North–South Trade and the Global Environment

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Differences in property rights create a motive for trade among otherwise identical regions. Two regions with identical technologies, endowments, and preferences will trade if one, the South, has ill-defined property rights on environmental resources. Trade with a region with well-defined property rights transmits and enlarges the problem of the commons: the North overconsumes underpriced resource-intensive products imported from the South. This occurs even though trade equalizes all prices, of goods and factors, worldwide. Taxing the use of resources in the South is unreliable as it can lead to more overextraction. Property-rights policies may be more effective. (*JEL* A13, F10, F02, K11, O10, Q20)

Why has the global environment emerged as a North–South issue? There is widespread concern about international problems such as acid rain, global warming, biodiversity, and the preservation of the world's remaining rain forests. In June 1992, one hundred nations agreed at Rio de Janeiro to consider 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.

In order to develop adequate environmental policies one needs to understand the connection between markets and the environment. Why do developing countries tend to specialize in the production and the export of goods which deplete environmental resources such as rain forests (see Chichilnisky and Geoffrey Heal, 1991)? Do they have a comparative advantage in "dirty industries," and if so, does efficiency dictate that this advantage should be exploited? Is it possible to protect resources without interfering with free markets? Are trade policies based on traditional comparative advantages compatible with environmental preservation?

This paper proposes answers to these questions. It does so by studying patterns of North–South trade in a world economy where the North has better-defined property rights for environmental resources than the South. Property rights have been neglected in the literature on the economics of environment and trade, although they have been recognized as important in other areas of resource allocation (Ronald Coase, 1960; Harold Demsetz, 1967; Jon S. Cohen and Martin Weitzman, 1975). The paper analyzes the interactions between property rights and international trade. It considers a trade model with two countries (North and South), two goods, and two factors, which extends that of Chichilnisky (1981, 1985, 1986; Chichilnisky and Heal, 1987). The environment, which is one of the factors of production, is owned as unregulated common property in the South, and as private property in the North.

Section IV of the paper considers a general completely symmetric case: a world economy consisting of two identical countries, both with the same inputs and outputs, and with the same endowments, technologies, and preferences. The two countries engage in free trade in unregulated and competitive

*Department of Economics, Stanford University, Stanford, CA 94305, and Columbia University. Research support from the U.S. National Science Foundation Grant No. 92-16028, Stanford Institute for Theoretical Economics, (SITE), and Monti di Paschi di Siena is gratefully acknowledged. This paper appeared as Technical Report No. 31 of SITE, in October 1991. I thank Joshua Gans, Geoffrey Heal, Christopher Stone, Wallace Oates, and anonymous referees for helpful comments and suggestions.

markets. The countries differ only in the pattern of ownership of an environmental resource used as an input to production. I consider this case to demonstrate that lack of property rights alone can create trade, and that trade itself can exacerbate the common-property problem. No trade is necessary for efficiency when the two countries are identical, yet trade occurs when they have different property-rights regimes. In this context I establish two general propositions. First, the country with ill-defined property rights overuses the environment as an input to production, and these ill-defined property rights by themselves create a motive for trade between two otherwise identical countries. Second, for the country with poorly defined property rights, trade with a country with well-defined property rights increases the overuse of resources and makes the misallocation worse, transmitting it to the entire world economy. Trade equalizes the prices of traded goods and of factors worldwide, but this does not improve resource allocation. In the resulting world economy, resources are underpriced; there is overproduction by one country and overconsumption by the other. These results have been extended to a dynamic context in Chichilnisky (1993c).

Section V of the paper explores more specific cases. Its purpose is to evaluate policies to check environmental overuse: taxes and property-rights policies. Here, in contrast with Section IV, I allow a realistic asymmetry between the North and the South. The South's resources are produced now either using capital or using labor from a subsistence sector. This labor is not directly traded in the market or employed in other sectors. Subsistence labor is only engaged in the extraction of the environmental resource, which is traded in exchange for capital-intensive goods. In this context I show that taxes on the use of environmental resources in the South are generally unreliable at deterring overextraction. Taxes can force lower-income harvesters to work harder and extract more resources to meet their consumption needs. Taxes can therefore lead to more rather than less extraction of the resource. Therefore, property-rights policies may be preferable in the South as a way of correcting environmental overuse. Examples of such policies are discussed.

Property rights can affect market behavior in many ways. Here I focus on their impact on the supply of resources; these are price-dependent, with their supply curves derived rigorously from micro foundations. I establish that with ill-defined property rights the supply of resources is more price-responsive than it is when property rights are well defined. This price responsiveness is crucial in determining the patterns of international trade; at each price the South offers more resources than the North, leading to apparent comparative advantages in resource-intensive products. This parallels the results of the original North–South model (Chichilnisky, 1981, 1985, 1986), where the price responsiveness of labor supply—called there abundance of labor—played an equally important role in determining the terms of trade and the welfare results from exports of labor-intensive products.

These results offer a new perspective on a current debate, initiated in 1992 by Lawrence Summers, a World Bank economist, about whether developing countries have a comparative advantage in "dirty industries" (see e.g., *The Economist*, 8 February 1992, Vol. 322, p. 66). If so, the argument goes, is it not efficient that they specialize in "dirty industries" and environmentally intensive production?

One response to this is that the apparent comparative advantages may not be actual comparative advantages, an issue which this paper addresses rigorously. They may derive neither from a relative abundance of resources nor from differences in productivity or preferences, not even from lower factor prices, but rather from historical and institutional factors: the lack of property rights for a common-property resource. In this context the South produces and exports environmentally intensive goods to a greater degree than is efficient, and at prices that are below social costs. This happens even if all factor prices are equal across the world, all markets are competitive, and the two regions have identical factor endowments, preferences and technologies. Under those conditions the trade patterns which emerge are inefficient for the world economy as a whole, and for the developing countries themselves. Developing countries are not made better off by specializing in "dirty industries," nor is the world better off if they do.

I. Empirical Motivation: Property Rights, Trade Patterns, and Taxes

The problems described in this paper appear when societies that are still in transition between agricultural and industrialized economies trade with societies already industrialized. Many traditional societies had well developed systems for inducing cooperative outcomes in the use of shared resources. Laws to protect the citizens' property rights in running water were in operation in the United Kingdom in the Middle Ages. Japan had well developed systems for the management of traditional communal lands (*Iriaichi*). Other examples are the communal-field agriculture in the Andes and in medieval England, and the successful sea-tenure systems in Bahia, Brazil, before the arrival of outsiders (see Daniel Bromley, 1992). These traditional systems, however, appear to lapse in the period of transition between agricultural and industrial economies.

Today many environmental resources are unregulated common property in developing countries. Examples are rain forests, which are used for timber or destroyed to give way to the production and export of cash crops such as coffee, sugar, and palm oil. Other examples include grazing land, fisheries, and aquifers, which by the nature of things must usually be shared property even when the land covering the aquifer is privately owned (see Partha Dasgupta, 1992). These are common-property resources whose ownership is shared with future generations. They are typically used as inputs to the production of goods that are traded internationally.

Recent studies show that 90 percent of all tropical deforestation is for the agricultural use of forests, particularly for the international market (C. S. Binley and Jeffrey R. Vincent, 1990; Torsten Amelung, 1991; Edward Barbier et al., 1991; W. F. Hyde and D. H. Newman, 1991). The Korup National Park between Cameroon and Nigeria, at 60 million years old, one of the oldest rain forests in the world and one of the richest in biodiversity, is exploited as an unregulated common-property resource for the production of palm oil, trapping, and other forest products sold in the international market (H. J. Ruitenbeck, 1990). So is the Amazon basin, which is cleared and used as a source of land for the production of cash crops, such as soy beans and coffee, for the international market.

In the now industrialized countries communal land was frequently observed prior to industrialization. Industrialization in England was preceded by the "enclosure" (privatization) of common lands (Cohen and Weitzman, 1975). Now, however, industrial countries have much better defined property rights for their resources than do developing countries. The United States has property-rights regimes for petroleum. These include laws to prevent the overexploitation of common-property resources such as the Conally "Hot Oil Act" of 1936 and "unitization" laws (Steven McDonald, 1971). Water, however, is still treated as common property in parts of Texas and California, leading to misallocation. Japan is well known for its protection of property rights in environmental resources, including even sunlight. Germany recently initiated a parallel system of national accounts which records the depreciation of environmental assets, effectively treating the accounting of national property on the same basis as that of private property. Indeed, the proposal to update all national accounting systems so that they record the depreciation of environmental assets (see Dasgupta and Heal, 1979) is a move toward treating national property on the same accounting basis as private property.

Although today's differences in property rights between industrial and developing countries are easily observed, only tentative explanations can be offered. It is known that the overexploitation of "the commons" emerges from noncooperative situations, or overuse by "free riders" (Dasgupta and Heal, 1979). Cooperative outcomes in the use of communal property resources, such as shared bodies of water, fisheries, and forests, are achieved through the enforcement of punishment and rewards within a stable group, the members of which share a common land site for many generations. One observes a "repeated game" which enforces cooperative outcomes without the need for formally defined individual property rights (Bromley, 1992).

In the period of industrialization, these age-old institutions cease to work, because small and stable populations become large and transient, so that cooperative solutions are more difficult to enforce. This may be why those societies that have completed the process of industrialization rely instead on formal property rights rather than on tradition and custom. The problems described in this paper appear because the South is still in transition, but it trades with already industrialized economies.

