Property rights and the dynamics of renewable resources in North-South trade, Chapter 1

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1.1 Property Rights and the Dynamics of Renewable Resources in North-South Trade

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ABSTRACT

To explain the patterns of world trade of resources, this paper combines the biological dynamics of the renewable resource and game theoretical explanations of its extraction under different property regimes, with a general equilibrium model of North South trade (Chichilnisky, 1981, 1986). The two regions produce, consume and trade two goods using two inputs, a renewable resource E and capital. To expose the importance of property rights in explaining trade, the two regions are taken as identical except for the property rights regimes on the pool from which the resource is extracted: the South has common property and the North private property. The paper formulates the Nash equilibrium of a game which explains the harvesting of the resource under different property rights regimes: more is supplied at each price under unregulated property rights than it is with private property (Lemma 1). Theorem 1 proves that the difference in property rights by itself explains trade between otherwise identical regions: the South exports the environmentally intensive product even though it has no comparative advantage and the North the capital intensive products. The North overconsumes the resource intensive products which it imports at prices which are below social costs. This occurs even though in equilibrium the prices of all goods and all factors of production are equal across the world. Resources are overextracted and the world pattern of consumption and trade of resources is Pareto inefficient. Several policies which could redress the inefficiency, particu-

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larly recent property rights policies towards biodiversity and land ownership in the Americas, are discussed in this paper.

1. INTRODUCTION

The global environment can be described by the physical dynamics and the economic use of the earth's resources. It has become, t a certain extent, a North-South issue.[2] Developing countries tend to specialize in the production and the export of goods which deplete environmental resources such as rain forests, or minerals 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 approximately 75% of the world's CO_2 emissions: the US alone consumes 25–30% of the world's oil production yearly (Chichilnisky, 1994a). When trying to define precisely the concept of sustainable development we are led therefore to question the role of international trade.[3] In practical terms: are trade policies based on the traditional comparative advantages of developing countries compatible with environmental preservation? Should the developing countries export more resource and land intensive products such as agricultural goods? Or should a new vision of international trade, one that is more consistent with the world's environment, replace the old?

This paper studies these issues within a two region world economy where the North represents the industrial countries and the South the developing countries. I consider a class of environmental issues arising from the use of renewable environmental resources as inputs to the production of traded goods. Typical examples are rain forests used for timber, or destroyed to give way to the production of cash crops such as coffee, sugar and palm oil.[4] In many developing countries, these are unregulated common property resources (Dasgupta and Heal, 1979) whose ownership is shared with future generations (Arrow and Fisher, 1974).

It could be argued that sustainable development is all about the proper management of the world's renewable resources. If petroleum is replaced by fuels based on biomass as currently done in parts of Brazil and Austria, and electricity is generated by wind or water power as is done in parts of Europe and the USA, then even energy can be obtained from renewable resources. The atmosphere can be considered a renewable or self-regenerating resource, as are bodies of water, forests and fisheries. To a great extent the global environmental dilemma is described by the dynamics of the productive use of the earth's renewable resources.

Following the Heckscher-Ohlin simple and powerful formulation, the problem of North-South trade is studied here in a two region world with two goods and two inputs of production each. I consider completely unregulated competitive economies which trade freely with each other in the international market. There are, however, two significant departures from traditional trade theory. One is that one input to production is an environmental resource. This environmental resource is self-renewable and in principle exhaustible, such as a forest or a fishery. Its population dynamics is represented by a differential equation which describes the demographic progress of the species, its stock through time. The ecological dynamics of the resource then merges with the functioning of the two region market economy which uses the stock of the resource as an input to the production of traded goods. Our concern is to study the impact that international trade between the regions has on the progress of the species. The second major departure from traditional theory is that the regions are characterized here by their property rights regimes for the environmental resource to emphasize the importance of property rights in explaining trade, the two regions are taken to be identical in every way (same technologies, inputs, preferences) except in the property rights regimes on a pool from which the renewable resources are extracted. In the North property rights are well defined, while in the South the environmental resource is common property.

It seems worth motivating this framework of analysis and relating it with the traditional theory of international trade. The regions in a Heckscher-Ohlin world differ solely in their relative factor endowments, and this difference suffices to explains trade flows. However, endowments do not always explain observed trade flows in environmental resources. For example Honduras is an active exporter of wood to the US, even though the US is overwhelmingly richer in forested land and Honduras relatively richer in labor. Ricardo's explanation of why countries trade does not work in this context either, because US labor is more productive in wood extraction than is Honduras'. It is worth observing however that Honduras' forests are mostly a national property, while wood cutting in the US occurs mostly in private land. Property rights in the two regions are different, with

Honduras treating its forests as unregulated common property. Another example is provided by the traditional rubber-tappers in the Amazon forest, who use the forest as a common property renewable resource; the Korub National Park in Cameroon at 60 million years of age, one of the oldest rain forests in the world, is also exploited as a common property resource to produce palm oil for the international market (Ruitenbeck, 1990). In the industrial countries the situation is quite different. Japan has well defined property rights for environmental resources such as sun light. The US has an extensive legal infrastructure for eliminating the overexploitation that accompanies common property resources, such as the Hot Oil Act of 1936 and "unitization" laws (McDonald, 1971). Citizen's property rights towards the use of running water are well established in the United Kingdom since the Middle Ages[5].

With such examples in mind, we consider two regions which differ solely in their property rights regimes for an environmental resource which is used as an input to production. It is important to distinguish property rights regimes from the regulation of markets. We consider here competitive and unregulated markets throughout. The environmental resource is renewable and in principle exhaustible. If left on its own it follows its own ecological dynamics which we represent by a standard differential equation. The equation is modified by the economic use of the resource as an input to production.

We prove that due to the differences in property rights for the resource, in a steady state the two regions will trade; indeed this difference alone explains the pattern of trade between the two regions. The difference in property rights for the environmental resource is shown to lead to a market induced "comparative abundance" of environmental inputs in the South, in the sense that at each market price, the stable steady state extraction of the environmental resource in the South exceeds that of the North, Lemma 1. The resource extraction in the South exceeds optimal extraction, so that there is overexploitation of the resource. In some cases this can lead to the extinction of the species.

A market-induced "competitive advantage" in resources arises in the South despite the fact that the two regions are identical in the economic sense: same endowments, technologies and preferences. Furthermore, neither region has environmental regulations, so that differences in market regulation do not explain why the South exports resources to the North.

At a free and competitive market equilibrium, all prices, for the traded goods and for all the inputs of production, are equal across the regions. Therefore the exports of the South are not explained by the South having lower input prices.

In the absence of any market intervention, it is shown that in a competitive and unregulated market, differences in properly rights between the two regions lead to a steady state pattern of international trade in which the South exports environmentally intensive goods, and overextracts and uses its environmental resources beyond what is Pareto efficient. In this world economy, international trade is explained solely by the difference in property rights between the two trading regions, Theorem 1.

Gains from trade must now be redefined since neither Heckscher-Ohlin nor Ricardo's concepts apply. This is achieved in Sections 2 and 3. There may be *private* gains from trade but due to the lack of property rights externalities in the extraction of the resources are not internalized. As shown in Sections 3 and 4, under 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 accompanied 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 overconsume 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 overconsumes. 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 US 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 transmitted and enlarged by the international market and becomes a problem for the world economy. The resulting allocation is inefficient 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 to be a poor choice for their exports. Such products could be produced for domestic use in the South, but exported 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 a more efficient use of 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-labor intensive products, such as consumer electronics, biotechnology, telecommunications and other manufactured products which are produced under conditions of external economies of scale, 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), and 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. A 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 paper is organized as follows. Lemma 1 studies the connection between different property rights regimes and the steady state 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 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. 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 conencted with externalities in production and consumption. Externalities come in 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 behavior 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; Baumol and Oates, 1974). 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, overfishing, the depletion of trees and shrubs from common land for use as fuel are familiar problems. They are traceable to the "common property" nature of such resources as grazing land, fisheries and forest cover.

