August 29, 1998

The Uncertain Benefits of Environmental Reform in Open Economies

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We compare the instantaneous and the long run effects of environmental reform in closed and open economies. Harmonization upward (decreasing distortions where they are most severe) or harmonization downward (increasing distortions where they are less severe), both tend to increase instantaneous world welfare. Environmental reform in a country with less severe distortions works against harmonization and may decrease welfare. Harmonization upward is more likely to have long-run benefits relative to harmonization downward. In the short run there is a conflict between environmental protection and reduction of unemployment, but in the long run the two goals are consistent.

JEL Classification Numbers: Q20, F10, H23

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

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1. Introduction

Environmental reforms which in a closed economy would benefit the environment and increase welfare, may have the opposite effect in the presence of international trade. These unintended consequences are likely where the reforming country begins with a higher level of environmental protection. Even if the reforming country benefits in the short run, both it and other countries may be harmed in the long run. These possibilities are related to, but distinct from, environmentalists' usual trade-related concern: International trade makes domestic environmental reform more difficult and expensive because it allows countries with lower environmental standards to attract polluting industries. Since reforming countries are reluctant to lose the jobs and profits associated with these industries, international trade supposedly makes them less willing to protect the domestic environment. Our point, however, is not that international trade makes it more expensive and politically difficult to implement environmental reform, but that reform might be counterproductive in an open economy.

This possibility is a special case of the theory of the second best. Suppose, for example, that in each of two countries there exists an environmental distortion, which is the only market imperfection. Under autarky, a reform which reduces the (sole) domestic distortion improves a country's welfare. With trade, there are two relevant distortions. The theory of the second best alerts us to the possibility that reform in one country, i.e., the reduction of its distortion, does not necessarily increase welfare in either country.

Inter-industry trade occurs because of differences between countries, such as differences in technology, factor endowments, or tastes. A number of recent papers, including Chichilnisky (1993, 1994), Copeland and Taylor (1994, 1995), Brander and Taylor (1996) and Karp, Sacheti

and Zhao (KSZ;1997), emphasize that differences in environmental regimes also provide an impetus for trade. When environmental reform occurs in the country which initially has a smaller environmental distortion, the difference between the countries increases. To the extent that trade is driven by this difference, trade is also likely to increase, and the welfare effects of reform are ambiguous.

Viewed in this light, the observation that domestic environmental reform might be counterproductive is quite obvious. Although not surprising to trade theorists, the observation is important for policy discussions, and appears to have been largely ignored. These discussions have concentrated on the possibility that trade encourages countries to lower (or fail to tighten) environmental regulations, in order to obtain competitive advantage in certain industries.[1] Whatever the merits of this particular anti-free-trade argument, it is unlikely to alter the movement toward trade liberalization. The focus should therefore shift to the appropriate design of environmental policy in an open economy.[2]

An important issue in designing such a policy concerns cross-country harmonization of policies. In a two-country model, reform in the country which initially has the larger environmental distortion narrows the cross-country difference in distortions, and therefore represents a "harmonization" of policies. Reform in the country with the smaller distortion, on

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[1]A growing empirical literature examines the effect of "pollution havens" on the location of production and on trade. Muthukumara and Wheeler (1997) find that changes in environmental regulation have short run effects on the location of dirty industries.

[2] A number of papers have studied environmental reform in open economies. Markusen (1975) and Krutilla (1991) analyze the terms of trade effects of environmental policies in a static setting. Copeland (1991) studies a small country model with several instruments. Markusen et al (1993) analyze the effect of policy on plant location under imperfect competition. Ulph (1994) surveys recent work in the field.

the other hand, is a movement away from harmonization of policies. Economists and environmentalists have disagreed on the merits of harmonization[3].

Environmentalists think that competitive pressures, which are heightened by trade liberalization, create a danger of a "race to the bottom" in environmental standards. They conclude that harmonization of policies is important to prevent this race. However, if their concern is with falling standards, then the remedy is to install mechanisms to maintain or improve environmental protection everywhere. It is misleading to speak of harmonization when environmentalists would be happy if standards were tightened everywhere, even if this meant that cross-country differences increased (i.e., that standards became "less harmonious").

Economists tend to oppose pressures for harmonization, arguing that differences in standards may 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. We agree that these considerations are important, but believe that in many cases differences in standards simply reflect different degrees of market failure. 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, harmonization may increase welfare.

Our model supports harmonization, but does so in a rather heretical manner. "Harmonization upward" benefits the environment and improves global welfare, even if there is

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[3] The arguments for and against harmonization are presented in many articles, including: Agras et al (1994); Bhagwati (1996); Bhagwati and Srinivasan (1996); Charnovitz (1993); Hoel (1993); Levinson (1996); Klevorick (1996); Marchant and Ballenger (1994); Nordhaus (1994); Rauscher (1994); Robertson (1992); Ulph (194); Wilson (1996). Krugman (1997) summarizes many of these arguments.

no danger of a race to the bottom. In the short run, "harmonization downward" also increases aggregate welfare. However, the two types of harmonization have different distributional effects. Our model emphasizes the importance of relative (rather than absolute) levels of market failure. Even here harmonization upward is likely to be better than harmonization downward when we include dynamic considerations or uncertainty.

An international dimension of environmental policy is usually associated with transboundary environmental problems. For these problems, there is widespread agreement that international cooperation is important. However, international trade causes "purely local" (in the physical sense) environmental problems in one country to affect those in another.[4] Local environmental distortions affect world prices. These prices influence producers and consumers and thus affect environmental problems in other countries. For transboundary environmental problems, the international dimension to policy is obvious and exists with or without international trade. For local environmental problems, trade *creates* the international policy dimension. We consider only local environmental problems, since the role for international environmental policy is probably less obvious, but no less important, for these.

Section 2 describes the autarkic and trade equilibria. This model was sketched by Chichiliniski (1994) and elaborated by KSZ (1997), who used it to compare welfare under autarky and trade, taking environmental policy as given. We use the model to show the different effects of policy reform under autarky and trade. Section 3 compares the static effects of reform

[4] This observation obviously applies to most "local" issues (e.g. labor standards). The recognition that trade causes "everything to be connected to everything" makes some economists reluctant to even consider the international dimension of such problems. They fear opening the floodgates to claims for trade protection. This response makes the profession irrelevant to many important policy questions.

in the two regimes, and Section 4 compares the dynamic effects. Section 5 discusses the generality of our model and summarizes our conclusions.

2. The Autarkic and Trade Equilibria

We describe the model and summarize the characteristics of the autarkic and trade equilibria which are important for our results concerning the effects of reform. Appendix A contains the algebraic details.