Patterns of trade in environmental resources can defy common wisdom. Small countries such as Honduras, with scarce forest resources, export wood to the United States, which has some of the largest forests in the world. Honduras's hardwood (e.g., mahogany) forests have been recently nationalized and are treated as unregulated common property, with no accounting of the depreciation of the forest as an asset, while the United States has better-defined property rights. Currently about two-thirds of Latin American exports are resources, and an even larger proportion holds for Africa. Many of these are produced from common-property sources: Korup National Park and the Amazon are valuable biodiversity reservoirs which are being destroyed in part for the production of export cash crops such as palm oil, soy beans, and coffee. These crops are exported to industrial countries with much higher agricultural productivity and with larger endowments of agricultural land. The puzzle is how to explain such patterns of trade. The exporters do not have a technical advantage in the sense of Ricardo, since their labor is not more productive, and it is unlikely that they have a comparative advantage in the sense of Heckscher-Ohlin either.

These issues are analyzed in Section IV, which establishes that, due to differences in property rights, the countries will trade following the empirically observed patterns of trade just discussed. Since under these conditions markets do not allocate resources efficiently, Section V examines policies to check environmental overuse: taxes and changes in property rights. In Section V, I introduce a realistic difference between the North and the South. In the North, resources are extracted using capital. In the South, resources are extracted either by using capital as in the North, or by using labor from a subsistence sector consisting of workers for whom there is no formal labor market. These workers extract environmental resources from the common-property pool such as a forest. Their labor is not traded directly: they use it to extract resources which are traded for capital-intensive goods at market prices. Workers employed in this fashion exist today in parts of Paraguay, Argentina, and Brazil; they are employed in a so-called "piecemeal" fashion, usually in environmentally related sectors such as timber and agriculture, and are unemployable in other sectors because of their lack of formal education. Workers who extract wood and trappings from common-property land, such the Korup rain forest in Nigeria, appear to conform to this pattern (see Ruitenbeck, 1990), and so do those who extract rubber in the Amazon. Such patterns also appear within firms: much of the Amazon's land is treated as unregulated common property by firms which buy forest products from their employees in a piecemeal fashion, at market prices. This specification also has some points in common with the formulation of abundant labor in Chichilnisky (1981, 1986), and it fits well with the results of empirical studies of subsistence labor in agriculture in Latin American countries, such as Thomas Schweigert's (1993) research on Guatemalan agriculture.

The first policy considered in Section V is a tax which the South levies on the use of environmental resources, the revenues of which are spent on the capital-intensive good. The intention is to raise the producer's costs and to deter its use of environmental resources. In this context I show that taxes will not always work as intended. As taxes decrease the demand for resources, the harvesters receive lower prices for their products. This can force the harvesters to work harder and lead them to extract more rather than less of the resources, a possibility which is explored rigorously in this paper (Proposition 2; see also World Bank [1992]). For this reason, taxes in the South are generally ineffective and can be unreliable: when the workers' demand for marketed goods is relatively inelastic, taxes can lead to more extraction of resources, defeating their original purpose (Proposition 3).

II. The North–South Model

Following Chichilnisky (1981, 1985, 1986), consider a model with two goods, two inputs, and two countries, similar to that of Heckscher-Ohlin, except that here the supplies of inputs are price-dependent. For example, the supply of resources is $E^s = E^s(p_E)$, where p_E is the price of the resource E. The model for one region is as follows. Capital (K) and the environmental resource (E) are used to produce two goods, A and B: one good, B, is more intensive in the use of the environmental resources than the other, A, which is more capital-intensive.[1] Production exhibits constant returns to scale; a concave utility function $U(A, B)$ is postulated. Both E and K are supplied by continuous supply functions $E = E(p_E)$ and $K = K(r)$, where p_E is the price of the environmental resource, and r is the rental of capital. E is extracted from a resource pool using an input x which has opportunity cost q; this cost q is endogenously derived in Proposition 2 and Appendix C, as are all other prices and quantities, in a general-equilibrium fashion. To show that the results are robust under different model specifications, the input used to extract E is taken to be quite general in this model: it can be capital (as in Section IV, Theorem 1), subsistence labor, or either of the two (as in Section V, Propositions 2 and 3). The supply of the environmental resource E is formally derived in Proposition 1, where it is shown to vary systematically with the property rights of the resource pool. Since endowments, technologies, and preferences are defined, all ingredients of a general-equilibrium model are provided. A one-region competitive equilibrium is a price vector $\mathbf{p}^*$ at which each of the four markets (for A, B, E, and K) clears.

The two-region model (North–South) is defined as usual by considering two one-region models together and, to allow for international trade, by relaxing the hypothesis that each commodity market (for A and B) clears in each region to require instead that the world markets for A and B must clear. Input markets clear in each country because, as is standard in international trade, the factors of production (K and E) are only traded domestically. Appendix B provides a set of equations and computes an equilibrium of the North–South model, which is shown to be unique in Appendix C.

The model differs from earlier versions of the North–South model (Chichilnisky, 1981, 1985, 1986) in that in those versions all goods were privately owned, and the supply functions of the endowments were exogenously given. Here, instead, the supply of input E is derived explicitly from microeconomic behavior and is shown to depend on the property-rights regime. There is, however, an unexpected similarity with the original North–South model: the crucial role played by the responsiveness of resource supplies to their price. With common-property regimes, more is supplied at any given price than is supplied with private-property regimes (Proposition 1). Since at each price the quantity supplied under common property exceeds that supplied under private property, resources appear to be more "abundant" with common property. A similar responsiveness of supplies, but of labor instead of resources, appears as a

[1] This is a standard assumption in trade theory; it means that the production of good B requires a higher ratio of input K than does the production of good A. This is formalized in Appendix B.

crucial parameter in Chichilnisky (1981, 1986): it measures "labor abundance" in the South and determines whether the country will benefit from increasing its exports of labor-intensive goods or not.

III. Property Rights and the International Supply of Resources

Property rights act on the market in many complex ways. Here I identify a simple but critical way in which property rights enter in a general-equilibrium trade model and propose a transparent and general explanation of how they determine the patterns of trade and the welfare of the traders. *The two regions are assumed to differ solely in their property rights for a pool of resources from which one input to production is extracted.* For example, the property rights on forests from which wood and pulp are produced are different in the North and the South.

How do property rights affect trade? Tracing the impact of property rights is nothing more and nothing less than a comparative-statics exercise: the comparison of a world equilibrium in which both regions have well-defined property rights with a second world equilibrium in which the South does not.[2] In principle, this could be a complex undertaking. However, when property rights involve solely an input of production as they do here, their effects can be summarized in a simple fashion: by their impact on resources supplied. Indeed, Proposition 1 below establishes that, for each price of the resource, more is supplied under unregulated common property than under private property. Therefore the comparative-statics exercise need only compare a world where the two countries have the same supply curve for resources with another world where the South has a different supply curve than the North: it supplies more at each price.

In practice, therefore, one compares the equilibrium of a market with two identical traders to the equilibrium of another market in which the traders are identical *except* for their supply of resources. In the first equilibrium both countries have the identical *private-property supply curve* $E^{P}(p_E)$. In the second, the South has, instead, a *common-property supply curve* $E^{C}(p_E)$, which prevails with ill-defined property rights. The North has one supply curve throughout, which arises with well-defined property rights. Why are the two curves different in the South?

Under unregulated[3] common-property regimes the harvester's cost of extracting an additional unit of E is relatively low. It merely reflects the opportunity costs of the inputs used to extract the resources: in the case of a fishery, the costs incurred in catching; and in the case of an aquifer, the costs incurred in obtaining the water. These costs do not reflect the full impact on other users of one individual's use of the resource pool. In the case of the fishery or a forest, each unit extracted decreases the stock available to others and increases their extraction costs. This could eventually lead to the depletion of the stock. In a private-property regime matters are different. Externalities are fully internalized so that the cost to a harvester of extracting the resource reflects fully the costs this imposes on the extraction by others and could increase rapidly with the level of extraction (Dasgupta and Heal, 1979 Ch. 3).

In its simplest possible form, the argument is that with private property the efficient harvester equates the relative prices of inputs and outputs to the *marginal* productivity. Instead, with common property and with many producers, the relative prices are often equated to *average* productivity. If production has decreasing returns to scale,

[2] At the second world equilibrium prices are distorted, since one of the traders, the South, does not satisfy the marginal optimality conditions (Proposition 1 below and Appendix A); therefore although the first world equilibrium is a competitive equilibrium, the second is a general equilibrium but is not a competitive equilibrium.

[3] I consider here unregulated common property, which is also called "open access"; it must be differentiated from regulated common property.

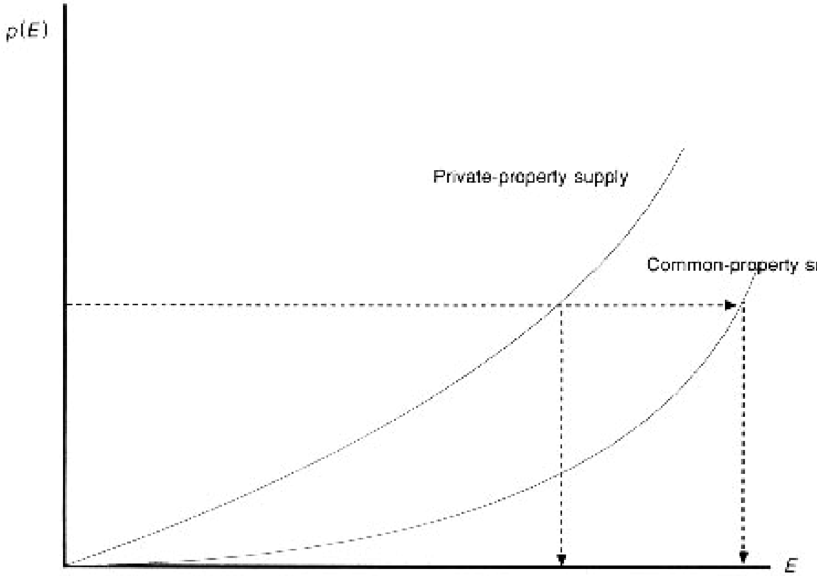

FIGURE 1. AT EACH PRICE, THE COMMON-PROPERTY SUPPLY EXCEEDS THE PRIVATE-PROPERTY SUPPLY.

then average productivity is always larger than marginal productivity, so that at the same prices there is always an incentive to produce more under common-property regimes. This argument is actually valid much more generally: it is true for any finite number of harvesters and without invoking marginal and average costs; under general conditions it leads to the following proposition, which is rigorously established in Appendix A within a Nash equilibrium framework.

