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Abstract

We compare the short-run and long-run effects of environmental reform and harmonization under autarky and free trade. When trade is driven by environmental distortions rather than real relative advantages, harmonization of environmental policies, even if achieved by lowering standards in one country, can improve short-run aggregate welfare. With the possibility of multiple steady states, long-run considerations favor a "race to the top" rather than a "race to the bottom" even when upward and downward harmonizations are equivalent in the short run. For a country trapped in a low (or bad) steady state, environmental reform may not move it to a high (or good) steady state under autarky. However, under trade, harmonization of policies may enable this country to reach the high steady state. Conversely, reforms that increase the relative differences in distortions may, under trade, cause economies to move to a low steady state.

JEL Classification: Q20, F10, H23

Keywords: International trade and the environment; environmental policy reform; international harmonization of environmental policies; environmental dynamics and trade.

1 Introduction

Environmentalists' distrust of international trade contributed to the failure of the November 1999 WTO meetings in Seattle, the inability of President Clinton to obtain fast-track negotiating authority, and the difficulty of passing NAFTA. Environmentalists fear that competitive pressures, heightened by trade liberalization, create a danger of a "race to the bottom" in environmental standards. They conclude that the international harmonization of policies is important to prevent this race.

Economists recognize that the harmonization of distortions such as tariffs improve welfare under plausible circumstances. However, they tend to oppose pressures for harmonization of environmental policies across nations, arguing that policy differences reflect differences in income, tastes, capital stocks, resource endowments, or a variety of other factors that contribute to inter-industry trade. In this case, harmonization is an attempt to thwart the efficient workings of the market.[1]

Several recent papers, including Chichilnisky (1993, 1994) Copeland and Taylor (1994, 1995), Brander and Taylor (1996, 1997) and Karp, Sacheti and Zhao (forthcoming), emphasize that differences in environmental regimes (or market failures) can provide an impetus for trade. Property rights may be weaker in some countries, and some countries may have been more successful in dealing with externalities. If this is the correct explanation for different standards, and if these different standards have a significant effect on trade flows[2], then harmonization may increase welfare.

Tariffs provide a useful analogy. Welfare is likely to improve whether harmonization is achieved by raising low tariffs or lowering high ones. This equivalence is due to the fact that welfare de-

[1]The arguments for and against harmonization are presented in many articles, including: Bhagwati (1996), Bhagwati and Srinivasan (1996), Charnovitz (1993), Hoel (1993), Levinson (1996), Klevorick (1996), Robertson (1992), and Wilson (1996). Krugman (1997) summarizes many of these arguments.

[2]It has been difficult to obtain convincing econometric (as opposed to anecdotal) evidence of the significance of pollution havens, but the belief that these are significant is central to environmentalists' concerns about trade. Mani and Wheeler (1998) present econometric evidence which suggests that trade may create transitory pollution havens.

pends on relative, not on absolute prices. To the extent that trade is driven by relative rather than absolute environmental standards, a similar equivalence is likely to hold. In this case, the environmentalists' goal of harmonization could be achieved by weakening standards where they are strict (i.e., by "downward" rather than "upward" harmonization). However, absolute environmental standards – unlike prices – have real effects, making it unlikely that upward and downward harmonization are exactly equivalent.

The opposing views regarding harmonization of environmental policies is at least partly explained by contradictory views about the reasons for the policy differences. Do they reflect different levels of distortions, or different tastes and endowments? In this paper we concentrate on the first explanation, so our model is biased in favor of harmonization.

We study the differing effects of absolute and relative levels of environmental distortions and environmental reform in both the short and long runs. We use a dynamic North-South trade model where a renewable environmental stock affects production costs. The change in the stock depends on production decisions, and these decisions depend on the trade regime (free trade or autarky) and on the absolute and relative levels of the environmental distortions. The key feature of our model is the possibility of multiple steady states. Under both trade and autarky the steady state may be unique, in which case it may be either low ("bad") or high ("good"); alternatively, both types of steady states might simultaneously exist. Environmental reform (and the trade regime) may affect the properties of these steady states – including their existence. Under trade, upward and downward harmonization equally improve aggregate welfare in the short run. However, in the long run the two types of harmonization may have very different effects: upward harmonization increases the likelihood that the economies reach the good steady states.

The trade regime influences the effects of environmental reform. In some cases, an autarkic country is trapped by tastes and technology at a low steady state: environmental reform does not

enable it to reach a high steady state. However, in the presence of trade, upward or even downward harmonization of policies sometimes enables the country to escape to a high steady state. In other cases, reform moves an autarkic economy to a high steady state, but moves a trading economy to a low steady state. Thus, reform can have very different effects under autarky and free trade.

In addition to illustrating these (and other) possibilities, the model identifies the factors that determine the various outcomes. For example, under trade, reform in the least distorted economy (a movement away from harmonization) is likely to be beneficial if the initial difference in environmental distortions in the countries is not great, or if the environmental problem is not severe. The same reform is likely to have perverse effects if the natural rate of growth of the environmental stock is small (i.e., if the environment is "fragile").

Our focus on the long run is particularly relevant for trade involving, directly or indirectly, renewable resources and stock pollutants. In these cases, trade and welfare in different time periods are connected, and long-run studies are needed to identify the overall effects of trade. Overtime, some countries seem to have been trapped in vicious cycles of low resource stock and low standard of living, while others enjoy high stocks and high welfare. Our emphasis on multiple steady states helps to explain this phenomenon and to show the role of trade and harmonization in breaking the vicious cycles.

Section 2 provides a graphical presentation which illustrates why multiple steady states arise, and the likely effects of environmental reform. Section 3 describes the analytic model and the equilibria under autarky and trade. This section summarizes results derived in Karp, Sacheti and Zhao (forthcoming) (hereafter KSZ), which we use in Section 4 and Section 5 to analyze the effects of reform in the short and the long run.[3] We discuss the generality of our model in Section 6.

[3]We use the same analytic model as in KSZ, but that paper focused on a comparison between free trade and autarky. Here we study the effect of environmental reform in general, and on harmonization of environmental policies in particular.

Section 7 summarizes and concludes.

2 Multiple Steady States: A Graphical Illustration

Our major results hinge on the possibility of multiple steady states in autarky and trade. To show how the multiplicity can arise in a general setting, we present a graphical model of international trade with renewable natural resources. This model shows (i) the possibility of multiple stable steady states under autarky and free trade, and (ii) the possible long-run effects of environmental reform under autarky and trade.

Suppose the production of final goods requires environmental services (E), the supply of which is endogenous. The cost of producing E decreases with the environmental stock Z. The E-producing industry has a market failure, such as imperfect property rights to the stock. The magnitude of the distortion is measured by δ; a larger value of δ implies a greater market failure (e.g. weaker property rights). The market failure leads to an inefficiently high exploitation of the environmental stock and an inefficiently high supply of environmental services, for a given stock level.

The equilibrium supply of E depends on both the market failure and the current stock, $E = E(Z, \delta)$. A larger environmental stock decreases the cost of supplying environmental services, so $E_Z \geq 0$. We also assume that $E_{ZZ} \leq 0$.[4] A larger market failure increases the equilibrium supply of environmental services for a given stock, so $E_\delta \geq 0$. Environmental reform means that the distortion is reduced (e.g. the property rights over the environmental stock are improved) so δ is reduced. For a given stock Z, environmental reform reduces the supply of environmental services.

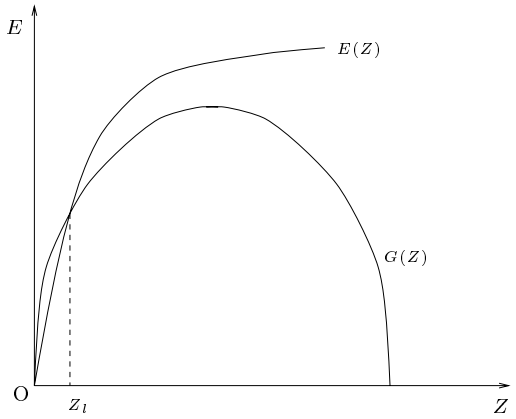
In order to obtain a specific functional form for $E(Z, \delta)$ we need to specify the market failure and the nature of the producer's optimization problem (among many other things). For example,

[4] This condition is satisfied under a variety of situations. For example, if $p(E)$ is the inverse demand for services and $c(E, Z; \delta)$ is the marginal cost (inclusive of user cost – i.e. the producers' shadow value of the stock), then the equilibrium level of E is given by $p(E) = c(E, Z; \delta)$. If c is convex in Z and p is not "too convex", then $E_{ZZ} \leq 0$.

