Resource and Energy Economics 19 (1997) 321–344

RESOURCE
and ENERGY
ECONOMICS

The trade-induced degradation hypothesis

Brian R. Copeland[a]*, M. Scott Taylor[b]

[a] *Department of Economics, University of British Columbia, Vancouver, B.C., Canada*
[b] *Department of Economics, University of British Columbia, Vancouver, B.C., Canada and NBER and CIAR*

Revised 1 November 1996

Abstract

This paper develops a simple two-sector dynamic model to examine the effectsof international trade when government policy regarding the environment is short sighted, but still responsive to changes in income levels and in the quality of the environment. We show that free trade can usher in a negatively reinforcing cycle of increased pollution, lower environmental quality, and lower real incomes. Such cycles are not possible in autarky. We link the potential for trade to cause 'large' environmental consequences to the structure of tastes and technologies and the attributes of industrial pollution. © 1997 Elsevier Science B.V.

Keywords: Trade-induced degradation hypothesis; Pollution policy

1. Introduction

During the past few years there has been a lively debate over the potential environmental consequences of free trade.[1] Some environmentalists have

---

* Corresponding author: Department of Economics, 997-1873 East Mall, University of British Columbia, Vancouver, B.C., Canada, V6T 1Z1. E-mail: copeland@econ.ubc.ca, taylor@econ.ubc.ca

[1] See for example the debate between Bhagwati, 1993 and Daly, 1993 in Scientific American. For empirical work, see Grossman and Krueger, 1993; Selden and Song, 1994. For theory, see Copeland, 1994; Copeland and Taylor, 1994; Copeland and Taylor, 1995a,b,c; Rauscher, 1991; Lopez, 1994; and the pioneering work of Markusen, 1975, 1976

PII S0928-7655(97)00015-8

argued that free trade may both worsen global environmental quality and allow rich countries to export their environmental problems to poor countries. Many economists are, however, sceptical of the pivotal role environmentalists often attribute to international trade. For example, in an influential study of the environmental impact of NAFTA, Grossman and Krueger (1993) voice a commonly held view that 'While the environmental groups have raised a host of valid questions, they have so far been unable to provide convincing and well supported answers to these questions. Many of their arguments fail to recognize all of the implications of trade liberalization'.

Grossman and Krueger provide empirical evidence that some aspects of environmental quality improve with income. This suggests that to the extent that trade promotes income growth, it can also lead to a cleaner environment. Environmentalists counter by suggesting that international trade can play a key role in initiating a vicious cycle in which trade-induced environmental degradation begets income losses, and not gains. Moreover, these income losses can then lead to further degradation (Daly, 1993). We refer to this argument as the *trade-induced degradation hypothesis*. In this paper we attempt to meet the Grossman and Krueger critique by providing a theoretical basis for the trade-induced degradation hypothesis. Our purpose in providing this example is not to argue against free trade or to provide aid and comfort to those who view 'protectionism' as protection for the environment. Rather our purpose is to identify another mechanism by which free trade may impact on the environment.

The trade induced degradation hypothesis has two elements. First, international trade allows consumers of final products to escape the pollution created by their production. As a consequence, in the words of Daly (1993), p. 57 by 'separating the costs and benefits of environmental exploitation, international trade makes them harder to compare. It thereby increases the tendency for economies to overshoot their optimal scale.' Second, Daly (1993), p. 57 goes on to note that since free trade is likely to stimulate the growth of output, 'Economic growth beyond that optimum would increase the environmental costs faster than it would the production benefits, thereby ushering in an anti-economic phase that impoverished rather than enriched. One can find disturbing evidence that we have already passed that point, and like Alice in Through The Looking Glass, the faster we run the farther behind we fall.' Others quite prominent in recent policy debates have expressed similar concerns.[2]

Although we still have only a limited understanding of the complex linkages between openness to international markets and environmental outcomes, it is clear that one of the key factors determining the effect of trade on the environment is the response of policy. It is well known that if pollution policy is either too weak or too rigid, then trade liberalization need not improve welfare because the costs of increased pollution can overwhelm the standard gains from trade.[3] The Grossman-Krueger argument that growth may improve environmental quality relies on an income-induced 'technique effect' – a tightening up of pollution policy in response to increased income. Without this technique effect, the increased scale of economic activity would tend to increase pollution, although changes in the composition of output may reduce pollution. Unfortunately, the technique effect is not an automatic response of markets. Rather, as higher income generates increased demand for environmental quality, the government must be willing and able to translate this increased demand into improved pollution regulations. In previous work, we have considered both the cases of fully optimal policy and of complete policy failure.[4] The reality lies somewhere in between, and in this paper we explore the implications of myopic policy — policy which responds fully to the short run effects of environmental degradation, but does not fully internalize the long run effects.