So too with the drawing of water from aquifers which by the nature of things must usually be common property even when the land covering the aquifer is privately owned" (Dasgupta, 1990).

Common property resources have the characteristic that one person's use interferes with the use by others, and diminishes the productivity of the resource to them. Hence private returns exceed social returns and there is overuse (Dasgupta and Heal, 1979). Because of the divergence between private and social prices, any standard measurement of comparative advantages and of gains from trade will be different if computed in terms of *social* costs than if computed with *private* costs. *Public* and *private gains from trade* will differ.

When the environment is taken seriously, and we have little choice in the matter, the classical theorems on international comparative advantages and gains from trade must be reconsidered. We must now account for *public* comparative advantages and for *public* gains from trade. Obviously these could be very different from their private counterparts.[6] We turn now to the formalization of this issue.

3. A GENERAL EQUILIBRIUM MODEL OF NORTH-SOUTH TRADE: PUBLIC VS. PRIVATE COMPARATIVE ADVANTAGES

We shall study *public vs. private comparative advantages* and *gains from trade* within a general equilibrium model in which the environment enters as an input of production. Environmental resource markets will be shown to reflect and transmit all aspects of the private vs. public dilemmas. Through these markets, environmental inputs have an impact on the general equilibrium of the economy: on the market price of goods, the distribution of income, the patterns of consumption and international trade.

The model we define is a two goods, two inputs, two country model similar to that of Heckscher-Ohlin (Ohlin, 1933), a version of the Arrow-Debreu model. However, in terms of the underlying analytical structure there is a major difference: the treatment of one of the inputs. This input is a renewable environmental resource with its own ecological dynamics. From the steady state behavior of this dynamics we derive the supply for the stock of the resource as a function of its price. The supplies of inputs in this economy, capital K and environmental resources E, are therefore price dependent, in contrast with the Heckscher-Ohlin theory where they are, instead, fixed.

In the next section we derive the steady state behavior of the supply of the resource as a function of prices. From the ecological dynamics of the resource and its economic use, we derive a steady state relation between the quantity of the extracted resource and the price of the resource, $E^s = E^s(p_E)$. This is generally an increasing function so that we may also write its inverse $p_E = p_E(E)$, where p_E is the price of a unit of the environmental resource E.[7] In this sense the model follows Chichilnisky's North-South model (1981, 1986) where inputs are price dependent, but here the inputs of production are capital and environmental resources, rather than capital and labor. A 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. This changes the analysis significantly, as shown in Lemma 1 and Theorem 1. There are two major differences with earlier versions of the North-South model. One is that here one of the inputs is a common property resource and its supply curve is shown to be determined by and to vary with, the structure of property rights in the economy (Section 4). In the North-South model (Chichilnisky, 1986) the inputs are private goods, and their price-dependent supply curves are fixed throughout, so that the impact of property rights on the supply of common property resources could not be examined. The effects of property rights regimes on the supply of resources were also examined in Chichilnisky (1991), but only within a static economy.

The model for *one region* is formalized as follows. There are two inputs of production, K, capital, and E, the environmental resource. They are used to produce two goods, A and B; B is more intensive in the use of the environmental resources than A, which is more capital intensive. The production functions are $A = f(K_A, E_A)$ and $B = g(K_B, E_B)$, both of which are concave and exhibit constant returns to scale. A strictly concave homothetic utility function $U(A, B)$ for goods is postulated; this could be considered the country's "community preference".[8] Initial endowments of E and K are given by the supply functions $p_E = p_E(E)$ and $r = r(K)$, where p_E denotes the price of the environmental resource, and r the rental price of capital. $E^s = E^s(p_E)$ is derived in the next section from the ecological dynamics of the renewable resource interacting with the optimal economic extraction rate. Here it suffices to note that both of these functions are continuous and increasing in their arguments, and in particular, invertible, $E = E(p_E)$ and $K = K(r)$. One of the goods, 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:

$$(D_A, D_B, D_K, D_E) = D(p_B, r, p_E) \tag{1}$$

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 labor 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:

$$\begin{aligned}&(D_A - f(K, E)) + p_B(D_B - g(K, E))\\&+ r.(D_K - K(r)) + p_E.(D_E - E(p_E)) = 0.\end{aligned} \tag{2}$$

A *one region equilibrium* is a price vector p^* at which each of the four markets clears[11] i.e. $p^* = \phi^{-l}(0)($ or $p^* \epsilon \{\phi^{-l}(0)\})$. 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 not traded internationally. For the same reason, in a world equilibrium the prices of these inputs could in principle be different in the two countries although we prove below that at a world equilibrium all prices, including input prices, are equal across the world economy.[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 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 each user has on others. This is formalized in the following section, where we show that at each market price the private[14] supply curve provides more E than the social supply curve. 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, in the South such property rights are not well-defined, so that the private and social curves are quite different. This 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 either. 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, 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 yields the *public production possibility set* $PPS^{\sigma} = \cup_p PP^{\sigma}(p)$, which is also convex.

At the *world equilibrium price*[15] $p_w^* = (p_B^*, r^{*N}, p_E^{*N}, r^{*S}, p_E^{*S})$, with superscripts indicating regions, the quantifies exported and imported of the two goods A and B match: the world's excess demand vector is zero, i.e. $p_w^* = \phi_w^{-1}(0)$. Note that the world's excess demand function $\phi_w(p_w)$ is a function of five relative prices[16] with values in six markets: the markets for goods A and B, and two markets for inputs K and E in each region (N and S). At the equilibrium price p_w^* in each region the supply of capital matches its demand $K(r^*) = D_K(p_w^*)$ and the supply of the environmental resources matches its demand as well, $E(p_{E^*}) = D_E(p_w^*)$.

Gains from trade are defined as usual: they are given by the increase in utility $U(A, B)$ associated from a move from an equilibrium allocation in autarky (each country in isolation) to a world equilibrium. Again we must differentiate between private and public gains. *Public gains* from trade are computed by comparing welfare in autarky and at a world equilibrium, with respect to the model with *public production possibility sets*. *Private gains from trade* are defined in the same fashion, but using the *private production possibility sets*.

Since private and public supply curves are similar in the North, the North's public and private production possibility sets are also similar. Thus private and public gains from trade are the same in the North. Not so in the South. The weaker the property rights in the South, the larger will be the divergence between the public and private supply curves, and between the private and public production possibility sets. Thus the weaker the property rights in the South, the larger will be the divergence between its private and its public gains from trade.

