Transboundary Pollution and the Gains from Trade

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Abstract
We analyse the effects of transboundary pollution on trade patterns and welfare in a general equilibrium trade model. Production in a dirty industry generates pollution that negatively affects productivity, both at home and abroad, in a clean industry. Trade may lead to the spatial separation of production but the existence of transboundary pollution can offset the benefits from specialization. We present a general model in which the effects of a country's pollution is country specific. We analyse particular cases that correspond to an acid rain problem and a problem in which one country has a cleaner technology than the other. We also present some results for small, open economies to examine the effects of transboundary pollution in the absence of terms of trade effects.

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1 Introduction

Concerns with the effects of freer international trade on environmental quality have been increasing in recent years. As trade patterns and the location of production change, there is concern about the spatial separation of polluting industries into pollution havens. While the creation of pollution havens may reduce domestic production of pollution in countries specializing in clean industries, the issue is complicated by the fact that pollution does not always respect national borders. Pollution of the Great Lakes in North America and the use of the Rhine River as a waste recipient for several European countries are two clear examples of pollution as a transboundary externality.

In this paper, we develop a model of trade between two countries in which the production in one industry confers a negative externality on the productivity of labour in another industry. As is well known (see Baumol and Bradford (1972)), a negative production externality renders the production possibilities set of a country non-convex. Our contribution is to consider the complications caused by transboundary pollution. The fact that pollution in one country may affect productivity in another causes the production possibilities sets of the two countries to be linked. Changes in the location of production caused by trade will not only affect domestic pollution, but will also change the position of the production possibilities frontier to the extent that foreign pollution changes.

The degree to which pollution has cross-border effects can temper the potential gains from trade of separating incompatible industries because trade will not necessarily remove the pollution problem. For example, Canada exports forest products and fishing trips to the United States and imports manufactured goods, some of which help produce acid rain. Acid rain generated in the United States, in turn, affects productivity in the forestry and freshwater fisheries industries of Canada. Since trade changes the location of production of different goods, it impacts on the extent to which transborder pollution occurs. Hence, the gains from trade may be offset or enhanced by changes in the location of dirty good production relative to autarky.

The current paper differs from much of the other work dealing with transboundary pollution and trade in its focus on production externalities. The literature generally assumes that pollution is detrimental because consumers suffer a disutility from pollution (Copeland (1996), Copeland and Taylor (1995a), Ludema and Wooten (1994), Markusen (1974, 1975), Rauscher (1991)). Dean (1991) provides a review of this literature.

The paper closest to the current one is Copeland and Taylor (1995b). They construct a dynamic model of trade between two countries in which production of one good detracts from a stock of environmental capital which is required for the production of another good. This results in a long-run production possibilities set that is non-convex. The non-convexity actually has the potential to be welfare-improving for both countries, as it tends to cause specialization, resulting in the separation of the conflicting industries. Clearly, transboundary pollution may temper these results, as separation is likely to be less desirable if the pollution simply drifts back across the border.

At the cost of modeling the dynamic evolution of environmental capital, we develop a general model to analyze the role of transboundary pollution. We allow for varying degrees of local versus transboundary pollution which nests the possibilities of pure local and pure global pollution. Indeed, the model nests a case that replicates the steady-state results of
Copeland and Taylor.

Our general model allows us to analyse interesting situations in more detail than that of Copeland and Taylor. We begin with an examination of two identical countries and show that (as in Copeland and Taylor) gains from trade do exist for at least one country and potentially both countries. Transboundary pollution in this case affects the range of demand preferences for the dirty versus the clean good over which specialization occurs.

We also also examine an acid rain problem in which transboundary pollution occurs in only one direction, though technologies in both countries are equally “dirty”. We show that trade changes the pattern of trade in a way that mitigates the transboundary externality. Although the “downwind” country experiences a reduction in pollution, it may actually lose from trade due to changes in the terms of trade.

Another interesting possibility is the use of technologies with different pollution intensities in the two countries. We show that if one country produces the dirty good with a cleaner technology than the other, trade may be detrimental for both countries. This occurs for a large set of plausible parameter values. In this case, the country with the superior technology may not have a comparative advantage in the polluting good, leading to the wrong pattern of trade from a social welfare perspective. An interesting result from this analysis is that “efficient” patterns of trade obtain only when transboundary pollution is relatively serious.

Finally, we examine the implications of our model for small open economies. The addition of a cross-border externality introduces an interdependence across neighboring small open economies that does not exist in the Copeland and Taylor model. We find that two small open economies that neighbor one another can have the same pattern of trade, in spite of having different patterns of comparative advantage initially. This somewhat surprising result occurs because in moving to free trade both countries experience the same direction of change in their patterns of comparative advantage due to the cross-border externality. In this situation we can expect to see spatial separation of industries by geographic regions containing several countries.