2.1 Description of the Model. Figure 1 is a flow chart of the economy, which produces two goods: the "subsistence good" A, which we choose as the numeraire, and the "composite good" B, which has price p. 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^*. This assumption, which requires that the environmental stock is sufficiently large, simplifies calculations but is not essential.

The two factors of production are labor, L, the supply of which is exogenously fixed, and environmental services, E, the supply of which changes endogenously over time. Competitive producers combine these factors, using Leontief technology, to produce goods A and B. Good B, in addition to being consumed, is used in conjunction with the current environmental stock, Z, to produce environmental services E. The stock of Z is fixed at a point in time; larger stocks

decrease the costs of producing E. The change in the environmental stock over time depends on the current environmental stock and the flow of environmental services.

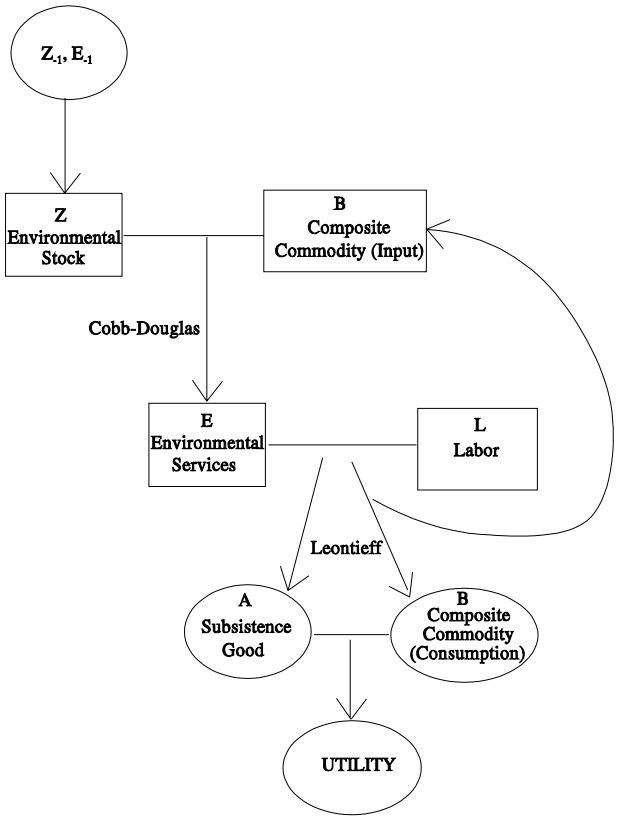

Figure 1: Flow Chart of the Economy

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 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 useable water.

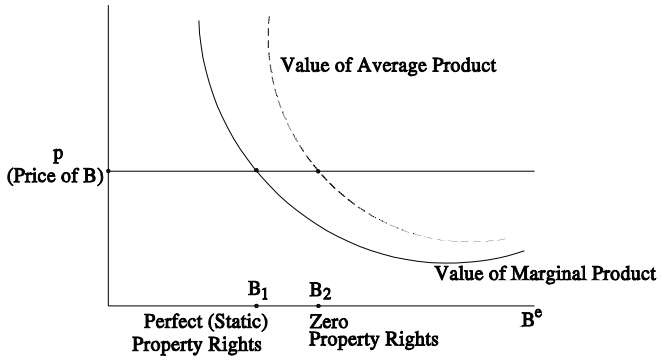

Figure 2: The Environmental Distortion

We assume that there are decreasing returns to scale in the environmental extraction sector, and we denote the aggregate amount of B used in that sector as B^e. Figure 2 graphs the value of B's average and marginal product for a given level of the stock of Z and a given price of output E. An increase in the environmental distortion increases the gap between the price of the input B and its value of marginal product in equilibrium. *Static* efficiency (which ignores that both the future stock of Z and future extraction costs depend on current extraction) requires setting the value of the marginal product equal to p, using B_1 units of the input. This outcome occurs if there is no static distortion, e.g. if E-producers have perfect *static* property rights. At the other extreme, if there is free entry into the environmental sector and no property rights, the sector uses B_2 units of the input. In this case, all rent in the environmental sector is dissipated

and the distortion is maximized. Intermediate levels of the input correspond to distortions of different magnitudes.

The source of the distortion is unimportant for our results, but it is important that the distortion is greater in one country. At given prices and stock level, the supply of the environmental factor is greater in the country with the larger distortion. In order to obtain a specific functional form, we assume that there are a fixed number of E-producers who choose their input level and receive a share of output proportional to their share of total inputs. For the aggregate production function $E = (B^eZ)^{.5}$, when each producer takes prices and the decisions of others as given, the aggregate (Nash equilibrium) supply function is $E = \delta Z p^e/p$. Here p^e is the price of E and the (fixed) parameter δ is an increasing function of the number of E-producers, and therefore 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, $\delta = 1$; for perfect static property rights, $\delta = .5$.

The supply of E depends on δZ, which we define as "apparent stock", to distinguish it from the physical stock, Z. A larger environmental distortion (larger δ) implies a larger apparent stock, and a larger supply of the factor E, for given Z and prices. Provided that the initial value of δ exceeds .5, as we assume throughout the paper, a small reduction of δ necessarily increases efficiency (for given Z and price), in addition to reducing the current supply of E.

There are two economies, North and South, which are identical except for their values of δ and (possibly) their stock levels. We assume that $\delta_S > \delta_N$, where subscripts represent the specific economies, 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: Environmental reform *in country i means a reduction in* δ_i. Harmonization of environmental policies[5] *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".

2.2 Description of the Equilibria. The Leontief technology and fixed labor supply imply that there are two possibilities in both trade and autarky equilibria: either labor is fully employed, or some labor is unemployed. Appendix A gives the formulae for the price of B and extraction of E in the different equilibria. First, suppose that labor is fully employed under both trade and autarky.[6] Since the world production of A is $2A^*$ in both cases, we know the aggregate (world-wide) amount of L and E used in sector A. Given the assumption of full employment, we can calculate the amount of labor available for sector B. Due to Leontief technology, we then know the aggregate amount of E used in sector B. Thus, we find the aggregate amount of E used by the world. This amount is the same under free trade and autarky, and due to the structure of our

[5] The magnitude of the distortion may depend on institutions (e.g., those which affect property rights) rather than government policies. In that case, harmonization means that the institutions become more similar.

[6] If labor is fully employed in one country, its price is positive. Under trade and with the assumption of factor price equalization, labor must also have a positive price and be fully employed in the other country. Under autarky, labor might be fully employed in one country and unemployed in the other.

model, is independent of the values of δ_i. However, the amount of extraction in each country does depend on δ_i.

