Common ground between free-traders and environmentalists

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Abstract

We use a North-South model with property right differences and resource dynamics to study the effects of trade on resource use and welfare. Autarky is likely to Pareto-dominate free trade in the long run when the environment is quite fragile, and the result is reversed when the environment is quite resilient. Trade may cause an environmentally poor country to “drag down” its richer trading partner; in this case, both countries degrade their stocks when these would be preserved under autarky. Alternatively, trade may enable the environmentally richer country to “pull up” its partner; in this case both countries preserve their stocks when these would be degraded under autarky. These results rationalize the positions of environmentalists and free-traders. The direction of trade may change over time, but in steady states it is either inefficient or indeterminate. In the former case, a switch to autarky would increase global welfare. (*JEL* D5, F1, O2, Q2)

1 Introduction

Many environmentalists think that free trade harms the environment and ultimately decreases human welfare. Most economists think that free trade is likely to improve welfare. The recent exchange between Daly (1993) and Bhagwati (1993) exemplifies this disagreement in academic circles. The debate in the US over passage of NAFTA and the recent discussion over "fast-track" authority for enlargement of the free-trade area illustrate the controversy in the political arena. Empirical evidence (General Agreement on Tariffs and Trade (1992), Low (1992) and Anderson (1993)) is anecdotal, and cannot resolve the debate. Theory is also ambiguous, because the theory of the second best implies that trade may reduce welfare in the presence of distortions. However, economic theory can clarify the issues that underlie the debate. By taking seriously environmentalist arguments against trade liberalization, we can make the arguments precise and identify the circumstances where they are plausible.

Environmentalists are particularly concerned about free trade's long-run effect on environmental stocks. They worry that trade liberalization will expand the scope of market failures, put added strain on the environment, and lead to degradation (even exhaustion) of stocks in the long run. Short-run welfare gains - when they exist - may not be sustainable. These concerns have an empirical basis: Thailand and the Philippines, major timber exporters in the 1970's and early 1980's, exhausted many of their forest stocks and became net importers of roundwood (FAO (1994)). Trade encouraged their over-exploitation of forest resources because of loosely-defined property rights and lax (enforcement of) environmental regulations (McDowell (1989)).

Environmentalists are especially opposed to trade liberalization involving countries at different stages of development. The environment was a major issue in the NAFTA debate, but was a secondary issue in discussions of "completion" of the EC market. Countries at different stages of development have qualitatively different institutional and regulatory environments, and thus different degrees of market failures. The difference - rather than the existence - of market failures in the countries that liberalize trade is an important reason for the environmentalists' position.

A number of papers have studied market failures and the long-run relationship between trade and the environment. Chichilnisky (1993) shows that (given a certain assumption) a country with weaker property rights for natural resources exports the resource-intensive good in the steady state. Brander and Taylor (1997b) show that in some situations the country with weak property rights imports the resource-intensive good in a steady state. Brander and Taylor (1997a) study a model in which trade reduces the steady state welfare of a small open economy which exports the resource-intensive good. Brander and Taylor (1998) extends this result to the case of two trading countries, where world prices are endogenous. These papers illustrate the possibility that in steady state, one country gains and the other loses from trade, due to difference in property rights.

We show that the long-run relationship between trade and the environment is more complicated than the previous literature suggests. Building on Chichilnisky (1994), we study North-South trade where the two countries differ only in property rights (with South having weaker property rights), and possibly in their initial environmental stocks. Environmental services, a factor of production, are extracted from the environmental stock. Imperfect property rights to this stock lead to excessive extraction, i.e. a larger supply of environmental services. A higher environmental stock reduces the extraction cost and increases the supply of environmental services. The environmental stock is a renewable resource and changes endogenously. By comparing the autarkic and free trade steady states, we show that in the long run South does not always lose from trade and North does not always gain. Both may gain or both lose from trade. The following two scenarios, out of many, illustrate the complexity of the long-run relationship between trade and the environment.

In the first scenario, South's initial environmental stock is large enough that its market failure would not have serious consequences either in the short or long run under autarky. North has smaller environmental stocks, but its property rights are strong enough to allow stocks to recover under autarky, so that in the long run its autarkic welfare is high. Now suppose that the countries begin to trade. South's relatively weak property rights magnify its comparative advantage in the resource-intensive good, which South initially exports. Trade enlarges the scope of South's market failure, and decreases the scope of North's market failure. Eventually, South's environmental stocks fall and its costs of obtaining environmental services rise enough that North begins to export the resource-intensive good. North's property rights are strong enough to allow it to recover from low stocks in autarky, but not strong enough to pull up a resource-impoverished trading partner. North's environmental stocks are eventually degraded and both countries are impoverished. With free trade, North first "drags down" South, and is then dragged down by South. In the long run, both countries are worse off as a result of trade.[1] In this pessimistic scenario, trade encourages both countries to play to their weaknesses. The market failure, which is unimportant in the long run under autarky, becomes disastrous under trade.

In the second scenario, trade benefits both countries in the long run. South's property rights are sufficiently weak that under autarky its environmental stock would be degraded, and South impoverished. North's property rights are strong enough that its steady state stock and welfare would be "quite high." When the countries begin to trade, South might initially export the resource-intensive good, further degrading its stocks. However, eventually North begins to export this good, allowing Southern stocks to recover. At some point Southern stocks are large enough that its weaker property rights enable it to recapture comparative advantage in the resource-intensive good. Thereafter Northern stocks grow. In this scenario, both countries have higher steady-state

[1]Newbery and Stiglitz (1984) provide a two-country example where trade lowers both countries' welfare because of missing insurance markets.

environmental stocks and higher welfare than they would have had under autarky.

Although these scenarios are stylized, they both have a ring of plausibility. Under the current property right regimes, will Thailand and the Philippines be able to recover their forestry stock by importing from forestry rich countries? Or will their imports eventually deplete the stocks of the current exporters? Environmentalists and free-traders disagree about which scenario is more plausible. One of the important contributions of our paper is to explain what determines the likelihood of a particular scenario: we emphasize the role of the (natural, uncongested) growth rate of the environmental stock in relation to property rights and other economic parameters. If this growth rate is small, we can think of the environment as being "fragile", since it cannot easily recover from low levels. If the growth rate is large, the environment is resilient. Casual reasoning does not suggest the direction of the relationship between this parameter and the different outcomes. For example, if free-traders believe that trade liberalization is likely to increase welfare and benefit the environment, they might think that free-trade is especially important when the environment is fragile. However, we show that the pessimistic scenario feared by environmentalists is more likely if the environment is "quite fragile", and that the optimistic scenario promoted by free-traders is more likely if the environment is "quite resilient." The disagreement between environmentalists and free-traders can thus be viewed as a difference of opinion regarding the fragility of the environment. Adoption of a neoclassical trade model does not prejudge the question, but instead provides a common ground for its discussion.

We also obtain a number of important secondary results. If the environment is "very fragile", trade has no long-run effect, since both countries are doomed (in the long run) to poverty and low environmental stocks under both free trade and autarky. If the environment is "very resilient", trade has a quantitative but not a qualitative long-run effect. In this case, trade benefits North and harms South. Most of the literature has concentrated on this scenario only (Chichilnisky (1993) and

Brander and Taylor (1998)), and their results are reproduced in our paper. In these two scenarios, trade is either irrelevant in the long run (when both countries have low steady-state stocks) or is dynamically inconsistent (when both countries have high steady-state stocks). In the latter case, there would always come a time at which the trajectories of both Southern and aggregate world welfare would be higher under autarky than free trade. We also derive a number of static welfare implications of trade. Finally, we address the environmentalists' concern that free-trade increases the equilibrium aggregate demand (and thus the equilibrium supply) for environmental services at a point in time (for given stocks). We show that trade either increases aggregate demand for environmental services or has no effect on aggregate demand, depending on the stock level.

Section 2 describes the economies of North and South and characterizes the static and dynamic autarkic equilibrium. Section 3 characterizes the static and dynamic equilibrium with trade. We analyze the static welfare implications of trade in Section 4. Section 5 presents our main results on the long-run welfare implications of trade. In Section 6 we discuss the plausibility of our assumptions and the generality of our results. Section 7 concludes.

2 An Autarky Economy

We begin by describing production and consumption in one of the two countries (North and South) and solve for the autarky equilibrium. A complete description of the model can be found in Chichilnisky (1994). Each economy contains three sectors. Sector A produces a pure consumption good, subsistence commodity A. Sector B produces commodity B which is both consumed and used as an input in the third sector E, which produces the environmental service E. Production of A and B uses two inputs, environment E and capital K, in fixed-proportions technologies given by

$$A^p = \min\left\{\frac{E_A}{a_1}, \frac{K_A}{b_1}\right\} \qquad\qquad B^p = \min\left\{\frac{E_B}{a_2}, \frac{K_B}{b_2}\right\}. \tag{1}$$

The superscript p denotes production, the subscripts A and B denote sectors, and a_1, a_2, b_1, b_2 are input-output coefficients. We assume that B is relatively resource-intensive, i.e. $\frac{a_2}{a_1} > \frac{b_2}{b_1}$. We normalize the price of A to be 1, and denote prices of B, E and K as P, w, and r respectively.

The supply of capital K is exogenously fixed: $K^p = \bar{K}$, the total capital available in the economy. The environmental service E is produced (extracted) using good B and the environmental stock Z. The environmental stock changes over time, but is fixed at a point in time. The variable E represents the flow of non-traded primary goods and services, such as clean air and water, energy and agricultural and forestry products. The stock Z represents farmland, forests, rivers and mines.

The technology of extracting E is given by $E = Z^{\frac{1}{2}} F^{\frac{1}{2}}$, where F is the aggregate amount of B used in the E sector. The market failure occurs in this sector: the environmental stock Z is a common property resource with n identical extractors. Extractor i contributes f_i (so $F = \sum_i f_i$) and receives the share of output proportional to her contribution ($\frac{f_i}{F}$). Extractors take the prices of E and B as given and treat Z as common property with a zero price (due to myopia). We can show that the supply function for the environmental service E is

$$E^p = \delta \frac{wZ}{P} \tag{2}$$

where $\delta = 1 - \frac{1}{2n}$. For $n = 1$, $\delta = \frac{1}{2}$ and as $n \to \infty$, $\delta \to 1$. The parameter δ represents the property-rights regime. When $\delta \approx \frac{1}{2}$ we have complete (static) property rights, and $\delta \approx 1$ corresponds to common property.

Commodity A is a subsistence good, for which demand is perfectly inelastic at A^*. When agents' income is sufficient to purchase A^*, remaining income is spent on consumption of B. In this case, the consumption level of B determines welfare. When agents' income is insufficient to purchase A^*, they spend everything on commodity A. In this case, the level of consumption of A determines welfare. More formally, if the price of A equal 1, $P =$ the price of B and $y =$ income, the indirect utility function is $v(y,P) = y$ for $y \leq A^*$ and $v(y,P) = A^* + \frac{y-A^*}{P}$ for $y > A^*$. The income elasticity of the demand for A is 1 for income less than A^* and 0 for income greater than A^*.

We assume $A^* < \frac{\bar{K}}{b_1}$, i.e. production of A^* is feasible when the supply of E is sufficiently large. Consumers own capital and the extraction firms in sector E. Total income equals the total rent to capital and the profit of the extraction firms, since production of A and B generates zero profit.

Many possibilities arise in the autarkic and trade equilibria. To enable us to concentrate on the most important situations, we assume throughout this paper that (i) agents are able to consume A^*, and (ii) in the trade equilibrium countries are incompletely specialized, so that relative factor prices are equal. These assumptions require that A^* is small and that the countries' stocks lie in a "cone of diversification."