4. THE DYNAMICS OF RENEWABLE RESOURCES WITH DIFFERENT PROPERTY RIGHTS

This section derives the supply curve for the renewable environmental resource E under different property fight regimes. We study the dynamics of the population of the renewable resource with and without economic use. From its steady state behavior we derive the supply curve as a function of its price. Finally we show

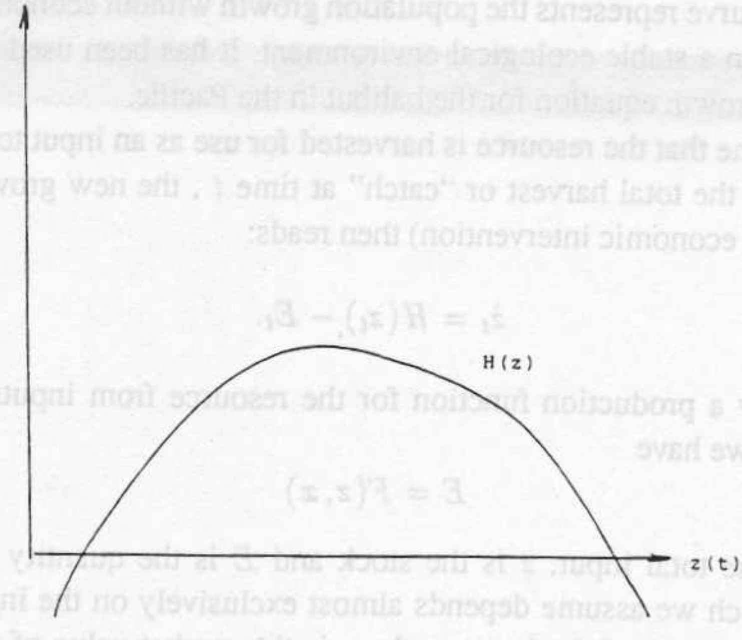

Fig. 1. The growth of the population increases with the population size until there is overcrowding.

how the long run supply curve of the resource varies with the property fights regimes.

4.1. The Dynamics of the Renewable Resource

A standard manner in which renewable resources – such as forests and fisheries – are modeled is by assuming a "population growth curve" that describes the demographic progress of the species. If z_t is the stock or population size at time t:

$$\dot{z}_t = H(z_t). \tag{3}$$

The function H is frequently assumed to have a form as depicted in Figure 1 below, implying that growth of the population increases with the population size until there is overcrowding. This assumes that the species progresses within a stable environment. A well known case is when H is quadratic in z,

$$\dot{z} = H(z) = \beta z - \gamma z^2 \text{ with } \beta, \gamma > O, \tag{4}$$

which we now assume. This integrates to yield the classic logistic curve

$$z_t = \beta z_o / [\gamma z_o + (\beta - \gamma z_o) exp(-\beta t)], \tag{5}$$

This logistic curve represents the population growth without economic intervention and within a stable ecological environment. It has been used *inter-alia* to describe the growth equation for the halibut in the Pacific.

Now assume that the resource is harvested for use as an input to production. If $E_t(\geq 0)$ is the total harvest or "catch" at time t , the new growth equation (ecology with economic intervention) then reads:

$$\dot{z}_t = H(z_t) - E_t. \tag{6}$$

Consider now a production function for the resource from inputs x. At each stock level z we have

$$E = F(z,x) \tag{7}$$

where x is the total input, z is the stock and E is the quantity harvested or extracted which we assume depends almost exclusively on the input x. If q is the opportunity cost of the input, and p_E is the market value of the resource, both given by the market in a competitive framework, then net profit at time t is

$$\pi_t = p_E F(z_t, x_t) - qx_t, \tag{8}$$

and optimal behavior under a private property regime implies that

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

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

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

which implies that

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

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

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

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

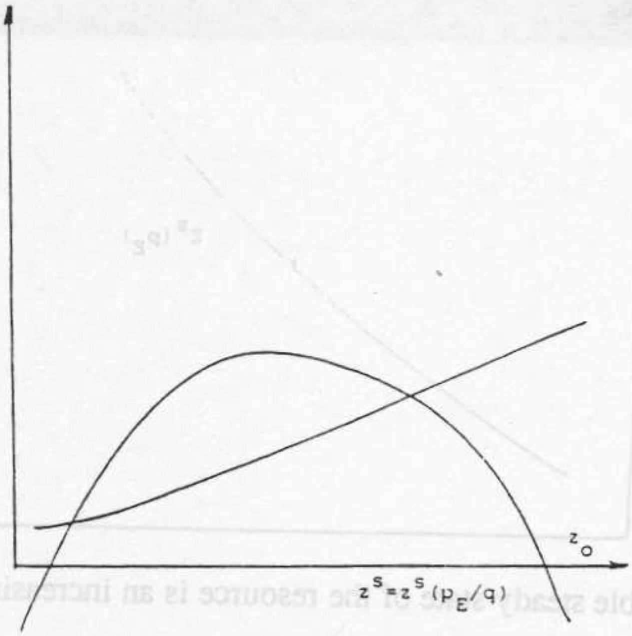

Fig. 2. The larger steady state z^s is stable under the assumptions.

the resource increases with profits as defined in (8) (see also Dasgupta and Heal, 1979, p. 122.) i.e.

$$\dot{x}_t = \mu \pi_t, \quad \text{where} \quad \mu > 0. \tag{13}$$

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 $E(z) = (p_E/qb)^{b/(1-b)}$ $z_t^{a/(1-b))}$ as illustrated in Figure 2. The larger steady state (denoted z^s in Figure 2) is stable under (13) when $\frac{\partial F}{\partial z} \sim 0$, 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 2. In this event, the population size tends in the long run to the steady state z^s as illustrated in Figure 2 below, where z^s is a function of p_E and q, $z^s = z^s(p_E/q)$. The corresponding harvest or extraction is $E^s = E^s(p_E/q)$.

4.2. *Resource Supplies and Property Rights*

The solution $z^s(p_E/q)$ describes the long-run behavior of the stock of the renewable resource E under private property regimes (equations 7 to 9). Note

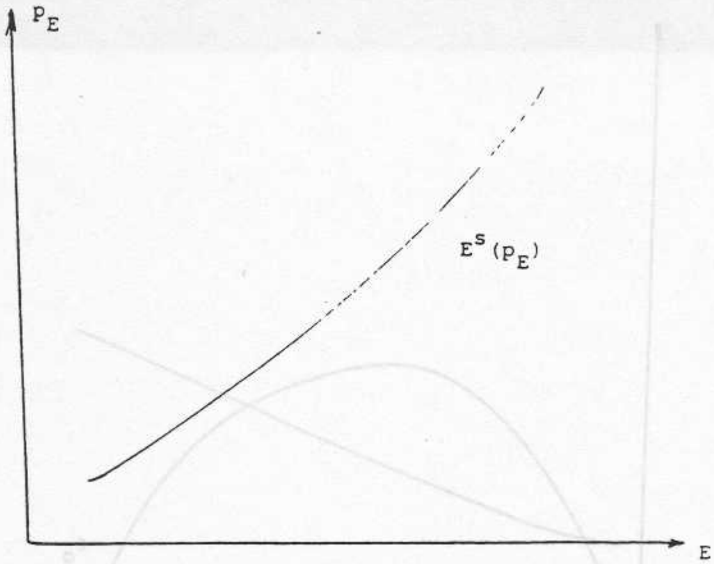

Fig. 3. The stable steady state of the resource is an increasing function of the market price p_E.

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 of p_E leads to an upwards vertical shift of the curve $(p_E b/q)^{b/(1-b)} z_t^{a/(1-b)}$ in Figure 2 which in turn implies a larger steady state harvest and a correspondingly smaller steady state stock z^s. For each q, let

$$E^s = E^s(p_E), \tag{14}$$

denote the supply curve of the resource E in a stable stationary state as a function of the price p_E. $E^s(p_E)$ is an increasing function of p_E as illustrated in Figure 3. The curve $E^s(p_E)$ in (14) is the *social supply curve* of the resource E as defined in Section 3, since it is derived using (9), i.e. maximizing profits and internalizing fully the impact of each unit extraction on the productivity of the following units.