2 The Model

Consider a two country, two good model of trade. The dirty good, good 1, is produced with constant returns to scale but generates a pollution externality that negatively affects the productivity of labour in industry 2. In each country there are two industries that produce the two goods with linear technologies. Firms in each country have access to the same technologies and each good is produced with only one factor of production, labour, which is not mobile internationally. The total amount of labour in each country is normalized to one. The production function describing the technology in industry 1 is:

\[ q_1^i = L_1^i, \quad i = A, B \]  

where \( L_1^i \) is the amount of labour used in industry 1 production by country \( i \). The production function describing industry 2 is also linear, but the marginal product of labour is subject to an externality from the production of good 1:

\[ q_2^i = [1 - \beta q_1^i - \gamma q_1^j]L_2^i, \quad i, j = A, B, i \neq j \]  

\( q_1^i \) is the amount of labour used in industry 1 production by country \( i \). The production function describing industry 2 is also linear, but the marginal product of labour is subject to an externality from the production of good 1.
where $\beta_i q_1$ is a measure of the local negative externality domestic production of good 1 confers on the production of good 2, and $\gamma j q_1$ represents the cross-border negative externality production of good 1 in the foreign country confers on the productivity of labour in the clean industry in the home country. We can think of the total pollution “output” of the dirty industry in a country as being represented by $(\beta_i + \gamma j) q_1$ where part is felt domestically and part in the foreign country. The pollution externality causes the marginal product of labour in good 2 production to be decreasing in good 1 production of both the domestic and the foreign economy. We assume that $\beta_i + \gamma j < 1$ which is sufficient to ensure that productivity in the clean industry is always positive. This specification of the production externality nests the case in which the externality is entirely local $(\beta_i > 0, \gamma j = 0)$ and the case in which the externality is purely global $(\beta_i = \gamma j > 0)$ $i, j = A, B$.

The externality imposed by good 1 production on good 2 labour productivity results in a convex production possibility frontier as has been shown by Baumol and Bradford (1972) and Copeland and Taylor (1995b). The production possibilities curve is depicted in Figure 1. The slope of the production frontier is given by:

$$
\frac{d q_2}{d q_1} = -[(1 - \beta_i q_1 - \gamma j q_1) + \beta_i (1 - q_1)]
$$

 Increases in the output of industry 1 reduces productivity in industry 2 resulting in a convex production possibilities frontier.

As stated above, the externality in Copeland and Taylor (1995b) derives purely from local rather than foreign production. In their model, a country that completely specializes in the production of good 2 experiences no negative effects on its productivity of labour, regardless of the production level in the foreign country. In the context of the current model this would imply that the productivity of labour in industry 2 at point T in Figure 1 would be equal to one, the same as in industry 1. This is a special case of the current model, the case where $\gamma j = 0$. However, if there are any cross-border externalities, $\gamma j > 0$, then the marginal productivity of labour in industry 2, $1 - \beta_i q_1 - \gamma j q_1$, will be less than one whenever one of the two countries produces some of good 1. As foreign production of good 1 increases, the home country’s production possibilities frontier rotates around point S in Figure 1. The production possibilities frontier $ST'$ would be consistent with a higher level of production of good 1 in the foreign country than that which generates ST.

Consumers have the same preferences regardless of location. Each country is represented by a single consumer with preferences given by:

$$
u(x_1, x_2) = b \ln x_1 + (1 - b) \ln x_2
$$

where $x_k$ is the amount good $k$ consumed by the representative consumer of country $i$ and $b \in (0, 1)$ is the share of spending on good 1 which is the same for both countries. As in Eithier (1982) and Copeland and Taylor (1995b) we impose the Mill-Graham assumption of constant budget shares. Given these preferences, demand in either country is

$$
x_1 = \frac{bw_i}{p_1}
$$

and

$$
x_2 = \frac{(1 - b)w_i}{p_2},
$$
for \( i = A, B \), where \( w_i \) is the wage rate in country \( i \) and \( p^1_i \) and \( p^2_i \) are the prices of goods 1 and 2 in country \( i \).

The indirect utility function corresponding to equation (4) is given by

\[
v_i (w_i, p^1, p^2) = K + b \ln \left( \frac{w_i}{p^1_i} \right) + (1 - b) \ln \left( \frac{w_i}{p^2_i} \right),
\]

where \( K = b \ln b + (1 - b) \ln(1 - b) \). The effects of trade on real wages therefore, completely determines whether or not a country gains from trade.

**Autarky**

Consider these two countries in the absence of trade. Although countries do not trade with one another in autarky, production of good 1 in country \( B \) affects the productivity of good 2 production and prices in country \( A \), and vice versa. As a result, the position of the production possibilities frontier, in either country, is dependent upon global rather than just local production of good 1. Given equations (1), (2), (5), and (6), and the Mill-Graham assumption of constant budget shares there exists a unique autarkic equilibrium. \(^1\) The autarkic equilibrium level of production of good 1 in each country is

\[
\tilde{q}_1^i = b.
\]

Equilibrium output in industry 2 is determined in part by the level of industry 1 output in both countries and given by:

\[
\tilde{q}_2^i = (1 - b)[1 - b(\beta^i + \gamma^i)]
\]

Industry 2 output, in either country, is negatively related to the output of industry 1 in the foreign country.

Relative prices in autarky for the two countries can then be derived by making use of equations (8) and (9) and the fact that the wage is equal to the value of the marginal product of labour:

\[
\frac{\tilde{p}_1}{\tilde{p}_2} = 1 - b(\beta^i + \gamma^i).
\]

As long as (i) preferences are the same in each country, (ii) the supply of labour is the same in each country, and (iii) the domestic externalities and the cross-border externality effects are of equal value across countries (\( \beta^A = \beta^B, \gamma^A = \gamma^B \)), autarky prices will not differ between the two countries. As the negative effects of pollution become more pronounced, \( (1 - b(\beta^i + \gamma^i)) \) decreases, and the price of the clean good falls.

For general values of \( \beta^i \) and \( \gamma^i \) the autarky price of good 2 is higher in \( A \) than in \( B \) if

\[
\left( \frac{\tilde{p}_1}{\tilde{p}_2} \right)^A \geq \left( \frac{\tilde{p}_1}{\tilde{p}_2} \right)^B
\]

or

\[
\beta^A - \gamma^A \leq \beta^B - \gamma^B.
\]

\(^1\)If, as in Ethier (1982), we also adopt a Marshallian adjustment process, the autarky equilibrium is stable.