Now consider the case where labor is unemployed in both countries, in autarky. In this case, 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. Thus, the aggregate supply of E is the same under free trade and autarky. However, both the aggregate and individual country supplies of E now increase in δ_i: Looser property rights lead to more extraction, which reduces unemployment

In autarky, labor is fully employed in country i if and only if the apparent stock, $\delta_i Z_i$, is sufficiently large, i.e. if and only if Z_i exceeds a critical value, which we denote as $Z^c(\delta_i)$. This result is intuitive. Labor is fully employed if and only if there is sufficient E, and the supply of E depends on $\delta_i Z_i$. Similarly, with trade, labor is fully employed if and only if the world supply of E is sufficiently large, which in turn requires that world aggregate apparent stocks, $\psi \equiv \delta_S Z_S + \delta_N Z_N$, exceed a critical level, which we denote ψ^c.

Under autarky, loose property rights lead to excessive extraction and welfare loss only when 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, in our model property rights always matter in trade, a result which is consistent with the concern that trade makes market imperfections more important.

The remaining two possibilities are: (i) labor is fully employed under free trade ($\psi > \psi^c$) but unemployed in one country under autarky ($Z_i < Z^c(\delta_i)$ for one country); or (ii) labor is

unemployed under free trade ($\psi < \psi^c$) but fully employed in one country under autarky ($Z_i > Z^c(\delta_i)$ for one country). Figure 3 shows the regions of (Z_S,Z_N) space where the various possibilities occur.[7] 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 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.

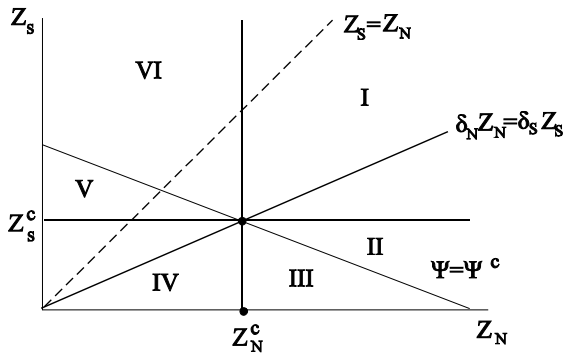

Figure 3: Regions of State Space

In region I, from the Heckscher-Ohlin-Samuelson theorem, and the assumption that the stock of L is the same in both countries, we know that the country with the larger supply of E exports the resource intensive good. Since supply of E_i is proportional to i's apparent stocks (recall that $E_i = \delta_i Z_i p^e/p$), a country's share of world supply of E equals its share of world

[7] Near the axes one country is specialized, and our description is no longer correct. Thus 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.

apparent stocks. The country with the larger apparent stock of resource exports the resource intensive good. For stock combinations below the No-Trade-Line (NTL) defined by $\delta_N Z_N = \delta_S Z_S$, North exports the resource intensive good. For stock combinations in the intersection of region I and the cone formed by the NTL and the 45^o 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.

3. Static Effects of Reform

We first consider the instantaneous welfare effects of environmental reform under autarky, and then under free trade. Welfare is measured by the amount of B that is available for consumption, since consumption of A is fixed at A*. Consumption of B equals production minus the amount of B used in extracting E and net exports (under trade).

3.1 Static Effects of Reform under Autarky. The situation under autarky is straightforward; here we drop the country subscript. We noted in the previous section that for $Z > Z^c(\delta)$, where labor is fully employed, the equilibrium supply of E (and thus production and consumption of B) is independent of δ. Thus, for $Z > Z^c$ environmental reform has no effect on static welfare under autarky.

For $Z < Z^c$, however, domestic welfare *and unemployment* are decreasing in δ. When labor is unemployed its price is zero, and national income equals rents in the E-producing sector, $p^eE(Z,B^e) - pB^e$. A larger value of δ implies a larger gap between the value of marginal product and price, and thus lower rents and lower welfare. An increase in δ also raises the apparent

resource stock, resulting in larger extraction of E, which requires that more labor is used to produce the input B.

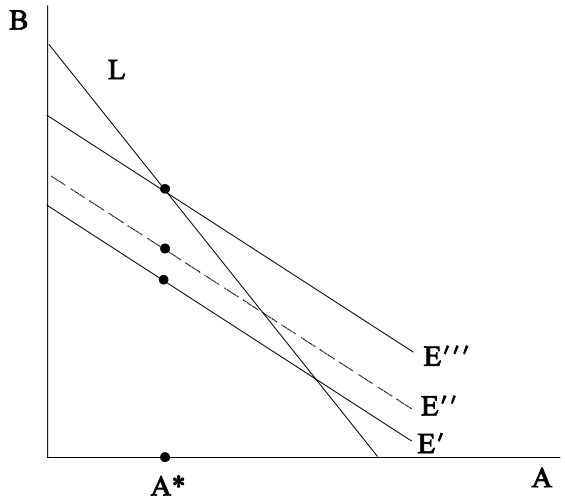

Figure 4: Effect of δ and Z on Output

Figure 4 illustrates the effects of changing δ for different values of Z, under the assumption that the stock is large enough for the country to be able to consume A^*. The line labeled L shows production pairs consistent with full employment of labor. The lines E′, E′′ and E′′′ are graphs of the environmental constraint for different values of E. The relative slopes of the lines imply that good B uses E intensively, but this assumption has no bearing on the results. If $Z \geq Z^c$, the equilibrium level of E must equal E′′′, with full employment of both factors and production of A^*. In this case a change in δ does not alter the level of E. For example, if the level of E were to rise following an increase in δ, maintaining production of A^* requires unemployment of E, and thus $p^e = 0$. In that case, however, no E would be produced, so this could not be an equilibrium.

If, however, $Z < Z^c$, the equilibrium level of E is at a level such as E′, with some labor unemployed and production of A^*. If δ increases, the supply of E increases to E′′, and

production of B increases. However, the increased supply of E requires higher input use, B^e. Since the value of the marginal product of B was already below its price, the increase in B^e must exceed the increased production of B. Thus, the amount of B available for consumption, and hence welfare, decreases. The increase of E from E′ to E′′ shifts the equilibrium closer to the full employment line L, and therefore decreases unemployment.

In this model, environmental reform has no static welfare effect when the environmental stock is large, but improves welfare when the environmental stock is small. This conclusion implies that reform is most important when environmental stocks are small. An environmentally rich country (large Z) does not benefit much from reform in the short run. Reform does benefit an environmentally poor country, even in the short run.

The model also supports the widely held belief that environmental and employment goals sometimes conflict.[8] When environmental stocks are low, greater environmental protection improves static welfare but increases unemployment. Governments which are more concerned with employment than with national income may be reluctant to adopt stricter environmental standards.

3.2 Static Effects of Reform under Free Trade. We saw that for stocks in region IV, autarky and free trade are equivalent. In this region, the benefits of environmental reform are also the same under trade and autarky. That is, domestic reform raises domestic welfare and unemployment, without affecting the other country.