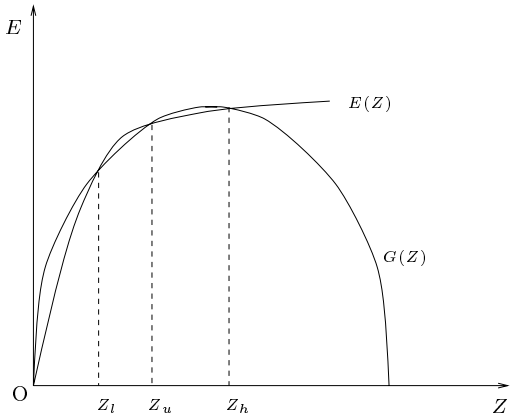
producers might be myopic or forward looking with rational expectations; they might be price takers or oligopsonists. At this stage, we do not need that degree of detail. The intuition for our results depends on the assumed properties of the extraction function: $E_Z \geq 0$, $E_{ZZ} \leq 0$, and $E_\delta \geq 0$. (In the rest of this section we assume that the inequalities are strict.) Many plausible models give rise to an equilibrium supply function with these properties.

To complete the description of the model we assume that the natural growth rate of the environmental stock (absent extraction) is a strictly concave function $G(Z)$ that increases for small Z, reaches a maximum, and then decreases to 0 (at the natural carrying capacity). The steady state of the autarkic economy depends on the relation between $G(Z)$ and $E(Z, \delta)$. Figure 1 illustrates three possible configurations. In panel (a) there is a unique low steady state, which we denote by Z_l, and in panel (c) there is a unique high steady state, which we denote by Z_h. Here the distinction between a low and a high steady state is that one is smaller than and the other larger than the level that maximizes $G(Z)$ – i.e. the level associated with the maximum sustainable yield. Panel (b) shows the intermediate case, where there is both a low and a high stable steady state, and an intermediate (unstable) steady state, denoted by Z_u. In this case the economy moves toward either the high or the low steady state, depending on whether the initial level of Z is above or below Z_u.

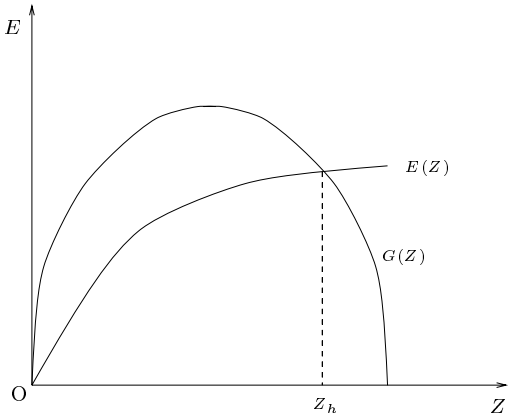
Environmental reform (the reduction in δ) shifts down the graph $E(Z, \delta)$. A small reform causes small increases in the stable steady states, and thus has only a *quantitative* effect. A large reform might change the type of steady state that the economy approaches, a change we regard as *qualitative*. For example, reform may change the relevant panel from (a) to (c), so that the unique steady state changes from low to high. In a less extreme case, reform might change the location of the unstable steady state so that it lies below rather than above the current level of Z. In that case, reform causes the economy to move to the high rather than to the low steady state.



(a) Unique Low Steady State



(b) Low and High Steady States



(c) Unique High Steady State

Figure 1: Possibilities of Autarky Dynamics

Since a higher environmental stock reduces extraction costs, reform improves long run (steady state) welfare. Reform may also lead to *static* welfare benefits, i.e. raising welfare at a given stock level. The market failure means that the environmental sector absorbs more inputs than is socially optimal. Static welfare might increase if these inputs were devoted to other activities.

Now consider a trade equilibrium. The two countries, North and South, trade commodities which use environmental services as inputs. At a point in time, their environmental stocks are Z_N and Z_S. As was the case under autarky, E_i (the equilibrium supply of environmental services in country i) depends on Z_i via its direct effect on production costs, and on the market failure, δ_i; E_i also depends on the price of environmental services, which depends on the aggregate (world) supply of services. Thus with trade, the supply of environmental services E_i in each country depends on the environmental stocks and the market failures in both countries. An increase in Z_N, for example, decreases North's relative costs of producing environmental services. Under plausible circumstances higher Z_N increases the equilibrium supply of E_N and decreases the equilibrium supply of E_S.

The heavy line in Figure 2 shows the $\dot{Z}_S = 0$ isocline in state space $Z_N - Z_S$. For low levels of Z_N ($Z_N < Z_{N1}$), South produces environmental services not only for domestic use, but also for export (possibly embodied in final products). Thus, under trade, a low level of Z_N implies that the graph of E_S (as a function of Z_S) is high in Figure 1. For this case, Figure 1(a) applies: $\dot{Z}_S = 0$ has a unique solution at a low steady state. Increases in Z_N shift down the graph of E_S (as a function of Z_S), thus increasing South's low steady state. When Z_N is high ($Z_N > Z_{N2}$), South produces a smaller flow of environmental services. In this case Figure 1(c) applies, so there is a unique solution to $\dot{Z}_S = 0$, the high steady state. Again, increases in Z_N raise this steady state. For intermediate levels ($Z_{N1} < Z_N < Z_{N2}$) the graph of E_S is as shown in Figure 1(b). In this case, there are two stable and one unstable solutions to $\dot{Z}_S = 0$. Over this region, an increase in

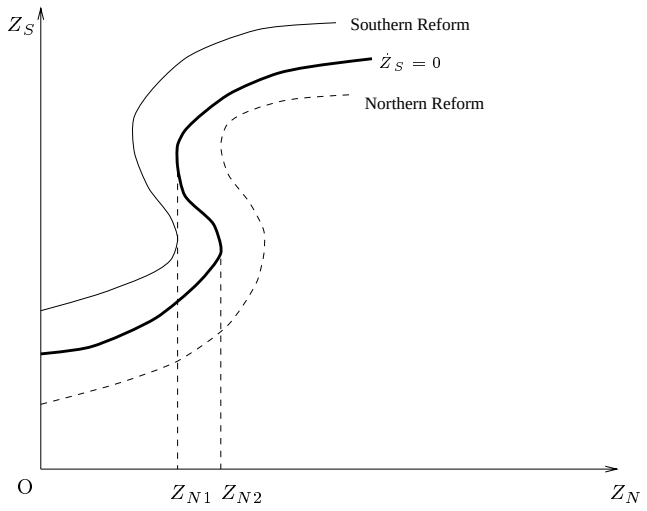


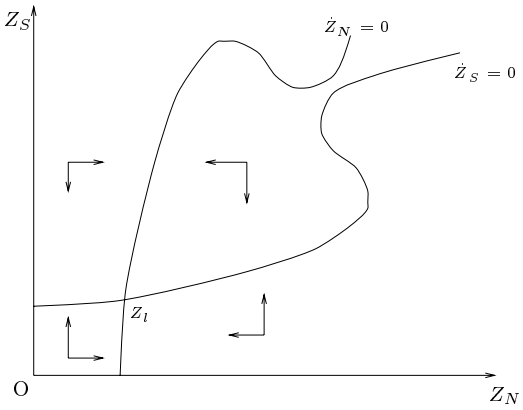
Figure 2: Phase Diagram of $\dot{Z}_S = 0$

Z_N increases both of South's stable steady states and decreases the unstable steady state.

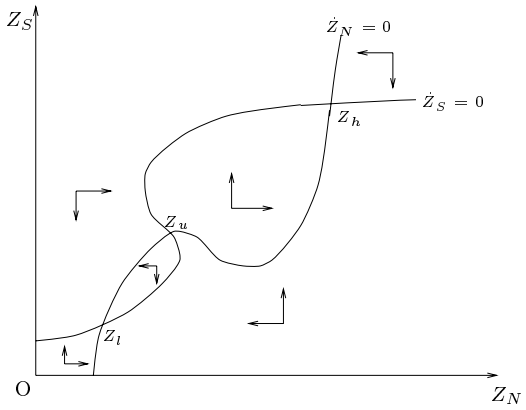
Environmental reform in one country reduces its comparative advantage in the environment-intensive good. Thus, its extraction level tends to decrease while that of the other country increases. For any level of Z_N, reform in South increases either of its stable steady states. The mechanism is the same as under autarky. Southern reform therefore shifts the $\dot{Z}_S = 0$ isocline up to the left (the thin solid curve in Figure 2). However, reform in North shifts production of environmental services to South, lowering South's stable steady states. Northern reform shifts the $\dot{Z}_S = 0$ isocline down to the right (the dashed curve in Figure 2).