\(^2\)We will use a "\( \tilde{\cdot} \)" to denote autarky variables throughout the paper.
Notice that the requirement for $A$ to have a comparative advantage in the clean good does not depend directly on the “cleanliness” of its technology, as measured by $\beta_A + \gamma_A$, but rather by the extent to which the pollution externality is felt locally versus externally.

**The pattern of trade**

The pattern of trade will depend on the relative demand for the two goods. If demand for the dirty good is high ($b$ is large), then both countries will produce good 1 and only one will produce good 2. For low demand for the dirty good, only one country will produce good 1 and both will produce good 2. Complete specialization, if it occurs, will occur for some intermediate value of $b$.

For most of what follows we will assume that both countries are the same in all respects except that $\beta_A - \gamma_A \leq \beta_B - \gamma_B$, i.e., $A$ has a comparative advantage in the clean good. The results that follow are nevertheless, completely symmetric in the sense that if $\beta_A - \gamma_A > \beta_B - \gamma_B$, $B$ has a comparative advantage in the clean good. The different patterns of trade are derived in the appendix and are summarized as follows:

**Proposition 1** If $\beta_A - \gamma_A \leq \beta_B - \gamma_B$, the pattern of production is as follows:

1. $q_A^1, q_A^2 > 0; q_B^1 > 0, q_B^2 = 0$ if $1/2 < b < 1$,
2. $q_A^1 = 0, q_A^2 > 0; q_B^1 > 0, q_B^2 = 0$ if $\tilde{b} < b < 1/2$,
3. $q_A^1 = 0, q_A^2 > 0; q_B^1 > 0, q_B^2 > 0$ if $b < \tilde{b}$,(13)

where $\tilde{b} = (1 - \beta_B)/(2 - \beta_B - \gamma_B)$.

**Proof:** See appendix.

This result is similar to that in propositions 4 and 5 of Copeland and Taylor (1995b), with the exception that we provide an explicit solution for the range of $b$ over which the different patterns of trade emerge. This is due to the simpler, static nature of this model. One advantage of this model over that of Copeland and Taylor is that the range of the parameter space over which the different patterns of trade occur can be analysed readily. The following corollary follows from comparative statics on $\tilde{b}$.

**Corollary 1** The range of values of $b$ in which complete specialization occurs

1) decreases with $\gamma_B$,
2) increases with $\beta_B$, and
3) increases with equal increases to $\gamma_B$ and $\beta_B$.

Part iii) of the corollary captures the notion of increasing the “dirtiness” of a country. As the intensity of the externality increases in the country that has a comparative advantage in the dirty good, complete specialization occurs for a wider range of $b$.

The equilibrium wages corresponding to each possibility in Proposition 1 are derived in the Appendix and presented in Table 1. The solution for the real wages will be used in examining the welfare consequences of trade. If the pattern of trade is sensitive to relative
values of the pollution externality parameters, we might expect that welfare results depend on these as well. Rather than attempt to categorize gains and losses from trade in the general case, we will examine results for particular subsets of the possible parameter values. We will begin with the case in which the two countries are identical.

3 Two Identical Countries

Suppose the pollution parameters are $\beta^A = \beta^B = \beta$ and $\gamma^A = \gamma^B = \gamma$. As long as countries are identical in all respects, the autarky equilibrium prices will be the same across countries. Though there are gains from trade to be made because of the convex production frontier, the autarkic equilibrium is a potential equilibrium, though not the only one, in a world where countries are open to trade. Any deviation of prices from the autarky equilibrium values however, may lead a country to specialize depending upon the effects of the externality. Thus there are other potential trading equilibria that will be analyzed in this section.

In what follows, we examine changes in welfare due to trade under the assumptions that the effects of pollution are primarily local, $\beta > \gamma$. If, on the other hand, $\gamma > \beta$, there is a stable non-trading equilibrium in which prices remain at their autarky values. When pollution effects are purely global, $\gamma = \beta$, prices remain equal across countries and there is a continuum of trading equilibria that differ only in the distribution of production between countries.

From the prices given in Table 1 it is easy to check that for $b > 1/2$, both countries gain from trade. Wages in terms of good 1 are equal to their autarky values and wages in terms of good 2 are higher than their autarky values. The trading equilibrium Pareto dominates the autarky equilibrium in this case.

In the complete specialization case, $b \in (\tilde{b}, 1/2)$, the country that specializes in the clean good (country A in Table 1) gains from trade. However, the country specializing in the dirty good may gain or lose from trade. Comparing $w_B/p_2$ to the autarky wage, $B$ will gain from trade for $b$ close to $1/2$, but will lose for $b$ close to $\tilde{b}$.

Finally, for $b < \tilde{b}$, the country specializing in the clean good again gains from trade, but the country specializing in the dirty good loses from trade. For low values of $b$, both countries produce the clean good, however the country that produces the dirty good as well increases its production of the dirty good. This causes a decline in productivity in the clean industry relative to autarky.

The country that specializes in the clean good (A) always gains from trade, while the country that specializes in the dirty good (B) may gain or lose depending on $b$. Two effects combine to generate losses for country B. First, B, by specializing in good 2, reduces its pollution. This causes B’s production possibility frontier to shift upwards along the good 2 axis. However, B, by specializing in good 1 production, limits the gains it realizes due to this productivity improvement. Second, the terms of trade move against country B. The extent of this terms of trade effect is governed by the share of expenditures spent on the dirty good. For a low share, the terms of trade deterioration is large and B suffers a loss in welfare. For a larger share the terms of trade do not deteriorate as badly for B leading to a deterioration relative to autarky prices.