PROPOSITION 1: *The common-property supply curve for the resource lies below the private-property supply curve, so that under common-property regimes, more is supplied at any given price. Both supply curves are increasing functions of resource prices.*

(Proposition 1 is illustrated in Figure 1.)

It is worth emphasizing that this proposition does not depend on what input is used for extracting the resource: for example the input used could be either capital or labor. Indeed, both inputs are considered in the paper. The difference of supplies with private and common property regimes has substantial practical implications. It leads by itself to different concepts of comparative advantages and of gains from trade. These are crucial to current policy because they clarify whether developing countries have a comparative advantage in environmentally intensive exports and, if so, whether such advantage should be exploited.

IV. Property Rights, Comparative Advantages, and Gains from Trade

The completely symmetric case of the North–South model is utilized in this section because it shows very clearly the role of property rights in determining patterns of trade. The comparative advantages of nations with price-dependent endowments are defined as follows: 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 supplies in region N. *Actual comparative advantages* rely on the private-property supply curve for E, which internalizes all the externalities that each unit of extraction has on others.

This is the supply curve corresponding to points in the economy's efficient frontier.

It is worth noting that this definition of comparative advantage, while rather natural, differs from classical ones. This must be the case because Ricardian comparative advantages cannot exist in a world where countries have identical technologies, as considered here. Nor can Heckscher-Ohlin comparative advantages be well defined here, since the endowments of factors are price-dependent, so at different prices the countries can exhibit different Heckscher-Ohlin advantages, measured as the relative endowments of production.

A correct understanding of the comparative advantages of developing countries is, as already pointed out, a substantial policy concern. To examine the matter it will prove useful to consider *apparent comparative advantages*. These are defined in the same manner as actual comparative advantages, but using for each price the supply curve corresponding to the prevailing property regimes in each region, which in the South corresponds to the case in which some externalities are not internalized. Apparent comparative advantages of the South reflect its institutional constraints, in this case inadequate property rights, which may hinder the attainment of full optimality. A market response by the South to these institutional constraints leads it to behave as if it has a comparative advantage even if it does not. When institutional constraints are binding, apparent comparative advantages prevail; observers could then attribute to developing countries a comparative advantage in exporting environmentally intensive products which they do not actually have.

It must be noted that here the two regions are identical except for property rights, so that neither region has a comparative advantage over the other. However, Proposition 1 established that the South, with ill-defined property rights, exhibits an *apparent* comparative advantage in the production of the resource-intensive good. This is because at each price the South supplies more resources than does the North, so its resources appear to be "more abundant."

Theorem 1 below uses another useful concept, *gains from trade*, which are measured as usual by the increase of utility $U(A, B)$ associated with a move from autarky (i.e., where each country maximizes utility within its own production possibility set) to a world equilibrium. Again it is useful to differentiate between apparent and actual gains from trade in the South. *Apparent gains from trade* are computed by comparing welfare in a model where the production possibility sets emerge from common-property supply curves. *Actual gains from trade* are defined, instead, by using the private-property supply curve. The weaker the property rights in the South, namely, the less the production externalities are internalized, the larger will be the divergence between its common-property and private-property supply curves, and between the apparent and actual production possibilities.[4] Thus the weaker the property rights in the South, the larger will be the divergence between its apparent and its actual gains from trade.

The following theorem shows that trade by a region with ill-defined property rights with another with well-defined rights leads to apparent comparative advantages when none exist, and to apparent gains but actual losses from trade. It is established for two identical regions with the same technologies and preferences, both using the same technology to extract resources E using capital K, $E = F(K)$; the initial endowment of capital $\overline{K}$ is the same in the two regions. The theorem compares two equilibria: one in which both countries have the same property rights (private property) over the resource pool, with another in which the South has common property. The model is formally defined in Appendix B; the theorem and its corollary are proved in Appendix C.

THEOREM 1: *Consider the North–South model in which both regions have identical*

[4] The North–South model has one parameter (α, a real number), which can be used to represent the degree of internalization of property rights (see Appendixes A and B).

technologies, the same homothetic preferences, and the same endowment of inputs $\bar{K}$. *(a) The model as defined in Appendix B has at most one competitive equilibrium. (b) If the pool from which the environmental resource is extracted is unregulated common property in the South, then the South exhibits apparent comparative advantages in environmentally intensive goods even though neither region has any (actual) comparative advantage over the other. (c) At a world equilibrium the two regions trade, and the South exports environmentally intensive goods at a price that is below social cost. The equilibrium is not Pareto efficient. (d) Trade makes things worse, in the sense that the overuse of the resource increases as the South moves from autarky to trade. Furthermore, trade leads to lower resource prices worldwide. (e) The South shows apparent gains from trade, even though it has no actual gains from trade. It extracts more environmental resources, and it produces and exports more environmentally intensive goods than is Pareto efficient.*

Note that the environmental overuse described in Theorem 1 is induced by a competitive market response. There is no regulation in either country, and all markets are free and competitive.

COROLLARY 1: *Trade between the North and the South leads to the equalization of the prices of all traded goods and of all inputs of production, and in particular to the equalization of the price of environmental inputs in the two regions. However prices for environmentally intensive goods are below social costs. At a competitive equilibrium the South uses more environmental resources and produces and exports more environmentally intensive goods than the North, and more than is Pareto optimal.*

This corollary calls attention to the possibility that the overexporting of environmentally intensive goods from developing countries, such as mineral by-products, wood products, or cash crops, may not be due to the fact that the production costs are lower in the South than in the North, as is sometimes thought. For example, under unregulated common-property regimes for environmental resources, a country such as Mexico would export environmentally intensive agricultural products, or products produced from "dirty industries," even if its forest land, clean air, and machinery were as expensive as they are in the industrial countries and even if it had the same technologies and preferences. Equalizing factor prices through the international market does not resolve the problem of overuse of environmental resources.

V. Environmental Policies

Since unregulated competitive markets do not lead to efficient allocations with ill-defined property rights, the task of this section of the paper is to analyze policies that could correct the problem of environmental overuse, focusing first on taxes. Taxes will be considered in a general-equilibrium framework, tracing their full incidence on all prices and quantities worldwide. This approach captures the impact of taxes in an economy where income effects prevail, a case particularly relevant to developing countries.

A realistic asymmetry is introduced between the North and the South in this section. In the South the environmental resource E is extracted either using capital as in Section IV above or, alternatively, by workers from a subsistence sector. These workers do not sell their labor directly in the marketplace. Instead, they use their labor to extract the resource, which they exchange for capital-intensive goods in the marketplace. This specification is less symmetric than that of Section IV. It captures a stylized fact in developing countries where many markets, including labor markets, are less developed than in industrial countries; empirical motivation for this was provided in Section I. Proposition 3 will contrast the effects of taxes within these two alternative specifications of the process for extracting E in the North and the South. The economy of the North remains as in Section IV.

A. *Lower Resource Prices Can Lead to More Extraction: The Opportunity Cost of Subsistence Labor*

Does the South extract more or less resources after taxes? This is studied rigorously in the next subsection and in Appendix C. Taxes alter extraction because they induce price changes. Here I trace how this occurs. In particular, I show how resource extraction changes with the opportunity costs of the inputs that are used to extract the resources.

No matter what input is used (labor or capital), and no matter what the property-rights regime, in this model the supply of the resource E always increases when the relative price of outputs to inputs increases (Appendix A). However, in a market economy the cost of an input is its opportunity cost, and this typically changes along with the price of the resource itself. The relevant issue is therefore whether the opportunity cost of the inputs relative to that of the resource increases.

What are the opportunity costs of inputs? How are they affected by resource prices? There is a simple answer when capital is employed to extract the resource: the opportunity cost then equals the rental on capital (r), and r varies across the equilibria of the model in a well-specified fashion: it is inversely related to the price of the resource [Appendix B, equation (3)].

A difficulty arises when E is extracted instead by subsistence workers. Since by definition no formal market exists for subsistence labor, market wages, which would be the natural proxy for the opportunity cost of labor, are not available. It is nevertheless possible to deduce implicitly the opportunity cost q of subsistence workers' time, to explore how this changes with the prices of the produced goods, and to see how this affects the extraction of resources. Proposition 2 shows how. Its formulation opens up a whole range of issues which are unobservable in a partial-equilibrium formulation, and which are useful for understanding the behavior of resource markets with low-income populations. It formalizes the intuition that a drop in the price of a resource can force lower-income harvesters to work harder and extract more resources in order to meet their consumption needs. Discussions about this phenomenon appear in the World Bank's 1992 *World Development Report*, without any formal analysis.

Assume that the harvesters' endowments consist solely of their labor input ($\bar{x} = 24$ hours a day). A harvester trades his harvest of resources E for the good A at competitive market prices. Each harvester has strictly concave increasing utility function $u_i(A, \bar{x} - x_i)$, which increases in leisure $(\bar{x} - x_i)$ and in consumption (A). The harvester's problem is

$$\max_{x_i} \left[u_i(A, \bar{x} - x_i) \right] \tag{1}$$

subject to

$$p_A A = p_E E^C(x_i)$$

For each p_A and p_E, the solution $E^C(x_i)$ is the optimal quantity extracted by the harvester, where p_A and p_E are determined by the market in a general-equilibrium fashion. Proposition 1 (proved in Appendix A) explains the quantity of resource extracted in a different manner: it shows that it depends on resource prices p_E and on the opportunity cost of labor, q. In a general-equilibrium world these two ways of explaining extraction must tally: this observation allows one to derive rigorously the opportunity cost q of a worker's labor (which was previously treated as an exogenous parameter) endogenously, as a function of the prices p_A and p_E. This derivation proves that, as is intuitively obvious, q equals the rate of substitution between leisure and consumption of A [see Appendix C equation (C7)]. Recall that the "terms of trade" between leisure and consumption are determined by the competitive market, because the market determines the price of the good A and the price of the good E which is exchanged for A by the harvester. Therefore the market determines implicitly the opportunity cost of subsistence labor, q.