Our next step is to study the variation of the stationary stock of E, or equivalently of the steady state solution z^s, with respect to different property rights regimes. We wish to compare the supply curve for the resource with a common property regime with the social supply curve $E^s(p_E)$ defined in (14).

4.3. Comparative Dynamics of the Stock of Environmental Resources with Respect to Property Rights

We wish to perform the comparative dynamics of the stock of the environmental resource with respect to property rights regimes across stationary states. For each properly rights regime, we must redefine the production function in (7) above to reflect the extent to which the harvester takes into consideration the externalities that its harvesting produces on the other harvesters at that regime. For example, in the private property regime already discussed the harvester fully internalizes the impact of its catch on the productivity of the next unit of input by taking into account the marginal productivity of the catch (9). With common property resources this may not be the case, leading in a limiting case to the so called "tragedy of the commons", as discussed below. In order to compare the supply curves in each case, we shall now derive explicitly the cost curves associated with the extraction of E from a *common property resource pool,* such as a fishery.[17]

Let there be N "harvesters" of a common properly resource, indexed $i = 1, ..., N$. Let x_i be the input of harvester i to harvesting the common property resource E. Let $x = \sum_{i=1}^{N} x_i$. We assume that the inputs of all harvesters are identical and interchangeable, so that for each stock z the total harvest can be expressed as a function $E = F(x)$ of the total input. We also assume that all harvesters are symmetric, so that for a stock z each harvester obtains as its output a fraction of the total output equal to the fraction that it supplies of the total input, formally $E_i = F(x)(x_i/x)$. These are all natural and standard assumptions, as in Dasgupta and Heal (1979), Chapter 3. We assume that for a stock z, each harvester chooses its input level x_i to maximize the value of its share of outputs net of costs, $p_E E_i(x_i) - q.x_i$, taking as given the output levels of others, E_j for $j \neq i$. Here p_E is the market induced price of the resource, which is an exogenous parameter for the competitive harvester, and q is the "opportunity cost" of the input x_i. We are therefore modeling a Nash equilibrium pattern of use of a common property resource. Finally, $F(x)$ is assumed to be strictly concave, so that for each stock z the production of the environmental good E is characterized by strictly diminishing returns, arising perhaps from the application of increasing mounts of variable input x to a fixed body of land or water. Under these conditions we show in the following lemma that the private supply curve of the common property resource lies below the social supply curve.

Lemma 1 *Under the assumptions listed above the private supply curve for the common property resource lies below the social supply curve, so that at each price more resources are supplied under common property than it is socially optimal.*

Proof. Consider a given level of the stock z, and let $F(z, x) = F(x)$. Then the marginal product of the input x is $F'(x)$, and the average product is $F(x)/x$. Observe that by strict concavity, $F(x)/x > F'(x)$. Look first at marginal products. The private marginal product of the input is denoted Pmp and the social marginal product is Smp. With identical harvesters, if harvester i uses inputs x_i, his/her yield is by assumption $y_i = x_i F(x)/x$, i.e. average yield per unit of input times amount of input. So harvester i's production function for E is given by

$$y_i(x_i) = x_i F(x)/x.$$

Now,

$$Pmp_i = d/dx_i[x_i F(x)/x] =$$
$$d/dx_i[x_i F(x_i + x_{-i})]/(x_i + x_{-i}) \text{ where } x_{-i} = \sum_{j \neq i} x_j.$$

Hence under the assumptions

$$Pmp_i = F(x)/x + x_i\{(xF'(x) - F(x))/x^2\} \tag{15}$$
$$= F(x)/x + (x_i/x)\{F'(x) - F(x)/x\}.$$

This analysis is independent of the number of harvesters as long as there is more than one, $N > 1$. Note that as the number of harvesters becomes very large, x_i/x goes to zero, and the private marginal product becomes the average product. In this limiting case we recover the well-known result that harvesters equate input prices to average return rather than to marginal product, the basis of the "tragedy of the commons". Our results, however, do not rely on any limiting assumptions on the number of harvesters. Since $Smp_i = F'(x)$,

$$Smp_i - Pmp_i = F'(x) - F(x)/x - (x_i/x)[F'(x) - F(x)/x] \tag{16}$$
$$= [F'(x) - F(x)/x][1 - x_i/x] < 0.$$

Therefore the social marginal product of the input is lower that the private one, and the curve in Figure 3 if defined with common property resources, is higher than the curve $E(z)$ defined under a private property regime. Since F is a concave

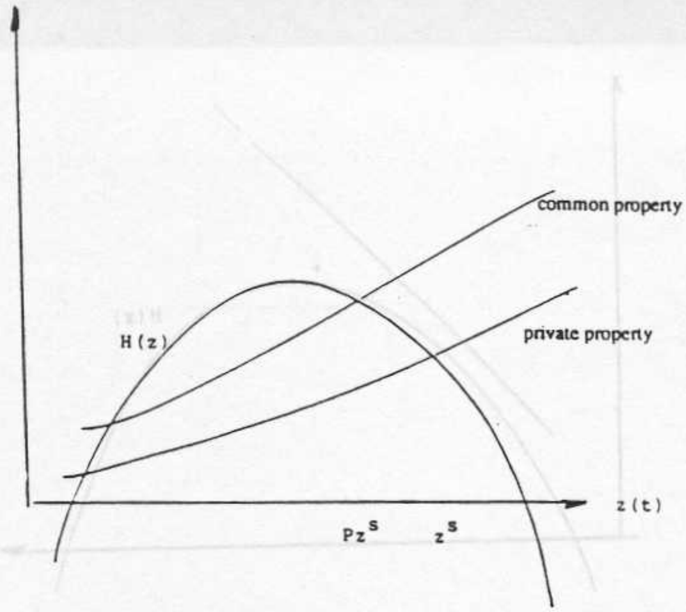

Fig. 4. The stable steady state extraction under common property regimes is larger than that under private property.

function of x, this implies that for each given z and at each value of p_E, the stable steady state quantity harvested under a common properly regimes PE^s (Figure 4) is larger than the corresponding amount E^s under private property. Or, equivalently, the long run steady state of the stock denoted is smaller in the case of common property resources than the same steady state with private property. In a limiting case the extraction with common property regimes is sufficiently high that no steady state with a positive stock exists (Figure 5). The species eventually disappears.