We now show that in region I aggregate welfare depends only on the relative distortions, but the distribution of welfare also depends on absolute levels of the distortions. We noted that

[8] See OECD (1997) for a thorough discussion of environmental policies and employment.

in region I with trade, aggregate supply of the factor E is independent of δ_i, but each country's share of that factor is equal to its share of aggregate apparent stocks. Environmental reform in country i decreases its share of world apparent stocks, causing production of E to shift to the other country. Given that the world supply of E is independent of δ_S and δ_N, as is the world supply of A (= $2A^*$), the supply of B must also be independent of δ_i. However, since each country's share of aggregate E depends on the δ's, the amount of B used to produce E, $B_S^e + B_N^e$, also depends on the δ's. Therefore the aggregate *consumption of B* (= production of B - B_S^e - B_N^e), which measures world welfare, depends on the δ's. Reform in North shifts production of E to South, where the marginal value of product is already lower (because $\delta_S > \delta_N$). This reform therefore decreases the amount of B available for consumption, and lowers world welfare. Reform in South increases world welfare.[9]

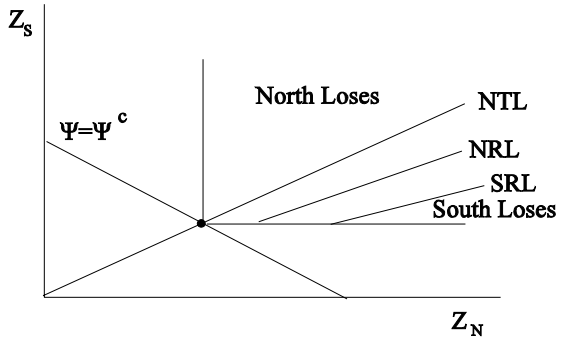

Figure 5: Country Effects of Reform in South

[9] Appendix E of KSZ (1997) shows that the total world amount of B used to extract the fixed amount of E increases in δ_S/δ_N, for $\delta_S > \delta_N$.

The effect of reform on individual countries' welfare is more complicated, because reform causes a change in the terms of trade in addition to a reallocation of production of E. In Appendix B.1 we show that if $\delta_S > 3/4$, South always benefits from domestic reform when stocks are in region I.[10] There is a line from the origin with slope $dZ_S/dZ_N = (3 - 4\delta_S)\delta_N/\delta_S$, lying below the No Trade Line (NTL), which we refer to as the Southern Regret Line (SRL) (Figure 5). For stocks below the SRL, South loses from domestic reform, and for stocks above that line, South benefits from reform. Reform in South causes a reduction in its supply of E. In order for North's supply to increase (noting that the total supply of E is fixed), the equilibrium p^e/p must increase. By the Stolper-Samuelson theorem, and our assumption that good B is E-intensive, p must increase. Above the NTL, where South exports B, the increase in p is an improvement in South's terms of trade, which reinforces the beneficial effect of reducing the market imperfection. For stocks below the NTL, where South imports B, the increase in p is a deterioration in South's terms of trade. If South is a sufficiently large importer of B, i.e. if stocks are sufficiently far below the NTL (more precisely, below the SRL), the deterioration in South's terms of trade more than offsets the direct benefit of reducing South's gap between the value of marginal product and price in the E-sector. In this situation, South is harmed by its reform.

Figure 5 also shows a line from the origin with slope $dZ_S/dZ_N = (3 - 4\delta_N)\delta_N/\delta_S$, labeled the Northern Regret Line (NRL), lying between the NTL and the SRL. For stocks above this line, North loses from Southern reform, and for stocks below the line, North benefits. Southern reform: (i) increases p and (ii) causes production of E to shift to the North, increasing the gap

[10] The analysis of regions II, III, V and VI yields no additional insight, so for the sake of brevity we ignore these.

between the value of marginal product and p in North's E-sector. The second effect always harms North, and the first benefits North only if North exports B. Thus, North benefits from Southern reform only if North is a sufficiently large exporter of B, which requires that stocks lie below the NRL. In order for both countries to benefit from Southern reform, stocks must lie in the region between the NRL and the SRL.

The analysis of reform in North is similar. North always benefits from its reform unless it is a sufficiently large importer of B; South always loses unless it is a sufficiently large exporter of B.

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. In order to maintain the same level of extraction, the price of the resource intensive good (B, in our example) must rise. Equal-proportionate reform thus benefits exporters of the environmentally intensive good and harms importers. 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."

3.3 Discussion of Static Effects. 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.[11] *(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 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.* ●

These results illustrate the importance of the trade regime in designing environmental reform. The lack of substitutability in our model emphasizes the role of relative rather than absolute distortions in the trade equilibrium. Harmonization improves world welfare: a race to the bottom can be as beneficial as a race to the top. Reform in North, without harmonization, lowers welfare. In a more general model (with substitutability) both relative and absolute levels of distortions would be important. In such a model, downward harmonization (or reform in North without harmonization) would produce two offsetting effects. Our model eliminates one of these effects; it identifies - and exaggerates - the importance of relative distortions.

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

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[11] 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 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.

unimportant. For these high stock levels, the absolute levels of the distortions remain unimportant in the trade equilibrium. Therefore, the effect of proportional reform in both countries is roughly the same under trade and autarky. However, under trade, relative distortions are important even for large environmental stocks. Reform with harmonization produces large welfare gains, but reform without harmonization may have negative effects on welfare.

If the level of the stocks is uncertain, upward harmonization may be strictly better than downward harmonization. For stocks in region I, harmonization upward and downward have the same effect on aggregate consumption. For stocks in region IV, harmonization upward benefits South and has no effect on North, while harmonization downward harms North and has no effect on South. If stock levels are uncertain and there is a positive probability that stocks are in region IV, expected world welfare increases more from upward than from downward harmonization.

4. Dynamic Effects of Policy Reform

We now turn to a dynamic model in order to study the effects of reform on environmental stocks, and thus on long-run welfare. We use the logistic growth function for the stock: $dZ_i/dt \equiv \dot{Z}_i = \eta Z_i - \gamma Z_i^2 - E_i$. The parameter γ measures the congestion effect in growth; $\gamma > 0$ 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 level of E_i is the amount of extraction at a point in time. As we previously discussed, in autarky the equilibrium E_i is an increasing function of $\delta_i Z_i$ for $Z_i < Z_i^c(\delta_i)$

and constant for $Z_i > Z_i^c(\delta_i)$. With free trade, the equilibrium E_i is an increasing function of $\delta_i Z_i$ for $\psi < \psi^c$ and an increasing function of $\delta_i Z_i/(\delta_i Z_i + \delta_j Z_j)$ for $\psi > \psi^c$.[12] Under both autarky and free trade there are two dynamic regimes, depending on whether labor is fully employed.