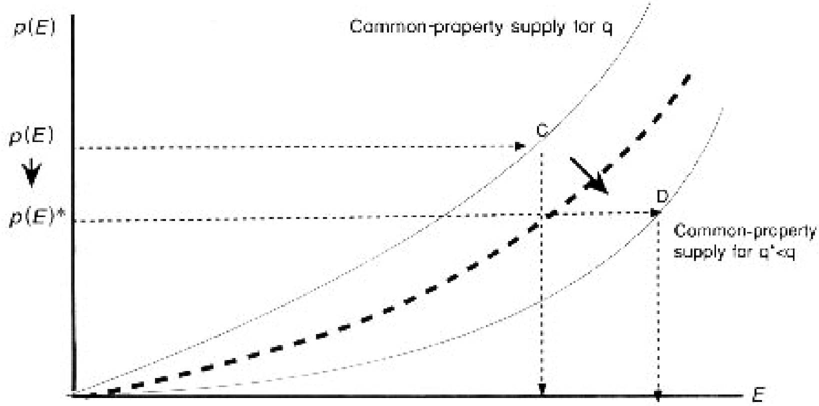

FIGURE 2. THE COMMON-PROPERTY SUPPLY CURVE SHIFTS WITH DROPS IN THE OPPORTUNITY COST OF THE INPUT USED IN EXTRACTING THE RESOURCE, q.

Note: As established in Proposition 2, the equilibrium level of output of E increases as $p(E)$ drops to $p(E)^*$, because the corresponding opportunity cost drops to q^*.

Consider now a North–South model as defined in Section II but with the addition indicated above. E is supplied by the type of harvesters just defined: they own only labor, extract and trade the resource E for the good A, and their utilities have elasticity of substitution $\sigma < 1$. I call this *the North–South model with a subsistence sector*. The following proposition studies the consequences of a drop in resource prices; its proof is in Appendix C.

PROPOSITION 2: *Under the assumptions made above, a drop in the price of resources leads to a drop in the opportunity cost of labor of the subsistence worker in the South. At the new, lower resource prices, more effort is applied by the harvester, and more resources are extracted.*

(Proposition 2 is illustrated in Appendix Fig. C1.)

Why do lower resource prices lead to more extraction? One explanation is that harvesters have relatively inelastic demand for the marketed good A. If so, as the relative price of the resource falls, the proportion of total expenditure spent on A rises, and the quantity of resources extracted must increase, because each unit of the resource brings now lower revenue. Here I do not assume this inelastic behavior of demand: I prove that it arises naturally from utility maximization on the part of the harvester when the harvester's utility u_i has an elasticity of substitution σ less than 1 (Appendix C). This result is useful in practice because the condition $\sigma < 1$ is plausible and rather general: for example, with constant-elasticity-of-substitution (CES) utilities, $\sigma < 1$ is always satisfied when the indifferences of u_i do not intersect the axis (see Hal Varian, 1992 pp. 19–20), which is a standard case. Note however that the proof of Proposition 2 applies to a general class of concave utilities with $\sigma < 1$ and does not require that u_i be CES or any other functional form.

The result in Proposition 2 has useful implications under more general conditions as well. It highlights the weakness of any policy that leads to a drop in resource prices in lower-income countries: as prices drop, by continuity, harvesters with relatively low elasticity of substitution do not decrease their extraction very much. Lower resource prices are therefore ineffective at deterring overextraction.

The proposition also highlights the crucial role of the opportunity costs of labor in determining the extraction of resources. This is of practical interest because the opportunity cost of subsistence labor q could be regarded as a policy variable: this opportunity cost could be increased by providing productive job opportunities for subsistence workers outside the environmental sector. The general point is that any policy that increases the opportunity cost of subsistence labor could have beneficial environmental effects. Figure 2 illustrates how: at each resource price, a lower opportunity cost q leads to a shift in the supply curve for resources as illustrated (and established rigorously in Appendix C). Under the conditions, lower resource prices lead to an even lower opportunity cost of labor, and the ratio of output to input prices q/p_E actually *increases*. Because of this, at lower resource prices the subsistence harvesters extract more resources than they did before. In Figure 2 this is shown as a move from point C to D.

In summary, in lower-income regions a drop in the price of resources can lead to more poverty, and this in turn can lead to more extraction. A policy that induces lower resource prices does not provide an effective way of checking environmental overuse. This provides a key to the following results on taxes.

B. *Taxes in the South*

The next proposition shows that the results of taxing the use of the resource could be just the opposite of what is expected if all prices are allowed to adjust to their new market-clearing levels: taxes could lead to more extraction. Intuitively this occurs because the resource is extracted by lower-income subsistence workers whose demand for consumption goods is somewhat inelastic. The trade literature has not covered this case, which is implicit in the discussions of the World Bank's 1992 *World Development Report* with respect to the effects of poverty on the environment. Exploring this possibility requires tracing all impacts of taxes on prices, quantities, and income, a somewhat complex task.[5] Most of the international trade literature on taxation uses a partial-equilibrium framework. However, some of the most important effects of taxes in developing countries are income effects, and these cannot be examined properly in a partial-equilibrium.

For example, corrective tariffs and subsidies in a partial-equilibrium framework have been studied in Dixit and Norman (1980). However, as in all partial-equilibrium analysis, these results occur in a world where the terms of trade and all factor prices remain fixed throughout. Consider for example a standard policy of taxing the use of the common-property resource in order to restrict its use. When prices remain fixed, such a tax has the effect of deterring use. The tax increases the relative price of the resource, and this leads to less use of it as an input.

It is not always realistic to assume that prices remain fixed after taxes. Taxes alter income and therefore alter demand and hence prices. The classical works of Abba Lerner (1936) and Lloyd Metzler (1949) analyzed tariffs on traded goods which have general-equilibrium effects on the terms of trade of the trading regions. I shall consider here, instead, a tariff which is levied domestically on the use of the resource E which is a (nontraded) input to production.

The complexity of tracing the effects of taxes on all prices and quantities is alleviated by an unusual feature of the North–South model which makes it particularly useful for this purpose: it has an explicit analytic solution, which is obtained by solving a second-order equation in the terms of trade, from which all other endogenous variables are determined explicitly. This

[5]In their *Theory of International Trade* (Section 2, Policy Responses to Distortions and Constraints"), Avinash Dixit and Victor Norman (1980 p. 176) state: "Having examined the terms of trade and interpersonal distribution at some length, we now put them aside by assuming a *small one-consumer economy* [i.e., partial-equilibrium analysis]. This is done in order to highlight the new questions that are raised by the presence of further constraints on policy. It is not in principle difficult to combine everything into a grand model, but its algebraic complexity obscures all economic understanding."

procedure was introduced in Chichilnisky (1981, 1986) and is the methodology that is used in establishing Proposition 3 below.

The relative price of exports and imports of the South, p_B/p_A ($= p_B$ since $p_A = 1$) are called the South's *terms of trade*.

PROPOSITION 3: *Consider the North–South model with a subsistence sector in the South which extracts the resource E from a common-property pool. The North has well-defined property rights. Assume further that a unit tax T is imposed on the producers in the South for their use of the resource E as an input of production: all producers pay $p_E - T$ per unit of the input E. Furthermore, assume that the tax revenues increase the domestic demand for the product that does not use the environmental resource E intensively, namely, for the good A. Then the tax always leads to:*

- (i) *a decrease in the price of the resource E,*
- (ii) *a drop in the South's terms of trade p_B,*
- (iii) *an increase in the extraction of the resource E in the South, and*
- (iv) *an increase in its exports of the environmentally intensive good B for some parameter values.*[6]

If the South produces E using capital, the tax leads also to (i), (ii), and (iv), but instead of (iii) to

(iii)′ *a drop in the extraction of the resource E in the South.*

(See Appendix C for the proof.)

An intuitive explanation for this proposition is as follows. A unit tax T on the use of the resource E is collected from the producers who use E as an input. The tax proceeds TE are allocated to increasing the demand of the non-resource-intensive sector, A, giving the tax the best opportunity to work in the intended direction, namely, reducing the demand for resource-intensive products. The relative price of the environmentally intensive good B then drops; this is (ii). The drop in demand for B leads to a decreased demand, and a lower price, for the resource E; this is (i). Therefore, after taxes, the price of resources, E, is lower.

Consider first the case when the harvesters use subsistence labor as an input. If the resource E is extracted by the subsistence sector, then after taxes the price of E is lower and the supply of E is higher (this follows from Proposition 2); this is (iii).

The second case is when E is extracted using capital as an input. Since p_E is lower after taxes, the cost of capital r is higher: these two variables are always inversely related across equilibria [see equations (B1) in Appendix B]. Since the opportunity cost of the harvesters' labor is higher and output prices are lower after taxes, the supply of the environmental resource decreases; this is (iii)′.

Finally the exports of B increase after the increase in p_E if and only if price effects dominate; when income effects dominate then exports decrease (see also Chichilnisky, 1981, 1986); this is (iv).

VI. Conclusions: Property Rights and North–South Trade

Differences in property-rights regimes for environmental resources can account for some puzzling aspects of the patterns of trade between the North and the South. The problems analyzed in this paper arise when societies which are in transition from agricultural to industrial economies, such as the South today, trade with already industrialized societies. The South exports environmentally intensive goods even if it is not well endowed with them. The South overproduces, and the North overconsumes, even if trade equalizes all traded goods and all factor prices worldwide.