Since the optimal catch curve is now higher for each z, then for $z = Pz^s$ we obtain the relation between the harvest size and its price, i.e. the *private supply curve* PE^s of the resource E. This is an increasing function of p_E giving a larger steady state harvest of E (and a smaller steady state of the stock) for each price p_E than does the social supply curve $E^s(P_E)$ in (14), i.e. for all p_E,

$$PE^s(p_E) > E^s(p_E) \tag{17}$$

as we wished to prove. ♦

Figure 6 illustrates the private and social supply curves for the environmental resource E. The social supply curve is obtained by equating the opportunity

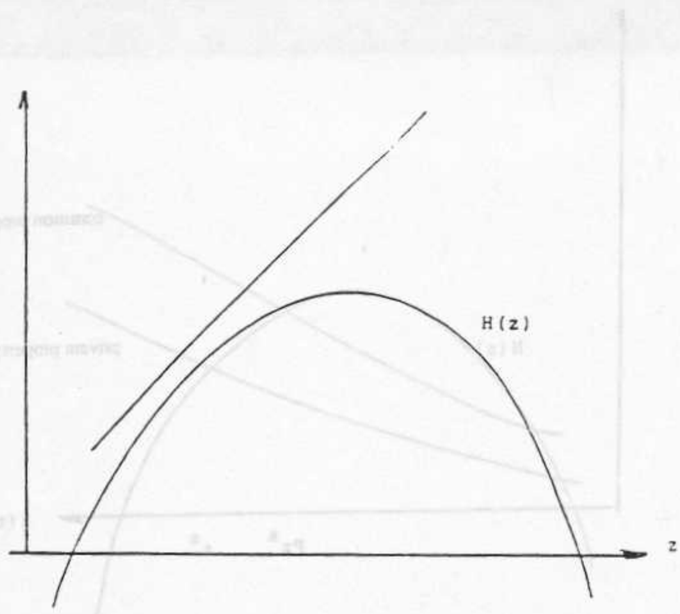

Fig. 5. Extinction of the Species in the Long Run

cost q with the value of Smp_i, $q = p_E.F'(z)$. Instead, the private supply curve is obtained by equating:

$$q = Pmp_i.p_E$$

5. PROPERTY RIGHTS AND NORTH-SOUTH TRADE

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

We already observed that the South 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 we shall establish that a reason for this is that common property resources are overused 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, we shall argue that the divergence between private and social costs is much 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

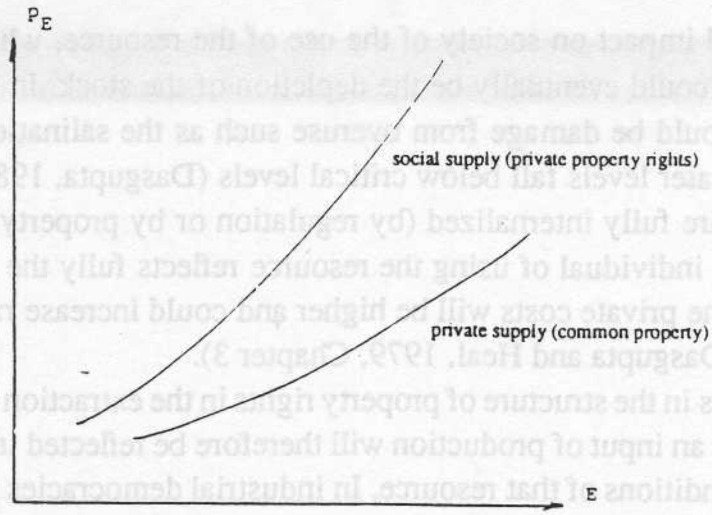

Fig. 6. The socially optimal supply curve is the social supply curve which internalizes all externalities (under private property regimes). The social supply curve supplies less resources at each price than does the private supply curve.

between private and social costs is, in turn, explained by the lack of property rights in common property pools from which the resource is extracted.

Consider the North-South model where the environment enters as an input of production, E. Environmental inputs will be shown to have a particularly pronounced effect on the pattern of international trade. This can be seen as follows.

Recall that our model has price-dependent supply functions for environmental resources, given by $p_E = p_E(E)$, where p_E is the price of a unit of the environmental resource E. The importance of this price dependence became clear in Lemma 1 where we proved that *the supply function of an environmental resource depends on the nature of the property rights for that resource.* This in turn will determine the patterns of trade.

Consider the common property resource E. If there are no regulations concerning the use of the resource and no enforceable private property rights in this resource, then the cost to an individual of extracting an additional unit of E as an input of production will be relatively low. This will merely reflect the private costs such as e.g. in the case of a fishery, the private costs of catching, and in the case of an aquifer, the private costs of obtaining the water. They will not reflect the full impact on society of the use of the resource, which in the case of the fishery could eventually be the depletion of the stock. In the case of the aquifer this could be damage from overuse such as the salination which takes place when water levels fall below critical levels (Dasgupta, 1982). If however externalities are fully internalized (by regulation or by property rights) so that the cost to an individual of using the resource reflects fully the social costs of its use, then the private costs will be higher and could increase rapidly with the level of use (Dasgupta and Heal, 1979, Chapter 3).

Differences in the structure of property rights in the extraction of the resource that is used as an input of production will therefore be reflected in differences in the supply conditions of that resource. In industrial democracies property rights are better established and more widely enforceable than in developing countries, and regulatory policies designed to internalize costs of using an environmental resource (such as polluting clean air with automobile exhaust fumes, or burning coal for heating purposes) are more widespread and widely enforced. This is due in part to the large costs associated with a legal infrastructure and a system of enforcement and control: such costs are relatively more accessible to rich industrial countries.

If the two regions are identical but only in the North are property rights for the environmental resource well-defined, then the private costs of an environmental resource as an input of production will be higher in an industrial democracy than those in a low income country. In both countries the social costs are the same, but in the low income country the private costs may be well below social costs. We saw in Lemma 1 that this implies that the supply for environmental resources will be larger (a larger slope of the supply curve) at each level of prices in the low income countries (the South) than in the industrial countries (the North). In general, the larger the divergence between private and social resource costs, the larger will be the divergence between social gains from trade and private gains from trade. When social prices differ widely from private prices what appears as a relative advantage may actually be a relative disadvantage. We can therefore expect that considering trade in a world where environment is a crucial input whose supplies are "abundant" in the South because of the divergence between private and social costs, will lead to substantial economic implications. This will be discussed below.

We may consider a wide variation in property rights, indeed a continuum of these, parameterized by the slope of the supply curve for the environmental resource used as an input of production. Two limiting cases will be explored:

when the input is a common property resource, and when the input is instead privately owned. Between these two limiting cases there is a wide variety of property rights regimes in which the input is partly private and partly commonly owned. As long as the input is not entirely private, the supply of the resource is determined without fully accounting for the costs of each individual's use to others, and therefore the extraction of the resource will yield a flatter curve, one which is more responsive to the market price of the input, than would be the case under a private property regime.

Observe that when the resource is privately owned, owned for example by one firm, or by a small cooperative of peasants in the region,[18] then the private and the social supply curves (or marginal cost curves) are one and the same. Our assumption is that this is often the case in an industrial democracy, and indeed many practical examples exist to substantiate this assumption. But this is often not the case in developing countries. This means that in an industrial democracy, which we call the North, there is essentially one price-dependent supply curve for the environmental resource (private and social costs being the same) while in the South there are two different curves, the private and the social curves. The social curve is a theoretical curve which would emerge if property rights were well defined in the South.

The private curve prevails in setting up the patterns of trade in free markets. For the same input, under the same production conditions, this difference in property rights leads to different effective supply curves in the North than in the South: a lower and flatter curve in the South. This is quite independent of any assumptions on input prices or in any other prices. The difference simply reflects the lack of property rights.

When social costs differ substantially from private costs and property rights are not well established, the social cost of the environmental input is substantially underestimated by market prices. This means that at the same price much more of the input would be provided than would be socially optimal. In other words, the South, because of lacking property rights, appears to have a relatively higher supply of environmental resources *at each price* than does the North. Indeed, at each price, the supplies offered will be higher than they ought to be if proper social costs were computed.

