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TRADE, SPATIAL SEPARATION,
AND THE ENVIRONMENT

Brian R. Copeland
M. Scott Taylor

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ABSTRACT

We develop a simple two-sector dynamic model to examine the effects of international trade in the presence of pollution-created cross-sectoral production externalities. We assume that the production of "Smokestack" manufactures generates pollution, which lowers the productivity of an environmentally sensitive sector ("Farming"). As a result, the long run production set is non-convex. Pollution provides a motive for trade, since trade can spatially separate incompatible industries. Two identical, unregulated countries will gain from trade if the share of world income spent on Smokestack is *high*. In contrast, when the share of world income spent on the dirty good is *low*, trade can usher in a negatively reinforcing process of environmental degradation and real income loss for the exporter of Smokestack.

Brian R. Copeland
Department of Economics
997-1873 East Mall
University of British Columbia
Vancouver, BC V6T 1Z1
CANADA

M. Scott Taylor
Department of Economics
997-1873 East Mall
University of British Columbia
Vancouver, BC V6T 1Z1
CANADA
and NBER

I. INTRODUCTION

In the last few years economists and environmentalists have engaged in a lively debate over the possible effects of international trade on the environment. Perhaps one of the most serious limitations of much of the recent theoretical work is that it ignores the long run effects of industrial pollution on nature's stock of "environmental capital." [1] Most of the existing work assumes that pollution is harmful only because consumers suffer a disutility cost from pollution, but for many environmentalists this is a major weakness of the economic approach to trade and the environment.

If trade degrades a nation's stock of environmental capital then it also jeopardizes long run sustainability and lowers the "competitiveness" of environmentally sensitive industries. There is already ample empirical evidence linking the emissions of Smokestack industries to reduced fishing and agricultural yields, to negative effects on the value of standing forests, and to beach closures that hurt tourism. Current estimates of environmental damage suggest that such external effects are not neglible. Pearce and Warford (1993, p. 28) report damage estimates from a low of .5-.8% of GNP for the Netherlands, to 4.6-4.9% of GNP for Germany, to a high of 10% of GNP for Poland. Specific industry studies are also available.[2]

Despite the apparent link between the output of heavy industry and damage to

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[1] See Grossman and Krueger (1994) and Selden and Song (1994) for empirical work. For theory, see Baumol and Oates (1971), Markusen (1975,1976), Copeland and Taylor (1994,1995), and Rauscher (1991). Dean (1991) and Beghin et al (1994) are useful surveys of the trade and environment literature. Lopez (1994) and Smulders (1994) examine growth and environment issues.

[2] A recent comprehensive study of European Forests by the International Institute for Applied Systems concludes that sulphur emissions alone cost Europe $30 (thousand millions) per year in forest losses (for a review of this research see Carrier and Krippi (1990)). Other supporting evidence can be found in the U.N. Environmental Data Report (1993) and the FAO Fisheries Technical Paper No. 172 (1977), entitled "Economic Impact of the Effects of Pollution on the Coastal Fisheries of the Atlantic and Gulf of Mexico Regions of the US."

environmentally sensitive sectors, economists are often skeptical of the potential for international trade to play a key role in reinforcing or reversing current trends. In this paper we show that trade may in fact play a key role in determining environmental outcomes by spatially separating incompatible industries.

The intuition for many of our results is straightforward. If free trade leads a country to increase its output in heavy industries it may simultaneously lower the productivity in other environmentally sensitive sectors of the domestic economy. These negative cross-industry external effects work against the standard gains from international trade. For the world as a whole though, trade may play a useful role in concentrating heavy industry in one country. By separating incompatible industries, the world as a whole reaps productivity gains. International trade plays a key role in this process because the separation of industries across countries requires imports to make up the difference between the pattern of domestic consumption and production. Moreover, the terms of trade between dirty and clean products determines how the productivity gains created by spatial separation will be shared across countries.

We construct a very simple dynamic model to make transparent the role trade can play in separating incompatible industries. There are only two industries: a manufacturing industry which we refer to as Smokestack and denote by M, and an environmentally sensitive industry such as agriculture, fishing or forestry denoted by A. For simplicity we refer to A as Farming output, but it should be thought of as a generic output from any environmentally sensitive sector.

Smokestack emits pollution, and over time the flow of these pollutants degrades the nation's environment. Since we assume that the free flow of services from the environment are inputs into farming, a lower stock of environmental capital necessarily lowers the productivity of primary inputs in the farming sector. Throughout we assume that pollution stays within the country of origin, that there is no regulation of emissions from Smokestack, and that emissions do not create a direct utility cost to consumers. This simple framework isolates the impact of free trade when industrial pollution creates a negative cross-industry externality.

Within this framework we derive several surprising results. First, we show that opening a country to trade at world prices that are arbitrarily close to autarky prices can lead to a very large discrete change in environmental quality. As Baumol and Bradford (1972) showed, a country's long run production possibility set may be non-convex when there are cross-sectoral production externalities. With non-convexities in the production set, an open economy has a tendency to specialize in production, and there is the potential for a small price change to result in a large expansion of the pollution-intensive sector.

Second, we find that two identical countries can gain from trade. The standard explanation for trade between similar countries rests on the benefits of concentrating industries with increasing returns to scale. Here we find that the benefits of *separating* incompatible industries provides an alternative mechanism through which identical countries can gain from trade. As the environmental literature has pointed out [e.g. Helfand and Rubin (1994)], the presence of non-convexities suggests that policy in many cases should encourage environmental damage to be spatially concentrated: if one industry harms another, then one solution is to separate them. We find that such spatial separation must occur as a result of trade: because the production frontier is convex, the market will provide incentives for the two countries to specialize in production. Thus, in some cases, an efficient allocation of production across countries can occur without the need for any environmental policy.

Third, the welfare implications of trade are quite surprising. We find that if the share of world income spent on the dirty product is large, then free trade must be welfare-enhancing for two identical countries. Conversely, if the share of world income spent on clean products is large, then one of the two countries must lose from trade. Moreover, losses are more likely the faster is the environment's regeneration rate and the smaller is the negative externality!

Lastly, once we introduce non-identical countries we show that free trade can lock in the wrong (inefficient) pattern of specialization across countries. Trade can leave the country with the greatest assimilative capacity specialized in the clean good, while its trading partner produces all of the dirty good. Similarly, trade can leave the most populous country diversified in production, when production efficiency requires just the opposite.

This paper integrates two strands of the literature, one from environmental economics, and the other from international trade. Our model can be interpreted as an open economy and dynamic extension of Baumol and Bradford's (1972) model of pollution. It also bears a strong family resemblance to the open economy models that Melvin (1969), Panagariya (1981), and Ethier (1982) developed to analyze external economies of scale.

In the environment literature, it is well known that pollution externalities can lead to non-convexities in the production set [Baumol and Bradford (1972)]. While this result is well known, it has had relatively little impact on the mainstream of the environment literature. In part, this seemingly benign neglect has arisen because much of the relevant policy analysis has been carried out in a partial equilibrium framework; and in part, because some authors, such as Burrows (1986) have argued that the theoretical difficulties that non-convexities create are of little practical significance for pollution policy. In contrast, we show that non-convexities generated by pollution externalities can play a critical role in determining the pattern of trade, the gains from trade, and the environmental consequences of free trade.

In the international trade literature, non-convexities play a central role. During the past twenty years, much of the new trade theory has examined increasing returns to scale as a determinant of trade. Many authors have modelled increasing returns as a positive externality external to firms, but internal to an industry [See Helpman (1984) for a review]. This generates potential gains from trade from concentrating industries with external economies in one location. In this paper, we consider the implications of a negative cross-industry externality.[3] Here the motive for trade is to spatially separate industries. In what

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[3] Panagariya considered negative externalities that were internal to an industry, and Ethier also briefly considered this case. This type of externality, however, tends to make the production frontier concave, and hence has much different effects.

follows we uncover a number of interesting parallels and contrasts between the implications of these two different, but similar, motives for trade.

In many ways our analysis continues a line of research originating with Frank Graham in the 1920's. Graham's argument was simply that free trade can create losses if trade changes the composition of national output in such a way as to reduce overall productivity. These trade-induced productivity losses then need to be weighed against terms of trade gains to determine the overall welfare consequence of international trade. As Ethier (1982) so clearly showed, Graham was right – free trade can create losses if there are external economies in one sector – although the conditions under which his hypothesis held were quite surprising and at odds with conventional wisdom. Here we identify another channel through which overall productivity can fall (or rise!) when a country enters into international trade. And, like Ethier (1982), we provide results that were initially at odds with our own intuition regarding the welfare (and environmental) consequences of free trade.

