. For each q, let

(14) $E^s = E^s(p_E)$,

denote the supply curve of the resource E in a stationary state as a function of the price $p_E$. $E^s(p_E)$ is an increasing function $p_E$ as illustrated in Figure 15.3.

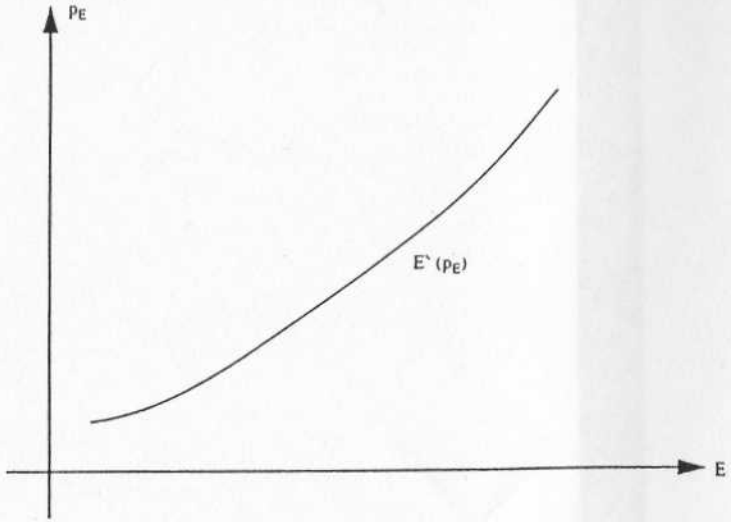



**Figure 15.3**

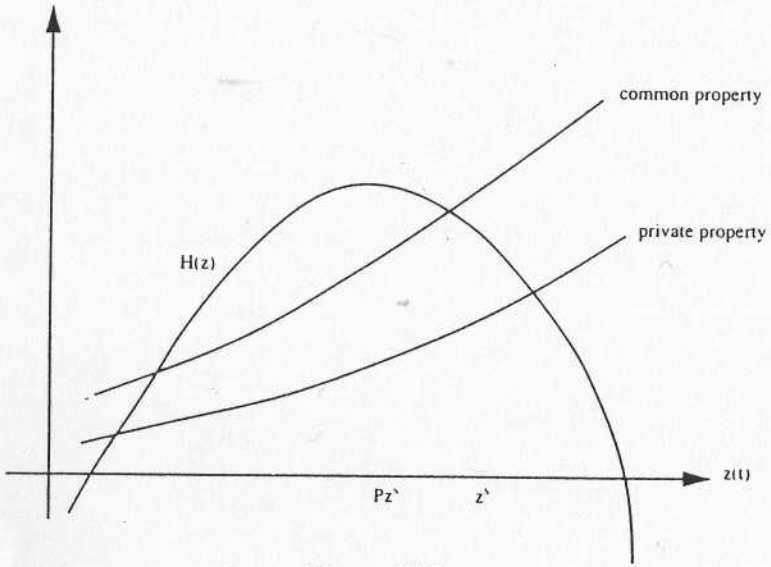



Figure 15.4

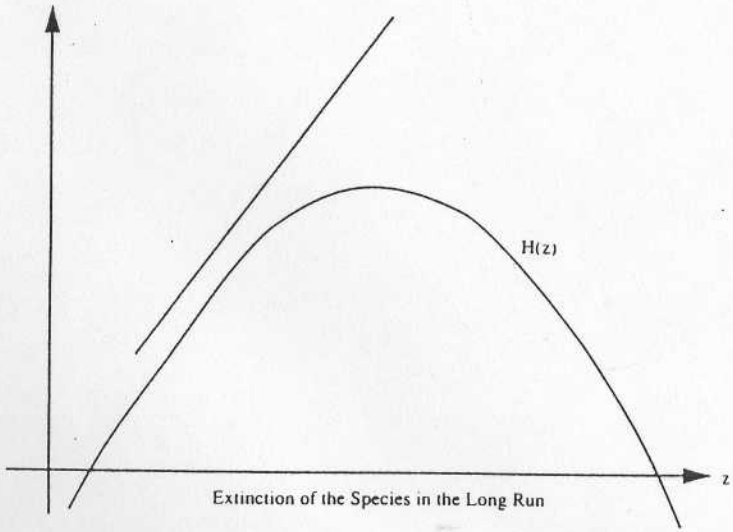



Figure 15.5



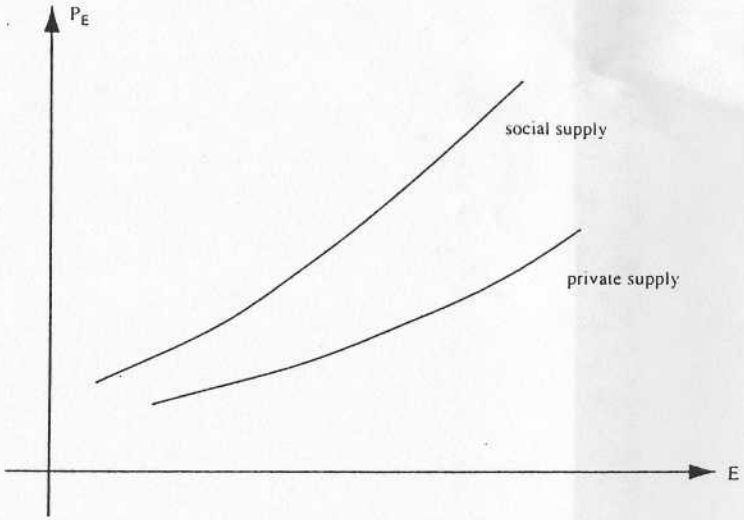



Figure 15.6

Figure 15.6 illustrates the private and social supply curves for the environmental resource E. The social supply curve was obtained by equalizing the opportunity cost q with the value of $S m p_i$, $q = p_E S m p_i$. Instead, the private supply curve by replacing (9) by

$q = P m p_i \; p_E$ . At each $p_E$, more E is supplied under common property regimes.

## 5. PROPERTY RIGHTS AND NORTH–SOUTH TRADE

I shall now use the results of Section 4 to study the behaviour of *competitive and unregulated markets*, by analyzing the properties of the market equilibria of the North–South model defined in Section 3.

It was already observed that the South often specializes in the export of environmentally intensive goods, such as timber, cash crops requiring forest clearing such as palm oil and sugar, and other resource intensive commodities. In this section I shall establish that the reason for this is that common property resources are over-extracted in the South, because the true social costs of intensive environmental use are not properly computed. This is also true in some measure in the North. However, I shall argue that the divergence between private and social costs is larger in the South than it is in the North. This divergence causes the South to specialize in the export of environmentally intensive goods. The divergence between private and social costs is, in turn, explained by the lack of property rights in common property resources.

*Theorem 1. Consider the North–South model where both regions have the same technologies, the same homothetic preferences, and the same natural endowment of environmental inputs, i.e. the same social supply curves. The model as defined in the Appendix has at most one competitive equilibrium. If the South has ill-defined property rights for the environmental input, e.g. the resource is common property, then at a world equilibrium the two regions will trade, and the South will export environmentally intensive goods. The South will exhibit private gains from trade (as defined in Section 3) but in a steady state it extracts more environmental resources, and it produces and exports more environmentally intensive goods (B) than is Pareto efficient.*