Figures 6 and 7 show three possible dynamic portraits for autarky and trade. Figure 6 shows the graphs of $\dot{Z}$ under autarky. Figure 7 shows the phase portraits under free trade. The qualitative dynamics, under both trade and autarky, depend on the magnitude of η. There are four critical values of this parameter, $\hat{\eta}^a$ and η^{*a} for autarky, and $\hat{\eta}$ and η^* for free trade. The three possible dynamic regimes under autarky are (Figure 6): (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 with unemployed labor, a high stable steady state with full employment (Z_h), and an intermediate unstable steady state (Z_u); (c) For $\eta^{*a} < \eta$ there is a unique high stable steady state with full employment. The three cases under free trade (Figure 7) are similar, although the critical values of η are different. The low stable steady state under trade, $\mathbf{Z_l} \equiv (Z_{Nl}, Z_{Sl})$, has unemployment in both countries, and the high stable steady state, $\mathbf{Z_h} \equiv (Z_{Nh}, Z_{Sh})$, has full employment. The unstable steady state is $\mathbf{Z_u}$.

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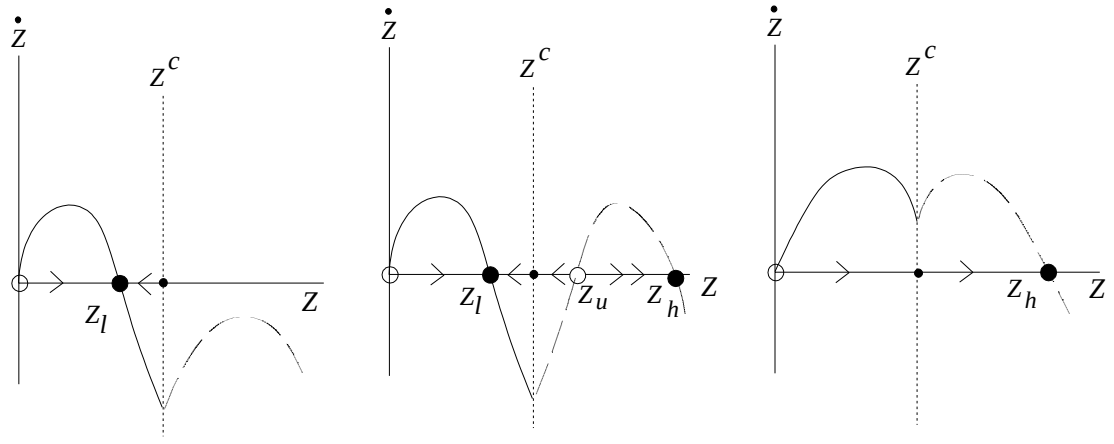
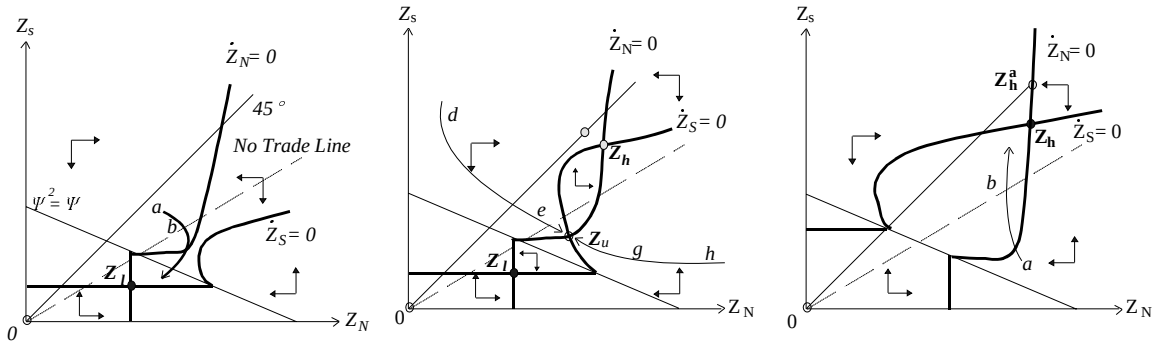
[12] The dynamic equilibrium is a sequence of the static equilibria studied in the previous sections. In section 2 we noted that the relative magnitude but not the source of the distortion is important in our model. We explained that the supply function $E = \delta Z p^e/p$ can be derived as a Nash equilibrium 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. would shift out the function $\Delta(Z)$. Therefore, we expect that the introduction of forward looking agents would not alter our qualitative results.



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

Figure 6: Autarkic Dynamics for Different η



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

Figure 7: Free Trade Dynamics for Different η

We study the dynamic effect of reform by examining the steady state effect of a non-marginal decrease in δ_i. A marginal change in δ_i could cause a non-marginal change in steady state only for "knife-edge" cases, where η or the initial value of **Z** was at a critical level. We are able to study the effect of non-marginal changes in δ_i using comparative statics because the important endogenous functions are monotonic in δ. When we say that reform has a "qualitative effect" we mean that it has the potential to change the characteristics of stock dynamics. For example, reform might change the dynamic representation from Figure 6a to 6b (or from 7a to 7b). In order for a qualitative change to occur, reform must change the critical values $\hat{\eta}^a$ ($\hat{\eta}$) and/or η^{a*} (η^*) by a large enough amount that their position relative to the fixed value of η changes. When we say that reform has only a "quantitative effect" we mean that it alters the position of steady states, but does not change the representation of stock dynamics. In this case, reform does not change the critical values of η by enough to alter their position relative to the fixed parameter η.

4.1 Dynamic Effects of Reform under Autarky. The dynamic effect of reform in autarky is straightforward. The comparative statics of critical values (derived in Appendix B.2) are

$$(a)\ \frac{d\hat{\eta}^a}{d\delta} = 0;\ (b)\ \frac{d\eta^{*a}}{d\delta} > 0;\ (c)\ \frac{dZ^c}{d\delta} < 0;$$
$$(d)\ \frac{dZ_u}{d\delta} = 0 = \frac{dZ_h}{d\delta};\ (e)\ \frac{dZ_l}{d\delta} < 0;\ (f)\ \frac{d(\delta Z_l)}{d\delta} < 0 \quad . \qquad \textbf{(1)}$$

Equation (1) has several implications for environmental reform under autarky. We noted in Section 3 that for $Z < Z^c$, reform increases both instantaneous welfare and unemployment and decreases the flow of environmental extraction. In the short run, environmental and welfare

objectives conflict with employment objectives. From (1f), in the long run these goals are compatible, even if the economy reaches a low steady state with unemployment.[13] In the long run, environmental reform allows the environment to improve sufficiently that employment is higher despite tighter regulations. A government's enthusiasm for reform depends on its short-run tradeoff between national welfare (and the environment) and employment, and also on its discount rate.