2.1 *Static Autarky*

The consumption of A equals A^*. There are three possibilities on the supply side (see Figure 8 of Appendix A which graphs the production possibility frontier of A^p and B^p): (i) full employment of both inputs E and K if $\frac{b_2}{b_1} < P < \frac{a_2}{a_1}$; (ii) full employment of E and partial employment of K if $P = \frac{a_2}{a_1}$; and (iii) full employment of K and partial employment of E if $P = \frac{b_2}{b_1}$. However, (iii) can never happen because E is costly to extract. We do not consider equilibria with $P > \frac{a_2}{a_1}$ or $P < \frac{b_2}{b_1}$ because markets do not clear at these prices.

For situation (i), Appendix A derives the equilibrium price of B and the amount of extraction E as:

$$P^{af} = \frac{b_2^2 \psi^a}{b_1 b_2 \psi^a - \phi D} \tag{3}$$

$$E^{af} = \frac{\phi}{b_2}, \tag{4}$$

where $D = a_2b_1 - a_1b_2 > 0$ because sector B is resource-intensive, $\phi = a_2\bar{K} - A^*D > 0$, and $\psi^a = \delta Z$. Superscript a denotes autarky and f denotes full-employment of K. The price of the resource-intensive good B, P^{af}, is decreasing in δZ. Following Chichilnisky (1994), we refer to δZ as the apparent resource stock. The apparent stock, rather than the real stock Z, determines prices.

For situation (ii), when capital is partially unemployed, $P^{au} = \frac{a_2}{a_1}$, and from (17) in Appendix A, $w^{au} = \frac{1}{a_1}$, and $r^{au} = 0$, where u denotes partial unemployment. These values and equation (2) imply the extraction of E as

$$E^{au} = \frac{\delta Z}{a_2}. \tag{5}$$

Whether (i) or (ii) occurs in an economy depends on the level of the apparent resource stock. To obtain the minimum size of the resource stock consistent with full employment, denoted as Z^c, we set $P^{af} = P^{au}$ and solve for Z to get

$$Z^c = \frac{a_2\phi}{\delta b_2}. \tag{6}$$

If the apparent resource stock δZ is sufficiently high (i.e. $Z > Z^c$), the supply of E adjusts to ensure full employment of capital. However, if the apparent resource stock is low, the economy cannot produce enough environmental input E, regardless of the prices P and w, to achieve full employment of capital K.

Note that while E^{au} increases in δ, E^{af} is independent of the property rights parameter. Thus whenever $Z < Z^c$, imperfect property rights cause sector E to use more of factor B than is socially optimal, and the representative consumer's welfare is decreasing in δ. When $Z \geq Z^c$, weak property rights do not affect production or welfare; the fixed proportion technology in sectors A and B *fixes* the amount of E that is demanded in the economy, regardless of P, w, or δ.

Allowing low environmental stocks to lead to unemployment of a factor of production is a distinctive feature of our model. This phenomenon frequently occurs in the real world: the death of the Aral Sea has destroyed many water and fishery related industries, such as irrigated agriculture; low stocks caused by overharvesting in Northeastern US fisheries caused unemployment. More importantly, our model captures the concern that imperfect property rights matter most when the environmental stock is degraded. For example, slash and burn, or swidden agriculture, a practice in which farmers periodically cut open access (or common pool) forestry for agricultural land, does not lead to excessive deforestation when the forestry stock is high (Eriksson (1992)). In fact, it may be more environmentally friendly than intensive agriculture with clearly defined property rights. However, swidden agriculture does hurt the forestry when the stock is low. It may even exhaust the forestry stock (Sharma (1990)).

Proposition 1 summarizes the characteristics of the static autarky equilibrium.

Proposition 1 *(i) When the resource stock is high ($Z \geq Z^c$), capital is fully employed. Looser property rights reduce the relative price of the resource-intensive good B, but do not affect output, extraction, or welfare. (ii) When the resource stock is low, capital is partially unemployed. Looser property rights raise the amount of extraction of the resource and the output of the resource-intensive good, and reduce welfare. Property rights do not affect prices.*

2.2 *Autarky With Resource Dynamics*

We use a logistic growth function, $\eta Z - \gamma Z^2$, to model stock dynamics. After accounting for extraction of E, which is given by (4) or (5) depending on whether $Z \geq Z^c$ or $Z < Z^c$, the rate of change of the resource stock is

$$\frac{\dot{Z}}{Z} = \begin{cases} \eta - \gamma Z - \frac{\delta}{a_2} & \text{for } Z < Z^c \\ \eta - \gamma Z - \frac{\phi}{b_2 z} & \text{for } Z \geq Z^c \end{cases} \tag{7}$$

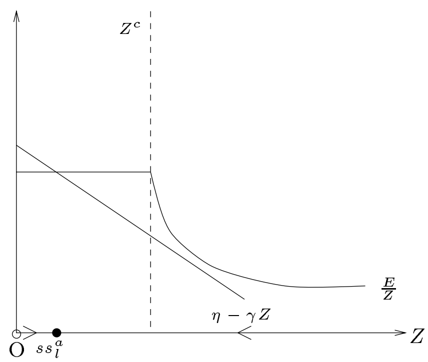
with $Z(0)$ given. Figure 1, which graphs the natural growth rate $\eta - \gamma Z$ and the harvest rate $\frac{E}{Z}$, shows how the set of stable steady states depends on the parameter η. The kink in the harvest rate occurs at the critical value Z^c. If $\eta < \hat{\eta}^a \equiv 2\sqrt{\frac{\gamma\phi}{b_2}}$, Z has a unique stable steady state at ss_l^a (Figure 1(a)). We choose parameter values (say a large γ) such that $\hat{\eta}^a > \frac{\delta}{a_2}$ to ensure $ss_l^a > 0$. If $\hat{\eta}^a < \eta < \eta^{*a} \equiv \frac{\delta}{a_2} + \gamma Z^c$, there are two stable steady states, ss_l^a and ss_h^a, separated by an unstable steady state sp_h^a (Figure 1(b)). Depending on the initial level of resource stock, either a high level of stock ss_h^a or a low level of stock ss_l^a is reached in the long run. Finally, if $\eta > \eta^{*a}$, the only stable steady state is ss_h^a (Figure 1(c)).[2]

The possibility of a low steady state captures an important empirical concern. When the natural growth rate of an environmental stock is low, weak property rights may cause near depletion of the stock.

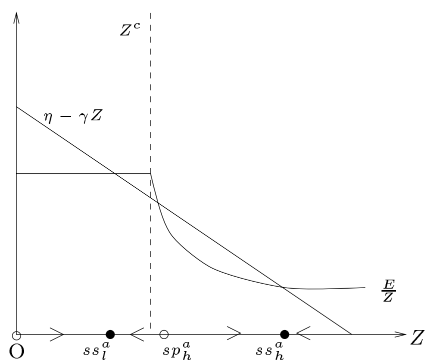
Proposition 1, equation (7), and Figure 1 imply that for a given initial value $Z(0)$, the level of property rights, δ, may have no effect on the autarkic equilibrium trajectories of Z and of welfare. In other cases, δ may affect the trajectories at every point in time; the trajectories for different δ may converge to either the same or different steady states. The values of η and $Z(0)$ determine which of these situations arise. Although δ affects the critical stock size Z^c and the critical parameter level η^{*a}, δ does not alter the evolution of the stock while Z exceeds Z^c.

For example, if two autarkic economies differ in property rights, but $\eta > \eta^{*a}$, they will have the same level of welfare at every point in time if $Z(0) \geq Z^c$ in both economies; if $Z(0) < Z^c$ in at least one of the economies, their trajectories of Z and of welfare will differ at every finite time, but will converge to the same steady state. Alternatively, if $\hat{\eta}^a < \eta < \eta^{*a}$ for both economies, their

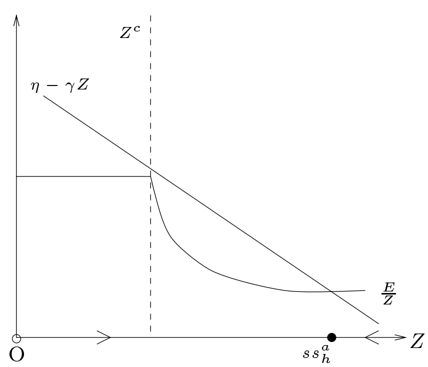
[2]For expositional clarity, we emphasize the role of η in determining the possible types of steady states. However, the possibilities also depend on other parameters, in particular γ. A smaller γ implies less "congestion" and a larger carrying capacity of the environment. It is clear that the critical values $\hat{\eta}^a$ and η^{*a} are increasing in γ (i.e. they are decreasing in the carrying capacity of the environment). In view of this monotonic relation, the reader can translate all of our statements about the critical values of η into statements about critical values of γ.



(a) $\eta < \hat{\eta}^a$



(b) $\hat{\eta}^a < \eta < \eta^{*a}$



(c) $\eta > \eta^{*a}$

Figure 1: Resource Dynamics Under Autarky and Steady-States: ∘ Unstable and • Stable

trajectories are identical if $Z(0)$ is greater than the unstable steady state sp_h^a in both economies; if $Z(0)$ is less than this value in at least one economy, the welfare trajectories are different and approach different steady states. There are other possibilities, such as when η lies above a critical level in one economy and below it in the other.

3 North-South Trade

We identify the two economies, South and North (described in Section 2) by subscripts S and N, and we assume that North has better property rights than South: $\delta_N < \delta_S$. The two economies are identical in all other aspects except (possibly) in initial resource stocks.

3.1 *Static Trade Effects*

The assumptions that both regions have the same technology and capital endowment $\bar{K}$, and that relative factor prices are equal under trade, means that with trade: (i) either capital is fully employed in both countries ($\frac{b_2}{b_1} < P < \frac{a_2}{a_1}$), (ii) or it may be partially unemployed in both countries ($P = \frac{a_2}{a_1}$). As with autarky, we can rule out the possibility that either region has partial employment of E ($P = \frac{b_2}{b_1}$), and also rule out $P > \frac{a_2}{a_1}$ and $P < \frac{b_2}{b_1}$. The assumption of factor price equalization excludes the possibility that capital is fully employed in one country and unemployed in the other.

When capital is fully employed, Appendix B derives the equilibrium price of B and the extraction in the two economics as

$$P^f = \frac{b_2^2 \psi}{b_1 b_2 \psi - 2\phi D} \tag{8}$$

$$E_N^f = \frac{2\delta_N Z_N \phi}{b_2 \psi} \qquad E_S^f = \frac{2\delta_S Z_S \phi}{b_2 \psi}, \tag{9}$$

where $\psi = \delta_N Z_N + \delta_S Z_S$ is the total world apparent resource stock, and superscript f denotes full employment of capital. Note that P^f is decreasing in ψ. Equations (9) and (4) imply that trade does not alter the total amount of resource extracted: $E^p_N + E^p_S = \frac{2\phi}{b_2} = 2E^a$. This result is a consequence of the constant returns to scale, fixed-proportion technology in producing A and B, fixed capital supply in each economy, and the constant consumption of A. These assumptions imply that world demand for the environmental input and for capital in sector A is fixed. The capital remaining to be used in sector B is therefore fixed. Full employment of that capital requires a fixed amount of environmental input. Consequently, the aggregate environmental extraction is fixed. However, the share of extraction in each country equals the country's share of apparent resource stocks. Thus, trade reallocates production of a fixed flow of environmental services.