The reality could be very different from the appearances. Even though here we assumed for simplicity that the two regions are identical, it is clear that the point is rather general. For example, when social costs are computed, the South could have a comparative disadvantage in the production of environmentally intensive goods even if it exhibits a private comparative advantage. E.g. the social cost of extracting the same amount of environmental resources could be higher in the South, due for example to a relatively smaller total stock. Everything else being equal, the lack of property rights in the South explains why the South specializes in the exports of environmentally intensive goods. This occurs with the functioning of markets in a classical model of trade through comparative advantages. Here, however, the comparative advantages are not real: they derive from a market failure to compute the true social costs of the environmental input.

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 ie. 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 extracted from a common property pool. 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 $pE^s(p_E)$ while the North's is its social supply $E^s(p_E)$. 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^* (see Appendix). However, since the supply curve of environmental resources in the South, $pE^s(p_E)$, was shown in Lemma 1 to be lower than the supply curve $E^s(p_{E^*})$ in the North, at the world's equilibrium price vector p^*_w, the South supplies more environmental resources than the North (Figure 6). 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, 1986).

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 theft uniqueness, is in the Appendix.

Now consider a different world equilibrium (denoted by the equilibrium prices p_w^{**}) where the South's property rights are well defined and therefore the supply of E is given by the social supply function $E^s(p_E^*)$.[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 $E^* = E^s(p_E^{**})$.

Now as shown above, in the world equilibrium (p_w^*) where the South has ill-defined property rights and therefore has a private supply curve for E, $pE^s(p_E)$, 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, $E^* = E^s(p_E^{**})$), exceeds the same quantity at the equilibrium p_w^{**}, which is $E^* = E^s(p_E^*)$. 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 *Free and competitive trade leads to the equalization of all goods and factor prices and in particular equalizes the price of environmental resources used as inputs in the two regions. Yet the South uses 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 its exports of environmentally intensive goods are its domestic production would have to be curtailed in order to achieve patterns of consumption which duplicate the North's social optimum. The equalization of factor prices is established in the Appendix.*

The corollary 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 is often thought. Equalizing prices through the international market will not resolve the problem of the world's overuse of environmental resources.

6. PROPERTY RIGHTS POLICIES

Consider, for example, a policy which improves the property fights of Amazonian small farmers such as rubber-tappers. This will change the supply function of Amazonian resources such as land, trees and biodiversity, and in turn affect relative input prices. It will in turn change 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 change property rights in the expectation of protecting environmental resources. Another example is provided by recent agreements between the US 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 i.e. will share property rights on biodiversity, see Chichilnisky (1993). The Costa Rican government, which has set aside 25 percent 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 isolated a compound from a medicinal plant in South America that it says is active against the influenza and herpes virus. Shaman has flied a patent and the drug is into clinical trials. The company intends to promote the conservation of the forests by channeling some of its profits back to the localities whose medicine people provided the key plants i.e. sharing property rights. The theory behind both ventures is that everybody wins: the world gets new drugs, the pharmaceutical companies earn profits, and people in the localities are justly compensated for their "intellectual property" and their conservation and collection efforts. Examples of highly successful medical rain forest discoveries include *aspirin, morphine*, the *curare plant*, discovered in the 1930's, *taxol*, and the discovery in the 1960's that the *rosy periwinkle* could be used to treat childhood leukemia and Hodgkin's disease.

7. CONCLUDING REMARKS

We showed that different property rights regimes for environmental resources can account for the pattern of trade between the North and the South. The South exports environmentally intensive goods even if it is not well endowed with them. We have discussed several examples of policies which could lead to the improvement of property rights in the developing countries, particularly in the case of biodiversity from rain forests. Improving the property rights of the local populations will lead to higher prices for the environmental inputs, lower extraction and exports by the South, and lower consumption by the North. All in all, property fights improvements in the South could check the main economic source of overuse: prices which are below social costs.

Similar examples hold for land resources. Recently the government of Ecuador allocated a piece of the Amazon of the size of the US state of Connecticut to its Indian population, a clear property rights policy.[22] Under the conditions of our theorem, this policy should lead to a better use of the forests' resources and to a more balanced pattern of trade between Ecuador and the US. Jose Maria Cabascango, the representative of the Indigenous Nationalities of Ecuador which comprises about two million people, has expressed resistance to the overuse of the Amazon for oil exploitation, or for growing cash crops for the international market. Several other examples of property rights policies were presented in some detail in Section 5. In particular, we discussed the property rights agreements of Merck and Co., the largest pharmaceutical firm in the world, in the Costa Rica rain forest (INBIO) and of Shaman Pharmaceuticals in Central and South America, see Chichilnisky (1993).

It is true, however, that property rights may change slowly because they require expensive legal infrastructure and enforcement. Poor countries may find themselves unable to quickly accommodate such policies. But the improvement of property fights of indigenous populations in developing countries, which make up most of the world's population, should certainly be considered a major policy goal. This represents a small but apparently growing trend in Brazil, Bolivia, Columbia. Ecuador, the French Guyana and Venezuela. Support from international organizations in establishing legal frameworks and enforcing the fights of indigenous populations should be most desirable. Reciprocally, any policy designed to remove the rights of locals and increase the land available for cash crops oriented solely to the exports market should be suspect. Indeed, recent studies show that 90% of the tropical deforestation occurs with the purpose of transforming forests for agricultural use, much of it for cash crops for the international market (Amelung, 1991; Barbier et al., 1991, 1992; Binkley and Vincent, 1990; Hyde and Newman, 1991). The World Bank's emphasis on exports of agricultural cash crops as a foundation for development is in this light contradictory with the North's stated desire to preserve global environmental assets. Such policy contradictions should be resolved immediately, since they lead to an enormous and dangerous waste of resources.

But property fights are only one manifestation of the North-South dilemma, one of its causes. There are other closely related causes: the endemic poverty experienced in many developing countries, particularly in those regions which have historically specialized in the export of environmentally intensive products, such as cash crops and minerals, namely Latin America and Africa. Two thirds of Latin American exports' today consist of resources, and the African countries exhibit larger proportions (Chichilnisky and Heal, 1987).

An intriguing link between overuse of resources and poverty was established in Chichilnisky (1991): any policy which leads to lower prices of resources will also lead to more overuse; this is due to poverty and the accompanying income effects. Another somewhat unexpected aspect of property rights policies is that they may be a precondition for successful taxation of environmental use. In the short run, taxes or outright bans on the use of environmental inputs such as forest products are seen as preferable since they require less fundamental changes than those implied by property rights. But taxes may only work appropriately when the property rights on environmental resources are improved (Chichilnisky, 1991). Legislation allowing indigenous peoples in Latin America and Africa to bring to the World Courts claims for their rights could work in tandem with taxes levied on the use of environmental resources towards checking the overuse of resources.

In summary: property rights policies, either through government action or through private enterprise as in the examples offered here, provide a hopeful, almost a necessary, foundation for resolving the North-South environmental dilemma. Improving property rights should also lead to better, more balanced income patterns, since one of the most direct causes of poverty in the developing countries is the lack of entitlement for land and resources (Dasgupta, 1983).

Similarly, as we have shown here, poverty can prevent environmental policies based on taxation to work its intended effects. Poverty and environmental abuse have a common root, and both are the core of the North-South environmental dilemma.

APPENDIX

A. 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) factors are 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 (1993).