Reform can also cause qualitative dynamic changes. There are three cases.

Case I: If $\eta < \hat{\eta}^a$, decreasing δ has no qualitative effect (from Equation (1a)). The economy always reaches a low steady state with unemployment. Reform has only the quantitative effects described in the previous paragraph.

Case II: If $\eta > \eta^{*a}$, reform has neither a (long run) qualitative nor a quantitative effect (from Equation (1b)). The only effect of reform is that for $Z < Z^c$, 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 6b continues to represent the dynamics, then the effect of reform depends on the initial condition, Z_o. When $Z_o < Z_u$ (which is independent of δ), reform has the quantitative effect described in Case I. When $Z_o > Z_u$, reform has no effect, as in Case II (with $Z_o > Z^c$). If the reform is sufficiently large, the post-reform dynamics are described by Figure 6c. In that situation, reform causes a qualitative change even for small initial stocks

[13]The increase in δZ_l caused by the decrease in δ results in an increase in the steady state supply of E. In terms of Figure 4, reform causes the E constraint to shift up, leading to less unemployment.

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:

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 results in a quantitative increase in long-run welfare and employment. Here, long-run welfare and employment goals are consistent; (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 can either increase or eliminate the low steady state, thereby decreasing or eliminating unemployment and improving welfare in the steady state.*●

4.2 Dynamic Effects of Reform Under Free Trade. We now consider the long run effect of reform in the free-trade equilibrium. Reform in country i has the same effect on the low steady state $\mathbf{Z_l}$ as under autarky: Z_{il} and $\delta_{il}Z_i$ increase, and Z_{jl}, $j \neq i$, is unchanged. A reduction in δ_i has indeterminate effects on the high steady state $\mathbf{Z_h}$. The only possibility that we can exclude is that reform in North decreases Z_{Nh} and increases Z_{Sh}.[14]

[14] 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 7 to shift down (for $\psi > \psi^c$), we can not rule out other possibilities.

The qualitative changes in the phase portrait are more interesting. Harmonization reduces the critical value of $\hat{\eta}$ (appendix B.3), i.e.:

$$\frac{d\hat{\eta}}{d(\delta_S/\delta_N)} > 0 . \qquad \textbf{(2)}$$

The critical value $\hat{\eta}$ depends only on relative property rights (relative distortions), measured by δ_S/δ_N. Harmonization of policies, achieved by either an improvement in Southern standards, or an equal-proportionate 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 $\mathbf{Z_l}$, where the environmental stock is low and there is unemployment. Harmonization may cause η to exceed the post-reform critical $\hat{\eta}$, thereby creating a high steady state. (The phase portrait changes from Figure 7a to 7b.) If the initial stocks, $\mathbf{Z_o}$, 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 instantaneous welfare losses (Remark 1).

Conversely, unilateral reform in North, which represents a movement away from harmonization, could cause η to fall below $\hat{\eta}$. Suppose, for example, that pre-reform $\eta > \hat{\eta}$ and $\mathbf{Z_o}$ lies above the convergent saddle path through $\mathbf{Z_u}$, so that the economy is moving toward $\mathbf{Z_h}$. If after Northern reform, $\eta < \hat{\eta}$, the economy approaches the low steady state $\mathbf{Z_l}$. 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 initial condition satisfies $\psi_o < \psi^c$ (low environmental stocks), the economies remain trapped at a low steady state even if harmonization changes the dynamics from Figure 7a to 7b.

Any initial condition $\mathbf{Z_o}$ that satisfies $\psi_o < \psi^c$ necessarily lies below the convergent saddle path through the unstable steady state (see Figure 7b). Equilibrium trajectories for initial conditions $\psi_o < \psi^c$ converge to the low steady state. The fact that the high steady state comes into existence is irrelevant (given sufficiently low initial conditions). 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.

The critical value η^* (above which only a high steady state exists) depends on both the relative and absolute values of δ_i; we noted that the critical value of $\hat{\eta}$ depends only on relative values. Reform in South decreases both the absolute distortion in South and its distortion relative to North. Consequently, $d\eta^*/d\delta_S > 0$ (Appendix B.4). Southern reform may cause the phase portrait to change from Figure 7b to 7c. In that case, if the economies were trapped at a low steady state, reform would cause them to move to a high steady state with full employment.

Northern reform increases the relative distortions but decreases an absolute distortion. The effect of Northern reform on η^* depends on which of those influences is stronger. This comparison depends on the severity of the environmental problem and the initial difference between δ_S and δ_N. We define the index $g \equiv \gamma a_2 \psi^c$ 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, defined in Appendix A, 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 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 δ_S^*, with $\delta_N < \delta_S^* < 1$ (Appendix B.4):

$$\frac{d\eta^*}{d\delta_N} \quad \begin{pmatrix} > 0 \quad \text{if } g < g^* \\ > 0 \quad \text{if } g > g^* \quad \text{and} \quad \delta_S < \delta_S^* \\ < 0 \quad \text{if } g > g^* \quad \text{and} \quad \delta_S > \delta_S^* \end{pmatrix} \qquad \textbf{(3)}$$

Equation (3) states that if the environmental problem is not "very 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 "very 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^*.[15] 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 certainly decreases η^*, but downward harmonization may increase η^*, creates a strong presumption in favor of upward rather than downward harmonization.

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

Remark 3 summarizes the implications of equations (2) and (3). When we say that an outcome is "less likely", we mean that the range 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 7a represents the dynamics), and more likely that there will be a unique high steady state (Figure 7c), 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 7a). Northern reform may raise* η^**, making it less likely that there will be a unique high steady state (Figure 7c), again leading to qualitative welfare and employment losses. (iii) Northern reform reduces* η^**, if: (a) the environmental problem is not too severe or (b) the initial difference between North and South is not too great. In this case, Northern reform makes it more likely that there will be a unique high steady state (Figure 7c), leading to qualitative welfare and employment gains.* ●

4.3 Comparison of Results Comparison of Remarks 3 and 1 shows 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. Upgrading Southern standards is a better option only if the level of environmental stocks is uncertain (with a positive probability that stocks are in the region where trade does not matter) or if distributional issues are important.

For the dynamic analysis, on the other hand, absolute as well as relative levels of standards are important. Consideration of long run effects creates an additional reason for preferring upward rather than downward harmonization. In the long run, reform affects environmental stocks. Harmonization upwards is more likely than harmonization downwards to cause a qualitative improvement in environmental dynamics and an increase in long run stocks, and consequently welfare.