If capital is unemployed, $P^u = \frac{a_2}{a_1}$ (thus $w^u = \frac{1}{a_1}$ and $r^u = 0$) in both regions. From (2) we have

$$E^u_S = \frac{\delta_S Z_S}{a_2} \qquad E^u_N = \frac{\delta_N Z_N}{a_2}. \tag{10}$$

Capital is fully employed if and only if the world apparent resource stock exceeds a critical value, ψ^c. We obtain this critical value by equating P^f and P^u and solving for ψ:

$$\psi^c = \frac{2a_2\phi}{b_2}. \tag{11}$$

We call the graph, in $Z_N - Z_S$ state space, of the relation $\psi = \psi^c$ the *full employment line* (FEL).

The effect of trade on resource extraction depends on the stock levels in both countries. Figure 2 divides the state space into six regions based on the employment levels of capital in autarky and trade.[3] In the figure, $Z^c_i = \frac{a_2\phi}{\delta_i b_2}$ for $i = \{N, S\}$ (cf. (6)). For stocks in region I, capital is fully employed under both trade and autarky in both economies. In region IV capital is unemployed under both trade and autarky in both economies. In regions II or VI capital is unemployed in one economy under autarky, but fully employed in both economies under trade. In regions III and V capital is unemployed in both economies under trade, but is fully employed in one economy under

[3] This figure shows the entire state space, but throughout our discussion we assume that both economies are incompletely specialized. By restricting exogenous parameter values, we can insure that the intersection of the cone of diversification and each of the six regions is non-empty.

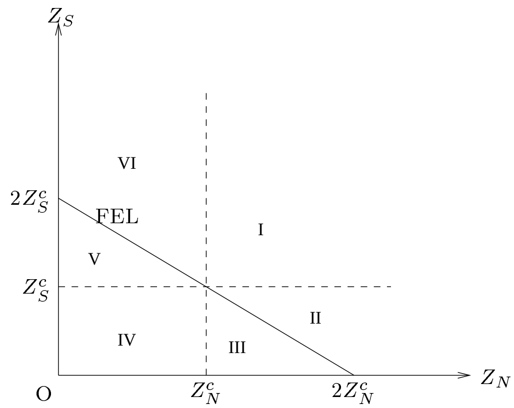


Figure 2: Possibilities of Going From Autarky to Trade

autarky. Proposition 2 describes the effect of trade on the flow of resource extraction.[4] Appendix C sketches the proof.

Proposition 2 *(i) When the world apparent resource stock is large ($\psi \geq \psi^c$), capital is fully employed in trade and there exists a unique trade equilibrium. A country's share of extraction of E equals its share of world apparent stock of the resource. (i.a) If the resource stocks are in region I of Figure 2, aggregate world extraction is the same in autarky and trade. (i.b) If the stocks are in regions II or VI, trade increases the aggregate extraction of E. (ii) When the world apparent resource stock is small ($\psi \leq \psi^c$), capital is partially unemployed in trade. (ii.a) If the stocks are in region IV, the autarkic and trade equilibria are equivalent. (ii.b) If the stocks are in regions III or V, trade increases world extraction of the resource.*

We see that trade either increases or leaves unchanged aggregate resource extraction. This conclusion is consistent with the environmentalist belief that trade exacerbates market imperfections and promotes excessive resource extraction. We also noted that for $Z \geq Z^c$ the autarkic equilibrium is independent of δ. However, the trade equilibrium depends on δ even when $Z \geq Z^c$ in both countries. Thus, in some circumstances imperfect property rights matter only in the presence

[4]Proposition 2 would be unchanged if good A were relatively resource-intensive. In that case, trade would decrease the domestic price of B in some regions, which would again increase w/P, increasing resource extraction.

of trade. This conclusion also supports the environmentalist belief that trade can make market imperfections more important.

3.2 *Trade With Resource Dynamics*

The evolution of resource stocks depends on the world apparent stock level. In view of our assumption of incomplete specialization, factor prices are equal in the two countries. Thus we only need to consider two cases: capital is fully employed in both countries, or unemployed in both countries. When $\psi < \psi^c$ the equilibrium extraction (10) implies the following dynamics

$$\dot{Z}_N = \eta Z_N - \gamma Z_N^2 - \frac{\delta_N Z_N}{a_2} \qquad \dot{Z}_S = \eta Z_S - \gamma Z_S^2 - \frac{\delta_S Z_S}{a_2}. \tag{12}$$

The isoclines $\dot{Z}_N = 0$ and $\dot{Z}_S = 0$ intersect at two points: $Z_N = Z_S = 0$, and at

$$Z_N = \frac{1}{\gamma}(\eta - \frac{\delta_N}{a_2}) \qquad Z_S = \frac{1}{\gamma}(\eta - \frac{\delta_S}{a_2}). \tag{13}$$

The origin $(0, 0)$ is an unstable steady state. The equilibrium given by (13), which we denote as ss_l, is a stable steady state (located below the 45^o line in $Z_N - Z_S$ state-space) if it is below the FEL. If this point lies above the FEL it is meaningless, since there the resource dynamics are not given by (12). The point ss_l is below the FEL if and only if $\eta < \eta^* \equiv \frac{\delta_N^2 + \delta_S^2 + a_2 \gamma \psi^c}{a_2(\delta_N + \delta_S)}$. Therefore, a low steady state with unemployment of capital (ss_l) exists with trade if and only if this inequality is satisfied.

When $\psi > \psi^c$, the resource dynamics are (using (9)):

$$\dot{Z}_N = \eta Z_N - \gamma Z_N^2 - \frac{2\delta_N Z_N \phi}{b_2 \psi} \qquad \dot{Z}_S = \eta Z_S - \gamma Z_S^2 - \frac{2\delta_S Z_S \phi}{b_2 \psi}. \tag{14}$$

Appendix D shows that the $\dot{Z}_N = 0$ and $\dot{Z}_S = 0$ curves do not intersect if and only if $\eta < \hat{\eta} \equiv \frac{2\sqrt{\delta_S^2 + \delta_N^2}}{\delta_S + \delta_N} \sqrt{2\gamma\phi / b_2}$. Otherwise, they may intersect at two points, sp_h and ss_h. ss_h is a stable steady state and is always above the FEL. sp_h is a saddle point and is above the FEL only when $\eta < \eta^*$.

Using (11) we can show that $\hat{\eta} < \eta^*$.[5]

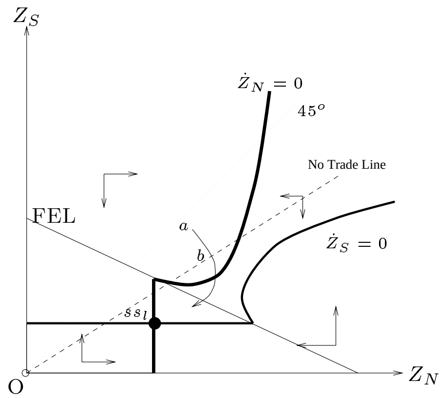
The 0-isoclines for (14) and (12) intersect the FEL at the same points. Therefore, the isoclines are continuous, as shown in Figure 3. The three panels of this figure show the relative positions of the isoclines $\dot{Z}_N = 0$ and $\dot{Z}_S = 0$ and the associated resource dynamics for different values of η, given other parameters.

When $\eta < \hat{\eta}$, the isoclines cross at only one point, ss_l, a stable steady state below the FEL in region IV (Figure 3(a)). When $\hat{\eta} < \eta < \eta^*$, the isoclines cross at three points: the low steady state ss_l, the saddle point sp_h, and the high steady state ss_h. The curve *degh* in Figure 3(b), which is part of the stable arm of the saddle point, divides the state space into two regions. Trajectories with initial conditions above the curve approach ss_h, and trajectories with initial conditions below the curve approach ss_l.[6] When $\eta > \eta^*$, the isoclines cross at ss_h, a unique stable steady state above the FEL (Figure 3(c)).

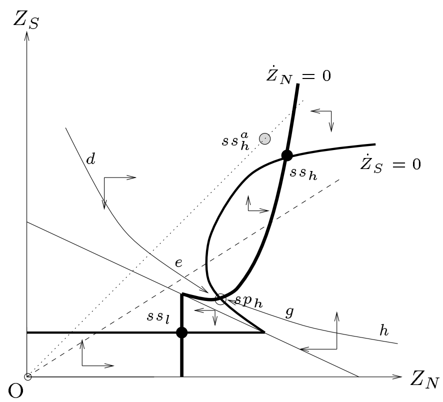
If $E_N^s = E_S^s$, the two countries have the same factor endowments and there is no reason to engage in trade. This equality holds if and only if North and South have the same apparent resource stock, i.e. $\delta_S Z_S = \delta_N Z_N$. This equality defines the *No Trade Line* in state space, (abbreviated as NTL in Figure 3). South has an "apparent" comparative advantage in the resource-intensive good B if $\delta_S Z_S > \delta_N Z_N$ and $\psi \geq \psi^c$. The situation is reversed when $\delta_S Z_S < \delta_N Z_N$. For values of the stock between the NTL and the 45^o line, the directions of real and apparent comparative advantage are reversed: trade induces the "wrong" country to increase extraction of the resource. For values of the stock outside this cone, where real and apparent comparative advantage have the same direction, the pattern (but not the volume) of trade is efficient.

[5]Again, instead of working with the critical values of η, we can define critical values of γ and characterize the steady states by comparing them with the actual γ value.

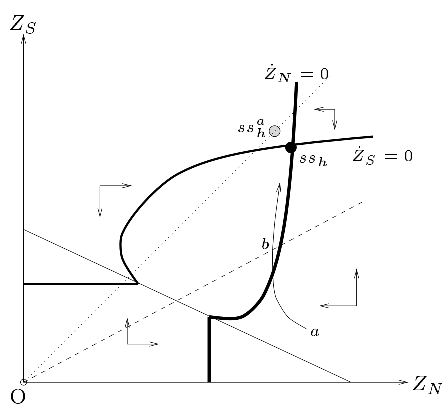
[6]Again, in order to limit the number of cases we need to consider, we assume that the saddle point lies in the region of incomplete specialization. We have verified that there are restrictions on parameter values which ensure that this assumption is satisfied. The high steady state always lies in the cone of diversification.



(a) $\eta < \hat{\eta}$



(b) $\hat{\eta} < \eta < \eta^*$



(c) $\eta > \eta^*$

Figure 3: Resource Dynamics Under Trade and Steady-States: $\circ$ Unstable and $\bullet$ Stable

The high steady state, ss_h, is between the 45^o line and the NTL (Appendix D).[7] Consequently, in a long-run equilibrium either South exports the resource-intensive good and the direction of trade is inefficient (at ss_h), or trade is irrelevant(at ss_l). We also note that if there exists a high steady state under both autarky and free trade, then the autarkic steady state lies on the 45^o line to the Northwest of the free-trade steady state, as shown in Figure 3(b) and Figure 3(c) (Appendix D).

As the resource stocks change, the pattern of trade may be reversed. Either country may lose its apparent comparative advantage in the production of a good. The trajectories ab in Figure 3(a) and Figure 3(c) illustrate situations where the country that begins at point a with the comparative advantage in B eventually loses it. The same possibility arises in Figure 3(b), but is not shown in order to decrease clutter.