The structure of the paper is as follows. We set up a simple dynamic model in section II and study autarky in section III. In section III-VI, we consider the effects of trade. In section VII, we briefly discuss possible extensions. Section VIII concludes.

II. THE MODEL

There are two primary factors: labor (L) and the stock of environmental capital (K). The level of K is given at any moment in time, but may be degraded or enhanced over time, depending on the flow of pollution and nature's regenerative capacity. We assume that K evolves according to $dK/dt = g(\bar{K} - K)$ where $\bar{K}$ is the "natural" level of environmental capital, and $g > 0$ measures the recovery rate of the environment. Absent any pollution, in the long run environmental capital would gravitate towards its natural steady state at the pristine level $\bar{K}$. Once we admit a flow of pollutants denoted by Z, the capital stock evolves according to:[4]

$$dK/dt = g(\bar{K} - K) - Z. \qquad (1)$$

There are two industries denoted M and A. M, or Smokestack manufacturing, is a dirty industry that uses labor as an input and emits pollution as a joint product of output. We assume that one unit of labour can produce one unit of manufactures, and generates λ units of pollution:

$$M = L_M, \qquad (2)$$

$$Z = \lambda L_M. \qquad (3)$$

Our other industry, denoted by A, is an environmentally sensitive industry that may be thought of as Farming.[5] Production of A uses labor as an input, but production is also dependent on the free flow of services (sun, rain, clean air and water, etc.) provided by the stock of environmental capital. Hence:

$$A = F(K)L_A, \qquad (4)$$

where L_A is labor allocated to agriculture and $F(K)$ is the flow of services arising from a capital stock of K. For simplicity, we let $F(K) = K^{\varepsilon}$, with $0 < \varepsilon < 1$.

We assume a representative consumer with current period utility given by:

$$U = b_m \ln(M) + b_a \ln(A) \qquad (5)$$

where b_m and b_a are the shares of spending on M and A. Our main results do not require constant budget shares, nor homotheticity. The Mill-Graham assumption of constant budget shares has a long history in the trade and external economies literature (see Melvin (1969), Ethier (1982), Panagariya (1981), etc.). It primary usefulness lies in the ability to link primitives to the existence of certain types of Pareto ranked equilibria.

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[4] We omit time subscripts to economize on notation. All variables refer to current period values unless indicated otherwise.

[5] Farming may be a bit of a misnomer, because agriculture is a major source of non-point source pollution. Our analysis applies to any two industries where one inflicts a negative production externality on the other.

III. AUTARKY

We begin by considering the steady state properties of the model in autarky. Our primary motivation for considering autarky is to establish a benchmark showing that under our specification, the autarky equilibrium is unique and stable even though our economy's steady state production possibility frontier is strictly convex. Although multiple equilibria and instability are endemic to models where production externalities lead to non-convexities, our assumptions rule out these complications in autarky. As a result, we are able to very clearly link free trade per se to the introduction of these complications.[6]

As a first step, we construct the economy's steady state production frontier to demonstrate that it is strictly convex throughout. Using (2) and (4), full employment of labor requires that at every point in time:

$$L = L_M + L_A = M + \frac{A}{K^{\varepsilon}} \quad . \tag{6}$$

This gives us an expression for the economy's short run production frontier. It is linear, reflecting the Ricardian structure of the economy in the short run. Points along this frontier are not necessarily sustainable, however, since the environmental capital stock K in (6) is dependent on the economy's past history of pollution discharge. Changes in M induce changes in pollution which in turn affect K. To obtain the steady state or sustainable production frontier, we use (3) and (2) in (1), and find that K evolves according to

$$dK/dt = g(\bar{K} - K) - \lambda M. \tag{7}$$

A steady state corresponds to $dK/dt = 0$ in (7). Provided specialization in M will not result in destruction of the entire capital stock,[7] the steady state relationship between Smokestack output and environmental capital is then given by

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[6] This is a common practice. Ethier (1982) imposes sufficient structure on preferences and technologies to render autarky a unique and stable equilibria for exactly these same reasons.

[7] That is, we assume that $\bar{K} - \lambda L/g > 0$. This will not affect the qualitative results.

$$K = \bar{K} - \lambda_M M, \tag{8}$$

where $\lambda_m \equiv \lambda/g$.

Using (8) to eliminate K in (6) and rearranging yields the steady state production frontier:

$$A = (L - M)(\bar{K} - \lambda_M M)^{\varepsilon} \tag{9}$$

This function is strictly convex, and is illustrated in Figure 1. The intuition for the convexity is as follows. If K were fixed at $K = \bar{K}$ there would be constant returns to scale, and the production frontier would be linear (as illustrated by the dotted line in Figure 1). However, points along the interior of this line segment are not sustainable. Starting at $M = 0$, increasing the allocation of labor to manufacturing generates pollution, which degrades the stock of environmental capital, thus reducing labor productivity in agriculture. Consequently, for any given level of Smokestack output, the level of farming output must lie somewhere below the dotted line. Moreover, since the steady state level of K is monotonically decreasing in the level of pollution, additional units of Smokestack output have further negative effects on farming labor productivity. As a result, the production frontier must be convex throughout as illustrated.

Not surprisingly, given our convex production frontier, the steady state supply curve for Smokestack output is negatively sloped over some range. To construct this supply curve consider first the conditions under which both sectors are active in steady state. For manufacturing, the zero profit condition requires, using (2):

$$p_M = w \tag{10}$$

Agricultural firms maximize profits, treating the environmental capital stock as given, and thus using (4), we must have:

$$p_a K^{\varepsilon} = w, \tag{11}$$

Dividing (10) by (11) yields

$$\frac{p_M}{p_a} = K^{\varepsilon}, \tag{12}$$

which tells us that at a point in time relative prices are determined by the environmental capital stock. Consequently, if both industries are active in steady state, then using (8) in (12), we have

$$p \equiv \frac{p_M}{p_a} = (\bar{K} - \lambda_M M)^{\varepsilon}, \tag{13}$$

which is a decreasing function of M. If $p_M/p_a < (\bar{K} - \lambda_M M)^{\varepsilon}$, for any M, it is profitable to shift labor out of M and into A, and conversely, if $p_M/p_a > (\bar{K} - \lambda_M M)^{\varepsilon}$, the M industry expands and A contracts.

The supply curve for M is illustrated in Figure 2 (and denoted "S"). Along the locus of points described by (13), the economy produces both M and A. Notice that the supply curve slopes downward in this range: an increase in M results in a lower steady state environmental capital stock and lower productivity in agriculture. This reduces the demand for labor in agriculture and hence lowers the minimum price required to support the increased supply. The supply curve contains two other segments, corresponding to specialization in either M or A. For $p_M/p_a < \bar{K}^{\varepsilon}$, then for $M = 0$, (13) is violated, it is profitable for A to expand, and the economy can specialize in A. Hence the vertical segment $[0, \bar{K}^{\varepsilon}]$ at $M = 0$ lies on the supply curve. Finally, at $M = L$, the economy specializes in M. For $p_M/p_a > (\bar{K} - \lambda_M L)^{\varepsilon}$, it is profitable for M to expand, and consequently, the economy can specialize in M for any such price. This leads to the right hand vertical segment of the supply curve.

As is standard in models with convex production frontiers, supply is not unique over a range of prices and there may be multiple equilibria in autarky. Nevertheless, with sufficient restrictions on demand there is a unique equilibrium. With our Mill-Graham preferences, the demand for M is given by

$$D_M = \frac{b_M wL}{p_M} = b_M L, \tag{14}$$

using (10). Hence the demand curve in autarky is vertical. Using (14) to replace M in (7), we obtain a simple linear differential equation governing the evolution of the capital stock from any initial value.[8] Solving this initial value problem shows the steady state is unique, globally stable, and convergence to the steady state is monotonic. Hence we have:

Proposition 1. A globally stable, unique steady state equilibrium exists in autarky.

The steady state equilibrium is at point M_0 in Figure 1.

IV. FREE TRADE IN A SMALL OPEN ECONOMY

We now consider trade. In autarky, domestic market conditions constrain the amount of pollution that the economy generates, and this in turn stabilizes the level of environmental capital. If Smokestack expands too much, farming output becomes scarce, relative prices adjust, and market forces encourage smokestack to contract, thereby reducing pollution. Although there is still too much pollution because of the externality, the market for farming output acts as a restraint on pollution in autarky.

Trade can eliminate this market-driven check on the level of pollution. This is illustrated most effectively by considering a small price-taking economy that faces a world relative price p* equal to its autarky price p_0. The autarky allocation must then also be a free trade equilibrium. However, because the demand curve is now perfectly elastic, there are two other steady state equilibria. These are illustrated in Figure 2. The original autarky diversified equilibrium is at M_0, but in addition there are two equilibria where the economy is specialized in either A or M.