In much of our earlier work we focused on pollutants that reduce utility but do not affect production possibilities. In some of the literature these are referred to as 'eyesore' pollutants. In Copeland and Taylor (1994) we examined how trade may affect the environment through the scale, composition, and technique effects. In Copeland and Taylor (1995a) we examined how income differences across countries affect the nature of strategic interactions over pollution policy and thereby affect the quality of the global environment. Given the emphasis environmentalists place on the 'real costs' of pollution, in Copeland and Taylor (1995c) we departed from our earlier work by assuming that pollution can affect a nation's production possibility set by degrading its stock of productive environmental capital. Within the context of a two country model (with no active pollution policy) we showed how international trade may provide benefits to both countries by spatially separating dirty and clean industries and thereby raising the world's production possibilities.

Here we combine and extend this earlier work. We follow our earlier work (1994, 1995a,b) by assuming that pollution creates an instantaneous 'eyesore' cost, and that governments are active in adjusting pollution policy when any

---

[2] For example, after alleging that today's trading patterns effect a massive transfer of the environmental costs of global gross national product to the poorer, resource based economies of the developing countries, MacNeill, 1989 p. 157 states that 'The basic economic capital of developing, and parts of some developed, countries - their environment and renewable resources - is being consumed faster than it can be restored or replaced. Some developing countries have depleted virtually all of their ecological capital and are on the brink of environmental bankruptcy...... With these factors as a backdrop, it is easy to envision the future as one of ever-increasing environmental degradation, poverty and hardship among ever-declining resources in an ever more polluted world'.

[3] See Copeland (1994) for an analysis of conditions under which trade liberalization may be welfare improving when pollution policy is inadequate.

[4] See Copeland and Taylor, 1994, 1995c.

change in income alters the demand for environmental quality. As a result we allow for the possibility of free trade raising incomes and thereby increasing the demand for tighter pollution regulation. We depart however from our earlier work in two significant ways.

First we allow for the realistic possibility that industrial pollution is a joint product. We assume that a unit of pollution creates both an immediate eyesore cost and a long run 'real cost' by degrading the environment's capital stock. For many environmentalists these long run stock effects are critical, since the flow of services from the stock includes cleansing the air we breathe, purifying the water we drink, and filtering the sun we rely on. And while the empirical evidence is not strong enough to warrant the alarmist predictions of some, there are numerous examples from the past which suggest that the productivity of resource-based industries can be adversely affected by poor environmental management.[5]

In a second departure from our earlier work we assume that while government policy is successful in internalizing the eyesore cost of pollution, it is myopic in that it ignores industrial pollution's long run effect on environmental capital. Therefore we examine the consequences of free trade within an already distorted economy, where pollution policy is active and responsive, but not perfect.[6] To keep matters simple we limit ourselves to a small open economy setting, and therefore cannot examine the effects of endogenous world prices on pollution flows, or examine how the spatial separation of industries across countries may affect world production efficiency. Throughout we assume that pollution stays within the country of origin. This simple framework is designed to isolate the impact of free trade when government policy is less than perfect but active and responsive to both changes in the environment and changes in income levels.

Our results indicate that trade can indeed set in motion a negatively reinforcing cycle of environmental degradation and real income loss that

---

[5] Denmark provides a classic example of this. It suffered an ecological crisis in the 16th century (see Kjaergaard, 1994). Too many trees were harvested near the ocean shore, and this allowed sand dunes to migrate further inland until up to half the country was affected. This reduced food production and sent the country into a downward ecological spiral. In Canada, conflicts between fishing and the forest and mining industries provides another important example. Mining and forestry can lead to contamination or blockage of streams which interferes with fish reproduction. Some local salmon stocks have been seriously depleted in British Columbia because of such damage. Gillis (1986) reviews the case of sawdust pollution in rivers in Eastern Canada. The routine dumping of sawdust into rivers was responsible for reducing fish populations and likely wiped out the shad fishery in the Bay of Fundy. Finally a third example is the effects of industrial pollution on fish, forestry and agriculture. Acid rain has damaged forests and fish in lakes, and industrial toxic emissions into waterways has had significant adverse effects on fish, especially in the Great Lakes.