We summarize the results of this section in

Proposition 3 *(i) A reversal in apparent comparative advantage in the resource-intensive good and the consequent reversal in the pattern of trade can occur for all values of the growth parameter* η. *(ii) In the long-run equilibrium, either capital is unemployed and trade is irrelevant, or South exports the resource-intensive good and the direction of trade is inefficient. (iii) When they exist, the high steady state under autarky has larger Southern stocks and smaller Northern stocks than the high free-trade steady state.*

4 Static Welfare Under Autarky and Trade

Here we study the static welfare implications of trade. Does trade improve welfare for given stocks in North and South? The standard second best result applies here: trade can decrease welfare when it occurs in the presence of distortions. The difference in property rights in the two countries causes

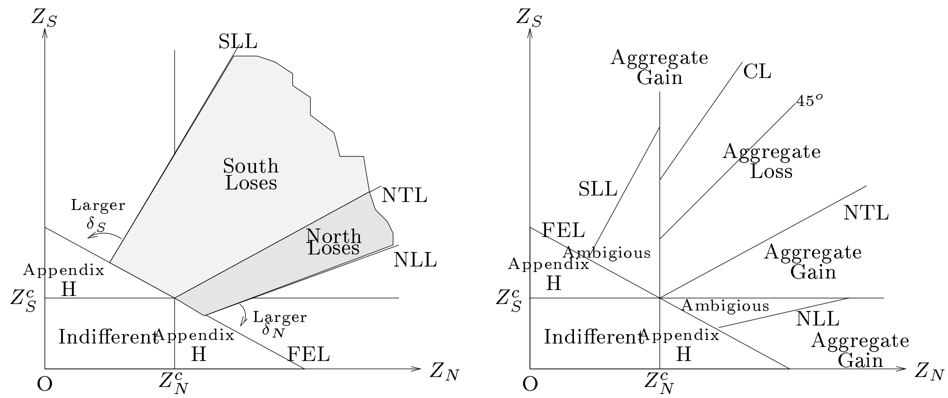
[7] The unstable saddle point, sp_h, is below the NTL (Figure 3(b)).

an inefficient volume, and possibly an inefficient pattern of trade. Because of these inefficiencies, trade may reduce welfare in one (but not both) country at a point in time. In this section we compare the autarkic and free-trade levels of aggregate and individual welfare for resource stocks in Region I of Figure 2. Similar analysis is conducted for stocks in Regions II, III, V and VI in Appendices G and H. We ignore Region IV, where trade does not affect the welfare of either country.

Since the consumption of A is fixed at A^*, the consumption of B, labeled B^c, determines social welfare. A country's consumption of B equals its production net of the amount that is used for resource extraction and exports. We compare social welfare under free trade and autarky by comparing B^c in the two regimes.

We first consider welfare implications for individual countries. The autarky welfare of country $i = \{N, S\}$ is $W_i^a = B_i^{pa} - F_i^a$, where B_i^{pa} is the autarky output of B and F_i^a is the amount of B used in extraction. The free-trade welfare is $W_i = B_i^d - F_i$, where B_i^d is the domestic supply of B (total production net of export) and F_i is the amount of B used in the extraction activity. The static gain from trade for country i is $G_i = W_i - W_i^a$.

Both countries have the potential to gain from trade by exercising their comparative advantage. The country that imports B also gains because imports reduce domestic extraction of E and thus ameliorate the common property problem. This country always gains from trade. For the country that exports B, trade increases extraction of E and thus exacerbates the common property problem. Whether this country benefits from trade depends on the relative magnitudes of the two welfare effects. For stocks near the NTL, the B-exporting country's comparative advantage is negligible, but the common property effect is significant, so the country loses from trade. Figure 4(a) shows the *Southern Loss Line* (SLL) and the *Northern Loss Line* (NLL). For stocks between the NTL and the SLL (respectively, the NLL) South (respectively, North) loses from trade. Appendix E



(a) Individual (b) Aggregate

Figure 4: Instantaneous Welfare Implications of Trade

derives SLL and NLL, and proves the following Proposition:

Proposition 4 *When stocks are in region I and the world moves from autarky to free trade: (i) The country that imports the resource-intensive good gains. (ii) The country that exports the resource-intensive good loses if its property rights are sufficiently weak or if the countries' apparent stocks are similar. (iii) Weakening a country's property rights increases the set of states for which the country loses from trade.*

To study the effect of trade on aggregate welfare we use the fact that aggregate extraction is the same under free trade and autarky in region I (see Proposition 2), which implies that world output of A and B are also the same. Thus, we only need to compare the aggregate amount of B used in extraction (under free trade and autarky) to determine the aggregate welfare effect of trade.

Efficiency requires higher extraction in the country with the higher resource stock. Aggregate welfare always increases if North exports the resource-intensive good (i.e., for stocks below the NTL) because the market failure is less severe in North. In the cone where apparent and real comparative advantages are reversed (see figure 3(a)) trade increases extraction in the country with the lower stock, and therefore decreases aggregate welfare. The more interesting result is that when the stocks lie in the cone bounded by the 45^o line and a line we refer to as the *Compensation Line* (CL), trade reduces aggregate welfare. For stocks in this cone, the pattern of trade is efficient, but the inefficiency of the volume of trade leads to aggregate losses. The aggregate welfare implications of free trade are illustrated in Figure 4(b) and summarized in the following Proposition (see Appendix F for proof):

Proposition 5 *Free trade improves aggregate static welfare if North exports the resource-intensive good B, or if South exports B and the resource stocks are above the Compensation Line. Otherwise, free trade reduces aggregate static welfare.*

5 Long-run Effects of Trade

In the short run, where environmental stocks are fixed, trade alters production and consumption. In the long run trade can also change the evolution of environmental stocks, changing the costs of extraction and production. Trade can also link the stock dynamics in different countries, even in the absence of a physical connection. These (long-run) dynamic effects of trade are probably more important than the short-run effects in the debate between environmentalists and free-traders. Here we compare the steady-state welfare under free trade and autarky. This comparison uses the information on welfare for different regions of state space, described in Section 4, and the role of η in determining steady states, summarized in Figures 1 and 3.

For given initial values of Z_i, $i = \{N, S\}$, the autarky steady state depends on the value of η relative to $\hat{\eta}_i^a$ and η_i^{*a}. Similarly, the steady state under trade depends on the value of η relative to $\hat{\eta}$ and η^*. Thus, it is necessary to compare these critical η values. Inspection of Figure 1 shows: (i) $\eta_S^{*a} > \eta_N^{*a}$: In autarky for a given stock of resource, North is more likely to achieve the higher steady

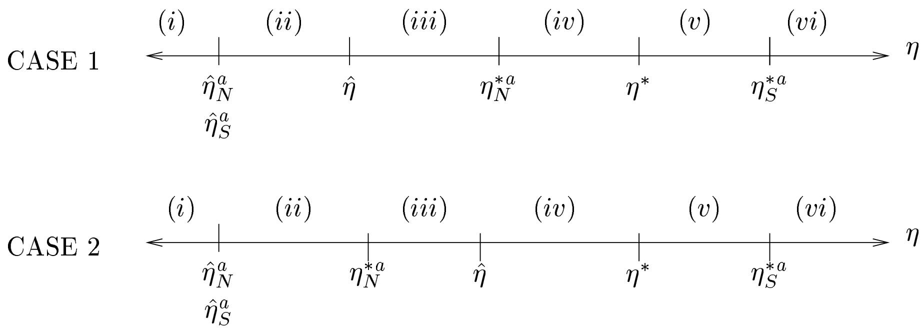


Figure 5: Possible Ranking Schemes of Critical η Values

state ss_h^a (i.e. to have Figure 1(c)) because of its better property rights. (ii) $\hat{\eta}_S^a = \hat{\eta}_N^a$: The critical value $\hat{\eta}_i^a$, below which only the low steady state exists, is independent of property rights under autarky. We denote the common value as $\hat{\eta}^a$. Appendix I contains the proofs for the following results. (iii) $\hat{\eta} > \hat{\eta}^a$: For some values of η high steady states exist for both countries under autarky, but only the low steady state exists under trade. (iv) $\eta_N^{*a} < \eta^* < \eta_S^{*a}$: For some values of η the unique steady state under trade is the high state, but under autarky South also has a low steady state.

Figure 5 summarizes the ranking of the critical values of η. The two possibilities, Cases 1 and 2 in the figure, depend on the relative magnitude of $\hat{\eta}$ and η_N^{*a}. For each case there are six intervals of η, identified as sub-cases. Table 1 summarizes the information on steady-state welfare comparisons. The first column identifies the range of values of η, using Figure 5. The second and third columns identify the dynamic phase diagram under autarky in Figure 1, for η values in the first column. The forth column identifies the phase diagram under free trade in Figure 3. The final column summarizes the steady-state welfare implications of trade, by comparing the welfare levels of the autarky and trade steady states, using the results of Section 4. In the case of multiple steady states, the long-run welfare comparison depends on the initial stock levels.

If the value of η is sufficiently low (Cases 1.i or 2.i), both countries are doomed to a low steady state under trade or autarky. This steady state is the same under trade or autarky, so in the long

Position in Figure 5	*Position in Figures 1 and 3*			*Welfare Implications of Trade*	
	South	*North*	*Trade*	*South*	*North*
1.i or 2.i	1(a)	1(a)	3(a)	Indifferent	
1.ii or 2.ii	1(b)	1(b)	3(a)	if Z_S $< sp_h^a$ indifferent; $\geq sp_h^a$ worse off	if Z_N $< sp_h^a$ indifferent; $\geq sp_h^a$ worse off
1.iii	1(b)	1(b)	3(b)	see Figure 6(a)	
2.iii	1(b)	1(c)	3(a)	if Z_S $< sp_h^a$ indifferent; $\geq sp_h^a$ worse off	worse off
1.iv or 2.iv	1(b)	1(c)	3(b)	see Figure 6(b)	
1.v or 2.v	1(b)	1(c)	3(c)	if Z_S $< sp_h^a$ better off; $\geq sp_h^a$ worse off	better off
1.vi or 2.vi	1(c)	1(c)	3(c)	worse off	better off

Table 1: Long-Run Welfare Effects of Trade

run trade does not matter.

If the value of η is sufficiently high (Cases 1.vi or 2.vi), both countries reach the high steady state under trade and autarky. The autarky steady state, ss_h^a, is to the upper-left of the trade steady state ss_h (Figure 3). Propositions 3(iii), 4 and 5 imply that in the long run trade harms South, benefits North, and leads to aggregate welfare losses. In addition, we see from Figure 3 that the transition between the two high steady states is monotonic. Using this result and Figure 4, any transition path between the two steady states remains in the cone where Southern welfare and aggregate welfare are higher under autarky. If, for example, the countries are originally at the high autarkic steady state, then the transition to the high steady state under free trade lowers Southern and aggregate welfare at every point in the future. Similarly, if the countries are initially at the high free-trade steady state, a move to autarky increases Southern and aggregate welfare at every point in the future.