I have discussed several environmental policies. Section V examined tax policies in the South and established that they are not always reliable. When environmental resources are extracted using subsistence labor, taxes can lead to more extraction. I

[6] Formally, exports increase if and only if the condition $c_2/D < 2p_E p_B$ is satisfied, a condition which is shown to be satisfied precisely when "income effects dominate" (see the penultimate paragraph of Appendix C).

showed that anything that decreases the price of the resource can increase poverty and lead to more extraction, an observation which was made in the World Bank's 1992 *World Development Report*. Taxes can have this effect, because they can decrease the demand for environmental goods, which are a main source of income for the subsistence sector.

A main argument in favor of property-rights policies is that once these have been implemented, no market intervention is needed. Consider, for example, any policy which improves the property of Amazonian small farmers, such as rubber-tappers. This will change the supply function of Amazonian resources as shown in Proposition 1, reducing output at each price. In turn this will change the computation of comparative advantages and of gains from trade from agricultural exports based on deforestation of the Amazon. Production patterns shift, and export patterns will reflect more fully the social cost of deforesting the Amazon.

Examples of such property-rights approaches are provided by recent agreements involving debt-for-nature swaps (Ruitenbeck, 1990). Another example is provided by recent agreements between the United States pharmaceutical industry and Costa Rica. The spearhead of this project is a pair of ingenious efforts to exploit the forests to obtain medicinal products.[7] 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, in turn, is supporting the prospecting effort financially and will share any resulting profits with Costa Rica. Thus Costa Rica has acquired property rights over the "intellectual property" embodied in the genetic information within its forests. A similar initiative was taken by a small Californian company, Shaman Pharmaceuticals, which is tapping the expertise of traditional healers, "Shamans" or medicine people, in various parts of the tropics (see Chichilnisky, 1993a). 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. 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.[8]

Similar examples hold for land resources. Recently the government of Ecuador allocated a piece of the Amazon the size of the state of Connecticut to its Indian population, a clear property-rights policy.[9] Under the conditions examined here, this policy should lead to a better use of the forest's resources and to a more balanced pattern of trade between Ecuador and the United States.[10]

However, property rights change slowly because they require expensive legal infrastructure and enforcement. Poor countries may find themselves unable to implement such policies quickly. The improvement of property rights of indigenous populations in developing countries, which house most of the world's population, should nevertheless

[7]The plans were described at a symposium held in January 1992 at Rockefeller University, organized jointly by the Rain Forest Alliance, and the New York Botanical Garden's Institute of Economic Botany (see e.g., the report in *Science Times*, science supplement to *The New York Times*, 28 January 1992, p. C1).

[8]Examples of successful medical discoveries from rain forests and other natural sources include widely used medicines such as aspirin, morphine, quinine, curare, the rosy periwinkle used to treat childhood leukemia and Hodgkin's disease, and (more recently) taxol.

[9]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 Ouiche Indians will soon administer an area where population density averages five people per square mile.

[10]In fact, forest and other environmental assets have public-good aspects, which have not been covered here. Markets with public goods have different behavior and require a different treatment. For example, Lindahl prices or particular distributions of endowments are needed for efficiency (see Chichilnisky et al., 1993).

be considered a major policy goal.[11] There is a small but apparently growing trend of this type in Brazil, Bolivia, Columbia, Ecuador, French Guyana, and Venezuela.[12] Property-rights policies, either through government action or preferably through private enterprise, as in the examples offered here, provide a hopeful foundation for resolving some North–South environmental issues. 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 entitlements for land and environmental resources such as clean water (Dasgupta, 1992). Similarly, as I have shown here, poverty can prevent environmental policies based on taxation from having their intended effects. Poverty and environmental overuse have a common root, and both are at the core of the North–South environmental dilemma.

Inexpensive environmental resources are a main source of environmental overuse. The statement that resources are overconsumed is practically equivalent to the statement that they are underpriced. Environmental overuse does not occur solely because the locals overconsume their resources, but because they export these resources to a rich international market at prices that are below social costs. This is why the global environmental issue is inextricably connected with North–South trade. The South overproduces, and the North overconsumes. The international market transmits and enlarges the externalities of the global commons. No policy that ignores this connection can work.

APPENDIX A: RESOURCE EXTRACTION AND PROPERTY RIGHTS

The Nash Equilibrium of the Harvester Extraction Problem with Unregulated Common-Property Resources.—The extraction of the input E is carried out by N "harvesters" of an unregulated common-property pool, indexed $i = 1, \dots, N$. Let x_i be the input of harvester i, and let $x = \sum_{i=1}^{n} x_i$. All harvesters are identical and interchangeable, so that the total harvest can be expressed as a function $E = F(x)$ of the total input. Assume also that all harvesters are symmetric, so that each harvester obtains as its output a fraction of the total output equal to the fraction that it supplies of the total input, formally, $E_i = F(x)(x_i/x)$. This insures uniqueness of the solutions. These are all standard assumptions (Dasgupta and Heal, 1979). Each harvester chooses its input level x_i to maximize the value of its share of outputs net of costs, $p_E E_i(x_i) - qx_i$, taking as given p_E, q, and the input levels of others, x_j for $j \neq i$. Here p_E is the market-induced price of the resource, and q is the "opportunity cost" of the input x_i; both q and p_E are endogenously determined in Appendixes B and C along with all other prices in a general-equilibrium fashion.

[11] Judge Alvaro Eduardo Junqueira declared that a shipload of mahogany sold by C&C Industria e Comercio was illegally felled and stolen from Indian reserves in the Amazon region, and he ordered the immediate seizure of thousands of cubic meters of mahogany bound to London. Tradelink, the London-based timber agent, stated that they will cease purchasing wood from C&C Industria e Comercio if the theft is confirmed (see *Financial Times*, 29 October 1993, pp. 1, 34). The matter is causing embarrasement for Britain's Timber Trade Federation: Britain imports about half of Brazil's entire mahogany exports.

[12] In the last three years, the Governments of Ecuador, Columbia, and Venezuela have restricted most of their Amazon areas as national parks or Indian reserves, as have Brazil and Bolivia, and France has made plans to protect a third of French Guyana. Last year, a coalition of Amazon Indians and foreign and local environmentalists confronted U.S. oil companies to induce them to abandon plans for extracting oil in Ecuador's Amazon (see J. Kane, 1993). Ecuador, one of South America's poorest countries, draws currently about $50 million yearly in revenues from oil exports. In the highlands of Ecuador, Indian groups have expressed similar resistance to export-oriented farming. José Maria Cabascango, 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., *New York Times*, 6 September 1992, p. L10. 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, 7 December 1992. A recent article in the *The New Yorker* (Kane, 1993) highlights the practical issues involved.

$F(0)=0$, $F'(x)>0$, and $F(x)$ is strictly concave, so there are strictly diminishing returns, arising perhaps from the application of increasing amounts of variable input x to a fixed body of land or water, and this insures existence of solutions. This models a Nash equilibrium pattern of use of an unregulated common-property resource, which is unique under the symmetry conditions.

PROOF OF PROPOSITION 1: The marginal product of input is $F'(x)$. The average product is $F(x)/x$, and by strict concavity $F(x)/x > F'(x)$. Look first at marginal products. The private-property marginal product of the input is denoted MP^{P}, and the common-property marginal product is MP^{C}. Now, $\mathrm{MP}_i^{\mathrm{C}} = d/dx_i[x_i F(x)]$ equals $d/dx_i[x_i F(x_i + x_{-i})]/(x_i + x_{-i})$ where $x_{-i} = \Sigma_{j \neq i} x_j$. Hence, under the assumptions,

$$\begin{aligned}\mathrm{MP}_i^{\mathrm{C}} &= F(x)/x + x_i\{[xF'(x) - F(x)]/x^2\} \\ &= F(x)/x \\ &\quad + (x_i/x)[F'(x) - F(x)/x].\end{aligned}$$

Note that the analysis provided here is independent of the number of harvesters as long as there is more than one ($N > 1$). As $N \to \infty$, $x_i/x \to 0$, and the common-property 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." Since $\mathrm{MP}_i^{\mathrm{P}} = F'(x)$,

$$\begin{aligned}\mathrm{MP}_i^{\mathrm{P}} - \mathrm{MP}_i^{\mathrm{C}} &= F'(x) - F(x)/x \\ &\quad - (x_i/x)[F'(x) - F(x)/x] \\ &= [F'(x) - F(x)/x][1 - x_i/x] \\ &< 0.\end{aligned}$$

Therefore the common-property marginal product is lower than the private-property one. The private-property supply curve E^{P}, is obtained by equalizing the opportunity cost q with the value of $\mathrm{MP}_i^{\mathrm{P}}$, $q = p_E \mathrm{MP}_i^{\mathrm{P}}$, and the common-property supply curve E^{C} is obtained by equating $q = \mathrm{MP}_i^{\mathrm{C}} p_E$: both supply functions of E as a function of p_E are parameterized by the opportunity cost q of the input x_i.

The last task is to show that, with both private- and common-property regimes, both supply curves increase with the price of the resource E at any given q. For simplicity in the rest of this proof I use E_i to indicate either the common-property supply curve or the private-property supply curve, because the argument that follows applies to both. For each p_E, the harvester's objective is to find x_i which optimizes

$$\text{(A1)} \qquad p_E E_i(x_i) - q x_i.$$

For each fixed q, the solution to this problem, denoted $x_i(p_E, q)$, is an increasing function of p_E: as the market price of E increases, the marginal productivity of x_i which maximizes the objective function of the harvester must satisfy $p_E(\partial E_i/\partial x_i) = q$. For each p_E and q, this maximization problem defines $E_i = E_i(x_i(p_E, q))$. Note that, for a given q, as p_E increases (A1) implies that $\partial E_i/\partial x_i$ must decrease. The concavity of E_i implies then that the optimal level of input $x_i(p_E, q)$ increases with p_E for any given q (i.e., $\partial x_i/\partial p_E > 0$). Therefore for any given q *the supply curve $E_i(x_i)$ is always increasing in the resource's price p_E*.