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 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 behavior on the part of the firms assures zero profits:

$$p_A = a_1p_E + c_1r \tag{A1}$$

$$p_B = a_2p_E + c_2r \tag{A2}$$

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

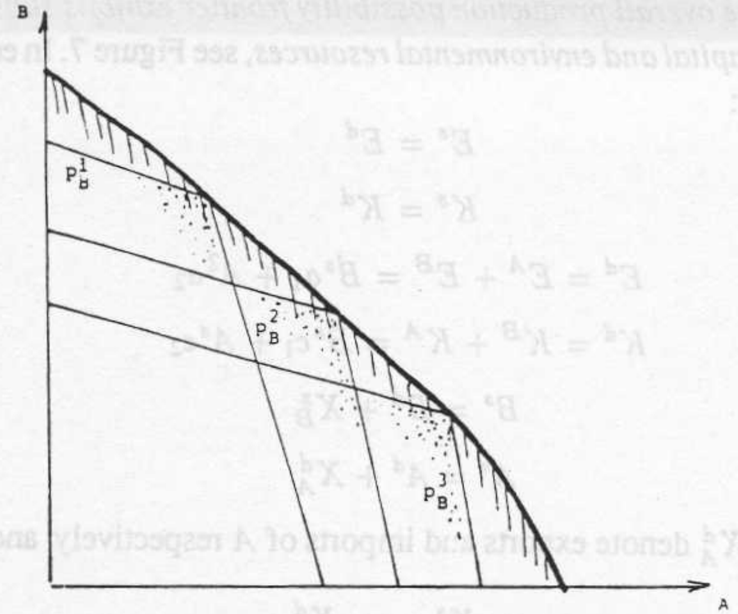

Fig. 7. As p_B changes, so do factor prices r and p_E (A1 and A2) and therefore factor endowments K^s and E^s vary. For each set of factor endowments we have a different production possibility set. As p_B varies, therefore, we obtain the overall production possibility set shaded above. This exhibits substitution in the use of the two factors: capital K and environmental resources, E. The substitution occurs through changes in the output mix.

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:

$$E^s = \alpha p_E / p_B + E^o \tag{A3}$$

where $\alpha > 0$ depends on the property rights regimes for E as established in Section 4, Lemma 1: a large α represents ill-defined property rights, such as the case of common property resources, and a small α represents better defined property rights for the resource E, such as private property. The parameter α 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 less are the externalities which one harvester produces to others internalized, the larger will be the slope of E^s, α. Similarly

$$K^s = \beta r + \bar{K} \tag{A4}$$

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 7. In equilibrium all markets clear:

$$E^s = E^d \tag{A5}$$

$$K^s = K^d \tag{A6}$$

$$E^d = E^A + E^B = B^s a_1 + A^2 a_2 \tag{A7}$$

$$K^d = K^B + K^A = B^s c_1 + A^s c_2 \tag{A8}$$

$$B^s = B^d + X_B^s \tag{A9}$$

$$A^s = A^d + X_A^d \tag{A10}$$

where X_B^s and X_A^d denote exports and imports of A respectively, and

$$p_B X_B^s = p_A X_A^d \tag{A11}$$

i.e. the value of exports equals the value of imports. The North is specified by a set of equations similar to (A1) to (A11) with the same technology parameters and the same capital supply functions, but with different supply functions (A3) for environmental resources, as explained in Section 4, denoted $E^s(N)$. In a world equilibrium, the prices of the trade goods (A and B) are equal and exports match imports:

$$p_A(N) = p_A(S) \tag{A12}$$

$$p_B(N) = p_B(S) \tag{A13}$$

$$X_A^s(N) = X_A^d(S) \tag{A14}$$

$$X_B^s(S) = X_B^d(N) \tag{A15}$$

where (S) and (N) denote the North and South respectively. Since the economies are identical except for property fights, in the two regions there are nine exogenous parameters: $a_1, a_2, c_1, c_2, \beta$,K, E^o, and $\alpha(N)$ and $\alpha(S)$. We add a price normalization condition

$$p_A = 1 \tag{A16}$$

and obtain a total of twenty six independent equations, (A1) to (A11) for the North and for the South, plus (A12) to (A16). There are in total twenty eight endogenous variables, fourteen for each region: $p_A, p_B, p_E, r, E^s, E^d, K^s, K^d$,

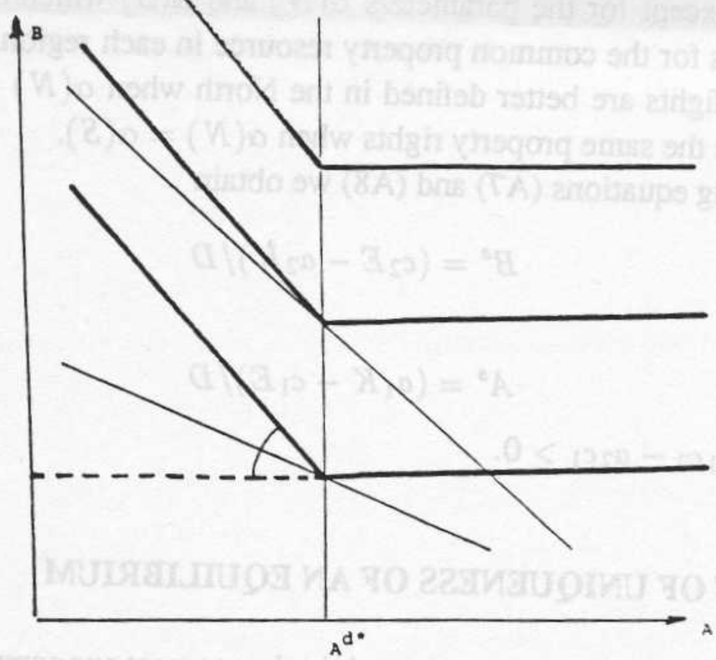

Fig. 8. The utility function $U(A, B)$ has indifference curves as indicated above. For a larger price range, the demand for A is A^{d^*}.

$A^s, A^d, B^s, B^d, X_B^s, X_A^d$, so the system is under determined so far up to two variables, which reflects the fact that demand has not been specified yet. We consider a demand specification which allows us to obtain simple analytics; more general utility functions such as Cobb-Douglas can be considered at the cost of more computation without affecting the results. Consider the utility function

$$U(A, B) = B + k \text{ if } A \geq A^{d^*}, k > 0, \text{ and}$$

$$U(A, B) = B + \gamma A \text{ otherwise } , \gamma = +k/A^{d^*} > 0$$

Then as shown in Figure 8, for $p_B > \gamma$, agents demand A^{d*} so by choosing k and γ in U appropriately, we may assume:

$$A^d(N) = A^{d^*}(N) \tag{A17}$$

and

$$A^d(S) = A^{d^*}(S) \tag{A18}$$

We have thus a system of twenty eight equations on twenty eight variables, depending on nine exogenous parameters. The economies of the two regions are identical except for the parameters $\alpha(N)$ and $\alpha(S)$ which depend on the property rights for the common property resource in each region. We shall say that property fights are better defined in the North when $\alpha(N) > \alpha(S)$; both countries have the same property rights when $\alpha(N) = \alpha(S)$.

By inverting equations (A7) and (A8) we obtain

$$B^s = (c_2 E - a_2 K)/D \qquad (A7')$$

and

$$A^s = (a_1 K - c_1 E)/D \qquad (A8')$$

where $D = a_1 c_2 - a_2 c_1 > 0$.

B. PROOF OF UNIQUENESS OF AN EQUILIBRIUM

The North-South model with property rights has at most one competitive equilibrium for any given set of parameters $\alpha(S)$ and $\alpha(N)$ representing the structure of property rights in the two regions.