If $\eta > \hat{\eta}$, under free trade, the state approaches either the high steady state or the low steady state. In the former case, at some point there would be an increase in Southern and aggregate welfare from switching to autarky. In the latter case, trade offers no benefits to either nation in the long run. Thus, free trade is never a dynamically consistent policy for either South or for a social planner interested in aggregate world welfare. There must eventually come a point where a switch to autarky improves or leaves unchanged the entire future trajectory of Southern and world welfare. In summary,

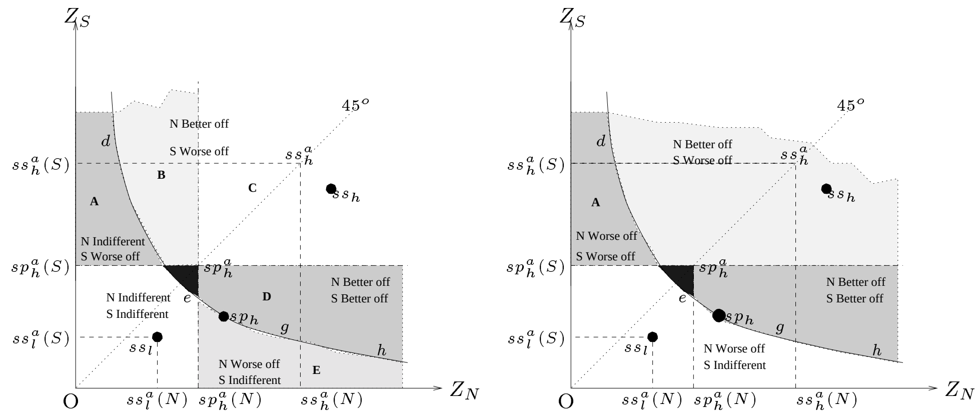
Proposition 6 *All free-trade trajectories eventually reach a point at which switching to autarky would either result in no welfare change, or would improve aggregate and Southern welfare and decrease Northern welfare at every time in the future. Thus free trade is dynamically inconsistent.*

For η values that are relatively low (Cases 1.ii, 2.ii, and 2.iii) there is a unique (low) stable steady state ss_l in free trade, while in autarky, both countries would achieve a high steady state given a sufficiently favorable initial condition. In these circumstances, free trade is Pareto inferior to autarky in the long run: trade reduces long-run welfare for both countries. If Z_i exceeds $sp_h^a(i)$ for $i = S, N$, the countries would reach a high steady state under autarky. When they begin to trade, Southern extraction increases, leading to a decline in its stock. Due to the low growth rate, Southern stocks are unable to recover. Eventually, North begins to extract more to compensate for low Southern extraction. In the process it drives its stocks to a low level. This circumstance illustrates the outcome environmentalists fear. Trade causes the two countries to drag each other down.

Cases 1.v and 2.v, where η is relatively high, describe a more optimistic scenario. The unique stable steady state in free trade is ss_h (Figure 3(c)). In autarky, South would have reached a low stable steady state ss_l^a if $Z_S < sp_h^a$ (Figure 1(b)), and North always reaches its high (autarkic) steady state. For example, suppose Southern resource stocks are close to ss_l^a. After trade begins, Northern stocks will eventually be large enough (regardless of their initial condition) so that North exports the resource-intensive good, allowing Southern stocks to recover and eventually reach their high steady state. At some point South begins to export the resource-intensive good. The relevant comparison for South is between a high and a low steady state, and South is better off at the former. The relevant comparison for North is between autarkic and free-trade high steady states, and North prefers the latter. North does well by doing good. In this scenario, trade causes North to pull up South, after which South returns the favor.

These two scenarios illustrate the possibilities that trade may cause the countries either to drag each other down or to pull each other up. The first possibility is roughly consistent with the fears of anti-trade environmentalists, and the second is consistent with the hopes of pro-trade economists. The fragility of the environment, measured by the growth parameter η, is one determinant of which possibility occurs. Our model implies that environmental fragility increases the likelihood of the environmentalists' scenario. The level of Southern stocks at the time of the policy change is the other factor that determines whether trade is Pareto inferior or superior in the long run. The first (pessimistic) possibility requires large Southern stocks, and the second (optimistic) possibility requires small stocks. Thus, it may be especially important for South to allow free trade when its resource stock is low. This conclusion may have important policy implications for developing countries such as Thailand and the Philippines, whose situation we discussed in the Introduction.

Figure 6 illustrates two interesting but somewhat complicated cases, corresponding to (1.iii), (1.iv) and (2.iv) in Figure 5. These figures show the steady states under free trade and autarky in the same phase space, together with the stable saddle path *degh*. We first discuss Figure 6(a). For initial conditions in regions A or E, trade causes the resource poor country to drag the resource rich country down to a lower steady state. Trade harms the resource rich country without benefiting the resource poor country. For initial conditions in regions B and D, trade enables the resource rich country to pull up the stocks of the resource poor country, leading to a qualitative improvement in



(a) Case (1.iii)

(b) Case (1.iv) and (2.iv)

Figure 6: Long-Run Welfare Implications of Trade For Some Cases

the latter's steady state. When North is resource rich (region D) both countries benefit from trade, but when South is resource rich (region B), trade harms it. For initial conditions in region C, trade harms South and benefits North in the long run. If the parameters are such that the black triangle exists, then for initial resource stocks in this region, trade benefits both countries. With trade they reach high stock levels at ss_h, but they reach low stock levels ss_l in autarky. Figure 6(b) can be analyzed in a similar fashion.

We summarize the long-run welfare implications of trade in

Proposition 7 *(i) If the environmental growth parameter is sufficiently low, the long-run free-trade and autarkic equilibria are identical for all initial conditions. (ii) For somewhat higher growth parameters, there are initial conditions such that both countries are worse off in the long run under free trade (the drag-down scenario). (iii) For still higher growth parameters, there are initial conditions such that both countries are better off in the long run under free trade (the pull-up scenario). (iv) If the growth parameter is sufficiently high, then for all initial conditions Southern and world welfare is lower in the long run under free trade, and Northern welfare is higher.*

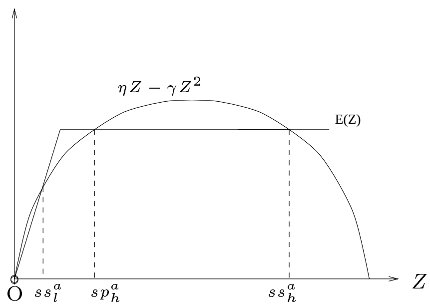
Note that Proposition 6 compares long run welfare under trade and autarky given an initial condition at a steady state. Proposition 7 compares long run welfare for more general initial conditions.

6 Generality of the Model

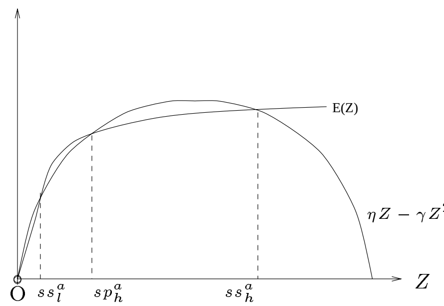
Our model makes a number of assumptions which may seem unfamiliar or arbitrary, thus calling into question the generality and usefulness of our results. This section discusses four features of the model: (i) the role and the plausibility of the functional forms – in particular the implied lack of substitutability; (ii) the assumption of fixed capital stock; (iii) the assumption that agents are myopic; and (iv) the assumption that the market distortion is constant.

The multiplicity of stable steady states creates the possibility that free trade leads to qualitative changes, and is thus a key feature of our model. There are many reasons why multiple stable steady states might arise in the real world. In our model they arise because of the lack of substitutability between capital and environmental services implied by the Leontief technology. When environmental stocks (and thus the flow of environmental services) are low, lack of substitutability means that environmental services have a high price. In this case, an increase in Z, which causes a fall in the cost of producing environmental services, has a relatively large effect on the supply of those services. Conversely, when environmental stocks and services are high, the price of those services is relatively low, and a cost reduction leads to a relatively small supply response. Together with our assumed utility function, Leontief technology implies that the elasticity of E with respect to Z is unity for low stock levels and zero for high stock levels, leading to possible multiple stable steady states (Figure 7(a)).

The Leontief assumption is clearly not necessary to obtain multiple steady states. Figure 7(b) shows that the multiplicity arises if the endogenous supply of E is sensitive to changes in Z when



(a) With current assumptions



(b) With relaxed assumptions

Figure 7: The Existence of Multiple Stable Steady States

stocks are low (i.e. when the supply of E is low) and less sensitive when Z is high. This relation may arise under a CES technology with low elasticity of substitution.[8] It may also arise when there is little substitutability of capital for E at low levels of E, and high substitutability at high levels of E. The latter scenario is empirically plausible: In the literature on sustainability, substitutability is a crucial issue and it is widely accepted that substitution between man-made and natural capital is difficult when the latter is limited (Toman, Pezzey and Krautkraemer (1995)). For example, in agricultural production, while capital and other inputs can easily substitute for land when the land endowment is high, substitution is difficult when the land endowment is low.

When agents solve a sequence of static problems, the endogenous extraction function is independent of the growth function. Consequently, given *any* concave nondecreasing extraction function, we can chose a concave growth function (not necessarily logistic) such that multiple stable steady states exist.

Our choice of utility function also deserves comment. In order to construct a North-South model which emphasizes asymmetry in property rights, we need a general equilibrium setting. Our utility function leads to a particularly simple demand structure, making it relatively simple to solve the

[8]Some of our incidental results would change with a CES technology. For example at low stocks trade would continue, since the model would not collapse to the one-factor Ricardian model with identical technology.

model and compare autarky with trade. This demand structure does not drive any of our results. A perturbation of the utility function would not change the qualitative features of the model.

Although we do not defend this utility function as an accurate representation of preferences, for our purposes it is probably a better representation than more familiar choices (e.g. Cobb-Douglas utility). In a two-good North-South model it is natural to regard one commodity as the subsistence good. The income elasticity of demand for this good should fall with income, as with our utility function.

In summary, the assumed lack of substitutability in both production and consumption is important in making the model analytically tractable, but is not essential for the qualitative results. In this sense, the model is robust to changes in technology and preferences. In addition, given the model's high level of abstraction and aggregation, the assumed lack of substitutability is at least as empirically plausible as the more familiar assumption of high substitutability.

Our model ignores the accumulation of non-environmental capital.[9] We know that the accumulation of such capital plays a central role in development. However, we are not trying to model development. If trade enhances capital accumulation, then we have neglected an important pro-trade argument and the reader should make a mental adjustment of our results. We have not tried to assess whether liberal trade benefits society "on balance," i.e., taking "all things" into consideration. Instead, we have developed a model which focuses on a narrow but important question: *Does trade exacerbate or ameliorate market imperfections that lead to excessive exploitation of the environment?* This is the question that many environmentalists care about. If trade theorists re-

[9]Our assumption of zero depreciation of the capital stock implies that in the low steady state capital is unemployed. With a positive rate of capital depreciation, capital would be fully employed in steady state. Since the rate of investment must also be positive in the steady state, the return on capital must be positive there. Including depreciation would complicate the analysis by requiring two additional state variables (capital stocks in the two countries), but it would not eliminate the possibility of multiple steady states. As Figure 7 shows, multiplicity of steady states requires that the extraction function $E(Z)$ is concave, a feature that does not depend on capital depreciation.

ply “Trade is beneficial in so many other ways that its effect on the environment is irrelevant,” they have disengaged from the controversy. We have tried to address the environmentalists’ question; we have not tried to provide an assessment of the *general* effects of trade.

Another important assumption is that agents are myopic. The two reasons for this assumption concern its plausibility and the simplicity that results from it. The obvious alternative to myopic agents are agents with rational expectations. Myopia is a plausible assumption because many environmental changes occur on a different time scale than human events. We can think of our continuous time model as a convenient way to study a process that occurs in discrete time, where each period lasts for ten or twenty years. Viewed in this light, the assumption that agents do not look beyond the current period is not absurd.