[6] Both the Denmark and sawdust examples cited in the previous footnote also illustrate the long lags that preceded an effective policy response. Denmark eventually reclaimed much of its land, but not before the country had suffered prolonged costly reductions in productivity. In the sawdust case, despite the passage of a law in 1865 which explicitly prohibited such dumping, it was not until after 1900 that the law was enforced.

appears to fit the trade-induced degradation hypothesis. We also show that such a vicious cycle is ruled out in autarky because domestic price and policy adjustments insulate the economy from extreme environmental outcomes. However, we also show that trade can instead initiate a virtuous cycle of environmental improvement, real income gain, and lower pollution levels. Therefore, while we find some support for the trade-induced degradation hypothesis, this support must be heavily qualified. Much of the paper investigates the conditions under which it may obtain.

Our work also has interesting parallels with the increasing returns literature (such as Ethier, 1982), where a positive externality internal to an industry leads to a market failure that can result in losses from trade. As well, free trade can lead to large changes in an economy's production structure in response to trade, and an economy can become trapped in the 'wrong' industry. In the model of this paper, a negative cross-sectoral externality leads to potentially large losses for somewhat similar reasons.[7] An important distinction, however, is that pollution policy is active throughout and endogenously changes in response to changed conditions. Only if the policy response is muted do we find losses from trade.

The structure of the paper is as follows. We set up a simple dynamic model in Section 2. In Section 3, we examine autarky while in Section 4 we consider the effects of trade for our small open economy. Section 5 examines the conditions under which free trade will create large consequences and Section 6 concludes.

2. The model

There are two primary factors: labour (L) and the environment's capital stock (K). The capital stock 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 the capital stock evolves according to the simple function[8]

$$\mathrm{d}K/\mathrm{d}t = g(\bar{K} - K) - Z \qquad (1)$$

where $\bar{K}$ is the 'natural' level of environmental capital, Z is the flow of pollutants, and $g > 0$ measures the recovery rate of the environment. Absent any pollution, in the long run the environment's capital stock would gravitate towards its natural steady state at the pristine level $\bar{K}$. Once we admit a flow of pollutants denoted by Z, the steady state level of K will be lower than $\bar{K}$.

---

[7] The parallels between the increasing returns literature and models with cross-sectoral externalities are discussed in depth in Copeland and Taylor (1995c).

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

There are two industries denoted S and F. S, or Smokestack manufacturing, is a dirty industry that uses labour as an input and emits pollution as a joint product of output. As shown in Copeland and Taylor (1994) we can equivalently treat pollution as if it were an input into production that can be varied to minimize costs. To keep the model simple, we adopt the following functional form:

$$S = G(L_s, Z) = \begin{cases} L_s^{1-\alpha} Z^{\alpha} & \text{if } Z/L_s \leq \lambda \\ 0 & \text{if } Z/L_s > \lambda \end{cases} , \tag{2}$$

where $\gamma > 0$, $\lambda > 0$, and $0 < \alpha < 1$. The extra constraint arises because pollution is in fact a by-product of production, and hence output must be bounded above for any given labour input. This constraint is reflected in the requirement $Z \leq \lambda L_s$ since this ensures that $S \leq \lambda^{\alpha} L_s$, i.e. output is bounded from above for any labour input. If pollution is unregulated, then $Z = \lambda L_s$.

Our other industry, denoted by F, is an environmentally sensitive industry that may be thought of as forestry, fishing, or farming.[9] Production of F uses labour 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:

$$F = \phi(K) L_A \tag{3}$$

where L_A is labor allocated to Farming and $\phi(K)$ is the free flow of services arising from a capital stock of K. For simplicity, we let $\phi(K) = K^{\epsilon}$, with $\epsilon > 0$.