*Proof*: Recall our assumption that the two regions are identical, but the South's supply of E is given by the private supply curve $E^{\pi}(p_E)$ while the North's is its social supply $E^{\sigma}(p_E)$. Consider the map from the world equilibrium commodity prices $p_A^*$ and $p_B^*$ to equilibrium factor prices in each region $r^*$ and $p_E^*$.[19] Under these conditions, at the world equilibrium price vector $p^*_w$, factor prices will be the same in the two regions, $p_E^*$ and $r^*$. However, since the supply curve of environmental resources in the South, $E^{\pi}(p_E)$, was shown in Lemma 1 to be higher than the supply curve $E^{\sigma}(p_E^*)$ in the North, at the world's equilibrium price vector $p^*_w$, the South supplies more environmental resources than the North (Figure 15.1). It follows that at $p^*_w$ the South produces a larger amount of B than does the North, since the production of B is intensive in the input E, which is more abundant in the South (see also Chichilnisky, 1981, 1988a).

Note that since the two regions have the same homothetic utilities, and at $p^*_w$ the two regions face the same relative prices for goods A and B, the North and the South demand goods A and B in the same proportions. Therefore, at the equilibrium price vector $p_w^*$ both regions demand the same proportion of A and B, but the supply of B in the South is proportionately larger. It follows that when the international markets clear, the South must export B, and the North import B, i.e. the South is an exporter of environmentally intensive goods at the world equilibrium. A computation of world equilibrium prices in this model and a proof of their uniqueness, is in the Appendix.

Now consider a different world equilibrium (denoted by the equilibrium prices $p_w^{**}$) where the South's supply of E is given by the social supply function $E^{\sigma}(p_E^*)$.[20] By assumption this equilibrium is unique, and by the first welfare theorem, the equilibrium allocation is Pareto efficient. In particular the quantity of environmental resources E used and the amount of B produced in the South is Pareto efficient at the equilibrium $p^*_E$, with $E^* = E^{\sigma}(p_E^{**})$.

Now as shown above, in the world equilibrium ($p_w^*$) where the South operates on its private supply curve for E, $E^{\pi}(p_E)$, the quantity of B produced by the South exceeds the quantity supplied by the North (which equals the Pareto optimum B*). Similarly, the quantity of E extracted at this new equilibrium, $E^* = E^{\pi}(p_E^{**}))$, exceeds the same quantity at the equilibrium $p_w^{**}$, which is $E^* = E^{\sigma}(p_E^*)$.