3 Throughout the paper we refer to a deterioration in the terms of trade as a deterioration relative to autarky prices.
gain in welfare relative to autarky.

To illustrate these welfare results we plot $v^i$ from equation (7), against $b$ for $\beta = 0.4$ and $\gamma = 0.1$ in Figure 2 for the autarky equilibrium and for the two countries in one of the trading equilibria (we assume $A$ specializes in good 2 and $B$ specializes in good 1). It is clear from Figure 2 that $B$ may gain or lose from trade in the completely specialized equilibrium.

The effect of transboundary pollution in this identical country case is quantitative rather than qualitative. If there were no transboundary pollution in this case ($\gamma = 0$), Figure 2 would look qualitatively similar. The effects of transboundary pollution are less benign when we allow countries to differ, as we do in the following 2 sections.

4 Acid Rain

Suppose that cross-border pollution only flows from country $A$ to $B$ but not in the other direction. This would occur, for example, when the direction of prevailing winds imply that one country does not absorb the full measure of pollution generated within its borders. The primary effect of cross-border pollution is to lower labour productivity in industry 2 in the downwind country. It is natural to ask to what extent trade will mitigate the harmful effects of acid rain. Two potentially conflicting forces are at work. First, trade may separate the industries in a beneficial way. Second, the terms of trade may adjust to offset the gains from separation.

The notion of acid rain can be captured in our model by imposing the following restrictions: $\beta^A, \gamma^A > 0; \beta^B > 0, \gamma^B = 0; \text{and } \beta^A + \gamma^A = \beta^B$. This last restriction implies that the pollution generated in the dirty industry is the same for both countries. The local effect is lower in $A$ than in $B$ due to some of the pollution crossing the border into $B$.

Country $A$’s technology for good 2 now reflects the fact that it receives no cross-border pollution from $B$ and can be rewritten as:

$$q^A_2 = (1 - \beta^A q^A_1) L^A_2$$

while $B$’s technology for good 2 production is unchanged:

$$q^B_2 = (1 - \beta^B q^B_1 - \gamma^A q^A_1) L^B_2$$

Relative autarky prices are still given by (10) for $B$ and $A$, where $\gamma^B$ is equal to zero for $A$. Country $A$ has a comparative advantage in the clean good since (12) clearly holds in this case: $\beta^A - \gamma^A < \beta^B$. Proposition 1 implies that in this case $A$ will specialize in production of the clean good. The country producing the acid rain has a comparative advantage in the non-polluting good. This is the “correct” pattern of trade from the point of view of mitigating the harmful effects of the transboundary externality. The question remains as to whether or not the countries gain from trade. Country $A$ reduces its output of the dirty good with trade, and since it encounters no extra pollution from $B$’s increased output, its productivity in the clean industry will rise. Country $B$ will increase production of the dirty good with no change in productivity in that industry. The question of gains or losses from trade will be answered by comparing these productivity changes with changes in the terms of trade.
Consider case i) of Proposition 1, high demand for the dirty good. A produces both goods while B specializes in good 1. In terms of good 1 there is no change in the real wages when countries trade, since both countries produce good 1 in this case. Consequently, welfare increases in a country if real wages rise in terms of good 2. For country A, a welfare improvement requires that
\[
\frac{w_A}{p_2} = 1 - \beta^A (2b - 1) > 1 - b \beta^A = \frac{\tilde{w}_A}{\tilde{p}_2},
\]
which is easily seen to hold. Thus A gains from trade. It decreases its production of good 1 relative to autarky, resulting in an increase in productivity in industry 2, since country B’s increased production of good 1 does not cause increased pollution in A. In addition, it experiences an improvement in its terms of trade.

Country B also sees a gain from trade. In this case, trade equalizes good 2 wages across the countries: \(w_A/p_2 = w_B/p_2\). Since the autarky good 2 wage is higher in A than in B, it follows that \(w_B/p_2\) must also be higher than in autarky. Since \(w_B/p_1\) is unchanged from autarky, B must gain. Although industry 2 productivity is harmed by the increase in good 1 production in B, this does not matter as B specializes in good 1.

Now consider case ii) of Proposition 1. Both countries completely specialize in production. Good 1 will be produced in Country B and good 2 in Country A. Specializing in good 2 production, combined with the lack of transboundary pollution from B, causes productivity in industry 2 in A to rise to one: \(w_A/p_2 = 1\). In order to not produce good 1, \(w_A/p_1 > 1\) must be true. Since wages in terms of both good rise in A, it gains from trade.

In country B wages in terms of good 1 are still equal to unity so welfare will improve if its wages in terms of good 2 increase:
\[
\frac{w_B}{p_2} = \frac{b}{1-b} > 1 - b (\beta^A + \gamma^A) = \frac{\tilde{w}_B}{\tilde{p}_2},
\]
or
\[
0 > 1 - (2 + \beta^B + \gamma^A) b + (\beta^B + \gamma^A) b^2.
\]
Is is easy to show that one of the roots of the right hand side of this inequality is less than 1/2. Thus, for some values of \(b\), B will also gain from trade. Less obvious is the possibility that \(b\) may be in the range where complete specialization occurs, yet B will lose from trade. This loss occurs because, for relatively small values of \(b\), B experiences a greater deterioration in its terms of trade and a fall in welfare. In spite of the fact that it completely specializes in production and does not experience any negative effects of pollution on productivity, the terms of trade can deteriorate sufficiently in country B to lower welfare. The extent of this deterioration is governed by the share of expenditures on the dirty good. For a “low” share, \(b\) near \((1 - \beta^B) / (2 - \beta^B)\), the terms of trade deterioration is large and Country B suffers a loss in welfare. For a larger share, \(b\) near 1/2, the terms of trade do not deteriorate as badly leading to a gain in welfare relative to autarky.