More significantly, the opportunity to trade has rendered the autarky equilibrium unstable. To see this, note that at the autarky equilibrium, we have, using (12):

$$p^* = K_o^{\varepsilon} ,$$

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[8] A few calculations will show $K(t) = K^S + [K(t=0) - K^S]e^{-gt}$ where K^S is the steady state capital stock given in eq. (8). $K'(t) < 0$ if $K(t=0) > K^S$ and $K'(t) > 0$ if $K(t=0) < K^S$.

where K_0 is the autarky stock of environmental capital, and K^{ε}_{0} is the slope of the temporary production frontier. Now suppose that M increases slightly from M_0. The ensuing increase in pollution depletes the stock of environmental capital, and renders farming less competitive. Thus a slight expansion in Manufacturing output creates a comparative advantage in M, and with a linear temporary production frontier and a fixed world price, the economy specializes in M. This generates yet more pollution, which further degrades K, and reinforces the newly-created comparative advantage in M. This process of cumulative causation locks the country into a high-pollution, low-environmental-capital steady state. Conversely, if manufacturing output were to decline slightly below M_0, then the relative productivity of A rises, and a similar process would lead the economy to specialize in farming.

In Figure 3 we illustrate the evolution of the stock of K. The environment's cleansing function is $g(\bar{K} - K)$. In autarky, pollution is $Z = \lambda M = \lambda b_M L$, and hence the unique steady state equilibrium is at K_0. In free trade, pollution emissions are now a step-function of M, and K_0 is unstable. If K drops slightly below K_0, the economy immediately specializes in M and pollution rises to $Z = \lambda L$. The economy converges to the steady state at K_S. On the other hand, if K rises slightly above K_0, then relative productivity in A rises, and the economy immediately specializes in A. Pollution emissions go to zero and the stock of environmental capital approaches $\bar{K}$. To summarize:

Proposition 2. If trade occurs at fixed world prices equal to autarky prices, there are three possible steady state equilibria. Only the two specialized equilibria are stable; the diversified autarky equilibrium is unstable.

While trade at autarky prices leaves us with two possible trading equilibria, trade at just above or below autarky prices leaves us with more determinate results. If the world relative price of M is slightly below the autarky price, then the free trade pollution function is to the right of the one shown in Figure 3, and the economy will specialize in farming. Alternatively, if the price of M is slightly above the autarky price, then this economy's free trade pollution function is to the left of the one shown in Figure 3, and the economy will specialize in smokestack.

Proposition 2 is a direct consequence of the convexity of our economy's long run production frontier, and as such it bears a strong resemblance to similar results in the trade and increasing returns literature. Its importance lies not in illustrating the theoretical possibility of instability, but rather in linking free trade with a cumulative process of environmental change begetting industrial restructuring that in turn begets further environmental change.

The intuition behind this result is very simple, and rests on little more than the obvious fact that international trade leads to a separation between the location of consumption and the location of production. With cross-industry externalities, such separation affects relative productivities and creates comparative advantage. And with a perfectly elastic demand curve, there is no market force in place either to prevent pollution from driving out the clean industry, or to prevent the clean industry from becoming so productive that it drives out the dirty industry.

Environmentalists have often made the point that trade can be harmful for the environment precisely because it separates the location of consumption from the location of production (see Daly, 1993, p. 57). The argument is that trade allows consumers of pollution intensive goods to escape the direct negative environmental consequences of their consumption. Our model provides one way of making this argument precise. However, in a world with pure production externalities, the concentration of environmental destruction may well be desirable. In fact, with no direct disutility cost of pollution, free trade is always welfare improving in our small open economy model, despite the absence of pollution policy. To see this, note that on impact, resources move into the sector that at free trade prices maximizes national income. Since the dynamics of environmental change magnify this original production shift by either raising the productivity in farming if the economy moves into farming, or by leaving unchanged the productivity of smokestack if the economy moves into the smokestack industry, national income cannot fall with trade (and must rise if autarky and free trade prices differ).

Proposition 3. Free trade is welfare improving for a small open economy.

Once we introduce some complexities into the model, the benefits of separating industries must be weighed against potentially offsetting factors. First, if there are disutility costs of pollution, then a small country may not gain from trade if it ends up specialized in Smokestack. In this case, the benefits of separating incompatible industries must be weighed against the utility costs of concentrating pollution in one location. Second, if we relax the small country assumption, trade may no longer be welfare improving even if there is no disutility cost of pollution. If relative prices can adjust along the transition path, then a country may end up "trapped" in an industry that at current world prices leaves it with lower real income than before trade. We consider this and related issues in the following sections.

V. TRADE IN A TWO-COUNTRY WORLD

We now consider trade between two countries. To abstract from all other motives for trade, we assume the countries are identical. Identical countries have identical stocks of environmental capital and identical relative prices in autarky. Consequently, autarky is a free trade equilibrium. This equilibrium is unstable, however, since any increase in Smokestack output by one country initiates a self-reinforcing cycle of pollution-induced declines in agricultural productivity, and increased comparative advantage in the Smokestack industry. Thus trade can emerge between two identical countries.

The standard explanation for trade between similar countries is based on increasing returns to scale. With increasing returns, there is an incentive for an industry to concentrate in one location to reap the benefits of positive external economies. Negative externalities across sectors provide an alternative, but closely related, motive for trade arising from the beneficial separation of incompatible industries. The analytics are closely related because of a symmetry imposed by general equilibrium resource constraints.

To see how this symmetry between external IRS in one sector and a cross-industry negative externality arises, suppose we move primary factors into Farming. Moving factors into Farming means drawing them from Smokestack. Smokestack pollution falls, the environment improves, and this increases the productivity of primary factors in Farming. Note that the same beneficial increase in Farming's productivity could have arisen had we assumed Farming had external IRS linked to its output level. A consequence of this symmetry is that some of the intuition for our results is similar to Ethier (1982), but the parallels are not exact as we show in section VI.

Given the Ricardian structure of the model there are three possible types of trading steady states. We consider each in turn below. In addition since we are starting with identical countries, there are always two symmetric equilibria of each type. For concreteness, in the following we will associate Home with the country that always produces farm output and can in some cases be entirely specialized in farming.

A. High demand for the dirty good

Provided the demand for smokestack output is "high", both countries must produce Smokestack in any trading equilibrium. In our model a "high" demand corresponds to $b_m > 1/2$, and this ensures that the only stable steady state has Foreign specialized in M, while Home produces both goods.[9] In this case, wages must be equal across countries,

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[9] Autarky is always an unstable trading equilibrium. Both countries must produce M when $b_m > 1/2$ since world demand is $b_m(wL+w^*L^*)/p_m = b_mL(w+w^*)/p_m$ and this always exceeds one country's maximum supply of L. To verify this note that if $w = p_m$, then $w^* \geq w$; or if $w^* = p_m$, then $w \geq w^*$; in either case we have $b_m(wL+w^*L^*)/p_m > L$ as required.

and both countries will gain from trade.

The transition from autarky to the trading steady state is shown in Figure 4. In autarky, both countries have K_o units of environmental capital and produce both goods. With the opening of trade, this equilibrium becomes unstable. Suppose Foreign output of M rises. This increases pollution, lowers K*, and gives Foreign a comparative advantage in M. If the demand for Smokestack is high, then Foreign must specialize in M. Foreign's pollution level shifts up to $Z^* = \lambda L^*$ as shown, and its stock of environmental capital falls toward K^*_S.

At the same time, Home begins to import Smokestack and its output of M falls. As long as Smokestack is produced in both countries, wages must be equalized across countries ($w = w^* = p_m$), and recalling (14), the world demand for M is given by

$$M^w = b_m(wL+w^*L^*)/\, p_m = b_m(L+L^*).$$

Because Foreign produces L* units of Smokestack when specialized, Home produces $M = M^w - L^*$ units. As a result, Home's flow of pollution in trade becomes

$$Z = \lambda M = \lambda\, [M^w - L^*] = \lambda\, [b_m(L+L^*) - L^*] = \lambda(2b_m - 1)L,$$

since $L = L^*$. This new pollution level is shown in Figure 4, and is positive if $b_m > 1/2$. Since this flow of pollution is less than its autarky level, Home's stock of environmental capital begins to recover and it gradually moves toward its diversified steady state value at K_D.

During the transition, relative prices adjust continuously to clear markets. Since Home produces both goods, it must be on the interior of its supply curve. Using (12), the relative price of A is always given by $p_a/p_m = 1/K^\varepsilon$. Hence as K rises, the relative price of A falls. This reinforces the international pattern of specialization. Consequently, the continuous increase in agricultural productivity at Home, combined with the decline in agricultural productivity abroad, ensures that once Foreign increases its output of M slightly above its autarky level, it becomes locked into specializing in Smokestack.