We assume a representative consumer with current period utility that is a function of both the flow of pollutants and the current state of the environment. To capture the real world attributes of industrial pollution we assume that Smokestack emissions create an instantaneous disutility cost arising from the flow, and that this disutility cost is higher in already very dirty environments. To avoid overly complicating our model, we adopt the separable form

$$U = b_s \ln(S) + b_f \ln(F) - \beta Z/K \tag{4}$$

As written, utility falls with an increase in the flow of industrial pollution Z and this disutility cost is higher in already very dirty (low K) environments. Hence, by construction the marginal damage from pollution will be increasing in Z since the flow of emissions lowers K in the long run.

We assume that in each period the government chooses the number of pollution permits to issue by weighing the current marginal cost of pollution (arising from the disutility of consumers) against the current marginal value of pollution (in raising goods production). We have adopted this myopic

---

[9] 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.

optimization rule as an approximation to the complex behavior that governments actually exhibit. While governments clearly do regulate some pollution, few would argue that they fully offset all externalities. Our specification simply reflects a view that governments respond to short run discomforts of the electorate, but for reasons of ignorance, political expediency, or intergenerational inequity, fail to properly manage the stock of environmental capital.

3. Autarky

At any moment in time the level of K is fixed, and our economy has a specific factors structure where the (endogenous) supply of pollution is the specific factor in manufacturing and labour is the mobile factor used in both sectors. The production side equilibrium conditions require zero profits in each industry and full employment. The unit cost function in Smokestack is $c(w,\tau) = a\rho^{\alpha}w$, where $\rho = \tau/w$, τ is the cost of emitting 1 unit of pollution, w is the wage rate and a is a constant. Unit costs in industry F are simply $w/\phi(K)$. Assuming both industries are active we have:

$$a\rho^{\alpha}w = p \tag{5}$$

$$w/\phi(K) = 1 \tag{6}$$

Since the economy is perfectly competitive, at each moment in time there is awell defined GNP function $G(p,L,Z;K)$. $G(p,L,Z;K)$ has the standard properties (see Woodland, 1982) with respect to p, L and Z. It is also necessarily increasing in K because an increase in environmental capital shifts this economy's production possibilities outward.

As in Copeland and Taylor (1995b), it is useful to characterize this economy'stemporary equilibrium (taking K as momentarily given) in terms of the demand and supply for pollution at a point in time. First consider pollution supply. The government maximizes the instantaneous indirect utility function Eq. 4 by choosing the number of pollution permits so that the market price of a permit, τ, reflects current period marginal damage. Since $\partial G(p,L,Z;K)/\partial Z = \tau$, we have:

$$\tau = -V_Z/V_I = \beta I/K \tag{7}$$

The marginal benefit of one more unit of pollution is given by its shadow value in production τ, and the marginal cost is given by marginal damage to consumers.[10]

---

[10] Note that Eq. 7 does not rely on our representative consumer assumption. With N distinct consumers note that the marginal damage of pollution for any one consumer 'i' is given by β/K written in terms of utility, it is equal to $\beta I^i/K$ written in terms of income (since $V_I = 1/I^i$ for consumer i), and adding up across all consumers $i = 1...n$, where $I = \Sigma_{i=1}^{n} I^i$ yields the sum of marginal damage $\beta I/K$.

We can rearrange Eq. 7 to obtain a relationship between the number of pollution permits issued and their relative price. To do so, note that the income derived from the issue of permits is rebated to consumers. Hence,

$$I = wL + \tau Z \tag{8}$$

Using Eq. 8 in Eq. 7 and rearranging yields the current period supply of pollution as a function of its relative price $\rho = \tau / w$:

$$Z^S = \frac{K}{\beta} - \frac{L}{\rho} \tag{9}$$

The supply of pollution for two different values of K is illustrated inFig. 1. It is increasing in the relative price of a permit, ρ, because a higher price for pollution reflects its greater value in the production of goods. Hence, as ρ rises consumers are implicitly being compensated by greater goods production when they allow increased pollution. Pollution supply is also increasing in K because a given unit of pollution has a lower disutility cost in a cleaner environment. Finally, it is decreasing in L because environmental quality is a