Finally, consider the possibility that demand for the dirty good is low, case iii) of Proposition 1. Both countries produce good 2, whereas good 1 is produced only in country B. Once again since there is no cross-border pollution from country B to A and country A does not produce good 1, therefore, A does not experience any pollution. This implies that wages
in terms of goods 2 are equal to one in country A, whereas wages in terms of good one are greater than one. Country A therefore, gains from trade.

Country B produces both goods and while it no longer receives any cross-border pollution from A, it generates greater levels of domestic pollution when it specializes in the production of good 1. In fact, if $\gamma^B > \gamma^A$, specialization on the part of B leads to a higher level of pollution and lower productivity in good 2 under free trade than autarky. Real wages in terms of good 2 are lower in country B under free trade, whereas wages in terms of good 1 remain unity. Country B consequently, loses from trade. Though trade patterns change in such a way that the cross–border pollution is eliminated, the “downwind” country experiences a deterioration in its terms of trade and still loses from trade.

The results of this section are summarized in the following proposition:

**Proposition 2** If $\gamma^A > 0, \gamma^B = 0$, and $\beta^A + \gamma^A = \beta^B$, and (12) holds, then A always gains from trade while B will gain from trade for “large” values of $b$ and lose from trade for “small” values of $B$.

These results are illustrated in Figure 3 for $\beta^A = 0.4, \gamma^A = 0.1, \beta^B = 0.5$ and $\gamma^B = 0$. The simulation results confirm those discussed above.

## 5 International Differences in Pollution Intensity

Suppose that the production technology in A is such that it produces less pollution than in B. For simplicity, assume that production of good 1 in A does not generate any pollution ($\beta^A = \gamma^A = 0$), whereas production in country B generates $\beta^B > 0$ units of local pollution and $\gamma^B > 0$ units of cross-border pollution. The production functions for the clean good in each country can be written as:

$$q^A_2 = (1 - \gamma^B q^B_1) L^A_2$$  \hspace{1cm} (19)$$

$$q^B_2 = (1 - \beta^B q^B_1) L^B_2$$  \hspace{1cm} (20)$$

The source of pollution in country A is solely due to pollution crossing the border from the production of good 1 in country B, whereas in country B, pollution is purely local. Notice that (12) holds only if $\beta^B > \gamma^B$.

In the autarky equilibrium relative prices in A are $1 - b\gamma^B$ whereas in B they are $1 - b\beta^B$. When (12) holds, Proposition 1 stipulates that A will specialize in the clean good which is the “wrong” pattern of trade. Ideally, the country with the clean technology for producing the dirty good should specialize in that good in a trading equilibrium. Since B’s good 1 output damages its domestic good 2 industry more than that in A, B will have a comparative advantage in good 1. Conversely, if (12) does not hold ($\beta^B < \gamma^B$), A will have a comparative advantage in the dirty good and the pattern of trade will be the “correct” one.

In what follows we first analyse the welfare effects of trade when (12) holds. Not surprisingly, we find that it is possible that both countries lose from trade when the “wrong” pattern of specialization results. On the other hand, both countries will gain from trade when pattern of trade is the “correct” one.

To begin consider the case when $b > 1/2$. Country A produces both goods while B completely specializes in good 1 production. Real wages across both countries remain
equal to unity in terms of good 1 and are equalized in terms of good 2. Country A is made worse-off with trade since its wage in terms of good 2 declines from the autarky level of 
\(1 - b^{\gamma}p^B\) to \(1 - \gamma^B\). The increase in B’s production of good 1 generates a larger amount of cross border pollution flowing from country B to A than in autarky, resulting in lower good 2 labor productivity and a drop in country A’s real wage in terms of good 2.

For country B, compared to the autarky good 2 wage of \(1 - b^{\beta}p^B\), it is clear that B will gain from trade if \(b > \gamma^B / \beta^B\). A low ratio of \(\gamma^B / \beta^B\) implies a large autarky price difference between country A and B, making it more likely that the terms of trade will improve for B. Country B has more pollution than A in autarky, \(\beta^B > \gamma^B\), and though free trade raises pollution levels in A, the price of good 2 for B is still lower than in autarky. On the other hand, if \(1/2 < b < \gamma^B / \beta^B\) both countries lose from trade since pollution in A increases beyond the autarky level in country B. Country B’s terms of trade therefore, deteriorate.

Wages in terms of good 1 are equal to one in Country B and \((1-b)/b > 1\) in Country A. Wages in terms of good 2 for Country A however, decline with trade and are given by:

\[
\frac{w_A}{p_2} = 1 - \gamma^B
\]  

(21)

When country B specializes in good 1 production, A experiences higher levels of cross-border pollution, lower productivity in good 2 production, and a fall in its real wage in terms of good 2. Country A may still gain from trade however, because its good 1 wage rises. For low values of \(\gamma^B\) relative to \(\beta^B\) combined with \(b\) close to \(1/2\), A gains from trade. The degree of cross-border pollution is now relatively low so that the increase in the real wage in terms of good 1 compensates for the loss in productivity in producing good 2. At the other extreme, \(b > \gamma^B / \beta^B\) both countries lose from trade since pollution in A increases beyond the autarky level in country B. Country B’s terms of trade therefore, deteriorate. Compare now the complete specialization case: \((1 - \beta^B)/(2 - \beta^B - \gamma^B) < b < 1/2\).