We can sketch the $\dot{Z}_N = 0$ isocline using analogous arguments. Figure 3 shows three of the many possible configurations for the two isoclines. In panel (a), there is a unique steady state where both countries have low environmental stocks; in panel (c) there is a unique steady state where both countries have high stocks; in panel (b) there are two stable steady states, one high (Z_h) and one low (Z_l), and a saddle point Z_u.

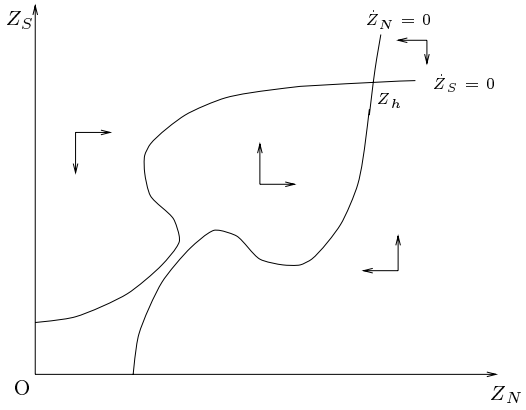
Figure 3, together with our previous comments about the manner in which reform shifts the isoclines, implies that reform has ambiguous steady state effects. Reform in one country shifts *both*



(a) Unique Low Steady State



(b) Low and High Steady States



(c) Unique High Steady State

Figure 3: Possibilities of Trade Dynamics

isoclines. For example, if the original configuration is as in Figure 3.c, Northern reform may alter the isoclines so that panel (b) represents the post-reform equilibrium. In this case it is possible that both countries move to the low steady state, when they would have certainly achieved the high steady state in the absence of reform. Alternatively, Northern reform may change the equilibrium from panel b to panel c.

At this level of generality we can only conclude that the effect of reform is ambiguous. In order to learn something about the relation between the economic (and environmental) fundamentals and the likely effects of reform, we need a less general model.

3 Special Model: the Autarkic and Trade Equilibria

In this section, we define the special model and describe the autarky and trade equilibria. The detailed derivation of these equilibria can be found in KSZ. This special model leads to a simple formula for the equilibrium extraction function $E(Z)$. We equate $E(Z)$ to the natural growth function of the resource to characterize the steady states under autarky and trade. To the extent that reform leads to *qualitative* welfare changes, the special assumptions we make do not matter at all, even though they do affect the specific welfare measurement used in the analysis.

3.1 Description of the Model

Figure 4 shows a flow chart of the autarkic economy. The first arrow shows that the stock and flow in the previous period (Z_{-1}, E_{-1}) affect the current stock, Z. We consider the static equilibria here, and return to the dynamic interaction in Section 5. There are two goods: the "subsistence good" A, which we choose as the numeraire, and the "composite good" B, which has price p. These goods are competitively produced using labor L and environmental services E with Leontief

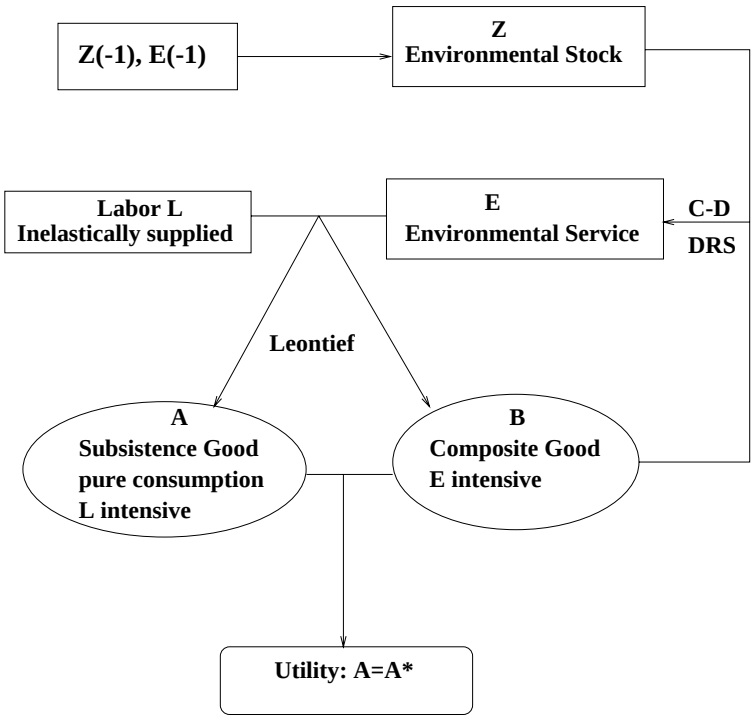


Figure 4: Structure of the Economy

technology:

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

B is relatively environment-intensive, i.e. $\frac{a_2}{a_1} > \frac{b_2}{b_1}$.

The representative consumer attempts to consume A^* units of A. If her income, y, is less than A^*, she spends everything on good A, receiving utility y (equal to the consumption of A). If her income exceeds A^*, she buys A^* units of good A and $(y - A^*)/p$ units of B, resulting in utility $A^* + (y - A^*)/p$. These preferences provide a simple way to describe a situation where the income elasticity for the subsistence good is very high at low income and is very low at high income. We assume that the representative consumer's income exceeds A^*. Section 6 discusses the assumptions regarding technology and preferences in greater detail, and explains the effect they have on our results.

The supply of labor is exogenously fixed at $\bar{L}$. Environmental services, E, are "extracted" from

the environmental stock Z using good B with a decreasing returns to scale technology. We denote the aggregate amount of B used in that sector as B^e. Larger stocks decrease the costs of producing E.

Imperfect property rights take the following form: There are a fixed number, n, of E-producers who choose their input level and receive a share of output proportional to their share of total inputs. They ignore the dynamic effects of their extraction activity.[5] The aggregate production function is assumed to be $E = (B^e Z)^{.5}$. The Nash equilibrium supply function is

$$E = \delta Z p^e / p. \tag{2}$$

Here p^e is the price of E and the (fixed) parameter $\delta = 1 - 1/(2n)$ is positively related to the magnitude of the environmental distortion (or negatively related to the degree of property rights). If there is open access with no property rights (i.e. $n = \infty$), $\delta = 1$; for perfect static property rights (i.e., $n = 1$), $\delta = .5$.

The assumption that income exceeds A^* implies that the consumption of A is fixed at A^*. In this case, the economy's welfare is measured by the consumption of B, which equals the production of B minus the amount used in the extraction industry B^e (and the net export in the case of trade). Whenever $\delta > 0.5$, the value of marginal product of B used in the production of E is less than the price of B. In this case, there would be a static efficiency gain from increasing the consumption of B and using less of it to produce environmental services. This efficiency gain is achieved by reducing δ.

To help fix ideas, we can think of good A as food, good B as steel, Z as the stock of water in lakes, and E as the flow of water used in production. Food is a pure consumption good, and its income elasticity falls as income increases. Steel can be consumed (in the form of cars) or used for

[5] In other word, E-producers do not have any dynamic property rights, and have only imperfect static property rights. Assuming away dynamic property rights greatly simplifies our analysis without changing the major conclusions.

pipes to transport water from lakes to agricultural and steel production. A low income economy uses steel only for pipes, but a richer economy also consumes cars. Water in lakes is a renewable resource, which provides benefits only as a source of a factor of production. (The consumer does not fish or swim.) A larger stock of water means that supplies are closer to production, so less steel is needed to obtain usable water.

The two economies, North and South, are identical except for their values of δ and (possibly) their stock levels. We assume that $\delta_S > \delta_N$, so the environmental distortion is worse in South. For the trade equilibria we restrict attention to the case where both economies are diversified in production, so that factor prices are equal.

Throughout the paper we use the following:

Definition 1 Environmental reform *in country i means a reduction in* δ_i. Harmonization *of environmental policies means a reduction in* δ_S/δ_N. Upward harmonization *means a reduction in* δ_S/δ_N *caused by a decrease in* δ_S. Downward harmonization *means a reduction in* δ_S/δ_N *caused by an increase in* δ_N.

Thus, downward harmonization is consistent with a "race to the bottom", while upward harmonization is consistent with a "race to the top."