While the effects of trade on the environment are very different across countries, both countries must gain from trade. Home gains from the increase in its production possibilities created by its improving environment, and Foreign gains from the terms of trade improvement brought about as the relative price of A falls. To verify these claims note that because both produce M, wages (and hence incomes) must always be equalized across countries. Purchasing power in terms of smokestack output is unaffected by trade ($w/p_M = 1$ before and after trade). Purchasing power in terms of Farm output is $w/p_a = K^{\varepsilon}$, and this must rise monotonically along the adjustment path. Thus we have shown:

Proposition 4. If $b_m > L^*/[L+L^*] = 1/2$, then in the only stable free trade steady state both countries produce Smokestack but only one country produces Farm output. Both countries gain from trade.

In this case, trade serves as a substitute for environmental policy. Because of the negative production externality, it is efficient to separate the two industries. International trade provides incentives for this separation to occur in a free market.[10] Separation per se is not, however, sufficient for trade to always benefit both countries. As we show below, when Smokestack is concentrated in one country alone, separation is almost complete, but the gains from this separation are not equally shared across countries. In fact, one country must lose from trade.

B. High demand for the clean good

Now consider the case where there is a relatively strong demand for the clean good ($b_a > 1/2$). Two types of equilibria may emerge, depending on the strength of this demand. If b_a is sufficiently large, then both countries must produce A in the steady state. On the other hand, for intermediate values of b_a, both countries may be specialized in

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[10] Notice, however, that the equilibrium is not Pareto efficient: because of the externality, there will still be excessive production of M in the country that produces both goods.

production. In either case, all of the manufacturing is concentrated in one country. As a result, wages need not be equalized across countries in free trade.

As before, the autarky allocation is an unstable free trade equilibrium, since any deviation in production patterns initiates a dynamic process that generates and reinforces comparative advantage. To analyze the adjustment path to the free trade steady state, suppose that Foreign deviates slightly from its autarky output levels and increases its output of M with the opening of trade. The ensuing pollution-created fall in K^* gives Foreign a comparative advantage in M and Home a comparative advantage in A. With a high demand for A, Home specializes in A. Foreign produces all of the world's M, but with K^* only marginally less than K, and with $b_a > 1/2$, Foreign must also produce some A.[11] Hence, at least in the early stages of adjustment, the Foreign country produces both goods, while Home is specialized in A. As we shall see, during the transition to the trading steady state Foreign could either remain diversified in production, or if the demand for Smokestack is sufficiently high, it may be driven to specialize. Home, on the other hand, must remain specialized.

Let us first consider the case where Foreign remains diversified in the steady state (b_a is large). The adjustment path is illustrated in Figure 5a, where we have plotted the regeneration function (1) and some pollution functions for the Foreign country, which we denote by Ω_i.

The pollution function Ω gives the level of pollution generated by Foreign as a function of the current level of K and K^*. Foreign pollution is a by-product of its manufacturing output, and since Home is specialized in A, Foreign must satisfy the world demand for M, which is

$$M^w = b_m(w^*L^* + wL)/w^* . \tag{15}$$

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[11] To prove this result note that: (1) both cannot be diversified since $K \neq K^*$; (2) Home must produce A since $K > K^*$; (3) since $b_a > 1/2$ both cannot produce M; (4) since $b_a > 1/2$ and K differs only marginally from K^* at the outset of trade, full specialization cannot occur.

To eliminate wages from (15), note that as long as both countries produce A, unit production costs must be equal across countries. This requires:

$$p_a = w/K^{\varepsilon} = w^*/K^{*\varepsilon}. \tag{16}$$

Using (16) in (15), and recalling that pollution is $Z^* = \lambda M^*$, yields an expression for the foreign pollution function when production is diversified:

$$\Omega(K,K^*) = \lambda b_m(L^* + LK^{\varepsilon}/K^{*\varepsilon}).$$

For given K, $\Omega(K^*;K)$ is a convex decreasing function of K*. The intuition is straightforward. If K* falls, Foreign productivity in A decreases. From (16), Home's wage must rise so that unit costs remain equal across countries. With a higher income, Home's demand for manufactures ($b_m wL/w^*$) must rise, thus increasing Foreign pollution. Foreign demand for manufactures, however, remains fixed at $b_m w^*L^*/w^* = b_m L^*$. Consequently, the world's derived demand for Foreign pollution rises as K* falls.

On the other hand, Ω is *increasing* in K. As K rises, Home's real wage rises, thus increasing its demand for foreign-produced M. This stimulates the Smokestack industry and increases Foreign pollution. Thus an increase in K in the Home country shifts up the Ω curve in Figure 5a.

Finally, we must note that Foreign pollution is bounded above by the possibility that it may eventually specialize in M. If Foreign specializes in M, then its pollution is $Z^* = \lambda L^*$. Thus, taking this into account, Foreign pollution in trade is given by:

$$Z^* = \text{Min}\ [\lambda L^*, \Omega(K^*;K)].$$

One such pollution function is shown in Fig. 5a by the bold line.

With this apparatus in hand consider the transition to free trade. At the outset of trade Home specializes in A, Smokestack shuts down, and Z = 0. Home's pollution function becomes coincident with the horizontal axis in Fig. 5a, and its environmental capital stock begins to recover. Over time it approaches $\bar{K}$. In contrast, when Home specializes in agriculture, Foreign initially doubles its manufacturing output.

Consequently, foreign emissions jump to point A on $\Omega_1(K^*;K_0)$. Since foreign pollution is now higher than the natural regeneration rate, foreign environmental capital K* starts to fall.

Over time, Foreign pollution rises for two reasons. First, as K* falls, Home's terms of trade improve. This creates additional Home demand for Smokestack, while Foreign's own demand for Smokestack is fixed at $b_m L^*$ because Foreign is diversified during this process. Consequently, world demand for Smokestack rises, as does the world's derived demand for Foreign pollution. In Figure 5a, this corresponds to a movement along $Z^* = \Omega_1(K^*;K_0)$ towards point B.

Second, Home's environmental capital K rises throughout the transition. This induces an increase in Home's real income that further raises Home's derived demand for Foreign pollution. In Fig. 5a, this is captured by continual upward shifts of Ω (K*;K) over time.

If the demand for the clean good is very strong, then Home cannot satisfy the entire world demand, and Foreign must remain diversified in the steady state. This is the case illustrated in Figure 5a. Foreign's steady state pollution function is $\Omega_2(K^*;\bar{K})$, and there is a stable steady state equilibrium at point C with $K^* = K_D^*$.[12] Foreign produces both goods, and Home is specialized in A.

Although the two countries are initially identical, their welfare outcomes diverge with trade: Home must gain, and Foreign must lose. To verify these welfare results, note first that there are no static gains from trade because the two countries are initially identical. However, as noted, during the transition, Foreign terms of trade deteriorate as its productivity in Farming falls, while Home's terms of trade improve. Thus Foreign welfare

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[12] Since $\Omega_2(K^*;\bar{K})$ is convex, there could be multiple diversified equilibria in the Foreign country, but only the equilibrium with the largest K* is stable. It is also possible that there may exist both a diversified and a specialized equilibrium for Foreign for given b_a. However, during an adjustment from autarky to free trade as described above, the economy would converge to the diversified equilibirum.

falls monotonically during the adjustment to a point like C in Figure 5a, while Home welfare rises.

This is confirmed by considering the evolution of purchasing power. Foreign purchasing power in terms of M is unaffected (since $w^*/p_m = 1$ before and after trade). However, Foreign's purchasing power in terms of A falls. Zero profits in the foreign A industry require $w^*/p_a = K^{*\varepsilon}$, and this declines monotonically as K* falls along the transition path. Since there are no static gains from trade, and there are dynamic losses, the Foreign country unambiguously loses from trade. Notice that Foreign is worse off despite our assumption that pollution has no direct negative effect on utility.

On the other hand, Home must gain. Home is specialized in A, and its purchasing power in terms of A is $w/p_a = K^{\varepsilon}$, which rises with K along the transition path. Its wage in terms of M is given by

$$w/p_m = w/w^* = w/\,p_a K^{*\varepsilon} = \left(\frac{K}{K^*}\right)^{\varepsilon} .$$

Since K rises and K* falls, Home's purchasing power in terms of M must also rise along the transition path.

Summarizing:[13]

Proposition 5. There exists some $\underline{b} > 1/2$ such that if $b_a > \underline{b}$, then in free trade Home specializes in Agriculture and Foreign diversifies. There are no static gains from trade, but Home experiences dynamic gains from trade, while Foreign suffers dynamic losses.