Reasonable people might disagree about which assumption – myopic or rational expectations – provides a more plausible description of the interaction between social and environmental forces. However, the assumption of myopic expectations certainly results in enormous simplification, since it means that we can solve a sequence of static equilibria, rather than a dynamic equilibrium. There are conceptual issues concerning the appropriate way of modeling imperfect property rights with price taking behavior in a dynamic setting. Even if those issues were resolved satisfactorily, the practical problem of characterizing an equilibrium in a model with two state variables (as would be necessary for the trade scenario) is daunting, to say the least. Moreover, we know that even for problems with one state variable, there are likely to exist a continuum of equilibria, due to the problem of the “incomplete transversality condition” (Tsusui and Mino (1990)). The same reason for indeterminacy exists in models with more than one state variables. Resolving all of these issues in a general equilibrium setting must await future research.

In any case, whether agents are myopic or forward looking is tangential to our model. The important assumptions are that a market imperfection leads agents extract too much of the environmental stock (relative to the first best extraction rate) and that over-extraction is more severe in South than in North. If, for example, agents were forward looking, they would impute a positive shadow value to the resource. The supply function would depend on that shadow value, which would typically be a function of the state. Equation (2) would be replaced by a nonlinear function of Z.

Our use of an underlying static model means that the discount rate plays no role. Thus, we have no way to aggregate short- and long-run changes in welfare. This inability is irrelevant for initial conditions in the neighborhood of the high autarkic or free-trade steady states. There, the short- and long-run welfare effects of a change in the trade regime have the same sign. For initial conditions away from the steady states, the short- and long-run effects may have different signs. However, there is little agreement about the appropriate means of making intergenerational welfare comparisons - and even less agreement about the appropriate discount rate. Since our results do not depend on making such comparisons, we have no need to engage in this debate.

The final assumption requiring discussion is that the market imperfection can be characterized by a constant (δ) which shifts out the supply function for environmental services (Equation (2)). It is worth restating the fact that this assumption does not mean that the effect of the distortion is constant. Under autarky the distortion has no real effect when stocks are high, but it decreases welfare when stocks are low. The *effect* of the distortion depends on the state variable, which changes endogenously. Nevertheless, the reader might object that the parameter δ should be endogenous. For example, perhaps the magnitude of environmental distortions (all of the factors that we capture with δ) and not simply the severity of their effect, decreases with the level of income. This possibility has empirical support from the literature on the "environmental Kuznets curve", which finds that the level of several pollutants decreases with income, for sufficiently high levels of income. If trade promotes income growth, it then leads to a decrease in environmental distortions and thus indirectly benefits the environment. Our model does not take into account this possibility, and thus ignores a potentially important environmental argument in favor of free trade.

A complete discussion of this issue would require (at least) another paper, so we restrict ourselves to a few comments. If income growth is due to the exercise of apparent rather than real comparative advantage, the higher income may disappear more quickly than the environmental damage that attends it. Furthermore, the exercise of apparent comparative advantage may lead to lower income even in the short run, as we saw in Section 4. Finally, even if trade does increase income, it may also increase the pressure on environmental stocks by raising the opportunity cost of their protection. For example, the value of forests for domestic consumption may be small, so that under autarky it is relatively easy to protect them. Trade may increase income, leading to improved property rights and greater environmental consciousness. This beneficial change may not be strong enough to offset the greater temptation to cut down the forest, once it is possible to export the timber.

These comments are not intended to refute the argument that trade may promote the endogenous improvement in environmental policies, via income growth. We view this as a serious argument, and we recognize that our model sheds no light on it. However, we do not think that it is such an overwhelming argument in favor of trade that other considerations are irrelevant.

7 Policy Implications and Conclusion

We have constructed a model that rationalizes the disagreement between free-traders and anti-trade environmentalists. The theory of the second best assures us that there are circumstances where either group is correct about the effects of trade liberalization. Our model helps to identify these circumstances.

In some respects, our model has a neoclassical bias. We treat the environment merely as a factor of production, but most environmentalists think that it has intrinsic value. Also, environmentalists worry that increased income or more severe market failures resulting from free trade will increase the demand for environmental services, whereas economists stress the role of trade in allocating resources. In our model there is a large region of state space where trade causes a reallocation, but no aggregate change in environmental production. In these respects, the model appears to favor the neoclassical arguments for trade.

In some circumstances trade leads to an increase, but it never leads to a decrease in the exploitation of the environmental stock. In circumstances where the market failure would have no effect under autarky, the equilibrium under trade does depend on the difference in the distortion in the two countries. In this sense, trade magnifies the importance of the market failure. In the steady state with trade, either there are no gains from trade, or the gains from trade are negative. In the latter case, the pattern of trade is inefficient. If we begin at a high autarkic steady state, North benefits from free trade, but South would be better off under autarky. Moreover, if the world is at the high steady state with trade, in every case there would be aggregate welfare gains, at every point in time, from reverting to autarky. Thus, free trade is inefficient regardless of the discount rate. Similarly, if the world is at a high steady state under autarky, and free trade is introduced, aggregate welfare falls at every point in time.

These conclusions – particularly those that rely on an initial condition at a steady state – are only a part of the story. The debate about trade and the environment is in large part a debate about dynamic effects. The anti-free-trade lobby suspects that trade will increase environmental degradation, resulting in countries dragging each other down. Pro-free traders hope that free trade will enable countries to pull each other up. Both of these beliefs are strongly held, but the mechanisms by which the results supposedly occur are usually not specified. This vagueness makes it impossible to argue the merits of the two positions.

Our model provides a relatively simple explanation for how either result might occur. If the environment is very resilient, i.e. the growth parameter η is large, then in the long run trade leads to an inefficient redistribution of environmental stocks. These changes are quantitative but not qualitative: the long run steady-state stocks are high under both autarky and free trade. If the environment is very fragile, i.e., the growth parameter is low, trade matters even less, since the long-run autarkic and free trade equilibria are identical, with low stocks.

The most interesting cases arise for intermediate levels of the growth parameter. If the environment is "quite fragile but not very fragile," and South initially has relatively high resource stocks, then trade is likely to harm both nations in the long run. Trade encourages South to produce too much of the environmentally intensive good, degrading its stocks. Eventually, apparent comparative advantage in the resource-intensive good shifts to North. Trade encourages North to degrade its environmental stock, and there is no recovery. Here trade causes the two nations to drag each other down. If the environment is "quite resilient but not very resilient," and South initially has relatively low resource stocks, trade enables both nations to pull each other up. Trade might lead to an initial further degradation of Southern stocks, but the eventual increased production in North enables Southern stocks to recover.

Our model thus rationalizes the positions of both environmentalists and free-traders. The debate can be seen as partly a disagreement about the difference in market failures and the size of resource stocks in North and South relative to the fragility or resilience of the environment. Although the model cannot resolve the debate between environmentalists and free-traders, it can be useful in shifting the debate in a more productive direction. At the very least, it illustrates that neoclassical analysis can explain many of environmentalists' concerns.

The danger of modeling second-best scenarios is that the results can be construed as a rationale for maintaining distortions: in this case, trade restrictions. We have been struck by the number of academic economists who have viewed our arguments (in previous versions of this paper) in exactly this light. However, there are too many characteristics of the real world that our (or any other) model ignores for this conclusion to be warranted. Nevertheless, we think that this kind of theory can improve our understanding of the complex interaction between social and environmental forces.

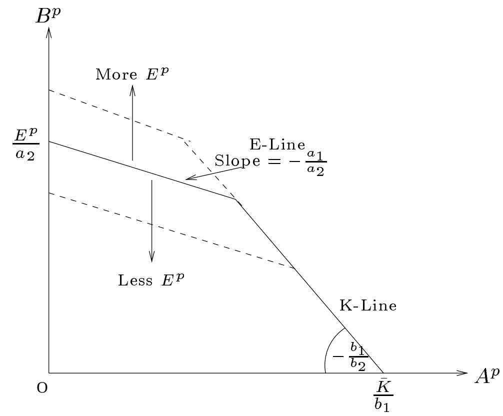


Figure 8: Production Feasibility Set

A Model Basics

Given the production technology (1) and factor supplies $\bar{K}$ and E^p, the Production Feasibility Set of the economy is defined by

$$a_1 A^p + a_2 B^p \leq E^p \qquad b_1 A^p + b_2 B^p \leq \bar{K} \tag{15}$$

with equalities defining the Production Possibility Frontier (PPF). Since the supply of environmental input E^p is an increasing function of δ, w, and Z, and a decreasing function of P, changes in these variables alter the PPF. Figure 8 shows how changes in E^p change the PPF.

Given the assumption of incomplete specialization, we know profit maximization in the production of A and B implies

$$A^p = \frac{E_A}{a_1} = \frac{K_A}{b_1} \qquad B^p = \frac{E_B}{a_2} = \frac{K_B}{b_2} \tag{16}$$

and zero profits implies $1 = a_1 w + b_1 r$ and $P = a_2 w + b_2 r$, i.e.

$$w = \frac{Pb_1 - b_2}{D} \qquad r = \frac{a_2 - Pa_1}{D}. \tag{17}$$

In equilibrium all markets clear:

$$E^p = E^d = E_A + E_B = A^p a_1 + B^p a_2 \qquad K^p = K^d = K_A + K_B = A^p b_1 + B^p b_2. \tag{18}$$

Substituting the equilibrium w in (17) into (2), we obtain $E^p = \delta Z \frac{Pb_1 - b_2}{DP}$, where $D = a_2 b_1 - a_1 b_2 > 0$ because sector B is resource-intensive. The derivation so far is valid regardless of whether both factors K and E are fully employed or not.

Solving for the full employment of E and K, and setting $A = A^*$ gives the relative output price in an autarky equilibrium under full employment (3). Equations (2), (3) and (17) then give the extraction of E in (4).

Finally, we know $\phi > 0$ because $A^* D = A^p D \leq \frac{\bar{K} D}{b_1} = \bar{K}(a_2 - \frac{a_1 b_2}{b_1}) < a_2 \bar{K}$.

B Trade Model

Country i's net exports of B and A are X_{B_i}, X_{A_i}. With trade, production equals domestic demand plus net exports,

$$B^p = B^d + X_{B_i} \qquad A^p = A^d + X_{A_i}. \tag{19}$$

The value of exports equals the value of imports, $PX_{B_i} + X_{A_j} = 0$, where P is the world relative price of B. Net demand equals 0: $X_{A_N} + X_{A_S} = 0$ and $X_{B_S} + X_{B_N} = 0$.

We can solve for the competitive equilibrium for any given set of property rights δ_N and δ_S and the level of stocks Z_N and Z_S. To do so, we invert (18) and get

$$A_i^p = (a_2 \bar{K} - b_2 E_i^p)/D \qquad B_i^p = (b_1 E_i^p - a_1 \bar{K})/D. \tag{20}$$

World aggregate demand of A, $2A^*$, must equal world production of A:

$$2A^* = A_S^p + A_N^p. \tag{21}$$

We substitute factor supply (2) into (20) and solve for A^p, and then substitute the result into (21), to obtain $2A^* = \frac{2a_2 \bar{K}}{D} - \frac{\psi b_2 (b_1 P - b_2)}{D^2 P}$. From this we obtain (8) in the text.

To find the equilibrium supply of E, substitute (8) into (17) and use the assumption of factor price equalization (i.e., incomplete specialization) to get w^f. Then substitute P^f and w^f into the supply function (2) to obtain equation (9) in the text.

C Sketch of the proof of Proposition 2

For stocks in region IV, both countries have unemployed capital in autarky and trade. Trade does not alter the amount of E extracted in either country. This is an obvious result: when capital is unemployed, the model collapses to the standard one-factor Ricardian model. Since both regions have the same technology, there is no incentive to trade. At $P = \frac{a_2}{a_1}$ any pattern of trade could occur, but each of these gives the same level of welfare as the autarkic equilibrium.