3.2 Description of the Equilibria

The derivation of the autarky and trade equilibria is outlined in Appendix A. The Leontief technology, fixed labor supply, and utility function imply that in an autarky equilibrium labor is fully employed when E is high and there is unemployment when E is low. Further, the specific extraction technology and form of property right imperfection imply that given prices of B and E, the extraction increases with δZ. We refer to δZ as the *apparent stock* of this economy. A

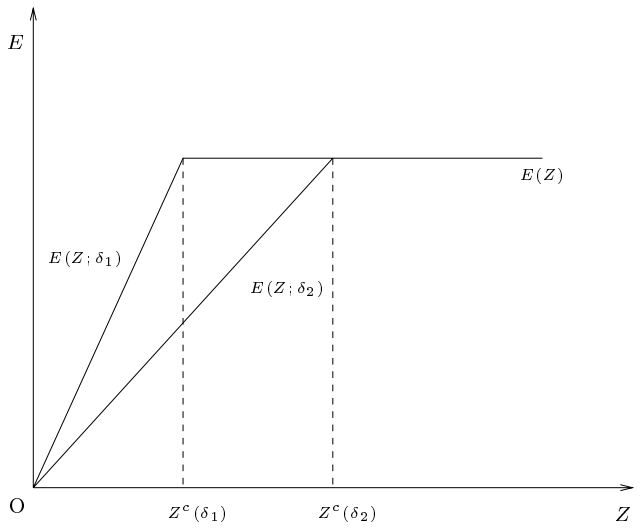


Figure 5: The Extraction Function: $\delta_1 > \delta_2$

larger distortion or a larger physical stock both increase the apparent stock. There exists a critical stock level $Z^c(\delta)$, a decreasing function of δ, such that labor is fully employed when $Z \geq Z^c(\delta)$ and partially employed when $Z < Z^c(\delta)$.

Our assumptions generate a simple equilibrium extraction function $E(Z)$. When labor is fully employed, the Leontief technology and fixed labor supply determines the amount of E demanded by the production sectors of A and B. Therefore, $E(Z)$ is a constant for $Z \geq Z^c(\delta)$. When labor is partially employed, $E(Z)$ is proportional to Z: $E = \delta Z/a_2$. Thus, environmental reform affects the level of extraction only for $Z < Z^c(\delta)$: reform reduces E and raises Z^c. For $Z > Z^c(\delta)$, reform affects neither the extraction nor the flow of welfare. Figure 5 graphs the extraction function for two levels of property right: $\delta_1 > \delta_2$. The extraction function is weakly concave, and is much simpler than in the general model of the previous section.

Now we consider free trade. The assumption that both countries are incompletely specialized means that factor prices are equalized under trade. Thus, labor is unemployed either in both countries or in neither country.

When labor is unemployed, there is only one constraining factor of production, E, so we have

the standard Ricardian model. In view of the assumption that countries have the same technology, there is no reason for trade: the autarkic and free trade equilibria are identical. In this case, the aggregate supply of E is the same under free trade and autarky. This supply is increasing in both δ_S and δ_N: reform in either country reduces the worldwide supply of E, and reduces employment in the reforming country.

If labor is fully employed, the technologies and utility function imply that the total amount of E used in the world production of A and B is again fixed. Further, aggregate E under trade equals the sum of the autarky full employment levels of E. However, the distribution of the aggregate level depends on the apparent stocks, and thus on the property rights. In equilibrium, $\frac{E_S}{E_N} = \frac{\delta_S Z_S}{\delta_N Z_N}$. Reform in either country affects extraction levels in both countries, but not aggregate extraction. However, reforms in both countries that leave δ_S/δ_N unchanged do not have any effect on extraction or welfare in either country.

Whether labor is fully employed in trade depends on the world total apparent stock, $\psi \equiv \delta_N Z_N + \delta_S Z_S$. There exists a critical level, ψ^c, such that labor is fully employed if and only if $\psi \geq \psi^c$. The relation between ψ^c and the autarky critical stock levels $Z^c(\delta)$ is given by $\psi^c = \delta_S Z^c(\delta_S) + \delta_N Z^c(\delta_N)$.

Depending on whether there is full or partial employment under autarky and trade, we can divide the state space $Z_N - Z_S$ into six regions, bordered by the lines of $Z_S = Z_S^c \equiv Z^c(\delta_S)$, $Z_N = Z_N^c \equiv Z^c(\delta_N)$ and $\psi = \psi^c$, shown in Figure 6.[6] In region I there is full employment under autarky and trade; in region IV, there is unemployment under both regimes. Regions II, III, V and VI comprise the sets of stocks where the remaining possibilities occur. For example, in region

[6] Near the axes one country is specialized, and our description is no longer correct. All of our remarks apply to the "cone of diversification." We do not include this cone in the figure in order to avoid clutter, and because we will not discuss regions of specialization. Similarly, our comments do not apply to an area in region IV near the origin, where the countries are too poor to be able to consume A^*. Suitable restrictions on parameters ensure that after excluding this area, none of the regions is empty.

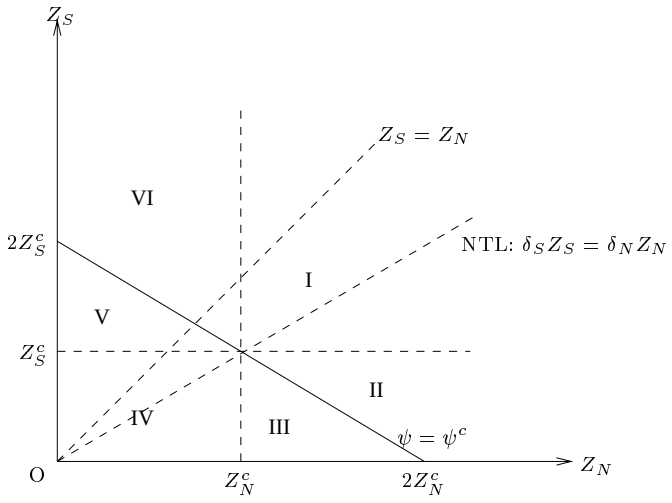


Figure 6: Regions of State Space

II labor is fully employed under trade, but unemployed in South under autarky. We concentrate on regions I and IV, in order to make our point about environmental reform as simply as possible. The results for other regions are similar to those in region I.

Since the countries are the same except for δ and Z, the country with higher supply of E has the comparative advantage in the resource-intensive good B. The supply of E is proportional to the apparent stock δZ (see equation (2)). Thus the country with higher δZ exports B. Trade does not occur when $\delta_S Z_S = \delta_N Z_N$, which defines the *No Trade Line* (NTL) in Figure 6. North (respectively South) exports B when the stock combinations are below (respectively above) this line. For stock combinations in the intersection of region I and the cone formed by the NTL and the $Z_S = Z_N$ line, South has an "apparent" but not a "real" comparative advantage in the resource intensive good. For these stock combinations, South exports the resource intensive good because its environmental distortion is greater, despite the fact that its extraction costs are higher.

Under autarky, loose property rights lead to excessive extraction and welfare loss (i.e., environmental reform matters in the short run) if and only if the resource stock is low ($Z < Z^c$). This result is an extreme version of the empirical observation that property rights matter most when

the resource base is weak. However, under trade, property rights always matter. In this sense, trade makes market imperfections more important.

4 Short-Run Effects of Reform

The major concern of this paper is with the long-run effects of environmental reform. To provide a basis for comparison, we first consider the short-run (static) effects of reform. We already noted that under autarky, environmental reform affects the economy only when $Z < Z^c(\delta)$. In this case, reform reduces the supply of E and therefore reduces the employment level, but improves welfare. To see this, note that with imperfect property rights, the value of marginal product of B in extracting E is lower than the price of B. National income equals rents in the E-producing sector, since when labor is unemployed its price is zero. A lower value of δ, leading to a lower equilibrium supply of E, implies higher profits in the extraction sector. This increase in national income raises static welfare.

Therefore, in autarky, environmental reform has no static welfare effect when the environmental stock is large, but improves welfare when the stock is small. This conclusion is an extreme form of the general result that reform is most important when environmental stocks are small. In this model, environmental and employment goals conflict when stocks are low.

With trade, reform in either country affects both countries. We concentrate on regions I and IV of Figure 6, as the results easily generalize to other regions. Consider first aggregate welfare. In region IV, where there is no trade, reform improves the reforming country's and thus the world welfare. In region I, upward or downward harmonization (smaller δ_S/δ_N) improves aggregate welfare equally, while an increase in $\frac{\delta_S}{\delta_N}$ decreases aggregate welfare. For example, Northern reform increases South's production of E and leaves unchanged the aggregate supply of E, A

$(= 2A^*)$ and B. Since $\delta_S > \delta_N$ the marginal value of product of B is lower in South. North's reform, by increasing the Southern extraction, decreases the amount of B available for consumption (since more is used for the production of the input E), and lowers world welfare. Reform in South increases world welfare.

Consider now the individual country's welfare. A country's reform reduces the inefficiency in its extraction sector, increases its partner's inefficiency, and raises the world price of the resource intensive good B. Thus, reform in a B-exporting country benefits that country and harms its trading partner. If the reforming country is an importer of B, its terms of trade deteriorate and the welfare changes in both countries are ambiguous.[7]

Equal-proportionate reform in the two countries which leaves relative distortions unchanged (i.e. reform, without harmonization) does not alter E_i or aggregate welfare. However, this reform reduces world apparent resource stocks and thus raises the price of B. Equal-proportionate reform thus benefits the exporter of the environmentally intensive good and harms the importer. Therefore, when evaluating a policy change which leaves δ_S/δ_N unaltered, exporters of the resource intensive good (B) prefer a "race to the top," and importers of B prefer a "race to the bottom."