Comparison of Remarks 3 and 2 shows 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. This result illustrates the importance of the trade regime in determining the effect of Southern environmental reform.

In a closed economy, reform always reduces the critical value η^{*a}, above which only a high steady state exists. Therefore, if an autarkic economy has both the danger of going to a low steady state and the possibility of reaching a high steady state, reform might ensure that the economy reaches the high steady state. With open economies, reform in the more distorted economy reduces η^*; reform in the less distorted economy 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. This result illustrates the importance of the trade regime in determining the effect of Northern environmental reform.

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, under either trade or autarky, environmental reform either decreases or eliminates it.

5. Discussion and Conclusion

Since our model is not completely standard, it is worth discussing the plausibility of its assumptions, and the bearing these have on our results. We assume that there is no substitutability in consumption, or in production of the final goods A and B. Neither of these assumptions is "realistic", although (arguably) they may be more realistic than those which are often invoked in models that require analytic solutions (e.g. constant expenditure or factor shares). Agents' preferences imply that the income elasticity of the subsistence good falls at high income. The assumption of Leontief technology is familiar.

The assumptions have a powerful implication: they result in two regimes and the possibility of multiple stable steady states under both autarky and free trade. When environmental stocks are low, supply of the fixed factor (labor) does not constrain production, and the environmental distortion lowers welfare by attracting too many resources into the environmental sector. When environmental stocks are high, the fixed factor is fully employed

and the environmental distortion is irrelevant under autarky. With high stocks, preferences and technology rather than the extent of market failure determine resource allocation. A concave growth function (logistic in our model), combined with two extraction regimes, leads to the possibility of multiple steady states.

The idea that market failures related to the environment are especially important when the environmental stock is low seems eminently sensible. The discontinuity in regimes (*but not in production and consumption decisions*) at a critical stock level is unrealistic, but also unimportant to our results. We could "smooth the kinks" in the indirect utility function and in the production possibility frontier, i.e. perturb the model by adding substitutability. This perturbation would cause the two regimes to "blend" (merge smoothly) at the critical stock level, while retaining the feature that the distortion is more damaging when stocks are low.

The perturbation would retain the possibility of multiple stable steady states, which drives our results on the long-run effects of environmental reform. The existence of two regimes means that extraction is an increasing function of stocks below a critical level, and constant for stocks above this level. The precise relation between flows and stocks is unimportant, but it is important (and plausible) that the elasticity of extraction with respect to stocks is a decreasing function of stocks. The perturbation we proposed retains this feature of the elasticity of extraction. Thus, even with the perturbation, multiple stable steady states can arise, which in turn means that environmental reform can have dramatic effects on the trajectory of an economy and on the long-run welfare.

Our model implies that in the short run trade equilibrium, both upward and downward harmonization improve welfare when stocks are high. In the long run, upward harmonization is more likely to increase (qualitatively) welfare and employment.

In the short run, if world environmental stocks are low, a country improves its welfare by unilateral reform. Reform is important but harmonization is irrelevant. If environmental stocks are high, harmonization increases efficiency. However, it does not matter if harmonization is achieved by relaxing standards where they are tight, or strengthening them where they are loose. Here, harmonization is beneficial but reform may be irrelevant (when it occurs in both countries) or harmful (when it occurs in the country with the stricter standards). Harmonization decreases the discrepancy between real and apparent comparative advantages. To the extent that trade is driven by differences in environmental standards, and thus by apparent as opposed to real comparative advantage, harmonization can improve welfare even if it involves lowering standards in one country.

This striking relation between stock levels and the differing importance of reform and harmonization in open economies is due to the assumptions of substitutability discussed above. If we "smoothed" the model by allowing substitutability, absolute as well as relative distortions would affect efficiency at both high and low stock levels. There would be preference for upward harmonization even in the short run.

Even without substitutability, absolute levels of distortion can be important, leading to arguments that favor upward rather than downward harmonization. First, absolute levels have significant distributional effects. Second, if there is uncertainty about the true level of environmental stocks, upward harmonization is more likely to produce efficiency gains.

Our dynamic analysis provides an even more important reason for preferring upward to downward harmonization. Non-negligible changes in policies can have dramatic effects in economies with multiple equilibria. Upward harmonization increases the chance of arriving at a high steady state. Downward harmonization, despite the fact that it may have identical instantaneous (efficiency) effects, can reduce the chance of arriving at a high steady state. In the long run, absolute as well as relative levels matter, and as environmentalists claim, upward harmonization is generally better than downward harmonization.

Increasingly open markets require that environmentalists adopt a global perspective, even for local pollution problems. It is also important to weigh the benefits of investing political resources to promote reform in different countries. Even if absolute levels of distortions were more important than relative levels (so that reform anywhere improves welfare), it is still likely that reform in the most highly distorted economies will produce larger benefits. Reform in those countries decreases both absolute distortions and differences in distortions. This conclusion has an tinge of "environmental imperialism". Developing countries sometimes advise environmentalists to put their own house in order before attempting to export environmental reform. This is bad advice, especially from the standpoint that developing nations are likely to have relatively serious environmental distortions.

We also used our model to describe the tension between the goals of decreasing unemployment and of improving welfare and the environment. As "jobs first" activists claim, raising environmental standards increases unemployment, when unemployment is initially positive. However, as environmentalists claim, in the long run improving environmental standards increases employment. Thus, it would be more accurate to describe the anti-environmentalist camp as "jobs *now* first".

Appendix A: Model Details

Goods *A* and *B* are produced using environmental service *E* and labor *L* with Leontief technologies: $A^p = \min\left\{\frac{E_A}{a_1}, \frac{L_A}{b_1}\right\}$ and $B^p = \min\left\{\frac{E_B}{a_2}, \frac{L_B}{b_2}\right\}$. The constant supply of labor is $\bar{L}$.

There are two autarky equilibria depending on whether labor is fully employed. With full employment, the price of *B* is $\frac{b_2^2\psi^a}{b_1 b_2\psi^a - \phi D}$, where $\Psi^a = \delta Z$ (Equation (4) of KSZ), 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 $\frac{\delta Z}{a_2}$ (Equation (6) of KSZ).

Similarly, there are two free trade equilibria. When labor is fully employed, world price of B is $\frac{b_2^2\psi}{b_1 b_2\psi - 2\phi D}$ (Equation (9) in KSZ), and the amount of resource extracted in country *i* is $E_i^p = \frac{2\delta_i Z_i \phi}{b_2\psi}$. (Equation (10) in KSZ). With unemployment, the world price and extraction are the same as under autarky.