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[13] From our diagrammatic account of the transition, it is apparent that: (1) a diversified equilibria will obtain if $g(\bar{K}- K^*) = \lambda b_m L[1+ (\bar{K}/K^*)^{\varepsilon}]$ has at least one positive solution for K* such that this positive solution, denoted $\hat{K}^*$, is less than K_s the environment's capital stock when all of Foreign's labor is allocated to Smokestack; (2), the largest such $\hat{K}^*$ is a locally stable equilibrium and is in fact reached in the transition to free trade; and (3), if b_m is sufficiently small (i.e. b_a sufficiently large) then we can guarantee at least one positive solution for $\hat{K}^* < K_s$ since a fall in b_m shifts the entire family of curves $\Omega\,(K^*;K)$ in towards the origin.

The contrast between Propositions 4 and 5 is striking. Trade is mutually beneficial only when the demand for the dirty good is sufficiently strong. With a strong demand for the clean good, one country must lose from trade even though trade still provides efficiency gains by separating incompatible industries.

Foreign losses accrue from mutually reinforcing sources. Foreign loses because when it raises Smokestack output, it degrades its environment and lowers the world supply of Farm output (its import good). As a result, Foreign suffers from a deterioration in its terms of trade as a direct consequence of its own environmental degradation! Moreover, this terms of trade deterioration for Foreign is a terms of trade improvement for Home. This raises Home's demand for Foreign manufactures, leading to yet more foreign pollution. The foreign environment worsens, productivity in the clean sector falls, and the entire cycle of environmental degradation and terms of trade deterioration repeats and reinforces itself over time.

There are several important points to note about this possibility of losses from trade. First, the key to Foreign losing from trade is the negative terms of trade effect created by its own environmental degradation. Thus Propositions 3 and 5 are not inconsistent. If the terms of trade were held constant, Foreign would immediately specialize in Smokestack (and remain specialized) when it degrades its environment. As discussed in section IV, depletion of its environmental capital in this case is essentially irrelevant to foreign welfare. Only when world prices adjust in reponse to changes in K and K* does Foreign potentially lose from trade.

Second, it is striking that losses from trade only occur if the demand for the clean good is sufficiently high. As well, from our diagrammatic account it is apparent that losses from trade are more likely when the environment's regeneration rate, g, is high, and when the externality is relatively weak (ε is low). An increase in g shifts the cleansing function $g(\bar{K} - K^*)$ outwards making a diversified equilibria with losses from trade more likely. If ε is small, then Foreign's pollution function is almost a flat line for any given K; moreover, if ε is small then the shift upwards in the pollution function is smaller. Consequently, for both reasons, the smaller is ε the greater the possibility of diversification and losses.[14]

These seemingly inexplicable results are not without reason. When Foreign has a greater regeneration rate, any increase in Smokestack pollution leads to a smaller reduction in environmental capital. Consequently, Foreign's terms of trade deteriorate less from an increase in pollution, and Home gains less from the change in world relative prices brought about by Foreign's environmental degradation. As a result, Home's demand for Smokestack is less, and this makes diversification (and losses) more likely for Foreign.

As well, if ε is small then when Smokestack pollution reduces Foreign's capital stock the fall in the output of the clean good is relatively small. Again, the induced terms of trade effect is small, and the attendant increase in the demand for Smokestack by Home is smaller as well. Consequently, diversification and losses for Foreign are more likely again.

One final point of note is that losses from trade are more likely when Foreign suffers relatively little from pollution in autarky. Losses from trade are more likely when the share of spending on the clean good (b_a) and the regeneration rate (g) are both large, and when the externality is weak (ε is small). In such cases, pollution is relatively low because the demand for the clean good is high, the relatively small amount of pollution created is readily assimilated by the environment because g is large; and even when the environment inevitably worsens, a relatively small ε means that the productivity in Farming is hurt only slightly by industrial pollutants. Surprisingly, we find that opening up to trade is most likely to be harmful in just those cases when a strong argument can be made that governments may not have had an incentive to develop the institutions and knowledge needed to fully account for the long run costs of pollution in autarky.

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[14] This does not imply that the losses from trade are greater when ε is small. We suspect that just the opposite is true: when ε is small a diversified equilibrium is more likely, but the losses from trade are smaller too. Note when $\varepsilon = 0$ there can be no losses (or gains) from trade.

C. Both countries specialized

Finally, we consider the intermediate case where both countries specialize in the the steady state. This occurs when $1/2 < b_a < \underline{b} < 1$: the demand for Smokestack is stronger than in the previous case, but not as strong as in part A of this section.

This possibility is illustrated in Figure 5b. In the steady state, Foreign's free trade pollution function is $\Omega_2(K^*; \bar{K})$ and the steady state equilibrium is at point C. Because of the relatively stronger demand for Smokestack during the transition, the foreign pollution function Ω eventually rises everywhere above the regeneration function. Consequently, Foreign specializes in Smokestack in the steady state.

The possibility of specialization has important welfare implications for the Foreign country. In the early part of the transition, Foreign is diversified in production, and its welfare falls as shown above. But once Foreign specializes, further depletion of its own environmental capital becomes economically irrelevant, and moreover, Foreign (an importer of A) now benefits from a terms of trade improvement as Home's production of A rises over time.[15] A Foreign worker's real wage in terms of manufactures is constant throughout, but his or her real wage in terms of A starts to rise once the country specializes. Whether or not Foreign gains or loses from trade depends on its discount rate and on the speed with which it specializes in M.

On the other hand, Home must always gain from trade in this case. As shown above, it gains while Foreign is diversified. It must continue to gain when Foreign specializes because its real wage in terms of Farm output continues to rise.[16]

Summarizing,

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[15] Home's environmental capital stock approaches its steady state value as t goes to infinity. Foreign specializes, if at all, in finite time.

[16] Consider Home consumers. The market clearing condition for M when Foreign is specialized is just $b_m(wL + w^*L^*)/p_m = L^*$. Solving for Home's real wage in terms of manufactures shows it is constant and greater than 1.

Proposition 6. If $b_a > 1/2$, and a stable diversified steady state does not exist, then both countries must specialize in production. Home (specialized in A) must gain from trade at every point during the transition. Foreign utility initially falls, and later rises during the transition from autarky to free trade.

VI. COMPARATIVE ADVANTAGE AND THE ALLOCATION OF ACTIVITIES ACROSS COUNTRIES

Thus far we have abstracted from differences across countries that could create a comparative advantage basis for trade. Pollution-created non-convexities will however interact with the more conventional determinants of trade in any world with non-identical countries. We concentrate on two key differences that are prominent in the literature: differences across countries in population density (L vs L^*), and differences in assimilative/regenerative capacity (g vs. g^*). Apart from examining how other determinants of comparative advantage may interact in our setting, we will show that once we admit non-identical countries free trade may now lock-in the "wrong" pattern of specialization across countries.

Suppose $g > g^*$, but countries are otherwise identical. Then the environment in Home has a uniformly faster rate of regeneration (perhaps because of prevailing weather patterns, proximity to oceans, or physical differences in the soil, etc.) In autarky, we have $K > K^*$ and Home has a lower relative price of the clean good. At the outset of trade Home will increase its output of A while Foreign increases its output of M. If $b_m > 1/2$, then both countries must produce manufactures in trade: Foreign specializes in M while Home produces both goods.[17] If $b_m < 1/2$, then Foreign produces Smokestack and perhaps some Farm output, Home specializes in Farming. Note that Home must always

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[17] The proof in footnote 9 also applies here because it does not rely on $g=g^*$.

gain from trade, while Foreign could lose from trade when $b_m < 1/2$.

World production efficiency requires that either both countries specialize, or if one country must be diversified it should be the country with the higher rate of regeneration. The logic is clear. Production efficiency requires that at least one country specialize. Both Foreign and Home produce identical amounts of either M or A when specialized. In contrast, the higher "g" country can produce more Farm output for any given level of Smokestack since its regeneration rate is greater. If Smokestack demand is so high that it must be produced by both countries, then Foreign should specialize in Smokestack while Home diversifies. This is in fact the pattern of trade predicted when $b_m > 1/2$, and hence free trade allocates activities efficiently in this case.

But if $b_m < 1/2$, and full specialization does not occur, then Foreign is diversified while Home is specialized in A. This allocation of activities is inefficient. If we forced Foreign to specialize in A and let Home diversify, then world output would be higher. Consequently, we have shown :

Proposition 7. The country with the faster rate of regeneration has the lowest autarky price of the clean good, exports the clean good in free trade, and always gains from trade. The allocation of production across countries in free trade is efficient if $b_m > 1/2$, or if full specialization occurs. It will be inefficient for b_m sufficiently small.