Wages in terms of good 1 are equal to one in Country B and \((1-b)/b > 1\) in Country A. Wages in terms of good 2 for Country A however, decline with trade and are given by:

\[
\frac{w_B}{p_2} = \frac{b(1 - \gamma^B)}{1 - b}. 
\]  

(22)

Compared to the autarky real wage in terms of good 2, B will gain from trade if \((1/b) < 1 + b^B - (1-b)\beta^B - \gamma^B\). This will occur if the local pollution effect in B is relatively large, \(\beta^B > (1/2 + \gamma^B)/(1-b)\). With a comparatively low cross-border effect, B can purchase good 2 at a lower price from A than it could produce it in autarky. Country B’s terms of trade improve and it is made better-off. Conversely, if the cross-border effect is large, B’s terms of trade deteriorate and it losses from trade because A experiences higher levels of pollution in free trade than B in autarky.

Finally, if \(b < (1 - \beta^B)/(2 - \beta^B - \gamma^B)\), A specializes in good 2 and B produces both goods. B’s real wage in terms of good 1 is unity and its good 2 wage is \(1 - \beta^B q^B\). Country B is diversified and increases its production of the dirty good thereby generating a higher level of domestic pollution in the free trade equilibrium. B’s real wage in terms of good 2 is now less than its autarky wage, \((1 - \beta^B b)/(1 - \beta^B q^B)\) and so B loses from trade.

Country A’s real wage in terms of good 1 rises with trade, \((q^B - b)/b > 1\), and its good 2 wage, \(1 - \gamma^B q^B\), falls. For values of \(\beta^B\) significantly greater than \(\gamma^B\), the amount of cross-border pollution is not sufficient to offset A’s terms of trade improvement and A gains from
trade. Alternatively, if $\gamma^B$ is relatively close in value to $\beta^B$, $A$ will lose from trade because the comparatively high levels of cross-border pollution in $A$ offset the benefits of higher real wages in terms of good one.

These results are summarized in the following proposition:

**Proposition 3** If $\beta^A = \gamma^A = 0$ and $\beta^B > \gamma^B$, both countries may lose from trade.

Figures 4 and 5 plot welfare versus $b$ for the two countries for a two different values of $\gamma^B$ relative to $\beta^B$. In Figure 4, $\gamma$ is relatively small so that $A$ gains from trade when $b$ is low and losses when demand for the dirty good is high. Country $B$ obtains the opposite pattern of welfare change, gaining when $b$ is high and losing when $b$ is low. Figure 5 shows as situation in which both countries lose from trade for any value of $b$. This occurs for relatively large values of $\gamma$.

Another interesting possibility when $A$ has a clean technology is the the case where $\beta^B < \gamma^B$. This possibility would occur when the downwind country possesses the clean technology and the prevailing “wind patterns” are such that a greater amount of the pollution generated in $B$ flows across the border into $A$. Within this framework we once again consider changes in the patterns of trade and the implications of trade for welfare.

**Proposition 4** If $\beta^B < \gamma^B$ there is no completely specialized equilibrium and both countries gain from trade.

**Proof:** If both countries completely specialize, $q^A_1 = 1$, $q^A_2 = q^B_1 = 0$ and $q^B_2 = 1$. Real wages are:

$$\frac{w_A}{p_1} = \frac{w_B}{p_2} = 1$$

(23)

Country $B$ doesn’t produce good 1 so there is no pollution in the world. Since Country $A$ does not produce good 2 its wage in terms of good 2 must be greater than 1 and the same holds true for the real wage in terms of good 1 in Country $B$. Solving for country $B$’s real wage in terms of good 1 yields, $w_B/p_1 = (1-b)/b$, from which it follows that $w_A/p_2 = b/(1-b)$.

For $A$ to specialize in good 1 then it must be true that $b/(1-b) > 1$ or that $b > 1/2$. Likewise, for $B$ to specialize in good 2 it must be true that $(1-b)/b > 1$ or that $b < 1/2$. Therefore, it is not possible for both countries to simultaneously specialize in production.

When $b < 1/2$, $A$ is diversified and $B$ specializes in good 2 and so world pollution falls to zero. All wages are equalized to unity, both countries experience an improvement in their terms of trade and gain from trade.

If, on the other hand, $b > 1/2$, Real wages in terms of good 1 are unity in both countries. In $B$, production of good one declines relative to autarky yielding lower levels of pollution. Labour productivity and real wages in terms of good 2 rise in both countries, so they both gain from trade. **Q.E.D.**

When $B$’s pollution is more cross–border than local, trade redistributes production in a mutually beneficial way. Production of the polluting good by the country with the dirty technology is minimized. This result at first seems puzzling. In the case where a country’s
pollution is felt more in the foreign country than at home, unrestricted trade provides the correct incentives to reduce production of the offending good. When the pollution has a larger effect on domestic productivity than foreign, trade actually provides the contrary incentive to raise production of the offending good in the dirty country. When pollution is primarily local, the dirty country, by harming its own environmentally sensitive industry relatively more, has a comparative advantage in the dirty good. This perverse pattern of comparative advantage cannot be reversed by free trade. A larger international externality is beneficial to both countries in this case.

6 International Trade: The Small Open Economy

In this section, we explore the effect of transboundary pollution when the two countries are small, so that a change in the output mix by one country does not affect the terms of trade. This allows us to isolate the effects of transboundary pollution on a neighboring country from terms of trade effects.

In Copeland and Taylor (1995b) when two small open economies have slightly different production parameters and, initially, different patterns of comparative advantage in autarky, they will have the opposite patterns of trade. In the current model however, the addition of a transboundary pollution effect inextricably links the trade pattern of a small country to its neighbors. Two small countries with slightly different patterns of comparative advantage in autarky could end up with the same patterns of trade.