Appendix B: Derivations

Appendix B.1: Southern and Northern Regret Lines (SRL and NRL)

The autarky welfare of country $i = \{N, S\}$ is $W_i^a = B_i^{pa} - B_i^{ea}$, where B_i^{pa} is the autarky output of *B* and B_i^{ea} is the amount of *B* used in extraction. The free-trade social welfare is $W_i = B_i^d - B_i^e$, where B_i^d is the domestic supply of *B* (total production net of export). The gain from trade for country *i* is $G_i = W_i - W_i^a$. Since W_i^a is independent of the property rights, the impacts of reform on a country's welfare equals its impacts on the gain from trade, G_i.

Appendix D of KSZ shows that $G_S = \frac{\phi^2[\delta_S Z_S - \delta_N Z_N][(2-3\delta_S)Z_S - \delta_N Z_N]}{b_2^2 Z_S \psi^2}$. Substituting $\delta_S = \beta\delta_N$ into G_S, and taking derivative with respect to β, we get $\frac{dG_S}{d(\delta_S/\delta_N)} \propto (3 - 4\delta_S)\delta_N Z_N - \delta_S Z_S$.

Thus South gains from its reform when $\frac{Z_S}{Z_N} > (3 - 4\delta_S)\frac{\delta_N}{\delta_S}$, that is, when (Z_N, Z_S) is above the Southern Regret Line. Note that South always gains from its reform if $\delta_S > 3/4$. We can identify the Northern Regret Line in a similar fashion.

Appendix B.2: Equation (1)

The geometric proof of equation (1) is based on the facts that $\dot{Z}$ is independent of δ for $Z > Z^c$ and $\dot{Z}$ is decreasing in δ for $Z < Z^c$ (see Section 2.2). In terms of Figure 6, the positions of

the dashed curves are independent of δ, and the solid curves are lower for higher δ. To verify (1a), suppose that $\eta = \hat{\eta}^a$, so that the dashed curve is tangent to the horizontal axis. Since a change in δ does not alter the position of this curve, there remains a single (low) steady state (even after δ has changed), which implies (1a). To verify (1b), suppose that $\eta = \eta^{*a}$, so that the two curves in figure 6 intersect on the horizontal axis (at Z^c). Since an increase in δ shifts down the solid curve without altering the position of the dashed curve, the curves must now intersect below the horizontal axis. Hence, there are two stable steady states, so after the increase in δ, η lies below the critical η^{*a}, implying equation (1b). Equation (1c) is obvious: a worse environmental distortion makes it more likely that labor will be fully employed for given Z, and thus decreases Z^c. To show this geometrically, we use the fact that an increase in δ shifts down the solid curves in figure 6, decreasing the point where the solid and dashed curves intersect. This intersection determines Z^c. The location of the unstable and high steady states (if they exist) are determined by the intersection(s) of the dashed curve with the Z axis. The dashed curve, and therefore the points of intersection, are independent of δ. The location of the low steady state (if it exists) is given by the intersection of the Z axis and the solid curve in Figure 6, which does depend on δ.

To verify (1f), note that 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 $\frac{d(\delta Z)}{d\delta} = \frac{1}{\gamma}(\eta - \frac{2\delta}{a_2})$. We can show that $\eta^{*a} < \frac{2\delta}{a_2}$ (Appendix H in KSZ), and since $\eta < \eta^{*a}$ whenever the low steady state exists, we know $\frac{d(\delta Z)}{d\delta} < 0$. That is, when a country improves its property rights (i.e. lowers its δ), its low steady-state apparent resource stock increases, and consequently steady-state employment increases.

Appendix B.3: Equation (2)

KSZ provide the formula $\hat{\eta} = \frac{2\sqrt{\delta_S^2+\delta_N^2}}{\delta_S+\delta_N}\sqrt{2\gamma\phi/b_2}$. It is then straightforward to derive Equation (2).

Appendix B.4 The signs of $\frac{d\eta^*}{d\delta_N}$ and $\frac{d\eta^*}{d\delta_S}$

KSZ show that $\eta^* = \frac{\delta_N^2+\delta_S^2+a_2\gamma\psi^c}{a_2(\delta_N+\delta_S)}$. Thus $\frac{d\eta^*}{d\delta_N} = Hf_N(\delta_S, \delta_N)$ 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 $f_S(\delta_S, \delta_N) = (\delta_S^2 + 2\delta_N\delta_S - \delta_N^2 - g)$. $\delta_S > \delta_N$ implies $f_N < f_S$, thus $\frac{d\eta^*}{d\delta_N} < \frac{d\eta^*}{d\delta_S}$.

We first show Equation (3). f_N is a quadratic function of δ_S, and we are concerned with its sign for the relevant range of δ_S, [δ_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 $g \leq g^*$, establishing the first part of Equation (3). This result is shown in Figure B.1.

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 the fact that $\eta^{*a} < \frac{2\delta}{a_2}$ (Appendix H in KSZ), 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 B.2, which also shows the definition of $\delta_S^* = \delta_{S2}$.

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 B.1 and B.2.

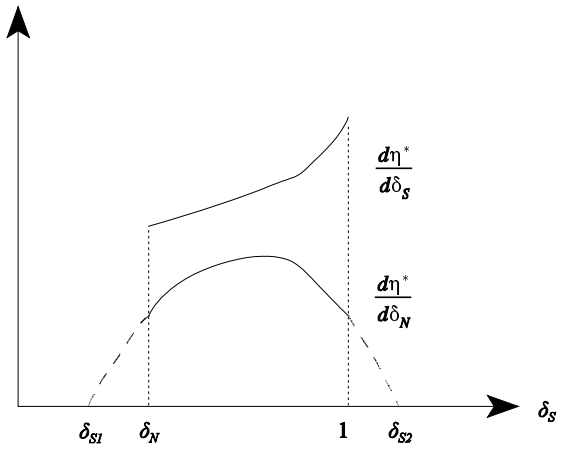


Figure B.1: Effects of reform: $g < g^*$

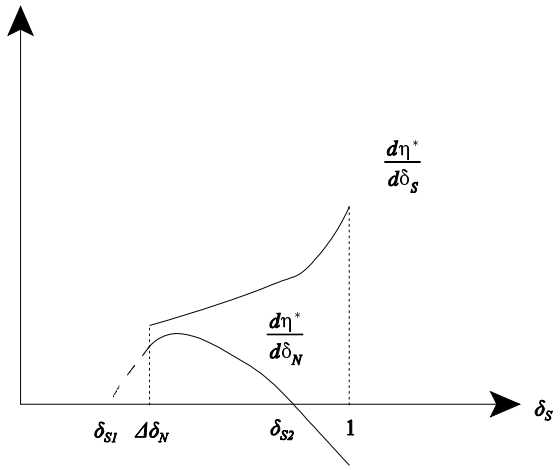


Figure B.2: Effects of reform: $g > g^*$

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