[19]The existence of such a function is well known (Stolper and Samuelson (1941)); within this North–South model it is established in Chichilnisky (1981,1988a) for the case where the two regions have the same constant returns to scale production functions without substitution, and it is also true for functions with substitution such as Cobb-Douglas with constant returns to scale.

[20]When resource supplies in both regions are given by the social supply curves, the countries do no trade in equilibrium, because they are identical in every way. This is an extreme specification which is easily relaxed. In general, when both countries operate at their social supply curves for E, trade will take place when either the technologies or the demand are different across the two regions.



Therefore at $p_w^*$ the South uses more resources (E) and exports more environmentally intensive goods (B) than is is Pareto efficient, as we wished to prove.

Note that the environmental overuse described in Theorem 1 is induced by a competitive market response to the lack of property rights in the South.

*Corollary 1. If exports of the environmentally intensive good B by the South lead to the equalization of the price of environmental resources used as inputs in the two regions, the South will still use more environmental resources than the North (and more than is Pareto optimal) unless property rights for the common property resources are improved in the South. If property rights are not improved in the South, then the exports of environmentally intensive goods and their domestic production would have to be curtailed in order to achieve patterns of consumption which duplicate the North's social optimum.*

This follows directly from Theorem 1 and Lemma 1. The interest of this corollary is to emphasize that the overuse of environmental resources by the South is not necessarily caused by their prices being lower in the South than in the North, as it is often thought. Equalizing prices through the international market does not resolve the problem of overuse of environmental resources.

## 6. PROPERTY RIGHTS POLICIES

Consider, for example, a policy which improves the land property rights of Amazonian small farmers such as rubber-tappers. They will change the supply function of Amazonian resources such as land, trees and biodiversity, and in turn affect relative input prices. This in turn changes the computation of comparative advantages and of gains from trade from agricultural exports based on deforestation of the Amazon. Production patterns will shift. Export patterns will reflect more fully the social cost of deforesting the Amazon. Examples of such property rights approach are provided by recent agreements involving debt-for-nature swaps (Ruitenbeck, 1990), which changed property rights in the expectation that the changes will protect the rain forest. An interesting example is provided by recent agreements between the U.S. pharmaceutical industry and Costa Rica among other countries. The spearhead of this project is a pair of ingenious efforts to exploit the forests to obtain medicinal products. The plans were described at a Symposium at Rockefeller University, January 1992, organized jointly by the Rain Forest Alliance, a non-profit organization, and the New York Botanical Garden's Institute of Economic Botany.[21] A Costa Rican research institute (INBIO) is prospecting for promising plants, microorganisms and insects to be screened for medical uses by Merck and Company, the world's largest drug company. Merck & Co., in turn, is supporting the prospecting effort financially and will share any resulting profits with Costa Rica. The Costa Rican government, which has set aside 25% of its land as forest preserves, will use the royalties and some of the initial payments to support the conservation efforts. In another effort, a small Californian company, Shaman Pharmaceuticals, is tapping the expertise of traditional healers – "shamans" or medicine people – in various parts of the tropics. This company has already

[21]See for example the report in *Science Times*, science supplement to the *New York Times*, 28 January 1992, page C1.

its intended effects. Poverty and environmental abuse have a common root, and both are the core of the North–South environmental dilemma.

## 8. APPENDIX

### The North–South Model and Its Solutions

This Appendix provides a general equilibrium formulation of the North–South model where one of the inputs of production in the South is a common property resource. Factor endowments in the two countries are not fixed as in the Heckscher–Ohlin model, but are variable, depending on factor prices. In this sense the model follows Chichilnisky (1981, 1986) but here the factor supply curves have slopes which depend on the property rights for the common property resource (as in Section 4) while in Chichilnisky (1981, 1986) all factors are, instead, private goods. In addition, Chichilnisky (1986) considers different technologies in the two regions, while here the technologies and the preferences are identical in the two countries. Except for the variable factor endowments, the model follows an Arrow–Debreu formulation of two competitive economies trading with each other. A comparison of the welfare properties of an equilibrium in the North–South model and the Arrow–Debreu model can be found in Chichilnisky (1990).

To simplify notation and computation we consider constant returns to scale production functions and simple utilities. The model and its results are extendable to a wide variety of utility functions and demand specifications and to Cobb-Douglas and CES production functions, but at the cost of significantly longer computations. For such extensions see Chichilnisky (1986).