Remark 1 summarizes the static effects of reform.

Remark 1 *(i) Under autarky, for sufficiently small stocks, environmental reform reduces extraction, increases welfare and unemployment. For large environmental stocks, the environmental distortion is irrelevant and reform has no effect on welfare or employment.*
(ii) Under free trade, with sufficiently low stocks in both countries (region IV), reform has the same welfare effect as under autarky.[8]

[7] Provided that $\delta_S < \frac{3}{4}$, w can show that a country loses from reform if it is a sufficiently large importer – i.e. if the terms of trade effect are sufficiently important. This condition requires that the reforming country's stocks are sufficiently small, relative to its partner's. Details are available upon request.

[8] The effect on unemployment is more complicated, because the free trade equilibrium is indeterminate in region IV. There we have the one-factor Ricardian model with identical technology and consumption fixed at A* in both

(iii) Under free trade, with sufficiently high stocks in both countries (region I), aggregate welfare depends only on relative distortions, but the distribution of welfare also depends on absolute levels of distortions. (a) Southern reform: (1) increases world welfare, (2) harms North unless North is a sufficiently large exporter of B, (3) benefits South unless South is a sufficiently large importer of B, and (4) has no employment effect. (b) Northern reform: (1) decreases world welfare, (2) harms South unless South is a sufficiently large exporter of B, (3) benefits North unless North is a sufficiently large importer of B, and (4) has no employment effect.

The lack of substitutability (in both production and consumption) in our model emphasizes the role of relative rather than absolute distortions in the trade equilibrium. Our results should therefore be interpreted in the following manner: When environmental stocks are large, the domestic distortion has little effect on the autarkic equilibrium, and reform is unimportant. For these high stock levels, the *absolute levels* of the distortions remain unimportant for aggregate welfare in the trade equilibrium. In this sense, proportional reform in both countries is still unimportant. However, relative distortions become important: Reform with (both upward and downward) harmonization improves aggregate welfare, but reform against harmonization may lower welfare. The equivalence between upward and downward harmonization in the short run is due to the assumed lack of substitutability in the economy. This assumption helps to identify the long-run effects of reform.

countries. A range of production points are consistent with free trade equilibria. Each of these involves the same level of welfare and supply of the factor E_i, but each has a different level of unemployment. The price of labor is zero, so the amount of employment does not affect welfare. We can show that reform in one country never increases, and may decrease, the maximum amount of unemployment in both countries.

5 Long-Run Effects of Reform

In the dynamic model, we assume a logistic growth function for Z, given by $\dot{Z}_i = \eta Z_i - \gamma Z_i^2 - E_i$, for $i = N, S$. The parameter γ captures the congestion effect of the stock; $\gamma > 0$ ensures that Z is bounded. The non-congested growth rate of the environment, η, provides a measure of environmental resilience. When η is large, the environmental stock recovers quickly from low levels. Thus, we associate a large value of η with a resilient environment, and a small value of η with a fragile environment. The carrying capacity of the stock is $\frac{\eta}{\gamma}$ and the stock that maximizes sustainable yield is $\frac{\eta}{2\gamma}$. The level of E_i is the amount of extraction (the flow of environmental services) at a point in time.

The dynamic equilibria for autarky and trade are sequences of the static equilibria studied in the last section, corresponding to the evolving stock levels.[9] The autarky and trade dynamics of our model are presented in Figures 7 and 8. The magnitude of η relative to critical values, $\hat{\eta}^a$, η^{*a} for autarky and $\hat{\eta}$ and η^* for free trade, determines which of the several phase portraits arises (Appendix B.1).

We define a low steady state as one that is less than $\frac{\eta}{2\gamma}$ (the stock level that maximizes sustainable yield), and the high steady state as one above this level. In our setting, there is unemployment at the low steady state and full employment of labor at the high steady state. The three possible dynamic regimes under autarky are (Figure 7): (a) For $\eta < \hat{\eta}^a$, there is a unique low stable steady state with unemployed labor, Z_l; (b) For $\hat{\eta}^a < \eta < \eta^{*a}$, there is a low stable steady state

[9] We noted before that the relative magnitude but not the source of the distortion is important in our model. We explained that the supply function $E = \delta Z p^e/p$ can be derived as a Nash equilibrium to a common property game with a fixed number of producers. We retain this supply function for the dynamic setting. If we allowed producers to be forward looking, we would need to solve the equilibrium for a differential game. This model would almost certainly be intractable. The autarkic supply function would be $\Delta(Z)p^e/p$, rather than $\delta Z p^e/p$ as we currently have. (The trade supply function would depend on both stocks.) That is, we would have replaced a simple function δZ by a complicated and unknown function $\Delta(Z)$. A larger distortion (weaker property rights) would still imply additional extraction, i.e. it would shift out the function $\Delta(Z)$. Therefore, we expect that the introduction of forward looking agents would not alter our qualitative results.

with unemployed labor, a high stable steady state with full employment (Z_h), and an intermediate unstable steady state (Z_u); (c) For $\eta > \eta^{*a}$, there is a unique high stable steady state with full employment.

The three cases under free trade (Figure 8) are similar, although the critical values of η are different. The low stable steady state under trade, $\boldsymbol{Z_l} = (Z_{Nl}, Z_{Sl})$, has unemployment in both countries, and the high stable steady state, $\boldsymbol{Z_h} = (Z_{Nh}, Z_{Sh})$, has full employment. The unstable steady state is $\boldsymbol{Z_u}$.

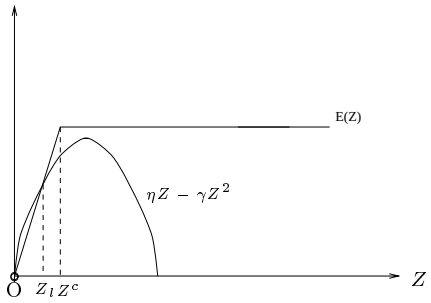
A marginal change in δ_i could cause a qualitative change in the steady state only for "knife-edge" cases, where the parameters of the model or the initial value of $\boldsymbol{Z}$ are at critical levels. In general, a qualitative change in the steady state requires a non-marginal change in δ, i.e., a large reform. We are able to use comparative statics to analyze large reforms because the critical values (at which a change in regime occurs) are monotonic in δ, for $\delta \in [1/2, 1]$.

5.1 Long-Run Effects of Reform under Autarky

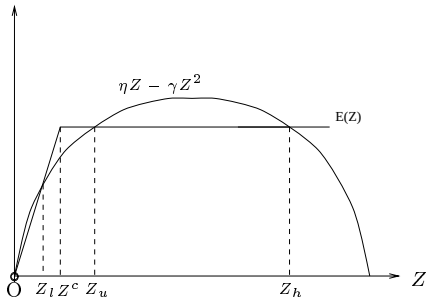
The dynamic effects of reform under autarky are straightforward. The comparative statics of the critical values (derived in Appendix B.2) are

$$\begin{aligned} &(a) \quad \frac{d\hat{\eta}^a}{d\delta} = 0; \qquad (b) \quad \frac{d\eta^{*a}}{d\delta} > 0; \qquad (c) \quad \frac{dZ^c}{d\delta} < 0; \\ &(d) \quad \frac{dZ_u}{d\delta} = \frac{dZ_h}{d\delta} = 0; \qquad (e) \quad \frac{dZ_l}{d\delta} < 0; \qquad (f) \quad \frac{d(\delta Z_l)}{d\delta} < 0. \end{aligned} \tag{3}$$

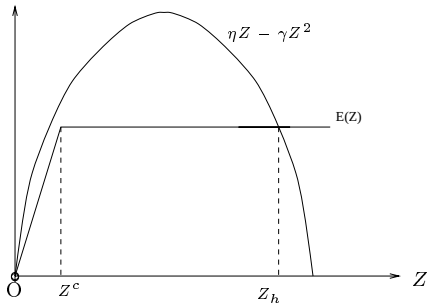
Equation (3) has several implications for environmental reform under autarky. We noted in the last section that for $Z < Z^c$, reform increases instantaneous welfare and decreases both the flow of environmental extraction and employment. In the short run, environmental and welfare objectives conflict with employment objectives. From (3f), these goals are compatible in the long run: reform raises δZ_l. The increase in δZ_l raises the steady state supply of E, and thus reduces