For stocks in regions II, III, V and VI, the North and South autarkic relative prices w/P are different, so trade alters the equilibrium. The Stolper-Samuelson theorem and our assumption that B is resource-intensive means that w/P is increasing in P. We also know from equation (2) that E is increasing in w/P for both countries. Therefore, trade increases resource extraction in a country if and only if it increases the equilibrium domestic price of B.

Capital is fully employed in autarky but not with trade for one country in regions III (North) and V (South). For the other country capital is always unemployed. For example, when trade begins and the stock is in region V, the price of B in North remains unchanged at $1/a_2$, so North's extraction is unchanged. Since trade causes capital to become unemployed in South, its price must fall. Zero profits require that w then rise. By Stolper-Samuelson, w/P and P also rise, increasing extraction in South. Thus, trade increases world extraction of E. We can show that in region V South exports B, although the volume of exports is indeterminate. In this case, South has enough resource stock to fully employ its capital in autarky. But with trade, given the high demand for B from North. South increases its production of B reduces that of A, using less capital and leading to the unemployment of K. Similarly, in region III trade increases extraction of E, and North exports B.

Capital is fully employed with trade but not in autarky for one country in regions II (North) and VI (South). For the other country capital is always fully employed. Trade causes the domestic price P to rise in one country and fall in the other, so the net effect on the aggregate extraction of E is not obvious. However, (under the assumptions which insure incomplete specialization) we can verify that trade increases aggregate extraction. This verification uses the facts that total extraction is $E^{af} + E^{au}$ in autarky and is $2E^{af}$ in trade, and the condition that $Z_i < Z_i^c$ for one country. In region VI, for example, trade increases the relative price w/P in the resource rich South, where the (positive) supply response is large. Trade decreases the relative price in the resource poor north, where the (negative) supply response is small. The net effect on supply is therefore positive. The same reasoning applies to region II.

D Steady States for $\psi > \psi^c$

To find the steady state, we simultaneously solve $\dot{Z}_N = 0$ and $\dot{Z}_S = 0$. After considerable algebraic manipulation, we find that for a solution to exist a necessary and sufficient condition is $\eta > \hat{\eta}$.

We now show that the high steady state ss_h lies between the 45^o line and the NTL. We use Figure 9 to sketch the procedure without going into the algebraic details. Let V_i be the maximum Z_N at which $\dot{Z}_i = 0$ crosses the NTL, and Y_i be the maximum Z_N at which $\dot{Z}_i = 0$ crosses the 45^o line, for $i = \{N, S\}$. When $\eta \geq \hat{\eta}$, i.e. when $\dot{Z}_N = 0$ and $\dot{Z}_S = 0$ intersect, we can show that $V_S > V_N$. This inequality, together with the fact that stability requires that the curve $\dot{Z}_N = 0$ crosses the curve $\dot{Z}_S = 0$ from below, implies that the isoclines are as shown in Figure 9, and that ss_h is above the NTL. Similarly, we can show that when $\dot{Z}_N = 0$ and $\dot{Z}_S = 0$ cross the 45^o line,

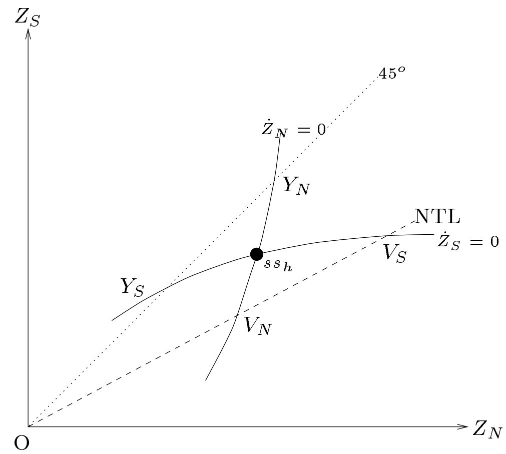


Figure 9: Position of ss_h

$Y_N > Y_S$, establishing that ss_h is below the 45^o line. It is possible that $\dot{Z}_S = 0$ does not cross the 45^o line. In this case, $\dot{Z}_S = 0$ lies strictly below the 45^o line, as does ss_h.

To show that the high autarkic steady state lies to the Northwest of ss_h, note that both lie in region I, where aggregate extraction is the same under free trade and autarky. The autarkic steady state lies on the 45^o line and ss_h lies in the cone formed by the NTL and the 45^o line. At any point on the 45^o line Southern extraction exceeds Northern extraction under free trade. In addition, the steady-state stocks are decreasing functions of the steady-state harvests. Therefore, a move from autarky to free trade must decrease the steady-state stock of South and increase that of North.

E Region I Individual Welfare Under Autarky and Free Trade

To calculate the autarky welfare, consider a country with resource stock Z. Since the supply of A is A^*, (16) implies that $E_A = a_1 A^*$ and $K_A = b_1 A^*$. Thus $K_B = \bar{K} - b_1 A^*$ and $E_B = \frac{a_2}{b_2}(\bar{K} - b_1 A^*)$. Then $E = E_A + E_B = \frac{\phi}{b_2}$. Substituting E into $F = E^2/Z$, we get $F_N^a = \frac{\phi^2}{b_2^2 Z_N}$ and $F_S^a = \frac{\phi^2}{b_2^2 Z_S}$. By combining E_B and (16), we obtain the autarky supply of B as $B_N^{pa} = B_S^{pa} = \frac{\bar{K} - b_1 A^*}{b_2}$. Then $W_i^a = B_i^{pa} - F_i^a$, for $i = \{N, S\}$.

To find the free-trade welfare, we substitute E_N^p and E_S^p from (9) into $F_N = {E_N^p}^2/Z_N$ and

$F_S = {E_S^p}^2/Z_S$ respectively, and get $F_N = \frac{4\phi^2\delta_N^2 Z_N}{b_2^2\psi^2}$ and $F_S = \frac{4\phi^2\delta_S^2 Z_S}{b_2^2\psi^2}$.

To calculate the domestic supply of B in free trade, consider South as an example. Suppose South produces B^p of B. Then $K_B = b_2 B^p$ and $E_B = a_2 B^p$ from (16). Thus $K_A = \bar{K} - b_2 B^p$ and $E_A = E_S^p - a_2 B^p$, where E_S^p is given in (9). Substituting K_A and E_A into $a_1 K_A = b_1 E_A$ and simplifying, we get: $B^p = \frac{b_1 E_S^p - a_1 \bar{K}}{D}$. Substituting this into E_A, we get: $A^p = \frac{a_2 \bar{K} - b_2 E^p}{D}$. From the trade balance condition, we know $A^* - A^p = P(B^p - B^d)$, where P is from (8). Solving for B^d, and substituting in A^p and B^p, we get $B_S^d = \frac{b_1 E_S^p - a_1 \bar{K}}{D} - \frac{1}{P}(A^* - \frac{a_2 \bar{K} - b_2 E_S^p}{D})$. W_S can then be calculated based on B_S^d and F_S. W_N can be similarly calculated.

The gains from trade for South are $G_S = W_S - W_S^a = \frac{\phi^2[\delta_S Z_S - \delta_N Z_N][(2-3\delta_S)Z_S - \delta_N Z_N]}{b_2^2 Z_S \psi^2}$. For North the gains from trade are $G_N = W_N - W_N^a = \frac{\phi^2[\delta_N Z_N - \delta_S Z_S][(2-3\delta_N)Z_N - \delta_S Z_S]}{b_2^2 Z_N \psi^2}$. Note that $\delta_S > 2 - 3\delta_S$ (because $\delta_S > 1/2$). Therefore, $(2 - 3\delta_S)Z_S < \delta_N Z_N$ if $\delta_S Z_S < \delta_N Z_N$. Thus $G_S > 0$ when $\delta_S Z_S < \delta_N Z_N$, i.e. when it imports B. Similarly, $G_N > 0$ when North imports B.

When South exports B, $G_S < 0$ if $\delta_S \geq \frac{2}{3}$. For $\delta_S < 2/3$, South loses from trade if the resource stock is between the NTL and the *Southern Loss Line* (SLL), given by a straight line from the origin with a slope of $\frac{dZ_S}{dZ_N} = \frac{\delta_N}{2-3\delta_S}$. Similarly, the *Northern Loss Line* (NLL) is a line from the origin with slope $\frac{dZ_S}{dZ_N} = \frac{2-3\delta_N}{\delta_S}$, which is below the NTL. North loses from free trade if the resource stocks are between these two lines (Figure 4(a)). As Southern property rights become weaker the SLL rotates anti-clockwise, increasing the set of states for which South loses from trade. Similar results hold for North.

F Region I: Aggregate Welfare and the Compensation Line

From Appendix E, we know the aggregate gain from trade $TG \equiv G_N + G_S = [F_S^a + F_N^a] - [F_S + F_N] \propto -(Z_N - Z_S)[\delta_S^2 Z_S^2 - \delta_N^2 Z_N^2] - 2Z_N Z_S[\delta_S Z_S - \delta_N Z_N](\delta_S - \delta_N)$. $TG < 0$ if (Z_N, Z_S) is between the

45^o line and the NTL in the state-space; $TG > 0$ if the stock is below the No Trade line. For (Z_N, Z_S) above the 45^o line, there are gains from trade if and only if the point is above the line $Z_S = \alpha Z_N$, defined as the *Compensation Line* (CL), with α increasing in $\frac{\delta_S}{\delta_N}$. Simplifying we obtain $TG \propto -3Z_N Z_S(\delta_S - \delta_N) + \delta_S Z_S^2 - \delta_N Z_N^2$. Now let $Z_S = \lambda Z_N$, and substitute it into TG. Setting this equation to zero, we get a quadratic equation in λ, $\delta_S \lambda^2 - 3(\delta_S - \delta_N)\lambda - \delta_N = 0$, where the unique positive root is $\alpha = \frac{3(\delta_S-\delta_N)+\sqrt{9(\delta_S-\delta_N)^2+4\delta_S\delta_N}}{2\delta_S}$.

G Regions II and VI: Gains from Trade

We first consider individual welfare implications in region VI. Since South fully employs capital in both autarky and trade, the analysis of Region I applies. South loses from trade for areas below the Southern Loss Line and gains for areas above it.

The welfare level for North with trade is given by the same formula as in region I. It is straightforward to show that its autarky welfare is $W_N^a = \frac{\delta_N Z_N}{a_2^2}(1-\delta_N) - \frac{a_1}{a_2}A^*$. The gain from trade for North is positive. Trade enables North to put its unemployed capital to work. To show this, We (through straightforward but tedious calculations) can express the Northern gain as $G_N = \frac{GC_1 * GC_2}{a_2^2 b_2^2 D\psi^2}$, where $GC_1 = b_2\psi - 2a_2\phi$ and $GC_2 = a_2 D\phi\psi - (b_2\psi + 2a_2\phi)D\delta_N Z_N(1-\delta_N)$. Since $\psi > \psi^c$, we know $GC_1 > 0$ (cf. (11)). We can split GC_2 into two parts, so that $GC_2 = GC_3 + GC_4$, with $GC_3 = a_2 D\phi(\psi/2 - 2\delta_N Z_N(1-\delta_N))$, and $GC_4 = D\psi(a_2\phi/2 - b_2\delta_N Z_N(1-\delta_N))$. Using the facts that $\psi > \psi^c$, $\delta_N Z_N < \psi/2$, and $\delta_N \geq 1/2$, we can show that $GC_3 > 0$ and $GC_4 > 0$.

Similarly, for region II, North gains if the stocks are below the Northern Loss Line, and loses if the stocks are above the line. South always gains from trade.