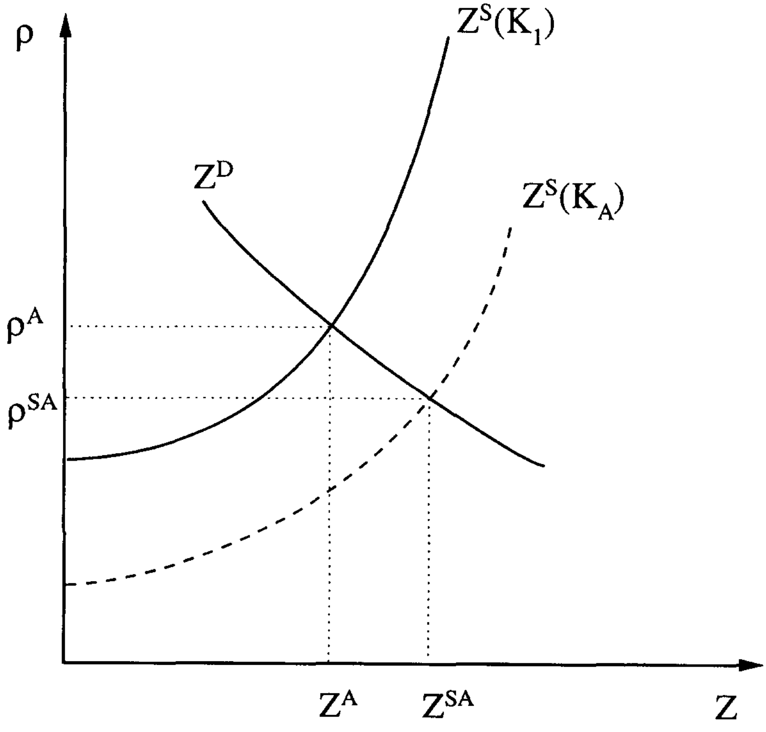

Fig. 1. Pollution supply and demand: temporary equilibrium.

normal good (income rises as the labour endowment of the representative consumer increases), and decreasing in β since the disutility cost of pollution rises with β.

The demand for pollution is derived from its use in the production of Smokestack output. Since b_s is the share of spending on Smokestack output, the demand for Smokestack is:

$$S = b_s I / p \tag{10}$$

Recalling that α is the share of pollution charges in the cost of good S, the derived demand for pollution is then given by:

$$Z = \alpha p S / \tau = \alpha b_s I / \tau \tag{11}$$

where the latter step uses Eq. 10. If we use Eq. 8 to eliminate income, we can simplify Eq. 11 to obtain the demand for pollution as a function of its relative price, ρ:

$$Z^D = \left[\frac{\alpha b_s}{1 - \alpha b_s} \right] \frac{L}{\rho} \tag{12}$$

The demand for pollution services is illustrated in Fig. 1. It is increasing in L since income and hence the demand for both goods rises with L. It is falling in ρ because an increase in the relative price of pollution permits raises the relative price of Smokestack output, reduces the quantity demanded, and reduces the derived demand for pollution. Not surprisingly, an increase in the pollution intensity of production (α) or an increase in the pollution intensity of consumption (b_m) both raise pollution demand.

Since our construction of the pollution demand and supply subsumed market clearing in goods and labour, the temporary equilibrium of our economy can be found simply by equating pollution demand and supply. We depict a typical temporary equilibrium in Fig. 1 using Eq. 12 and Eq. 9 to solve for the equilibrium level of emissions Z^A and the equilibrium relative price of a permit ρ^A (ignore for a moment the dashed line). Solving for Z^A yields:

$$Z^A = \frac{\alpha b_s K}{\beta} \tag{13}$$

We refer to Eq. 13 as the autarky pollution function because it gives us this economy's temporary equilibrium flow of pollution in autarky, for any possible value of the capital stock, K. As Eq. 13 shows, the flow of pollution rises with increases in the stock of environmental capital, rises as manufacturing becomes more pollution intensive (α rises), as preferences shift to Smokestack output (b_s rises), or as pollution becomes less damaging (β falls).

Solving for the temporary equilibrium price of a pollution permit we find:

$$\rho^A = \left(\frac{L}{K}\right)\left(\frac{\beta}{1-\alpha b_s}\right) \tag{14}$$

Hence pollution is a relatively expensive input into production when the disutility of pollution is high (β large), when the environment is already very degraded (K low), when manufacturing is very pollution intensive (α large) or when the share of manufacturing in national income is large (b_s large).