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

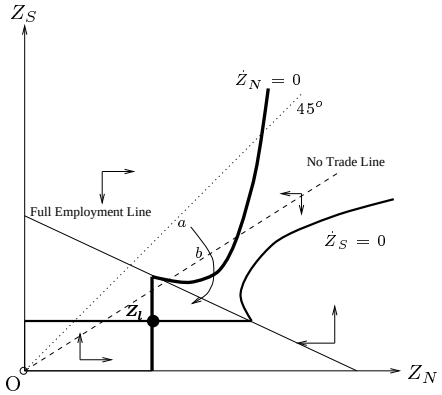


(b) $\hat{\eta}^a < \eta < \eta^{*a}$

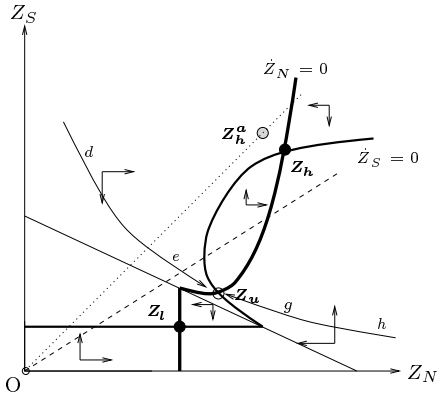


(c) $\eta > \eta^{*a}$

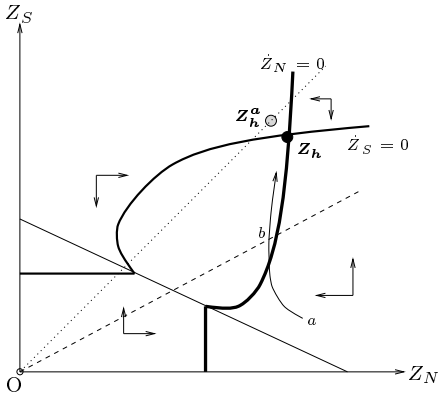
Figure 7: Resource Dynamics Under Autarky



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



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



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

Figure 8: Resource Dynamics Under Trade: ∘ Unstable and • Stable

unemployment.[10] In the long run, reform leads to a large enough improvement in the environment to increase employment despite tighter regulations. In this model, a government's enthusiasm for reform depends on its short-run trade-off between national welfare (and the environment) and employment, and also on its discount rate.

The three possible long run effects of a non-marginal reform are:

Case I: If $\eta < \hat{\eta}^a$, environmental reform does not enable the economy to escape from a low steady state with unemployment (See Equation (3a).)[11] Reform has only the quantitative effects described in the previous paragraph.

Case II: If $\eta > \eta^{*a}$, the economy always reaches the high steady state, and reform has neither a qualitative nor a quantitative effect (See Equation (3b)). Reform's only effect is that during a period when $Z < Z^c$, both unemployment and welfare are higher, and the environment recovers more rapidly.

Case III: For the intermediate case, $\hat{\eta}^a < \eta < \eta^{*a}$, the magnitude of the reform is important. If the reform is "moderate", in the sense that Figure 7(b) continues to represent the dynamics, then the effect of reform depends on the initial condition, Z_0. When $Z_0 < Z_u$ (which is independent of δ), reform has the quantitative effect as described in Case I. When $Z_0 > Z_u$, reform has no effect, as in Case II (with $Z_0 > Z^c$). If the reform is sufficiently large so that η^{*a} decreases to below η, the post-reform dynamics are described by Figure 7(c). In that situation, reform causes a qualitative change for small initial stocks, since the stock approaches a high rather than a low steady state. For large initial stocks, a large reform has neither a quantitative nor a qualitative effect.

We summarize these conclusions in the following Remark.

[10] The result occurs because there is unemployment at the low steady state, as shown in figure 7a. Reform causes the increasing part of the extraction function to rotate down, leading to a higher steady state and a higher flow of E – and therefore more employment.

[11] See Figures 5 and 7a. By varying δ we can choose a steady state anywhere between 0 and the carrying capacity $\frac{\pi}{\gamma}$, but for all of these values there is unemployment.

Remark 2 *Under autarky:*

(i) If the resource is sufficiently resilient ($\eta > \eta^{*a}$), reform does not have any long-run effects;

(ii) If the resource is sufficiently fragile ($\eta < \hat{\eta}^a$), reform increases long-run welfare and employment, but it does not enable the economy to escape from a low steady state with unemployment.

(iii) If the regenerative capacity of the resource is moderate ($\hat{\eta}^a < \eta < \eta^{*a}$), reform can result in a qualitative improvement in the long-run welfare and employment if the initial stock is low;

(iv) Reform might increase (as in (ii)) or eliminate (as in (iii)) the low steady state, thereby decreasing or eliminating unemployment and improving welfare in the long run. Reform never reduces the long-run welfare.

5.2 Long-Run Effects of Reform under Free Trade

We now consider the long-run effects of reform in the free-trade equilibrium. As in equation (3), we study how changes in δ_S and δ_N affect the critical levels of the stock and of η. Labor is partially employed in both countries at the low steady state $\boldsymbol{Z_l}$. Thus the autarky and trade equilibria are identical at $\boldsymbol{Z_l}$. Consequently, reform in country i has the same effect on the low steady state $\boldsymbol{Z_l}$ as under autarky: Z_{il} and $\delta_i Z_{il}$ increase, and Z_{jl}, $j \neq i$, is unchanged. A reduction in δ_i has indeterminate effects on the high steady state $\boldsymbol{Z_h}$. The only possibility that we can exclude is that reform in North decreases Z_{Nh} and increases Z_{Sh}.[12]

The qualitative effects of environmental reform depend on the change in $\hat{\eta}$ and η^*. From equation (11) in Appendix B.1, the critical value $\hat{\eta}$ depends only on relative property rights (relative distortions), measured by δ_S/δ_N. Harmonization (in either direction) reduces $\hat{\eta}$:

$$\frac{d\hat{\eta}}{d(\delta_S/\delta_N)} > 0. \tag{4}$$

[12]We expect that in the "usual case," Northern reform would increase Z_{Nh} and reduce Z_{Sh}, as production of E shifts to South. However, since a reduction in δ_N causes both isoclines in Figure 8 to shift down (for $\psi > \psi^c$), we can not rule out other possibilities.

Harmonization of policies, achieved by either an improvement in Southern standards, or a deterioration in Northern standards, reduces δ_S/δ_N. If $\eta < \hat{\eta}(\delta_S/\delta_N)$ prior to harmonization, the unique steady state is $\boldsymbol{Z_l}$, where the environmental stock is low and there is unemployment. Harmonization may reduce the critical $\hat{\eta}$ by enough that it is less than η, thereby creating a high steady state (when the phase portrait changes from Figure 8a to 8b). If the initial stocks, $\boldsymbol{Z}_o$, are sufficiently large, harmonization causes the economies to move toward the high steady state. In this case, harmonization benefits both North and South in the long run, even if either of them suffers welfare losses in the short run (cf. Remark 1). Here, harmonization shifts production of the resource-intensive good away from South, possibly altering the nations' apparent comparative advantage and reversing the direction of trade for a time. The lower level of exploitation enables South's stocks to recover. In the long run, South exports commodity B and North's stocks also recover.

Unilateral reform in North, which represents a movement away from harmonization, could cause $\hat{\eta}$ to exceed η. Suppose, for example, that pre-reform $\eta > \hat{\eta}$ and $\boldsymbol{Z}_o$ lies above the convergent saddle path through $\boldsymbol{Z_u}$, so that the economy is moving toward $\boldsymbol{Z_h}$. If after Northern reform, $\eta < \hat{\eta}$, the economy approaches the low steady state $\boldsymbol{Z_l}$. In this case, even if North and/or South benefit from Northern reform in the short run, both lose in the long run.

If the economies are initially close to the low steady state, harmonization may change the phase portrait from Figure 8(a) to 8(b), but the economies remain trapped at $\boldsymbol{Z_l}$. In this case, harmonization has no qualitative effect. Reform in either country increases its apparent and real environmental stock in the long run and thus increases that country's steady state welfare, without altering the other country's steady state welfare.

For $\eta > \eta^*$ only a high steady state exists. From (12) in Appendix B.1, the critical value η^* depends on both the relative and absolute values of δ_i. (In contrast, $\hat{\eta}$ depends only on relative

δ values.[13]) Southern reform, which decreases both the absolute distortion in South and its distortion relative to North, reduces the range of values of η at which the low steady states exist; that is (Appendix B.3),

$$d\eta^*/d\delta_S > 0. \tag{5}$$

Southern reform may cause the phase portrait to change from Figure 8(b) to 8(c). If this occurs, Southern reform causes the economies to move to a high steady state with full employment even if they were previously trapped at a low steady state.