Appendix B: Formulation of the North–South Model

Consider a Heckscher-Ohlin formulation of two competitive economies trading with each other, except that factor endowments in the two countries are not fixed, but variable, depending on factor prices. This follows Chichilnisky (1981, 1985, 1986, 1990, 1993b) but differs from these works because they considered privately owned goods only. Variable factors are crucial in the consideration of property rights: Proposition 1 showed that at each price the supply of resources under common-property regimes is larger than with private property, a characterization which requires price-dependent endowments. This paper considers simple production functions with constant returns to scale; the model and its results have been extended to a variety of utility demand specifications, to Cobb-Douglas and CES production functions, and to economies with increasing returns (Chichilnisky, 1993b). Specify first one economy: the South. It produces goods A and B using two inputs, E and K. I consider a fixed-proportions technology in each sector, although there is substitution of factors at the aggregate level. This is because changes in factor prices lead to changes in factor endowments and so to changes in the composition of output and the factor intensity of final production. This could not happen in a Heckscher-Ohlin model, but *can* happen here because factor supplies vary with prices (see also Chichilnisky, 1986).

Production is specified by $B^S = E^B/a_1 = K^B/c_1$, and $A^S = E^A/a_2 = K^A/c_2$, where the superscript S denotes supply and superscripts A and B denote sectors, and where a_1, a_2, c_1, and c_2 are input–output coefficients. $E^S = E^B + E^A$ varies with prices, and so does $K^S = K^B + K^A$. The good B is more resource-intensive than A so that $D = (a_1c_2 - a_2c_1) > 0$. The following equations identify an equilibrium. First, with zero profits in the production of A and B,

$$\text{(B1)} \qquad p_A = a_1 p_E + c_1 r$$
$$p_B = a_2 p_E + c_2 r$$

or

$$p_E = \frac{p_B c_2 - c_1}{D} \qquad r = \frac{a_1 - p_B a_2}{D}$$

where p_A and p_B are the prices of A and B, respectively, p_E is the price of E, and r is the rental on capital, K. Consider next the exogenously given supply functions for the inputs E and K. It was established in Proposition 1 (see Appendix A) that the supplies of the environmental resource E increase with p_E/q, where q is the opportunity cost of the input used in extracting E. To simplify the computation of solutions consider a simple form of the supply function:

$$\text{(B2)} \qquad E^S = \alpha p_E/q + E^0 \qquad \alpha > 0.$$

The variable q in (B2) takes different values depending on the input used to extract E: q is r when E is produced from capital K; when E is produced from subsistence labor, p_B is an appropriate proxy for q. Note that when the supply function has the form in (B2) the slope α represents the property-rights regimes for the pool from which E is extracted: as established in Proposition 1 (proof in Appendix A), the supply of E has a larger slope when resources are common property and a smaller one in the case of private property, quite independently of which input is used to extract E. The assumptions made on the property-rights regimes of the economies of the North and the South made in Section III translate therefore into: $\alpha(\mathrm{N}) < \alpha(\mathrm{S})$ and $\alpha(\mathrm{S})$ large, where the letters in parentheses denote the North and the South. The supply for capital is similarly

$$\text{(B3)} \qquad K^S = \beta r + \overline{K}$$

where $\beta \geq 0$; everything that follows applies for $\beta = 0$ as well (i.e., when K^S is a constant $\overline{K}$). In equilibrium all markets clear:

$$\text{(B4)} \qquad E^S = E^D \qquad K^S = K^D$$

$$\text{(B5)} \qquad E^D = E^B + E^A = B^S a_1 + A^S a_2$$
$$K^D = K^B + K^A = B^S c_1 + A^S c_2$$

where superscript D denotes demand. When the extraction of E uses capital, $K^D = K^B + K^A + K^E$,

$$\text{(B6)} \qquad B^S = B^D + X_B^S$$
$$A^S = A^D + X_A^D$$

where X_B^S and X_A^D denote exports of B and imports of A, respectively, and

$$\text{(B7)} \qquad p_B X_B^S = p_A X_A^D$$

(i.e, the value of exports equals the value of imports). The North is specified by a set of equations similar to equations (B1)–(B7) with the same technology parameters and the same capital supply functions, but with different α's (i.e., different supply functions for environmental resources E), as explained in the paragraph following (B2), and discussed in Section III. The two supply functions are now denoted $E^S(S)$ and $E^S(N)$. In a world equilibrium, the prices of the traded goods (A and B) are equal, and exports match imports:

$$\text{(B8)} \qquad p_A(N) = p_A(S)$$

$$p_B(N) = p_B(S)$$

$$X_A^S(N) = X_A^D(S)$$

$$X_B^S(S) = X_B^D(N)$$

where the terms in parentheses, (S) and (N), indicate the North and South, respectively. Since the economies are identical except for property rights, in the two regions there are nine exogenous parameters: a_1, a_2, c_1, c_2, β, $\bar{K}$, E^0, and $\alpha(N)$ and $\alpha(S)$. I add a price-normalization condition $p_A = 1$ and obtain a total of 26 independent equations, (B1)–(B7) for the North and for the South, plus (B8) and $p_A = 1$.[13] There are in total 28 endogenous variables, 14 for each region: p_A, p_B, p_E, r, E^S, E^D, K^S, K^D, A^S, A^D, B^S, B^D, X_B^S, and X_A^D, so the system is underdetermined so far up to two variables, which reflects the fact that demand has not been specified yet. I consider a demand specification which leads to simple analytics (more general utility functions can be considered at the cost of more computation). In each region consider the utility function:

$$\text{(B9)} \qquad U(A,B) = B + k \qquad \text{if } A \geq A^{D*}$$

where $k > 0$, and

$$U(A,B) = B + \gamma A \qquad \text{otherwise}$$

where $\gamma = k/A^{D*} > 0$. For $p_B > 1/\gamma$, agents demand A^{D*} so by choosing k and γ in U appropriately, one may assume:

$$\text{(B10)} \qquad A^D(N) = A^{D*}(N)$$

$$A^D(S) = A^{D*}(S).$$

Thus, I have a system of 28 equations on 28 variables, depending on nine exogenous parameters, and the model is now fully specified. 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. I shall say that property rights are better defined in the North when $\alpha(N) < \alpha(S)$; both countries have the same property right when $\alpha(N) = \alpha(S)$. Note that by inverting equations $E^S = a_1 B^S + a_2 A^S$ and $K^S = c_1 B^S + c_2 A^S$ one obtains

$$\text{(B11)} \qquad B^S = (c_2 E - a_2 K)/D$$

$$A^S = (a_1 K - c_1 E)/D$$

where as before $D = a_1 c_2 - a_2 c_1 > 0$. When the extraction of E uses capital, K in the two equations in (B11) is replaced by $K - K^E$.

Appendix C: Proofs of the Results

Proof of Uniqueness of a Competitive Equilibrium.—The North–South model defined in Appendix B has at most one competitive equilibrium for any parameters $\alpha(S)$ and $\alpha(N)$ representing the structure of property rights in the two regions. In the following, the supply function of resources in (B2) is $E = \alpha p_E / p_B + E^0$, which, as discussed in the paragraph following (B2), corresponds to the case in which E is extracted using subsistence labor, as in Section V. Similar computations obtain when E is extracted using capital (K) as an input; in this latter case, q is replaced by r in (B2) and $K^D = K^S = K^A + K^B + K^E$, where $F(K^E) = E$

[13] Walras's law assures market-clearing in one of the markets whenever all other markets clear, thus reducing the number of equations presented here by one.

(see Proposition 1). From (B8) and (B10),

$$\text{(C1)}\quad A^{D*}(S) - A^{S}(N) = A^{S}(N) - A^{D*}(N).$$

Now rewrite (C1) as a function of one variable only, p_B. Substituting equations (B1)–(B8) and (B11) into (C1), one obtains:

$$\text{(C2)}\quad p_B^2[\psi(S)+\psi(N)] + p_B[A^{D*}(S)+A^{D*}(N)+\Gamma(S)+\Gamma(N)] - [\rho(S)+\rho(N)] = 0$$

where

$$\psi = \beta a_1 a_2 / D \qquad \rho = \alpha c_1^2 / D^2$$

and

$$\Gamma = (1/D)\left[c_1 E^0 - \alpha_1 \overline{K} + (1/D) \times (\alpha c_1 c_2 - \beta a_1 a_2)\right].$$

Equation (C2) 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^* one obtains in each country the equilibrium levels of all other variables: p_E^* and r^* from (B1), E^{S*} and K^{S*} from (B2) and (B3), B^{S*} and A^{S*} from (B11), X_A^{D*} from (B10), and A^{D*}, A^{S*}, and X_B^{S*} from (B7) and (B8), so the (unique) full equilibrium of the North–South model is computed.

PROOF OF THEOREM 1:

The completely symmetric case of the North–South model is utilized here because it shows very clearly the role of property rights in determining patterns of trade. Here, the two regions are identical except for property rights: same inputs K and E, same produced goods A and B, same production functions for A and B, and same preferences. In the two regions E is produced by harvesters using an exogenous, fixed endowment of capital $\overline{K}$ as an input, where $\overline{K}$ is the same in the two regions, and using the same production technology $f\colon K \to E$ (see Proposition 1). The South extracts E from an unregulated common-property pool, and the North does so under private-property regimes. The market-clearing condition for K is $K^D = K^A + K^B + K^E = \overline{K}$, where $F(K^E) = E$ as derived in Proposition 1. In sum, the two regions are identical, but the South's supply of E is given by the common-property supply curve $E^C(p_E)$ while the North's is given by the private-property supply curve $E^P(p_E)$ (see Appendix A). At each price vector, the supply of E in the South exceeds that of the North (see Proposition 1; proof in Appendix A).