Suppose countries A and B are identical in all respects and face world prices that are fixed at the original autarky price ratio given by equation (10). These two economies are small in the sense that they take world prices as given, yet they are isolated from the rest of the world with respect to pollution. If A were to slightly increase its production of good 1, then the ensuing decrease in the productivity of industry 2 would result in a fall in the domestic price of good 1. Country A would then gain a comparative advantage in the production of good 1. With a convex production possibilities frontier, this implies that A will specialize in the production of good 1 and produce one unit of the dirty good. Complete specialization would therefore result in a welfare improvement for this country because it shifts out of production of the environmentally sensitive good and specializes in the production of good 1 for which the productivity of labour does not change. Country A moves from a point of diversification on the ST production possibilities frontier in Figure 1 to point S and trades at the same world price so that utility rises.

Country B now experiences a greater level of cross-border pollution due to the rise, from b to one, in good 1 production for country A. This leads to a change in B’s PPF that is analogous to moving from ST to ST’ in Figure 1. Productivity in good 2 production declines in B. Therefore, B also gains a comparative advantage in good 1 production, completely specializes in good 1, trades at the same world prices and is made better-off.

At the opposite extreme, if A were to slightly increase its production of good 2 from its autarky level it would gain a comparative advantage in good 2 production. Country A will now completely specialize in the environmentally sensitive good and will be made better-off with trade. Since A is a small open economy and trades at the same world price it, gains from trade as it moves from a point on the interior of the ST PPF to point T in Figure 1.
Likewise, $B$ realizes an improvement in good 2 productivity as cross-border pollution from $A$ falls to zero. Country $B$’s response mirrors that of Country $A$, it completely specializes in good 2, trades at world prices and gains from trade.

The model yields three possible equilibria. In all three equilibria the pattern of trade in one small open economy is directly linked to that in a neighboring small open economy. If the autarky price is slightly below the world price, a small open economy will completely specialize in the production of good 1. This causes a neighboring small open economy that experiences cross-border pollution to also specialize in good 1. Conversely, if autarky prices are slightly above world prices, and neighbouring country $B$, will completely specialize in good 2. These results are a direct consequence of the convex production frontier. Finally, if the autarky price is equal to the world price these countries have no incentive to trade.\footnote{One could also apply models developed in the previous section to the case of two small open economies. In the acid rain scenario, it is possible for $p_A > p_B > p_w$. Country $A$ has a comparative advantage in good 2 and country $B$ in good 1. As $A$ specializes in good 2 however, the relative price ratio in $B$ rises as it receives less cross-border pollution. Under certain parameter values, this can lead to a shift in the pattern of comparative advantage in $B$ so that both small open economies specialize in good 2 production.}

The analysis of this section suggests that trade may result in separation of incompatible industries across regions. In world made up of geographically dispersed small, open economies, we might expect to observe clustering of countries by specialization.

\section{Conclusion}

We have developed a relatively simple model to analyze the effects of pollution externalities on trade. The model is quite general in that it nests a variety of interesting possibilities: pure local pollution, pure global pollution, acid rain, and differences in cleanliness of technologies. A general result is that, even if trade causes output patterns to change in a way that reduces the extent of the international externality, countries may still lose from trade.

Clearly these results suggest that there is the potential for environmental or trade policy intervention to play a beneficial role in mitigating the damage caused by pollution. Analysis of the effects of environmental policy without consideration of its impact on the terms of trade however, may provide misleading conclusions. For example, in Section 5, we showed that a country with a clean technology may not gain from trade because of the negative terms of trade effects. If a country were to attempt to clean up its emissions unilaterally, negative terms of trade effects may cause a net loss in welfare.
A Appendix

Proof of Proposition 1

The three cases enumerated in Proposition 1 are the only possible trading patterns. We look at each one in turn and derive the restrictions on the parameter values under which each obtains.

Consider \( i \). Since both countries produce good 1, we must have

\[
\frac{w_A}{p_1} = \frac{w_B}{p_1} = 1. \tag{24}
\]

For \( B \) to produce no good 2, wages in terms of good 2 in \( B \) must be as follows:

\[
\frac{w_B}{p_2} > 1 - \beta^B q_1^B - \gamma_A q_1^A. \tag{25}
\]

Finally, for \( A \) to produce good 2 requires

\[
\frac{w_A}{p_2} = 1 - \beta^A q_1^A - \gamma^B q_1^B. \tag{26}
\]

Since country \( B \) does not produce good 2, \( q_1^B = 1 \). World consumption of good 1, from (5) is \( x_1 = 2b \), hence \( q_1^A = 2b - 1 \). This implies

\[
\frac{w_A}{p_2} = 1 - \beta^A (2b - 1) - \gamma^B. \tag{27}
\]

Wages in terms of good 2 are equal to the marginal product of labour in good 2 production in country \( A \). We can then write

\[
q_2^A = (2 - 2b) \frac{w_A}{p_2}, \tag{28}
\]

which implies, after equating world demand and supply in the market for good 2, that

\[
\frac{w_B}{p_2} = \frac{w_A}{p_2}. \tag{29}
\]

For \( B \) to not produce good 2 requires

\[
\beta^B - \gamma^B > (2b - 1) (\beta^A - \gamma^A), \tag{30}
\]

which is true if \( b < 1 \) given our assumption that \( \beta^A - \gamma^A < \beta^B - \gamma^B \). Thus, if \( A \) remains diversified with trade, \( B \) will specialize in the dirty good.