Now suppose $L^* > L$, but countries are otherwise identical. In autarky, we have $K > K^*$ and the less densely populated country has a comparative advantage in the clean good. At the outset of trade, Home increases its output of A while Foreign increases its output of M. If b_m is sufficiently large, then both countries must produce manufactures in trade: Foreign specializes in Smokestack while Home produces both goods. If b_m is sufficiently small, then both countries must produce A: Home specializes in A while Foreign diversifies. Home must always gain from trade, while Foreign can lose if b_m is sufficiently small.

Efficiency now requires that the most densely populated country always specialize in production. The logic is again clear. Efficiency requires that the smallest number of workers in the clean sector be subject to the productivity reducing effects of Smokestack pollution. Hence when the demand for Smokestack is high, both countries must produce it, but efficiency requires that Foreign specialize in Smokestack since this minimizes the number of workers in the clean sector who have their productivity reduced. This is in fact the pattern of specialization created by trade. Trade in this case leads to an efficient allocation of activities across countries. To verify this claim note that if $b_m (L+L^*) > L^* > L$, then both countries must produce Smokestack. World demand for M is then $b_m(L+L^*)$. When Foreign specializes in M, world farm output is

$$A^{*w} = (1 - b_m)\{\bar{K} - (\lambda/g)[b_m(L^*+L) - L^*]\}^{\varepsilon}(L^*+L).$$

Now reverse the pattern of specialization by assuming Home specializes in M, and denote world farm output in this case as A^w. Then

$$A^{w} = (1 - b_m)\{\bar{K} - (\lambda/g)[b_m(L^*+L) - L]\}^{\varepsilon}(L^*+L).$$

Comparing, we find that $A^{*w} > A^w$ if $L^* > L$, and hence Foreign specializing in farm output is efficient.

When the demand for Smokestack is low (the demand for the clean good is high) it should only be produced in the less populated country to minimize the number of workers in the clean industry that are disadvantaged by Smokestack's productivity reducing effects. Suppose world demand for M is L_m^* units, and this is less than L. If Home specializes in A, we have

$$A^{w} = \bar{K}^{\varepsilon}L + [\bar{K} - (\lambda/g)L_m^*]^{\varepsilon}(L^* - L_m^*).$$

If Foreign specializes in A, we have

$$A^{*w} = \bar{K}^{\varepsilon}L^* + [\bar{K} - (\lambda/g)L_m^*]^{\varepsilon}(L - L_m^*).$$

Consequently, $A^{*w} > A^w$ if $L^* > L$. But with a strong demand for the clean good the less populous country specializes in Farming in free trade and this is inefficient. Hence we have shown:

Proposition 8. The more densely populated country has the lowest autarky price of the dirty good and will export it in free trade. The less densely populated country always gains from trade, the more densely populated country can lose when b_m is sufficiently low. The allocation of production activities across countries is efficient if $b_m > L^*/(L+L^*)$, and will be inefficient if b_m is sufficiently low.

Proposition 7 and 8 provide several surprising results. Proposition 7 tells us that the country with the greatest assimilative capacity has a comparative advantage in the clean good and will shift its production towards the clean good with trade. Conversely, the country with the relatively slow regeneration rate takes on more dirty good production with trade. The opposite prediction is often offered in the policy debate. A common line of argument is that a greater regeneration rate means a cleaner environment for any given amount of pollution, and hence weaker standards on pollution control and a comparative advantage in the dirty good. Comparative advantage in the dirty good is predicted from a political economy argument linking the state of the environment to the demand for pollution control, and then to relative costs across dirty and clean industries. Here we show that if there is no regulation of pollution, then there is a direct link between an environment's assimilative capacity and comparative advantage through the general equilibrium effects of a cross industry externality.

Similarly, Proposition 8 predicts that the more densely populated country has a comparative advantage in the dirty good. Again, conventional wisdom links population density to a greater demand for environmental protection and a comparative disadvantage in the dirty good. Here we again show that if there is no regulation of pollution, then there is a direct link between a country's population density and comparative advantage through the general equilibrium effects of a cross industry externality.

Finally, both Propositions show that trade need not lead to an efficient allocation of activities across countries. This is in sharp contrast to Ethier (1982) where free trade leads to an efficient pattern of specialization across countries. The reason is straightforward: concentration and separation are not equivalent, except in the sole case where both countries specialize completely. If we concentrate all of Smokestack in one country, we have not completely separated Smokestack from the environmentally sensitive industry. Since the productivity effects induced by trade arise from separation in our case, (and not concentration as in Ethier (1982)), our results differ.

For example, in an external economies model like Ethier (1982), whenever the demand for the increasing returns (IRS) good is low so that the IRS industry can fit into the smallest country, then it doesn't matter whether the larger or smaller country produces all of the IRS good. The logic is simply that there are benefits to concentrating IRS production in one country, but the concentration is complete if either of the two countries produces all of the IRS good. In contrast, when the demand for Smokestack is low so that Smokestack can fit inside the smallest country, efficiency is not met by either country taking all of the dirty industry production. Alternatively, when the demand for Farm output is so low that Farming can fit inside the smallest country, efficiency is again not met by either country taking all of the clean industry production. In both cases, because Smokestack affects the productivity of those workers remaining in the clean industry, it now matters which country gets the Smokestack industry.

VII. EXTENSIONS AND QUALIFICATIONS

The model we constructed in Section III was designed to illustrate as cleanly as possible that even a "small amount" of international trade could have surprisingly large environmental impacts. While this stripped down model was useful to illustrate our basic point, its simplicity may belie important qualifications. Here we consider just three limitations of our analysis and briefly report on their likely significance to the main results.

A simplifying assumption of our model was that each country consisted of only one region so that Smokestack and the environmentally sensitive industry could not separate geographically within a country. Clearly for large countries this form of domestic separation is possible in practice, although its feasibility is dependent on both the exact form of pollution emitted by Smokestack and by the mobility of factors across regions. If we maintain our 1 factor model, assume perfect mobility of labour, and introduce two regions within a country (each with their own environmental sink), then industries will separate across regions in autarky and free trade will provide no additional service in separating incompatible industries. Free trade at autarky prices will be a stable equilibrium and no trade will occur at these prices.

Alternatively, if there is zero factor mobility and two regions within a country, then there will be some spatial separation across regions in autarky but it is now limited by the immobility of factors across regions. In this context, trade can again play a role in separating incompatible industries much as described in our earlier sections. Hence the degree of internal factor mobility is a key determinant of whether trade can play a useful role in separating incompatible industries.

In reality many environmentally sensitive industries are likely to be tied geographically by the location of specific factors. Tourism is tied to lakes, trees and mountains; fishing to streams and coastal areas. Unfortunately perhaps, forestry, pulp and paper, electricity generation and many other heavy industries are also tied to these same specific factors (trees, streams, rivers and access to water). Since many of these specific factors are highly concentrated geographically, then so too will be incompatible industries. As a result, free trade can again provide for further spatial separation and the logic of our model follows as before.

Another simplifying assumption was our choice of a 1-factor model. While the Ricardian nature of the model at each point in time brings strong tendencies towards specialization, it is important not to attribute too much to this assumption. Our results rely most heavily on the non-convexity introduced by cross-industry externalities. If we were to add more factors and let the industries differ in factor intensities, then there would be two forces at work determining the steady state production possibility frontier. The cross-industry externality tends to make the frontier bowed in to the origin while differences in factor intensities work in just the opposite direction. Our very simple steady state production frontier that was uniformly convex to the origin would be replaced by one with alternating concave and convex segments. If the autarky equilibrium occurred in a region where marginal rates of transformation were declining, then free trade at autarky prices would again be an unstable equilibrium. Free trade at autarky prices would again bring very large environmental consequences, although it would not bring about full specialization as in our Ricardian formulation. Consequently, we view the 1 factor assumption as a useful vehicle for illustrating our main points, but it is not wholly responsible for our results.

Finally, throughout we have ruled out pollution policy. We have adopted this assumption not because we believe that it is necessarily an accurate description of the real world, but because a serious consideration of policy would detract us from our main focus. If pollution policy was designed to correctly account for the negative long run consequences of Smokestack pollution, and if pollution policy was flexible and could respond to the changing conditions brought about by trade, then free trade could never lead to losses. Alternatively if we assume that pollution policy was a rigid technological standard on emissions (such as a restriction on an allowable λ), then our results carry through as before. As well, once we allow for active pollution policy it is necessary to ask whether such a policy may be used as disguised trade policy. In our two-country model several strategic issues arise, and a full examination of these issues must be left to further work.