Consider now a world equilibrium commodity price vector $\mathbf{p}_w^*$; at the equilibrium, factor prices p_E^* and r^* are the same in the two regions because the two regions have the same technologies (i.e., the same a_1, a_2, c_1, and c_2), and by the zero-profit conditions on the production of A and B given in (B1). However, the South supplies more environmental resources than the North by Proposition 1. By inverting the two linear equations $E^S = a_1 A^S + a_2 B^S$ and $K^S - K^E = c_1 B^S + c_2 A^S$ one obtains

$$B^S = \frac{c_2 E - a_2(K - K^E)}{D}$$

which increases with E because $D > 0$. It follows that at $\mathbf{p}_w^*$ the South produces a larger amount of the traded good B than does the North; intuitively this is a consequence of the fact that B is intensive in the input E, which is more abundant in the South.

When the two regions have the same homothetic utilities, since at $\mathbf{p}_w^*$ the two regions face the same relative prices for goods A and B, the North and the South demand goods for A and B in the same proportions. Since in equilibrium the supply of B in the South is proportionately larger, when the international markets clear, the South must export B, and the North must import B; that is, the South is an exporter of environmentally intensive goods at the world equilibrium.

Next I establish formally the intuitively obvious proposition that in the move from autarky to trade, the South produces more resources. First I establish that from autarky to trade the relative price of the environmentally intensive good B must increase from the autarchic level in the South. To establish this, I show that, in autarky, the relative price p_B/p_A (recall $p_A = 1$), must be larger in the North than it is in the South, that is, in autarky,

$$(C3)\quad (p_B/p_A)(N) > (p_B/p_A)(S).$$

This is also intuitively obvious because preferences are the same in both countries, and the South has an institutional comparative advantage in B. Formally, it is seen as follows. It is known that *at any given price* the South produces more B than the North because of common-property regimes (Proposition 1). If, in contradiction with (C3) $(p_B/p_A)(N) < (p_B/p_A(S)$, then this effect is emphasized according to Proposition 1 and equations (B1), and therefore in autarky the South supplies more B than the North. But preferences are assumed in this theorem to be homothetic, so that if $(p_B/p_A)(N) < (p_B/p_A)(S)$, in autarky the North consumes proportionately more B than the South. This contradicts the assumption that the two countries are both in an autarchic equilibrium: they are identical, but the South produces proportionately more B than the North, and it consumes proportionately less than the North. Therefore, in one of these countries the market for B must fail to clear, a contradiction. Since the contradiction arises from negating (C3), inequality (C3) must hold.

Now it is straightforward to show that a move from autarky to trade leads to a world price of B that is higher than the autarky price was in the South (i.e., that $p_B^* > (p_B/p_A)(S)$. Assume not; then, by the above,

$$(C4)\quad (p_B/p_A)(N) > (p_B/p_A)(S) > p_B^*.$$

Since preferences are homothetic, (C4) implies that the proportion of goods B/A consumed in both countries increases after trade. However, the proportion of goods B/A produced in both countries decreases, because as p_B decreases, so does p_E, while r increases [equation (B1)], so that the harvesters extract less E, and the B good, which is E-intensive, is produced in smaller quantities while the A good is produced in higher quantities.

As shown above, (C4) implies that at a trade equilibrium the proportion B/A in which goods are produced decreases in both countries with respect to autarky, while the proportion B/A in which goods are consumed increases in both countries. This implies that markets cannot clear at the trade equilibrium when (C4) is satisfied, a contradiction. Therefore at a world equilibrium it must be true that $p_B^* > (p_B/p_A)(S)$ as I wished to prove. Similarly I have proved that p_B^* is lower than the autarky price in the North, $p_B/p_A(N)$.

Having proved that p_B/p_A increases in the South from autarky to trade, it follows immediately that the extraction of E increases in the South after trade. As the price of the environmentally intensive good B increases from autarky to trade, the price E must increase, and the rental on capital r, which moves in the opposite direction to p_E, decreases [see equations (B1)]. Therefore, after trade, the harvesters face lower opportunity costs for their input, K, and higher prices for the output, E. They therefore harvest more (see the proof of Proposition 1 in Appendix A), and the extraction of E increases.

Since the two countries are identical except for property rights, when the two have well-defined property rights they do not trade (i.e., the result is autarky). By the first theorem of welfare economics, when $K^S = \bar{K}$ the private-property competitive equilibrium is Pareto efficient, and as proved above in this appendix, it is unique. Since as seen in the previous paragraph the South produces more E when it moves from autarky to trade, at a trade equilibrium (with common property) its production of E is larger than is Pareto efficient. Its equilibrium price is lower than in autarky (i.e., when both countries have well-defined property rights), since $p_B^* < (p_B / p_A)(N)$.

PROOF OF COROLLARY 1:

The fact that factor prices in the two regions are equalized at a competitive equilibrium follows immediately from equations (B1), which shows that the factor prices are determined by the traded-goods prices p_A and p_B and by the technical coefficients a_1, c_1, a_2, and c_2, which are identical in equilibirium in the two regions.

PROOF OF PROPOSITION 2:

The resource E is supplied to the market by harvesters as specified in Appendix A. The harvesters own only their input $\bar{x}$ of labor, they exchange their harvest of E for A, and they have utilities $u_i(A, \bar{x} - x_i)$ which depend on consumption of A and on leisure, with elasticity of substitution between leisure and consumption, $\sigma < 1$. Consider the harvester's optimization problem:

$$\text{(C5)} \quad \max\left[u_i(A, \bar{x} - x_i)\right]$$

$$\text{subject to } p_A A = p_E E(x_i)$$

where $E(x_i) = E^C(x_i)$ is as defined in Proposition 1. At each relative market price p_E / p_A the harvester chooses x_i so that

$$\text{(C6)} \quad (p_E / p_A) E_i'(x_i) = \left[\partial u_i / \partial(\bar{x} - x_i)\right] / \left[\partial u_i / \partial A\right].$$

The solution to (C6) is denoted $x_i(p_E, p_A)$. The opportunity cost of the input q must satisfy

$$\text{(C7)} \quad (p_E / p_A) E_i'(x_i) = q$$

so that by (19),

$$q(p_E, p_A) = \left[\partial u_i / \partial(\bar{x} - x_i)\right] / \left[\partial u_i / \partial A\right].$$

That is, *the opportunity cost $q(p_E, p_A)$ of x_i is the ratio of the marginal utility of leisure and the marginal utility of consumption*, as stated in Section IV-A.

In (C7), q appears explicitly as a function of p_A and p_E. Using (C7) one can now explore how the extraction of the resource E changes with its price p_E, and how the opportunity cost q of the input x_i, varies across equilibria. First recall that the workers' elasticity of substitution between leisure and consumption, which measures precisely how substitutable one good (A) is for the other (leisure, $\bar{x} - x_i$), is assumed to be less than 1, that is

$$\sigma = \frac{\partial\left(\dfrac{A}{\bar{x} - x_i}\right)}{\partial\left(\dfrac{p_A}{q}\right)} \left[\frac{\dfrac{p_A}{q}}{\dfrac{A}{\bar{x} - x_i}}\right] < 1$$

(Varian, 1992 p. 44). This implies immediately, by definition, that as the relative price of A increases, leisure decreases. This in turn implies that extraction has increased. Figure C1 illustrates this fact: as the relative price of A increases, the proportion of consumption of A and of leisure must go down by a smaller proportion, because $\sigma < 1$. The vertical segment between the two indifference surfaces in Figure C1 represents the change in prices, while the part of this segment indicated with Δ, which indicates the change in the proportion of consumption of A and of leisure, is smaller, leading to less leisure after the price of A increases.[14] More effort x_i is applied, and therefore there is more extraction of E as the price p_E drops. Note that the utilities used here are quite general, requiring only continuity, strict concavity, and $\sigma < 1$. For example, with CES utility functions (which are not required here),[15] the assumption $\sigma < 1$ simply means that the indifference surfaces of a worker's utility do not cross the axis, which is a standard assumption.

[14] For example, if utilities are Cobb-Douglas, one obtains the limiting case of constant supply of the resource E as p_E / p_A decreases.

[15] CES utilities are of the form $u(A, \bar{x} - x) = [dA^\rho + e(\bar{x} - x)^\rho]^{1/\rho}$, and their elasticity of substitution is $\sigma = 1/(1 - \rho)$ (see Varian, 1992).

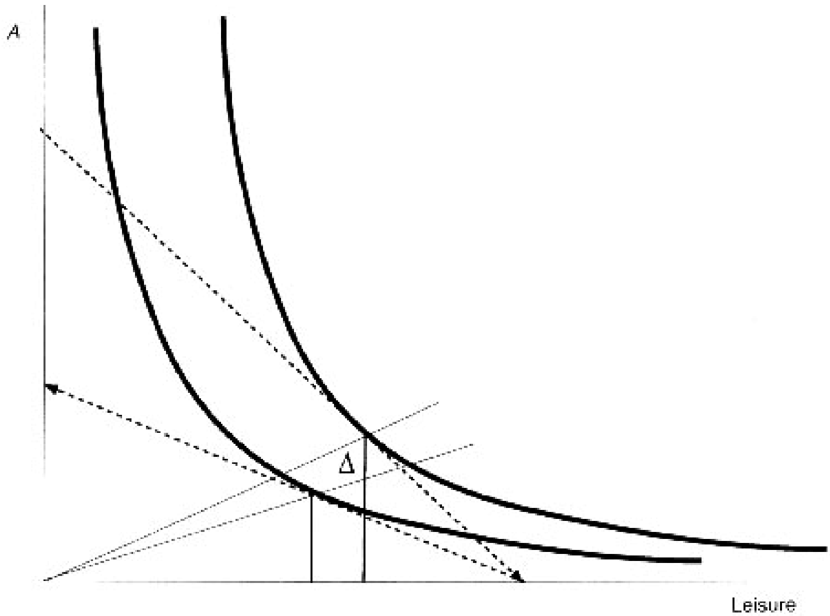

FIGURE C1. THE HARVESTER MAXIMIZATION PROBLEM

Notes: The curves represent indifferences of the harvester between consumption of A and leisure. The two dashed lines represent budget lines at different prices. They converge to a point on the horizontal axis which is the harvester's initial endowment of labor. With harvesters owning only labor, and with elasticity of substitution less than 1, as the relative price of resources increases (the price of A increases) leisure decreases, and more is harvested.