The aggregate welfare implications can be derived using the measures of individual welfare. In Region VI, both countries are better off under trade for stocks above the Southern Loss Line, so

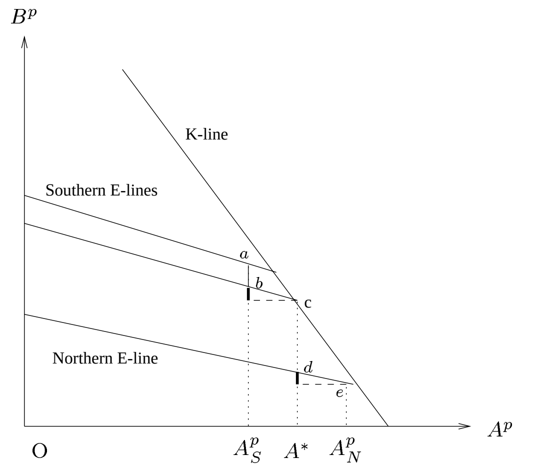


Figure 10: Production Feasibility Set

there are aggregate gains from trade. Similarly, in Region II below the Northern Loss Line there are aggregate gains from trade. However, in Region VI below the Southern Loss Line and in Region II above the Northern Loss Line, the impacts of trade on aggregate welfare are ambiguous, since one country gains and the other loses.

H Regions III and V: Gains from Trade

Again, we first consider individual welfare implications. In region V, North has the same welfare before and after trade since it faces the same price vector and extracts the same amount of resource. It produces more A and less B with trade, but the consumption of A and B is fixed, as is illustrated in Figure 10. North produces at point d in autarky and at e with trade. By exporting $A_N^p - A^*$, it imports a certain amount of B (indicated by the bold black line below d) so that its domestic supply of B, B_N^d is the same as in autarky.

South produces at point c in autarky, and at a in trade. The Southern E-line shifts up with trade because of the higher price of B. After accounting for export of B indicated by the bold line below b, Its net increase in domestic availability of B is indicated by the line ab. The net change of B for domestic consumption equals ab minus the additional B that must be used to extract the additional E.

We now show that South benefits from trade if $\delta_S = 1/2$ (that is, if it has perfect property rights) and loses from trade if $\delta_S > 4/5$. For δ_S between 1/2 and 4/5, the result depends on the stock level. First, we observe that the increase in extracted E is given by $\triangle E_S = \frac{\delta_S Z_S}{a_2} - \frac{\phi}{b_2}$. Note that the additional domestic availability of B (i.e. ab line in Figure 10) is $\triangle B_S^d = \frac{\triangle E}{a_2}$. The extra effort needed to extract the additional resource, $\triangle F_S$, can be easily calculated. Then the Southern gain from trade is $G_S = \triangle B_S^d - \triangle F_S = G(Z_S)$, where $G(Z_S) = \frac{\delta_S Z_S}{a_2^2}(1-\delta_S) + \frac{\phi}{b_2}(\frac{\phi}{b_2 Z_S} - \frac{1}{a_2})$. It is easy to show that $G(Z_S^c) = 0$, and $G'(Z_S) > 0$ if and only if $Z_S > \tilde{Z}_S \equiv Z_S^c\sqrt{\frac{\delta_S}{1-\delta_S}}$. Thus, if $\delta_S = 1/2$, $G'(Z_S) > 0$, and South gains from trade. If $\delta_S < 4/5$, $G'(Z_S) < 0$ and South loses from trade. The sign of G' is ambiguous for other δ_S values. It is straightforward to show that $\frac{dG}{d\delta_S} < 0$ for $\delta_S > 1/2$.

Similar results hold for region III, where trade does not affect Southern welfare, and North benefits if it has perfect property rights and loses if $\delta_N > 4/5$, with ambiguous results for δ_N between 1/2 and 4/5.

Based on the individual welfare implications, we know that in region V, aggregate welfare improves in free trade if South has perfect property rights and decreases if $\delta_S > 4/5$. In region III, aggregate welfare improves if North has perfect property rights and decreases if $\delta_N > 4/5$. Otherwise, the result is ambiguous.

I Proof of Comparisons of critical η's

We first show $\eta_S^{*a} > \eta_N^{*a}$. From Section 2.2, we can write $\eta^{*a} = \frac{\delta}{a_2} + \frac{\gamma a_2 \phi}{\delta b_2}$, and we only need to show $\frac{d\eta^{*a}}{d\delta} > 0$. We know that when $\eta = \eta^{*a}$, $\dot{Z} = 0$ derived from the two trajectories in (7) cross at Z^c. That is, $\frac{\eta^{*a} - \delta/a_2}{\gamma} = \frac{\eta^{*a} - \sqrt{\eta^{*a2} - 4\gamma\phi/b_2}}{2\gamma}$. From this, we know $\eta^{*a} < 2\delta/a_2$, i.e.

(i) $\delta > \frac{a_2 \eta^{*a}}{2}$. Further, since $\eta^{*a} > \hat{\eta}^a$, we know (ii) $(\eta^{*a})^2 > 4\gamma\phi/b_2$. The derivative of η^{*a} is $\frac{d\eta^{*a}}{d\delta} = \frac{1}{a_2} - \frac{\gamma a_2 \phi}{b_2 \delta^2} > \frac{1}{a_2}(1 - \frac{4\gamma\phi}{b_2 \eta^{*a2}}) > 0$, where the first inequality follows from (i) and the second from (ii).

We use a proof by contradiction to verify that $\hat{\eta} > \hat{\eta}^a$. Suppose to the contrary that $\hat{\eta} < \hat{\eta}^a$, and consider an η that satisfies $\hat{\eta} < \eta < \hat{\eta}^a$. If this inequality is satisfied, the dynamics for both countries under autarky are described by Figure 1(a), so there exists a unique (low) steady state. The dynamics with trade are described by Figure 3(b) or Figure 3(c), so there exists a high steady state, ss_h. Consider resource stocks at ss_h, where $\dot{Z}_S < 0$ in autarky (from Figure 1(a)). Trade increases South's extraction, so $\dot{Z}_S < 0$ under trade. However, ss_h is a steady state under trade. This contradiction implies $\hat{\eta} > \hat{\eta}^a$.

We show that the inequality $\eta_S^{*a} > \eta_N^{*a}$ implies $\eta_N^{*a} < \eta^* < \eta_S^{*a}$. Suppose to the contrary that $\eta^* < \eta_N^{*a}$. Consider an η that satisfies $\eta^* < \eta < \eta_N^{*a}$. This inequality implies that in autarky North has a low steady state as in Figure 1(b) or Figure 1(a). The dynamics with trade are described by Figure 3(c), where there is a unique (high) steady state. Consider resource stocks at ss_l. We know $\dot{Z}_N = 0$ in autarky (from Figure 1(b)), and since in region IV North extracts the same amount of resource under autarky and trade, $\dot{Z}_N = 0$ with trade also. But this violates the fact that $\dot{Z}_N > 0$ in trade (from Figure 3(c)). This contradiction implies $\eta^* > \eta_N^{*a}$. Similarly, we can show $\eta^* < \eta_S^{*a}$.

References

Anderson, Kym, "Economic Growth, Environmental Issues and Trade," *Centre for Economic Policy Research*, 1993, *830*.

Bhagwati, Jagdish, "Trade and the Environment: the False Conflict?," in Durwood Zaelke, Paul Orbuch, and Robert Houseman, eds., *Trade and the Environment*, Washington, D.C.: Island Press, 1993, chapter 13, pp. 159–190.

Brander, James A. and M. Scott Taylor, "International Trade and Open Access Renewable Resources: the Small Open Economy Case," *Canadian Journal of Economics*, 1997, *30* (3), 526–552.

___ **and** ___ , "International Trade Between Consumer and Conservationist Countries," *Resource and Energy Economics*, 1997, *19* (4), 267–297.

___ **and** ___ , "Open Access Renewable Resources: Trade and Trade Policy in a Two-Country Model," *Journal of International Economics*, 1998, *44* (2), 181–209.

Chichilnisky, Graciela, "North-South Trade and The Dynamics of Renewable Resources," *Structural Change and Economic Dynamics*, 1993, *4* (2), 219–248.

___ , "North-South Trade and the Global Environment," *American Economic Review*, 1994, *15* (1), 851–874.

Daly, Herman E., "Problems With Free Trade: Neoclassical and Steady-State Perspectives," in Durwood Zaelke, Paul Orbuch, and Robert Houseman, eds., *Trade and the Environment*, Washington, D.C.: Island Press, 1993, chapter 12, pp. 147–158.

Eriksson, Arne, "Vietnam: Environmental Policy and Programme Priorities for an Economy in Transition," Technical Report, FAO 1992.

FAO, *FAO Yearbook*, Rome: UN FAO, 1994.

General Agreement on Tariffs and Trade, "Trade and Environment Report," in "International Trade 90-91 vol. 1," Geneva: GATT, 1992.

Low, Patrick, *International Trade and the Environment*, Washington, D.C.: The World Bank, 1992.

McDowell, Mark A., "Development and the Environment in ASEAN," *Pacific Affairs*, 1989, *62*, 307–29.

Newbery and Stiglitz, "Pareto Inferior Trade," *Review of Economic Studies*, 1984, pp. 1–12.

Sharma, Prem, "Report on Review of Present Status in Watershed Management and Future Needs for Immediate Action in Vietnam," Technical Report, FAO 1990.

Toman, Michael, John Pezzey, and Jeffrey Krautkraemer, "Neoclasical Economic Growth Theory and "Sustainability"," in Daniel Bromley, ed., *Handbook of Environmental Economics*, Cambridge, MA: Blackwell, 1995, chapter 7, pp. 139–165.

Tsusui, S. and K. Mino, "Nonlinear Strategies in Dynamic Duopolistic Competition with Sticky Prices," *Journal of Economic Theory*, 1990, *52*, 136–161.

List of Symbols

Symbol	***Definition***
	Production
A^p	Production of good A
B^p	Production of good B
E_A	Use of environment E in sector A
E_B	Use of environment E in sector B
K_A	Use of capital K in sector A
K_B	Use of capital K in sector B
a_1, a_2, b_1, b_2	input-output coefficients
D	$\equiv a_2 b_1 - a_1 b_2 > 0$
ϕ	$\equiv a_2 \bar{K} - A^* D > 0$
$\bar{K}$	total capital in the economy
	Demand
A^*	maximum demand for A
	Prices
P	relative price of good B
w	price of E
r	price of K
	Property Rights
n	number of producers
δ	level of property rights
	Resource Growth
Z; $Z(0)$	resource stock, initial level of stock
Z^c, Z^*	critical Zs
ψ^a; ψ	apparent stock of, a country in autarky, and world in trade
ψ^c	critical ψ
η, γ	resource growth equation parameters
$\hat{\eta}^a$, η^{*a}; $\hat{\eta}$, η^*	critical ηs for autarky, and trade
ss_l^a, ss_h^a, sp_h^a	autarky steady states
ss_l, sp_h, ss_h	trade steady states
	Welfare
B_i^{pa}	autarky output of B in country i
B_i^d	domestic supply of B in country i
B^c	level of B available for consumption
f_i	contribution of producer i to E production
F_i^a; F_i	total extraction cost in country i under autarky, and trade
W_i^a; W_i	social welfare of country i under autarky, and trade
TG	total gains from trade
	Abbreviations Used in Figures
CL	Compensation Line
NTL	No Trade Line
FEL	Full Employment Line
SLL; NLL	Southern, and Northern Loss Line
SRL; NRL	Southern, and Northern Regret Line