Northern reform increases the relative distortions but decreases an absolute distortion. The effect of this reform on η^* depends on which of the two influences is stronger. In particular, it depends on the initial difference between δ_S and δ_N and the severity of the environmental problem. The relative distortion matter more if the initial difference $\delta_S - \delta_N$ is large, and when the environmental problem is "more severe".

We define the index $g = \gamma a_2 \psi^c$ as a measure of the severity of the environmental problem. This index depends on the physical/biological process, and on the economic variables which describe production and preferences, but not on δ_i. The index is an increasing function of the congestion parameter γ. Greater congestion tends to make the environmental problem more severe. The parameter a_2 is the amount of the environmental factor needed to produce a unit of commodity B. An increase in a_2 means that the environment becomes more important to production, and low environmental stocks become more damaging. Finally, ψ^c, which is a function of all of the economic parameters except δ_i, is the minimum aggregate apparent stock needed for full employment. An increase in ψ^c also means that the environment, and thus environmental problems, are more

[13]The location of the high steady state $\boldsymbol{Z_h}$ depends only on the relative property rights, while the location of the low steady state $\boldsymbol{Z_l}$ depends on both individual property rights. Thus, $\hat{\eta}$, which affects the existence of $\boldsymbol{Z_h}$, depends only on the relative property rights, while η^*, which affects the existence of $\boldsymbol{Z_l}$, depends also on the absolute property right levels.

important.

The effect on η^* of δ_N depends on whether the index g exceeds a critical level, defined as $g^* \equiv \delta_N^2 + 2\delta_N - 1$, and on whether δ_S exceeds a critical value $\delta_S^*(\delta_N, g)$, which is increasing in δ_N and decreasing in g, with $\delta_N < \delta_S^* < 1$ (Appendix B.3):

$$\frac{d\eta^*}{d\delta_N} \begin{cases} > 0 & \text{if} \quad g < g^* \\ > 0 & \text{if} \quad g > g^* \quad \text{and} \quad \delta_S < \delta_S^*(\delta_N, g) \\ < 0 & \text{if} \quad g > g^* \quad \text{and} \quad \delta_S > \delta_S^*(\delta_N, g) \end{cases} \tag{6}$$

Equation (6) states that if the environmental problem is not "severe" ($g < g^*$), then the absolute effect of Northern reform always dominates the relative effect, and Northern reform decreases the critical value η^*. If, on the other hand, the environmental problem is "severe" ($g > g^*$), then either the absolute or relative effect may dominate. If the difference between the property rights is large ($\delta_S > \delta_S^*$), the relative effect dominates, and Northern reform increases the critical value of η^*.[14] If the difference between the economies is small ($\delta_S < \delta_S^*$), the absolute effect dominates, and Northern reform decreases the critical value of η^*.

The fact that upward harmonization (through reducing δ_S) certainly decreases η^*, but downward harmonization (through increasing δ_N) may increase η^*, is a strong argument in favor of upward rather than downward harmonization. This argument is based on the long-run effects of reform.

Remark 3 summarizes the implications of equations (4) - (6). When we say that an outcome is "less likely," we mean that the set of parameter values for which the result occurs is smaller.

Remark 3 *(i) Southern reform (upward harmonization) decreases both the critical values $\hat{\eta}$ and η^*. Reducing these values makes it less likely that there will be a unique low steady state (Figure 8(a)),*

[14] Since g^* is increasing in δ_N, for larger Northern distortions it is less likely that $g > g^*$, and therefore less likely that $d\eta^*/d\delta_N < 0$.

and more likely that there will be a unique high steady state (Figure 8(c)), creating the possibility of qualitative improvements in welfare and employment.

(ii) Northern reform raises $\hat{\eta}$, making it more likely that there will be a unique low steady state (Figure 8(a)) and welfare losses.

(iii) Northern reform reduces η^*, making it more likely that there will be a unique high steady state (Figure 8(c)) and welfare gains if and only if: (a) the environmental problem is not too severe or (b) the initial difference between North and South is not too great.

5.3 Comparison of Results

Remarks 3 and 1 show how the dynamic and static effects of reform differ under free trade. In region I, where "trade matters," instantaneous aggregate welfare depends only on the relative distortions. Harmonization, whether achieved by upgrading Southern standards or degrading Northern standards, has the same instantaneous effect on aggregate welfare. In the long run, however, absolute as well as relative levels of standards are important. Harmonization upwards is more likely than harmonization downwards to increase long run stocks and welfare.

Remarks 3 and 2 show how the dynamic effects of reform depend on the trade regime. In a closed economy, reform does not alter the critical value $\hat{\eta}^a$, below which only a low steady state exists. If a country under autarky is trapped in a steady state with low environmental stocks and unemployment, technology and preferences determine its destiny. Environmental reform cannot lead to a qualitative improvement (high stocks and full employment). In contrast, if open economies are trapped in a low steady state with unemployment, harmonization of environmental policies (which reduces $\hat{\eta}$) may enable them to escape to a full-employment high steady state.

In a closed economy, reform always reduces the critical value η^{*a}, above which only a high steady state exists. Therefore, if both the high and low steady state exist in an autarkic economy,

reform might eliminate the low steady state, ensuring that the economy reaches the high steady state. With open economies, reform in the more distorted economy reduces the critical value η^* above which only a high steady state exists. Reform in the less distorted economy, which reduces harmonization, may increase this critical value. Therefore, in open economies, reform in the less distorted economy can either increase or decrease the danger that environmental stocks move to a low steady state.

In addition to illustrating these possibilities, the model shows how the plausibility of a particular outcome is related to the intrinsic growth rate of the environment. If η is small then the environment is "fragile", in the sense that it regenerates slowly. If we think that the environment is fragile (in this sense), then changes in $\hat{\eta}$ and $\hat{\eta}^a$ are more important than are changes in η^* or η^{*a} (since the actual value of η is more likely to be close to the first pair of critical values). Thus, "fragility" of the environment makes it more likely that harmonization – even if achieved by lower standards in North – improves the environment and welfare in both the short and the long run. If, on the other hand, the environment is "resilient" (η is close to η^* or η^{*a}), unilateral reform in North may lead to long run improvements, at the cost of short run welfare losses.

Finally, the three Remarks show that environmental reform has different short and long run effects on unemployment. Under both free trade and autarky, environmental reform always increases unemployment in the short run, when this is initially positive. In the long run, however, the environmental and employment goals are compatible. When unemployment is positive in the steady state, environmental reform decreases it under either trade or autarky.

6 Discussion of the Model

Since our model is not completely standard, it is worth discussing the plausibility of its assumptions, and the bearing these have on our results. One of our major assumptions is the lack of substitutability in consumption and in production of the final goods A and B. The assumption is not "realistic," although (arguably) it might be more realistic than those which are often invoked in models that require analytic solutions (e.g. constant expenditure or factor shares). It enables us to obtain an extremely simple equilibrium extraction function $E(Z)$ that is piece-wise linear, leading to analytical characterization of the steady states. As shown in Section 2, "smoothing" of $E(Z)$ by introducing more substitutability to consumption and/or production will *not* affect the possibility of multiple steady states.[15] That is, the major result of this paper, i.e., the (qualitative) long-run effects of reform in both trade and autarky, will hold in a more general model.

Introducing substitutability into the model would change some of our special results. For example, equilibrium extraction will increase with looser property rights even for high stocks, and unemployment may not arise. In this case, reform matters for all stock levels, and in the short run upward harmonization may improve the aggregate welfare more than downward harmonization. Although the lack of substitutability in our model is at best an exaggeration of reality, it does lead to a plausible implication: environmentally-related market failures are especially important when the environmental stock is low. The existence of unemployment is not critical to our model. However, our special structure illustrates the possibility of long-run compatibility between environment and employment goals. Most significantly, by constructing a model where upward and downward harmonization are equivalent in the short run, we are able to identify the factors that favor upward harmonization in the long run.

[15] For example, we can adopt a more traditional approach, such as the one used in Brander and Taylor (1998), to smooth out $E(Z)$. We may still be able to obtain multiple steady states, as argued in Section 2, but finding the steady states will be much more difficult.

Another simplifying assumption of our model is that the producers in the extraction industry are myopic. They do not optimize dynamically; instead, they respond to the existing resource stock and prices to choose the current extraction level. Again, introducing dynamic behavior is not likely to alter the features of $E(Z)$ presented in Section 2, such as the monotonicity of $E(\cdot)$. However, it would be very difficult to obtain analytic results with a model of forward-looking agents. Given that environmental evolution typically takes place over a much longer time scale than human activities (especially human planning), myopic behavior may be a better approximation of reality than rational expectations.