The last task is to explain Figure 2, which indicates how a decrease in opportunity cost of labor increases extraction. First note that the opportunity cost of the input x_i decreases with p_E: as p_E/p_A decreases, the quantity of $x_i(p_E, p_A)$ supplied increases (as in Fig. C1), so that the supply of the resource $E = E(x_i(p_E, p_A))$ also increases. By the concavity of the production function for E, this implies that as p_E/p_A drops, the derivative $E_i'(x_i(p_E, p_A))$ must also drop. Since p_E/p_A decreases and $E_i'(x_i)$ has not increased, the opportunity cost q defined in (C7), $q(p_E, p_A) = (p_E/p_A)E_i'(x_i)$ must have decreased as well. As the relative price of the resource p_E decreases, the opportunity cost of labor q drops, and the supply curve of resources shifts as was indicated in Figure 2.

PROOF OF PROPOSITION 3:

Consider a unit tax T on the use of the resource E in the South, which increases the value of demand for A, $A^{D*}(S)$, by TE^* (recall that $p_A = 1$). I shall now consider the cross-equilibria relationship between p_B and $A^{D*}(S)$ to determine the changes in prices of the resource-intensive good A in a new equilibrium, following the tax. From (C2), by the implicit-function theorem, across equilibria,

$$\text{(C8)}\quad \frac{\partial p_{B^*}}{\partial A^{D*}(S)} = \frac{-p_{B^*}}{2p_B[\Psi(S)+\Psi(N)]+\Gamma(S)+\Gamma(N)+A^{D*}(S)-A^{D*}(N)}$$

which, when $\alpha(S)$ is sufficiently large, is always negative [see (C2) and also Chichilnisky, 1986 p. 15]. Now, by assumption, the tax proceeds lead to a higher level of demand for the capital-intensive good A in equilibrium, A^{D*}. Therefore by (C8) the tax leads to a drop in the equilibrium price p_B^* of the resource-intensive good, B.

Finally, when $c_2/D < 2p_E/p_B$ and α is large, the equilibrium level of exports of B increases as their price p_B drops since $X_B^S(S) = B^S - B^D = B^S - (p_E E + rK - A^{D*})/p_B$ so that

$$\text{(C9)} \quad X_B^S(S)$$

$$= \frac{c_2 E - a_2 K}{D} - \frac{p_E E + rK - A^{D*}}{p_B}$$

$$= \left(\frac{\alpha c_1}{D^2 p_B}\right)\frac{c_2 - c_1}{p_B} + \left(\frac{\beta a_1}{D^2}\right)\frac{a_2 - a_1}{p_B}$$

$$+ \frac{c_1 E^0 - a_1 \overline{K}}{D p_B} + \frac{A^{D*}(S)}{p_B}$$

and thus,

$$\text{(C10)} \quad \frac{\partial X_B^S}{\partial p_B} = \frac{\alpha c_1}{D^2 p_B^2}\left(\frac{2c_1}{p_B} - c_2\right) + \frac{\beta a_1}{D^2 p_B^2}$$

$$+ \frac{a_1 \overline{K} - c_1 E^0}{p_B^2} - \frac{A^{D*}(S)}{p_B^2}$$

(see also Chichilnisky, 1981, 1986). When α is large, (C10) implies that $\partial X_B^S/\partial p_B$ has the sign of $2c_1/p_B - c_2$, which is equal to that of $c_2/D - 2p_E/p_B$ by (B1). Since by assumption $c_2/D < 2p_E/p_B$, (C10) is negative; therefore taxes lead to a lower p_B and to an increase in exports $X_B^S(S)$. Notice that when α is large, c_2/D is the term representing the supply (B^S) response to the change in terms of trade p_B, while $2p_E/p_B$ is the demand response to p_B. Therefore the inequality $c_2/D < 2p_E/p_B$ implies that an increase in the price of B leads to a larger increase in the demand for B than in supply of B, a situation which is described by stating that "income effects dominate" in the market for B. The rest of the proof follows from Proposition 2.

To simplify computations, in this proof I have taken utility functions which effectively make the demand for A in each region an exogenously chosen parameter at an equilibrium [see equation (B10)]. This follows Chichilnisky (1981, 1986, 1993b), where it is also shown that the results generalize to more general utilities and demand functions. This procedure allows one to explore the effect of a tax which unequivocally increases the demand for non-resource-intensive goods, the most favorable conditions for the tax to work in the intended direction. Proving the results under such assumptions gives a stronger result than if demand for the resource-intensive goods also increased after taxes.

REFERENCES

Amelung, Torsten. "Tropical Deforestation as an International Economic Problem." Unpublished manuscript presented at the Egon-Sohmen Foundation Conference on Economic Evolution and Environmental Concerns, Linz, Austria, 30–31 August 1991.

Barbier, Edward B.; Burgess, J. C. and Markandya, Anil. "The Economics of Tropical Deforestation." *AMBIO*, April 1991, *20*(2), pp. 55–58.

Binkley, C. S. and Vincent, Jeffrey R. "Forest Based Industrialization: A Dynamic Perspective." World Bank (Washington, DC) Forest Policy Issues Paper, 1990.

Bromley, Daniel W., ed. *Making the commons work*. San Francisco: ICS Press, 1992.

Chichilnisky, Graciela. "Terms of Trade and Domestic Distribution: Export-Led Growth with Abundant Labour." *Journal of Development Economics*, April 1981, *8*(2), pp. 163–92.

______. "International Trade in Resources: A General Equilibrium Analysis." *Proceedings of the American Mathematical Society*, 1985, *32*, pp. 75–125; reprinted in Robert McElvey, ed., *Environmental and natural resource mathematics*. Providence, RI: American Mathematical Society, 1985, pp. 75–125.

______. "A General Equilibrium Theory of North–South Trade," in Walter P. Heller, Ross M. Starr, and David A. Starrett, eds., *Essays in honor of Kenneth Arrow*, *Vol. 2: Equilibrium analysis*. Cambridge: Cambridge University Press, 1986, pp. 3–56.

______. "On the Mathematical Foundations of Political Economy." *Contributions to Political Economy*, 1990, *9*, pp. 25–41.

______. "Biodiversity and Property Rights in the Pharmaceutical Industry." Case study, Columbia University School of Business, 1993a.

______. "Traditional Comparative Advantages vs. External Economies of Scale." Report to the Economic Commission for Latin America and the Caribbean, Project on Trade Liberalization in the Americas, United Nations, New York, 1993b; *Journal of International Comparative Economics* (forthcoming).

______. "North–South Trade and the Dynamics of Renewable Resources." *Structural Change and Ecnomic Dynamics*, December 1993c, *4*(2), pp. 219–48.

Chichilnisky, Graciela and Heal, Geoffrey M. *The evolving international economy*. Cambridge: Cambridge University Press, 1987.

______. *Oil in the international economy*. Oxford: Clarendon, 1991.

Chichilnisky, Graciela; Heal, Geoffrey M. and Starrett, David. "International Markets with Emission Permits: Equity and Efficiency." Working paper, Stanford Institute for Theoretical Economics, December 1993.

Coase, Ronald H. "The Problem of Social Cost." *Journal of Law and Economics*, October 1960, *3*, pp. 1–44.

Cohen, Jon S. and Weitzman, Martin L. "A Marxian Model of Enclosures." *Journal of Development Economics*, February 1975, *1*(4), pp. 287–336.

Dasgupta, Partha. *The control of resources*. Cambridge, MA: Harvard University Press, 1992.

Dasgupta, Partha and Heal, Geoffrey M. *Economic theory and exhaustible resources*. Cambridge: Cambridge University Press, 1979.

Demsetz, Harold. "Towards a Theory of Property Rights." *American Economic Review*, May 1967 (*Papers and Proceedings*), *57*(2), pp. 347–57.

Dixit, Avinash and Norman, Victor. *Theory of international trade*. Cambridge: Cambridge University Press, 1980.

Hyde, W. F. and Newman, D. H. "Forest Economics in Brief—With Summary Observations for Policy Analysis." Unpublished manuscript (draft report), Agricultural and Rural Development, World Bank, Washington, DC, 1991.

Kane, Joe. "Letter from the Amazon." *New Yorker*, 27 September 1993, *69*(31), pp. 54–79.

Lerner, Abba P. "The Symmetry Between Import and Export Taxes." *Economica*, August 1936, *3*(11), pp. 306–13.

McDonald, Steven L. *Petroleum conservation in the United States: An economic analysis*. Baltimore, MD: Johns Hopkins University Press, 1971.

Metzler, Lloyd. "Tariffs, the Terms of Trade, and the Distribution of National Income." *Journal of Political Economy*, February 1949, *57*(1), pp. 1–29.

Ruitenbeek, H. J. "The Rainforest Supply Price: A Step Towards Estimating a Cost Curve for Rainforest Conservation." Development Research Programme Working Paper No. 29, London School of Economics, 1990.

Schweigert, Thomas. "Commercial Sector Wages and Subsistence Sector Labor Productivity in Guatemalan Agriculture." *World Development*, January 1993, *21*(1), pp. 81–91.

Varian, Hall. *Microeconomic analysis*, 3rd Ed. New York: Norton, 1992.

World Bank. *World development report: Development and the environment*. Oxford: Oxford University Press, 1992.