We next turn to the condition under which \( A \) will remain diversified with trade. Consider \( ii \), the case of complete specialization: \( q_1^A > 0, q_2^A = 0, q_1^B = 0, q_2^B > 0 \). Since only country \( A \) produces good 2,

\[
\frac{w_B}{p_1} = 1 \quad \text{and} \quad \frac{w_A}{p_1} > 1, \tag{31}
\]

and, since country \( B \) does not produce good 2,

\[
\frac{w_B}{p_2} > 1 - \beta^B q_1^B \quad \text{and} \quad \frac{w_A}{p_2} = 1 - \gamma^B q_1^B. \tag{32}
\]
Since country B devotes all available labour to good 1 production, \( q_B^1 = 1 = x_1 \). Consumption by country B is \( x_1^B = bw_B/p_1 = b \), hence, \( x_1^A = 1 - b \) must be true. Therefore, since \( x_1^A = bw_A/p_1 \), then \( w_A/p_1 = (1 - b)/b \). For A to set \( q_A^1 = 0 \) in a specialized equilibrium, \( (1 - b)/b > 1 \), or \( b < 1/2 \).

Country A devotes all its resources to production of good 2, thus \( q_A^2 = 1 - \gamma_B \), since \( q_A^1 = 1 \). World demand for good 2 is
\[
    x_2 = (1 - b) \left( \frac{w_A}{p_2} + \frac{w_B}{p_2} \right) = 1 - \gamma = q_2^B.
\]
Since, \( \frac{w_A}{p_2} = 1 - \gamma_B \),
\[
    \frac{w_B}{p_2} = \frac{b(1 - \gamma_B)}{1 - b}.
\]
For country B to not produce good 2, it must be the case that, from equation (32),
\[
    \frac{b(1 - \gamma_B)}{1 - b} > 1 - \beta_B,
\]
or,
\[
    b > \frac{1 - \beta_B}{2 - \beta_B - \gamma_B}.
\]
For \( \beta_B > \gamma_B \), it is easy to see that the right hand side of (36) is less than 1/2. Thus, the trading equilibrium will involve complete specialization if \( b \in \left( \frac{1 - \beta_B}{2 - \beta_B - \gamma_B}, \frac{1}{2} \right) \).

Finally, a trading equilibrium will involve only one country producing good 1 and both producing good 2 (case iii of Proposition 1) if demand for good 2 is relatively high, i.e. \( b \in \left[ 0, \frac{1 - \beta_B}{2 - \beta_B - \gamma_B} \right] \). Country A devotes its entire labour force to production of good 2. Production of good 2 by country B is
\[
    q_2^B = x_2 - q_2^A = (1 - b) \left[ \frac{w_B}{p_2} + \frac{w_A}{p_2} \right] - (1 - \gamma_B q_A^1).
\]
Using equilibrium real wages we see that
\[
    q_2^B = (1 - b) \left[ 2 - (\beta_B + \gamma_B) q_A^1 \right] - 1 + \gamma_B q_A^1.
\]
The technology of good 2 production implies
\[
    q_2^B = (1 - \beta_B q_A^1) (1 - q_A^1).
\]
Thus,
\[
    \beta_B [q_A^1]^2 - [1 + b(\beta_B + \gamma_B)]q_A^1 + 2b = 0
\]
defines output of \( q_A^1 \), which is
\[
    q_A^1 = \frac{1 + b(\beta_B + \gamma_B) - \sqrt{[1 + b(\beta_B + \gamma_B)]^2 - 8b\beta_B}}{2\beta_B}.
\]
Wages are then
\[
    \frac{w_A}{p_1} = \frac{q_A^1 - b}{b} = 1 - \gamma_B q_A^1 \quad \frac{w_A}{p_2} = 1 - \beta_B q_A^1
\]
\[
    \frac{w_B}{p_1} = 1 \quad \frac{w_B}{p_2} = 1 - \beta_B q_A^1
\]
References


Table 1: Equilibrium wage rates

<table>
<thead>
<tr>
<th>$b &gt; 1/2$</th>
<th>$b \in (\bar{b}, 1/2)$</th>
<th>$b &lt; \bar{b}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$w_A/p_1$</td>
<td>1</td>
<td>$(1 - b)/b$</td>
</tr>
<tr>
<td>$w_A/p_2$</td>
<td>$1 - \beta^A(2b - 1) - \gamma^B$</td>
<td>$1 - \gamma^B$</td>
</tr>
<tr>
<td>$w_B/p_1$</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>$w_B/p_2$</td>
<td>$1 - \beta^A(2b - 1) - \gamma^B$</td>
<td>$b(1 - \gamma^B)/(1 - b)$</td>
</tr>
</tbody>
</table>

Where $\theta = \frac{1 + b(b^A + \gamma^B) - \sqrt{(1 + b(b^A + \gamma^B))^2 - 4b^2\gamma^B}}{2b^A}$
Figure 1: Production Possibilities Frontier

Good 2

T

T'

S

Good 1
Figure 2: Welfare versus expenditure share of dirty good
Identical Countries
$\beta^A = \beta^B = 0.4, \quad \gamma^A = \gamma^B = 0.1$

Figure 3: Welfare versus expenditure share of dirty good: Acid Rain
$\beta^A = 0.4, \quad \gamma^A = 0.1, \quad \beta^B = 0.5, \quad \gamma^B = 0$

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Figure 4: Welfare versus expenditure share of dirty good
No pollution produced by country A
$\beta^A = 0$, $\gamma^A = 0$, $\beta^B = 0.4$, $\gamma^B = 0.1$

Figure 5: Welfare versus expenditure share of dirty good
No pollution produced by country A
$\beta^A = 0$, $\gamma^A = 0$, $\beta^B = 0.3$, $\gamma^B = 0.25$