Ultimately, our special model should be viewed as a particular mathematical representation of the scenario presented in Section 2. With the added structure, we are able to examine the likely long-run impacts of environmental reform and harmonization under trade and autarky, in a situation when multiple steady states can arise.

7 Conclusions

We studied the differing effects of environmental reform in the short and the long run, under both free trade and autarky. Under autarky there is a single distortion, which causes a real effect only when the stock is low. Environmental reform either increases welfare or has no effect.

Under trade, there are two distortions in the two countries, so both the absolute and relative levels of these distortions may be important. In line with the theory of the second best, decreasing a single distortion does not necessarily improve welfare. In the short run, the race to the bottom and the race to the top increase (or have no effect on) aggregate welfare: only relative distortions matter. In the long run, the absolute levels of distortion are also important. Reform in the less distorted economy ameliorates an absolute distortion but worsens the relative distortion, and has

ambiguous welfare effects. The net effect of this reform is more likely to be positive if the initial gap between the distortions is not large, if the environment is not important, and if the environment is resilient. Thus, long-run considerations tend to favor upward harmonization, relative to downward harmonization.

Under autarky, the environmental distortion has no real effect when stocks are large, but under trade the environmental distortion always has real effects. Consequently, reform always has real effects under trade, but not necessarily under autarky. Trade increases the ability to use environmental reform to improve welfare. However, trade also makes it possible that environmental reform has perverse results.

A Model Details

The derivation of the autarky and trade equilibria is straightforward and rather standard. We refer readers to Chichilnisky (1994) and KSZ for details. There are two instantaneous autarky equilibria depending on whether labor is fully employed. With full employment, the price of B is $\frac{b_2^2 \delta Z}{b_1 b_2 \delta Z - \phi D}$, and the amount of environmental extraction is $\frac{\phi}{b_2}$, where $\phi = a_2 \bar{L} - A^* D > 0$, and $D = a_2 b_1 - a_1 b_2 > 0$. With unemployed labor, the price of B is $\frac{a_2}{a_1}$ and the amount of extraction is $\frac{\delta Z}{a_2}$. Labor is fully employed if and only if $Z \geq Z^c$, where

$$Z^c \equiv \frac{a_2 \phi}{b_2 \delta}. \tag{7}$$

Similarly, there are two instantaneous free trade equilibria. When labor is fully employed, the world price of B is $\frac{b_2^2 \psi}{b_1 b_2 \psi - 2\phi D}$, and the amount of resource extracted in country i is $E_i^p = \frac{2\delta_i Z_i \phi}{b_2 \psi}$, where $\psi = \delta_N Z_N + \delta_S Z_S$. With unemployment, the world price and extraction are the same as under autarky. Labor is fully employed if and only if $\psi \geq \psi^c$, where

$$\psi^c \equiv \frac{2 a_2 \phi}{b_2}. \tag{8}$$

B Derivations

B.1 Critical η Values

The critical values $\hat{\eta}^a$ and η^{*a} are determined by checking the existence (and nonexistence) of solution to $\dot{Z} = 0$ for E functions associated with partial and full labor employment. $\hat{\eta}$ and η^* are determined by checking the existence of solution to the simultaneous equations $\dot{Z}_S = 0$ and $\dot{Z}_N = 0$. We refer readers to KSZ for derivation details. The following gives the specific values.

$$\hat{\eta}^a = 2\sqrt{\frac{\gamma\phi}{b_2}} \tag{9}$$

$$\eta^{*a} = \frac{\delta}{a_2} + \gamma Z^c \tag{10}$$

$$\hat{\eta} = \frac{2\sqrt{\delta_S^2 + \delta_N^2}}{\delta_S + \delta_N}\sqrt{2\gamma\phi/b_2} \tag{11}$$

$$\eta^* = \frac{\delta_N^2 + \delta_S^2 + a_2\gamma\psi^c}{a_2(\delta_N + \delta_S)}. \tag{12}$$

We can further show that (Appendix I of KSZ)

$$\eta^{*a} < \frac{2\delta}{a_2}. \tag{13}$$

B.2 Proof of Equation (3)

(3a) is straightforward from (9). Differentiating (10) with respect to δ and using (13), we get (3b). (3c) is straightforward from (7), and (3d) and (3e) are clear from Figures 5 and 7. Now we prove (3f). Given the resource dynamics $\dot{Z} = \eta Z - \gamma Z^2 - \frac{\delta Z}{a_2}$, we know the low steady-state resource stock is $Z_l = \frac{1}{\gamma}(\eta - \frac{\delta}{a_2})$. Thus $\frac{d(\delta Z_l)}{d\delta} = \frac{1}{\gamma}(\eta - \frac{2\delta}{a_2})$. From (13) and $\eta < \eta^{*a}$ whenever the low steady state exists, we know $\frac{d(\delta Z_l)}{d\delta} < 0$.

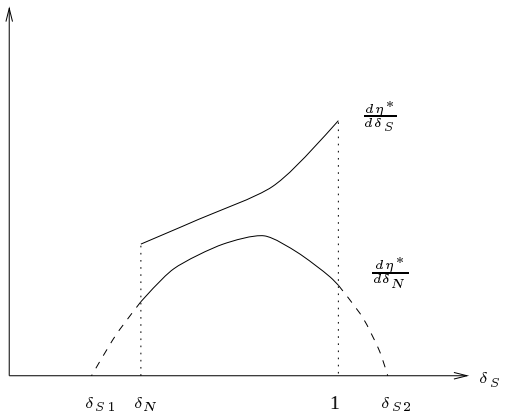


Figure 9: Effects of reform: $g < g^*$

B.3 The signs of $\frac{d\eta^*}{d\delta_N}$ and $\frac{d\eta^*}{d\delta_S}$

From (12), $\frac{d\eta^*}{d\delta_N} = Hf_N(\delta_S, \delta_N)$ and $\frac{d\eta^*}{d\delta_S} = Hf_S(\delta_S, \delta_N)$, where $H > 0$ is a constant independent of δ_S and δ_N, $f_N(\delta_S, \delta_N) = (-\delta_S^2 + 2\delta_N\delta_S + \delta_N^2 - g)$ and $f_S(\delta_S, \delta_N) = (\delta_S^2 + 2\delta_N\delta_S - \delta_N^2 - g)$, with $g = \gamma a_2 \psi^c$. $\delta_S > \delta_N$ implies $f_N < f_S$, thus $\frac{d\eta^*}{d\delta_N} < \frac{d\eta^*}{d\delta_S}$.

We first show Equation (6). f_N is a quadratic equation in δ_S, and we are concerned with its sign for the relevant range of δ_S, $[\delta_N, 1)$. The two roots of $f_N = 0$ are $\delta_{S1} = \delta_N - \sqrt{2\delta_N^2 - g}$ and $\delta_{S2} = \delta_N + \sqrt{2\delta_N^2 - g}$, and $f_N > 0$ for $\delta_S \in (\delta_{S1}, \delta_{S2})$. It is straightforward to show that $\delta_{S1} < \delta_N$ and $\delta_{S2} \geq 1$ when $g \leq g^* \equiv \delta_N^2 + 2\delta_N - 1$, establishing the first part of Equation (6). This result is shown in Figure 9.

For $g > g^*$, $\delta_{S2} < 1$. To determine the position of δ_{S1}, we argue that f_N is positive at $\delta_S = \delta_N$. To show this, we use (13), from which we can show that $g < 2\delta_N^2$. That is, $f_N(\delta_N, \delta_N) > 0$. Therefore, $\delta_{S1} < \delta_N$. This scenario is depicted in Figure 10, which also shows that δ_S^*, described above (6), is defined as the larger root of f_N: $\delta_S^* \equiv \delta_{S2}$.

Now we show $\frac{d\eta^*}{d\delta_S} > 0$. It is straightforward to show that f_S is increasing in δ_S for $\delta_S \in [\delta_N, 1)$. From the fact that $f_S > f_N$ and $f_N > 0$ when $\delta_S = \delta_N$, we know $\frac{d\eta^*}{d\delta_S} > 0$. This result is illustrated in both Figures 9 and 10.

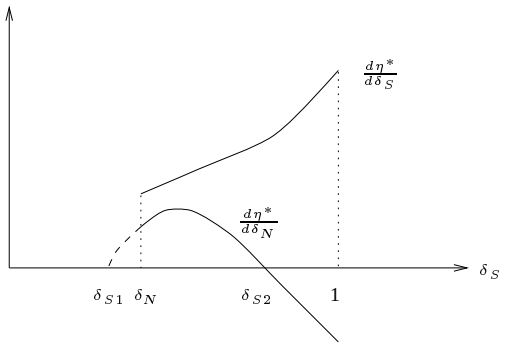


Figure 10: Effects of reform: $g > g^*$

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