We specify first one economy: the South. It produces goods A and B using two inputs: E and K. We consider a fixed proportions technology in each sector, although there is substitution of factors at the aggregate level, as is shown below, because endowments are variable, see Figure 15.7. Efficient production plans satisfy $B^s = E^B/a_1 = K^B/c_1$, and $A^s = E^A/a_2 = K^A/c_2$, where the superscript s denotes supply. Recall that $E^A + E^B = E^s$ varies with prices and so does $K^A + K^B = K^s$.

We assume that B is more resource intensive than A so that $D = (a_1c_2 - a_2c_1) > 0$. The following equations define an equilibrium. Competitive behaviour on the part of the firms assures zero profits:

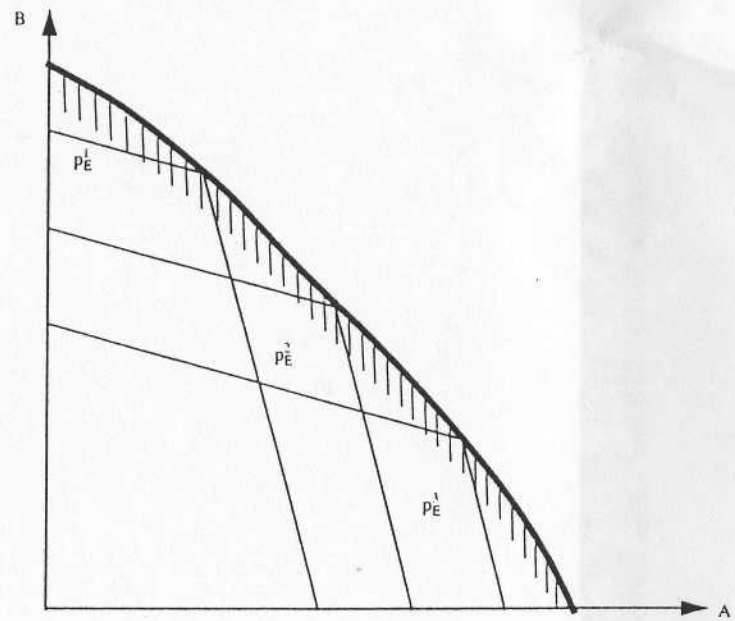
$$(A1)\ p_A = a_1 p_E + c_1 r$$
$$(A2)\ p_B = a_2 p_E + c_2 r$$

where $p_A$ and $p_B$ are the prices of A and B respectively, $p_E$ is the price of the resource, and r is the rental on capital. As shown in Section 4, the environmental resource E supplied in equilibrium $E^s$ is an increasing function of $p_E$ for any given q. To simplify the computation of solutions we assume here a simple form of this relation:

$$(A3)\ E^s = \alpha\ p_E + E^\circ$$

where $\alpha > 0$ depends on the property rights regimes for E as established in Section 4. Lemma 1: A large parameter $\alpha$ represents ill-defined property rights, such as the






As $p_B$ changes, so do factor prices r and $p_E$ (A1 and A2) and therefore factor endowments K' and E' vary.

For each set of factor endowments we have a different production possibility set. As $p_B$ varies, therefore, we obtain the overall propuction possibility set shaded above. This exhibits substitution in the use of the two factors: capital K and environmental resources, E. The subsitution occurs through changes in the output mix.

Figure 15.7

case of common property resources, and a small $\alpha$ represents better defined property rights for the resource E, such as private property. The parameter $\alpha$ can vary as a continuum, indicating a variety of "shades" of property rights between the two extreme cases. Because of Lemma 1 we know that the slope of $E^S$, $\alpha$, increases with the lack of internalization of externalities that each harvester produces on the others.

$$(A4)\ K^s = \beta r + K^\circ$$

where $\beta \geq 0$; everything that follows applies for $\beta = 0$ as well, i.e. when $K^s$ is a constant. For a given property rights regime, factor supplies vary with factor prices, so that *the overall production possibility frontier exhibits substitution in the total use of capital and environmental resources*, see Figure 15.7. In equilibrium all markets clear:

$$(A5)\ E^S = E^d$$
$$(A6)\ K^S = K^d$$

This is a quadratic equation in $p_B$ which has at most one positive root because the constant term is negative. Therefore there is at most one equilibrium price $p_B{}^*$. From $p_B{}^*$ we can obtain in each country the equilibrium levels of all other variables: $p_E{}^*$ and $r^*$ from (A1) and (A2), $E^{s*}$ and $K^{s*}$ from (A3) and (A4), $B^{s*}$ and $A^{s*}$ from the production functions, $X_A^{d*}$ from $A^{s*}$, $A^{d*}$ and $X_B^{s*}$ from (A11), so the (unique) full equilibrium of the model is computed.

Note that in order to simplify computations, we have taken utility functions which effectively make the demand for A in each region an exogenously chosen parameter at an equilibrium. This follows Chichilnisky (1981, 1986), where it is also shown that the results generalize to more general utilities and demand functions.

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