VIII. CONCLUSION

Free trade may have little or no effect on a polluted small open economy, but it may also have some quite surprising and significant effects as well. When industrial pollutants lower the productivity in environmentally sensitive sectors, non-convexities arise. Despite these pollution-created non-convexities, the domestic price adjustment mechanism typically ensures a diversified equilibria in autarky. Domestic prices thus insulate the economy from extremely clean or dirty equilibria. In any trading equilibrium, the world prices a country faces are only partially determined by its own country specific conditions. Consequently, the insulation provided by domestic price adjustment in autarky may be lost in trade. Trade, even at autarky prices, can have large environmental consequences.

Large environmental consequences follow from trade precisely because trade allows for the spatial separation of incompatible industries. While many environmentalists are concerned that trade allows for the spatial separation of dirty product consumers and dirty product producers, we find that such separation can bring benefits in terms of production efficiency. These productivity enhancing effects of separation are the key to the gains from trade for our small open economy.

But separation can create both winners and losers. Separation of incompatible industries may also mean the concentration of pollution in some countries, and this may have direct utility costs that are ignored here. Moreover, in a two country world, trade can set in motion a negatively reinforcing cycle of environmental degradation and productivity losses that leaves a dirty product exporter worse off in trade. Hence while the separation of incompatible industries brings productivity gains to the world, the division of these gains across countries depends sensitively on parameters of the model.

Accordingly, we find that the type of separation matters and several surprising results follow: two identical countries can engage in mutually beneficial trade; trade will be mutually beneficial if the demand for the dirty good (Smokestack) is high; one country must lose if the demand for the clean good (Farming) is high; and losses are more likely the less sensitive is Farming to industrial pollutants, and the faster is the environment's cleansing rate. These results seem at first inexplicable, but they are in fact by-products of the terms of trade effects created when the spatial separation of industries creates productivity changes across countries.

Although our model is highly stylized and as such overlooks many channels through which trade may affect the environment, it has shown quite clearly the role that pollution created non-convexities may play. Empirical testing will surely need to follow and identify those situations when trade may create large effects, but our model provides at least a starting point for such an exercise.

In addition, we believe that our model may play a useful role in bridging the sometimes large communication gap between environmentalists and economists. Part of the problem may be that much of a typical economists' intuition is drawn from models with convex production sets and smooth substitution possibilities. Within these models, small changes in relative prices brought about by trade bring about small environmental consequences. In contrast, environmentalists often appear to have an underlying model where small changes can bring about large outcomes by initiating some process of cumulative causation. While our results do not provide carte blanche approval to such claims, they do provide some insight and support for their concerns. More importantly we hope that by identifying the conditions under which trade can have large consequences, we have simultaneously sharpened the focus of the current debate and provided a basis for future beneficial exchange between the pro-free trade and pro-environment camps.

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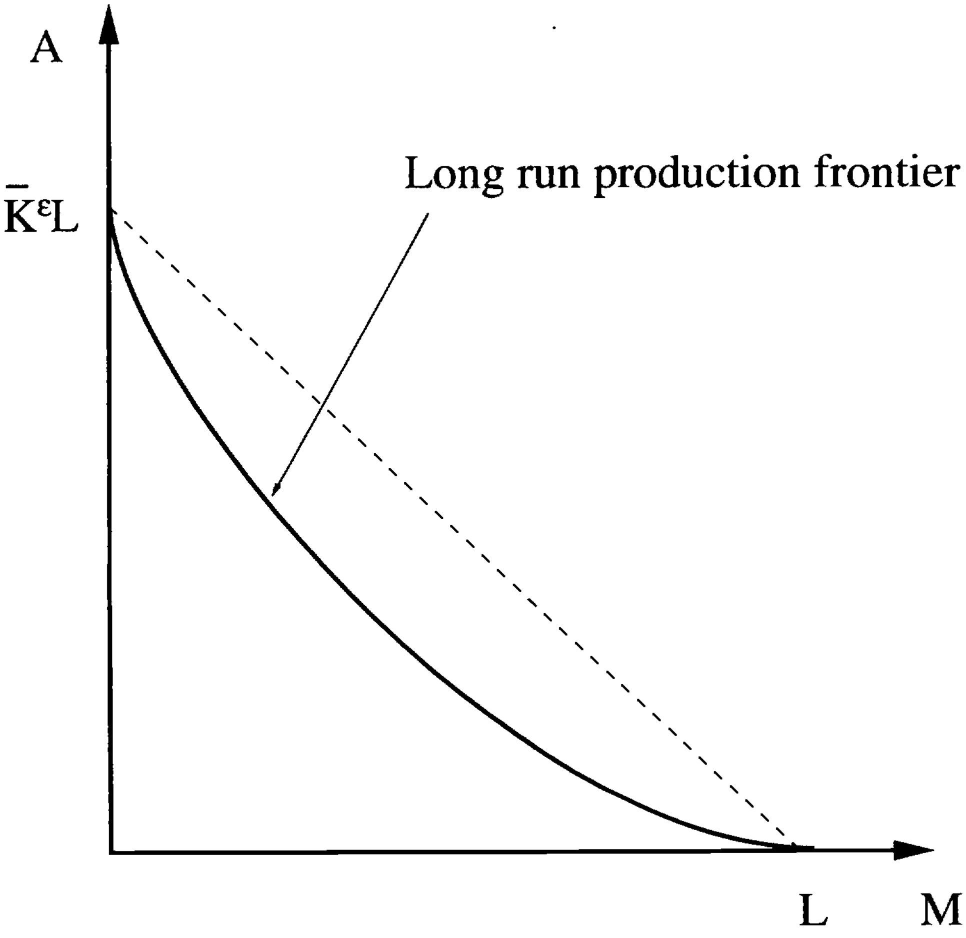