Proof. From (A15) (A17) and (A18) we have

$$A^{d^*}(S) - A^s(S) = A^s(N) - A^{d^*}(N) \qquad (A19)$$

Inverting (A1) and (A2) we obtain

$$p_E = (p_B c_2 - c_1)/D \text{ and } r = (a_1 - p_B a_2)/D$$
$$\text{where } D = a_1 c_2 - c_1 a_2 > O. \qquad (A20)$$

We may now rewrite (A19) as a function of one variable only, p_B. Substituting equations (A3), (A4), (A20), (A21), and (A16) into (A19) we obtain:

$$p_B^2[\Psi(S)+\Psi(N)]+p_B[A^{d^*}(S)+A^{d^*}(N)+\Gamma(S)+\Gamma(N)]-[\rho(S)+\rho(N)] = 0 \qquad (A21)$$

where $\Psi = \beta a_1 a_2/D \quad \rho = \alpha c_1^2/D^2$ and $\Gamma = (1/D)[c_1 E^o - a_1 K + (1/D)(\alpha c_1 c_2 - \beta a_1 a_2)]$. 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 (A7′) and (A8′), $X_A^{d^*}$ from A^{s^*}, A^{d^*}, and $X_B^{s^*}$ from (A11), so the (unique) full equilibrium of the model is computed.

At a world equilibrium factor prices are the same in both regions: this obtains from equation (A20) noting that by (A12) and (A13) $p_B(N) = p_B(S)$.

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.

NOTES

1. Hospitality and financial support from the Stanford Institute for Theoretical Economics and Monte dei Paschi at the Università di Siena is gratefully acknowledged. Research support was provided by NSF Grant No. 92-16028 and the Institute for International Studies at Stanford University.
2. Such as e.g. problems related to 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.
3. 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. 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) and I. Waiter (1982). The potential implication of policy measures to protect the environment on international trade was also studied by Krutilla (1976), Maier (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 externalizes in a partial

equilibrium framework, see e.g. Dixit and Norman (1980). 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.

4. Recent studies show that 90% of ail tropical deforestation is for the agricultural use of forests, particularly for the international market (Amelung, 1991; Barbier et al., 1991, 1992; Binkley and Vincent, 1990; Hyde and Newman, 1991).
5. Traditional societies managed common property resources often succesfully, using cultural custom enforced by punishment, in what can be described as repeated games strategies, see Chichilnisky, G. (1994); in the transition to industrialization traditional practices cease to work succesfully because populations are larger and more transient, and more formal, individualistic, property rights are often needed instead.
6. The term "comparative advantage" encompasses two different definitions: one originates in the classical work of Ricardo (1817) with one input of production (labor); the other in the two country, two factor, two good Heckscher-Ohlin model (Ohlin, 1933; Jones, 1956, 1965). In the former, labor produces goods A and B. Labor requirements per unit of A at Home is a_{LA} and for B is a_{LB} and the same numbers for the foreign country are a^*_{LA} and a^*_{LB} respectively. Then Home has a comparative advantage in A if the ratio of the unit requirement in A to that of B is lower at Home than in the foreign country, i.e. $a_{LA}/a_{LB} \leq a^*_{LA}/a^*_{LB}$. In other words, if Home's relative productivity in A is higher than it is in B, Home has a comparative advantage in the production of A. In the two input two good Heckscher-Ohlin model the relative advantage is measured instead not by the relative productivity of labor in the two sectors of the country (since technologies are typically the same in the two countries) but rather by the relative abundance of the two factors which enter as inputs in the production of the two goods A and B. Here A and B are produced using capital K and labor L. The total supply of L and K are fixed in each country, e.g. at home $L = L_0$ and $K = K_0$; in Foreign, $L = L^*_0$ and $K = K^*_0$. Let A be more labor intensive than B in both countries. Then Home has a comparative advantage in the production of A if the ratio $L_0/K_0 \geq L^*_0/K^*_0$. In this case Home will export A and Foreign B. *Gains from trade* are measured by considering welfare before international trade (in autarky) and after trade (in a world market equilibrium). Typically gains from trade emerge from an expanded choice set, since in autarky the countries consume what they produce, while when trade takes place they consume what they can afford in the budget set which is determined by international prices and what they produce. The latter set is typically larger than the former, because the former is the production possibility set of the country, while the latter is a half space containing the production possibility set.
7. The supply of the resource E depends also on the opportunity cost of the input used to harvest it, q as shown in Lemma 1 below. The North-South model of Chichilnisky (1981) has in general different welfare properties from those of the Arrow-Debreu model, for example, the competitive equilibria need not be Pareto efficient, see e.g. Chichilnisky (1990).

8. This has the advantage of avoiding problems of aggregation. Chichilnisky and Heal (1983) established necessary and sufficient conditions on individual preferences for the existence of a well-defined community preference.
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 Appendix, factor prices will equalize across the two regions at an equilibrium even though the factors, K and E, are not traded.
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 (1986).
14. $E(p_E)$ is the inverse function of $p_E(E)$; it is assumed to exist and to be continuous.
15. Conditions to insure the existence and uniqueness of an equilibrium in this model are given in Chichilnisky (1986); the Appendix to this paper establishes the uniqueness of the equilibrium.
16. Namely p_B, r^N, r^S, P_E^S, if e.g. $p_A = 1$.
17. This analysis differs from other approaches to the study of the costs or the value of common resources, for example that of H.J. Ruitenbeck (1990) who is concerned with the value of a rainforest from the point of view of establishing the correct amount of a transfer to an LDC from the rest of the world, to prevent deforestation in the LDC. His definition is closer to a "shadow" price; we seek instead those general equilibrium prices actually prevailing in the market, in connection with different property rights regimes.
18. The economic characteristics of the owners matter. For example, (see Chichilnisky, 1991) the properties of the supply curve of the resource depend on the endowments and the utilities of the harvesters. Here we have assumed that a harvester' endowment is only labor. The opportunity cost of labor is q.
19. The existence of such a function within this North-South model it is established in Chichilnisky (1981, 1986) 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, i.e. when both countries have well defined property rights, 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.

21. See for example the report in *Science Times*, science supplement to the *New York Times*, January 28, 1992, page C1.
22. Indian groups will gain title to land in Pastaza Province, a traditional homelands area covering 4,305 square miles in eastern Ecuador. Ecuador's move is part of a wider trend in the Amazon basin. Achuar, Shiwiar and Quechua Indians will soon administer an area where population density averages five people per square mile. In the last three years, the Governments of Ecuador, Columbia and Venezuela have restricted most of their Amazon areas as national parks of Indian reserves, as have Brazil and Bolivia, and France has made plans to protect a third of the French Guyana. Last year, a coalition of Amazon Indians and foreign and local environmentalists helped force oil companies to abandon plans for producing oil in Ecuador's Amazon. Today another coalition is waging a similar campaign against another oil project. Ecuador, one of South America's poorest countries, draws currently about 50% of its tax revenues from oil exports. In the highlands of Ecuador. Indian groups have expressed similar resistance to export oriented farming. Jose Mafia Cabascango, a leader of Indigenous Nationalities of Ecuador which is said to represent the nation's estimated two million Indians, states: "We should only produce food for our own consumption" "The Amazon region has a very fragmented ecology and to continue colonization would destroy it". See e.g. James Brooke, *New York Times*, Sunday September 6, 1992, p. 10–L. Similar concerns were expressed by Antonio Macedo, Coordinator of the National Council of Rubber-Tappers of the Amazon, of Cruzeiro do Sul, Acre, Brazil, in a recent interview at Columbia University, New York, December 7, 1992.

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