Figure 1

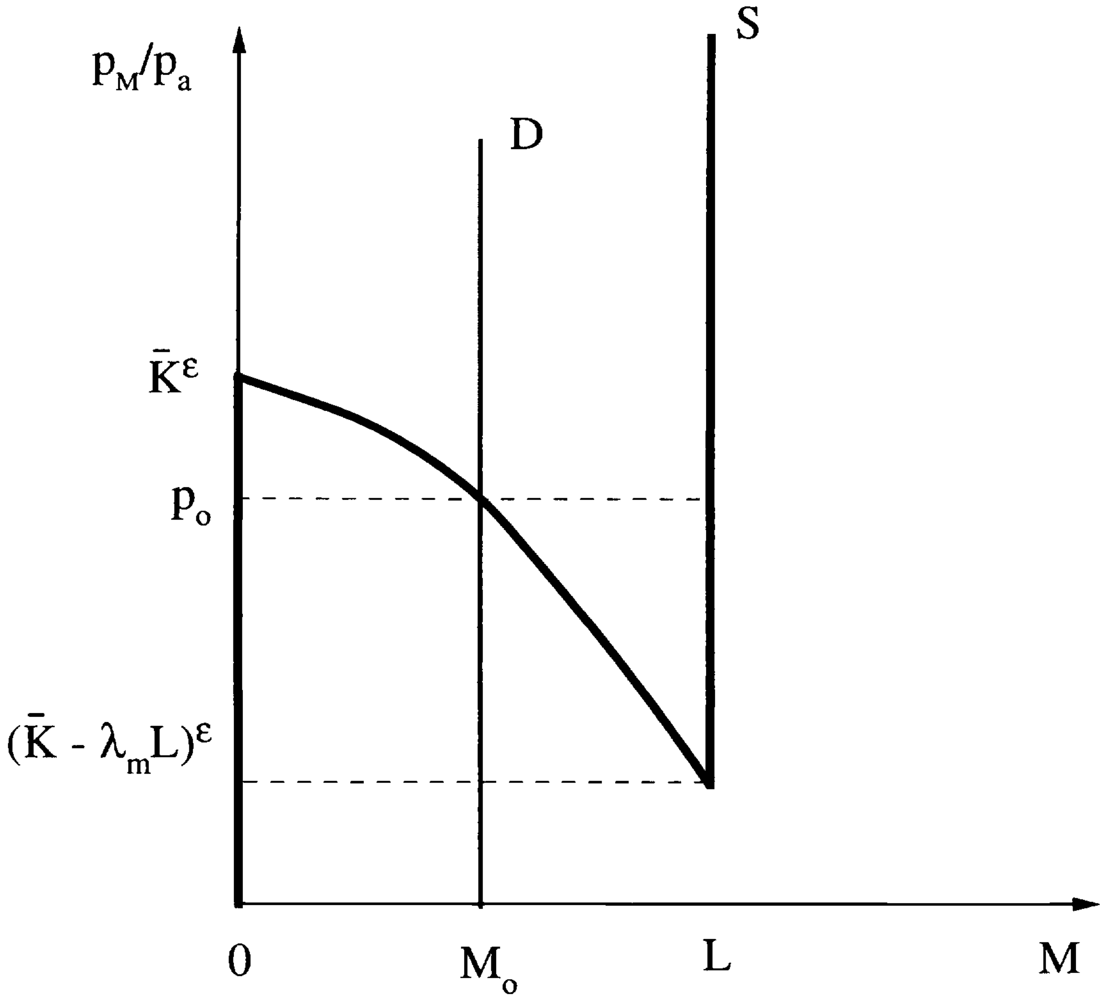

Figure 2

Free Trade for a Small Open Economy

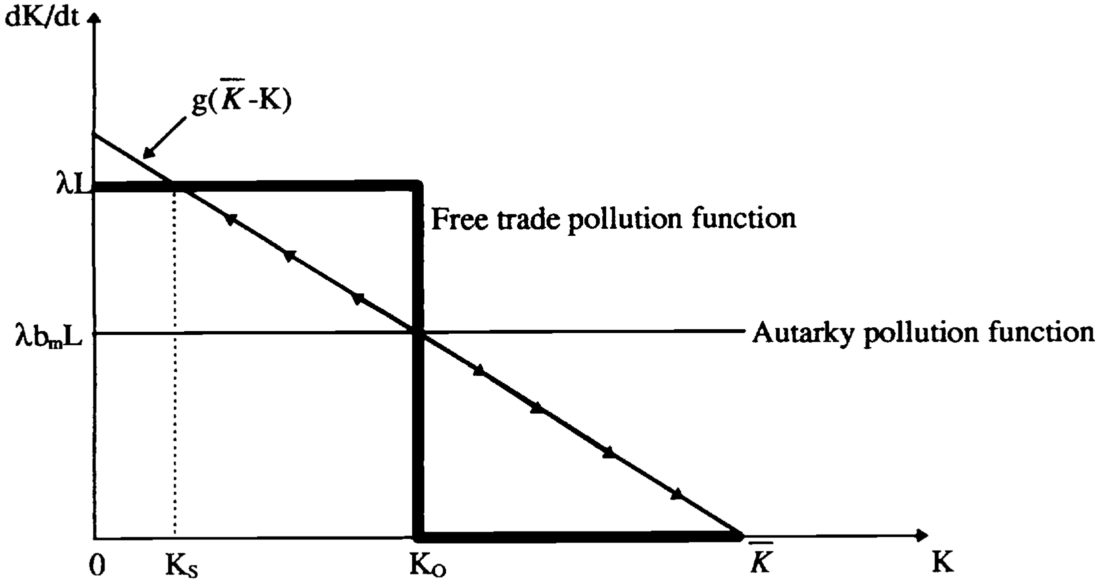

Figure 3

High Demand for Smokestack: Transition Dynamics to a Diversified Steady State

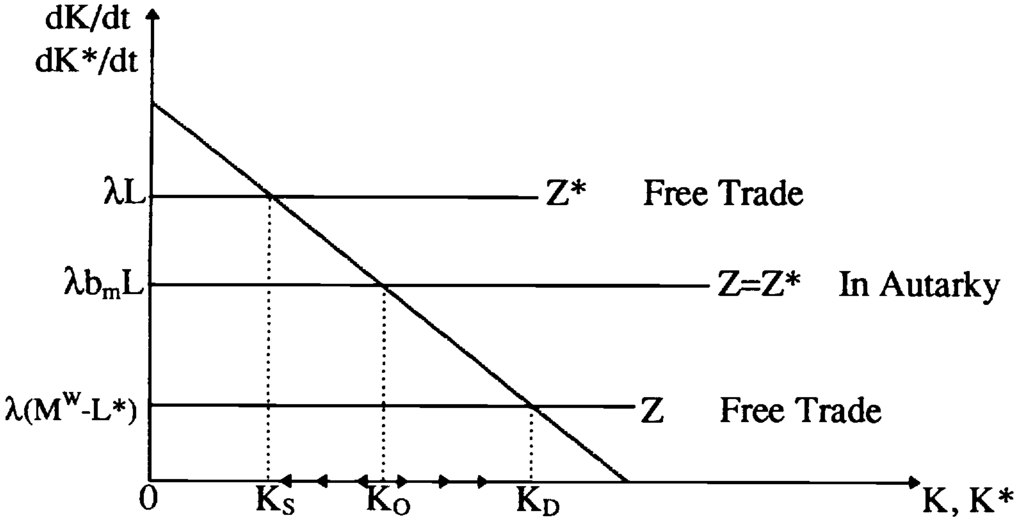

Figure 4

High Demand for Agriculture:
Transition Dynamics to a Diversified Steady State

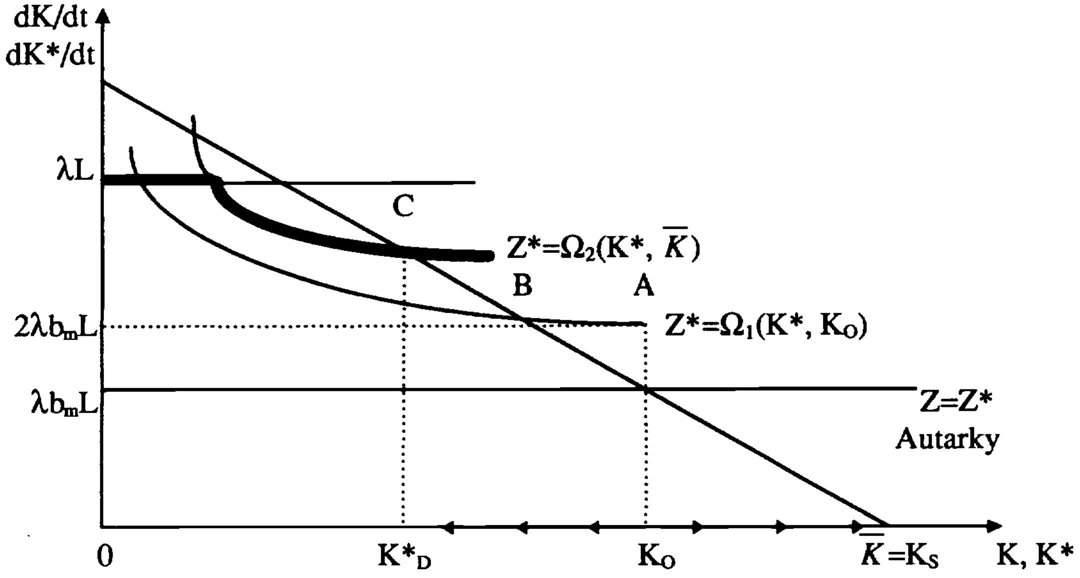

Figure 5a

High Demand for Agriculture:
Transition Dynamics to a Fully Specialized Steady State

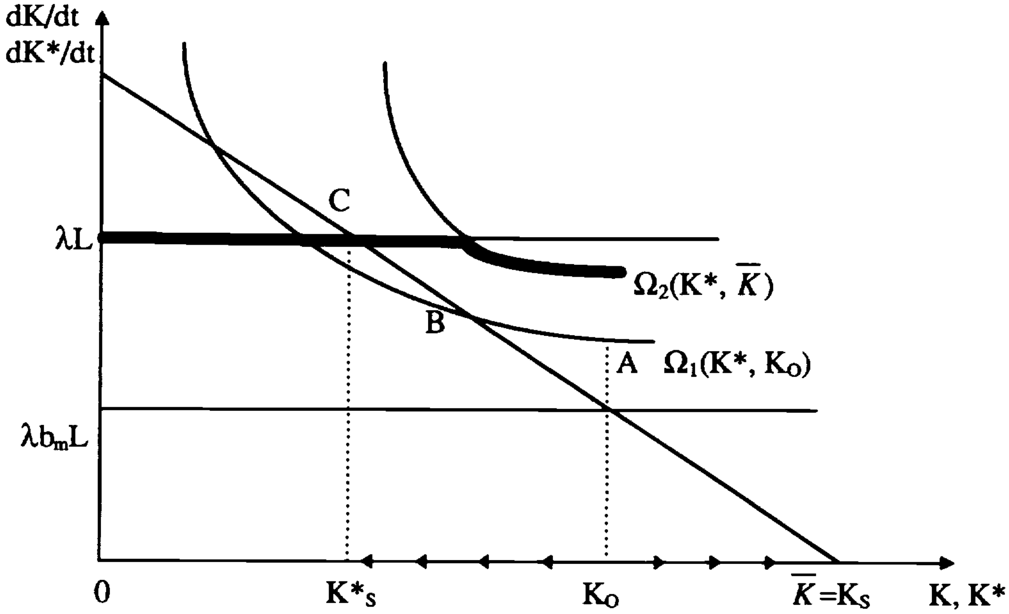

Figure 5b