The dynamics of our economy are determined by the environment's ability to cleanse itself in the face of the economy's current flow of pollutants. In Fig. 2 we plot the environment's regeneration function Eq. 1 and the economy's autarky pollution function Eq. 13. The intersection of the two solid lines defines an autarkic steady state where $\mathrm{d}K/\mathrm{d}t = 0$. Suppose this economy starts out in the temporary equilibrium at point A where pollution is Z_1, and the capital stock is K_1. The environment's cleansing capacity at K_1 (the

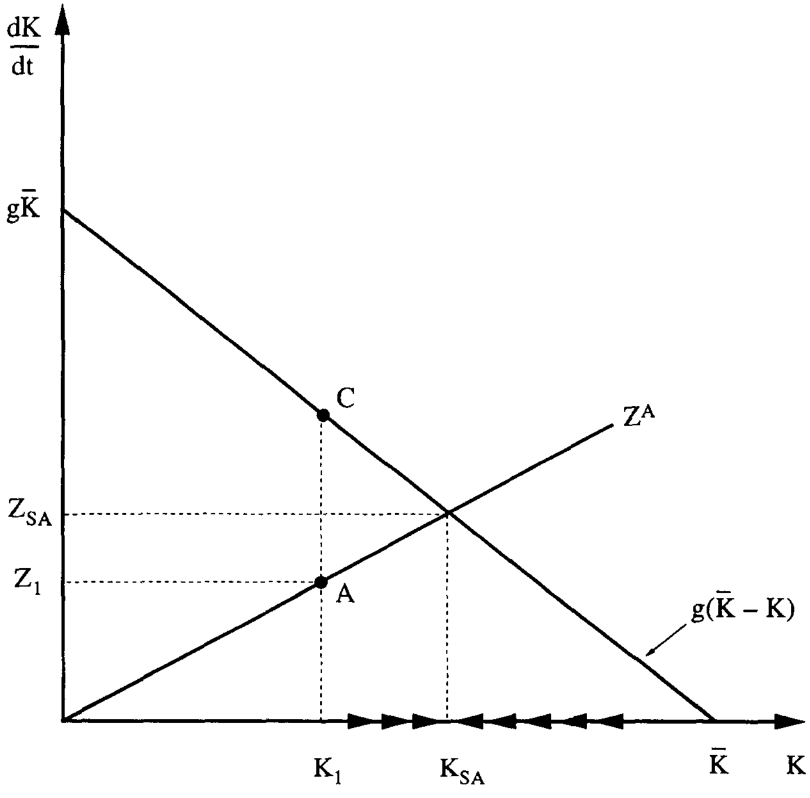

Fig. 2. Pollution and environmental capital dynamics.

vertical distance CK_1) exceeds the flow of pollutants given by Z_1, and hence the capital stock increases. As K rises over time the pollution supply curve shifts outward, and since the demand for pollution is unaffected, the temporary equilibrium flow of pollutants rises with K. This is shown in Fig. 1 by the dashed lines for the new pollution supply function that arises as K increases. Eventually this process of adjustment terminates when the economy reaches its autarkic steady state at K_{SA} and Z_{SA}.

It is apparent from Fig. 2 that had we started from any $K > K_{SA}$ then emissions would have exceeded the environment's cleansing capacity and K would fall towards K_{SA}. Hence our autarky steady state equilibrium is globally stable and unique.

Before considering the effects of trade on our small open economy it is important to understand why autarky is a stable equilibrium with both industries remaining active in steady state. Given the negative production externality that Smokestack inflicts on farming we might expect Smokestack to drive out the clean industry over time. Alternatively, since an increase in environmental capital raises production possibilities and income we might expect the clean industry to drive out Smokestack over time as higher income levels lead to tighter and tighter pollution regulations.

We are assured of a diversified equilibrium in autarky because if farming output becomes scarce as Smokestack expands, the relative price of Farm output rises. This relative price change has two effects. First, labour is drawn into Farming and away from Smokestack. By itself this would tend to curtail the unbridled growth of the dirty industry. But there is an additional second effect because the value of pollution as an input falls as prices adjust and labour reallocates. As a result, the regulator reduces the quantity of pollution permits supplied, which in turn lowers the value of the marginal product of labour in Smokestack, and pushes yet more labour into Farming. Thus the policy response further insulates the economy from extreme outcomes.

Similarly if Farming expands and Smokestack shrinks, then Smokestack's relative price rises and this curtails the expansion of farming because of both price and pollution policy adjustments. In short, the price and policy adjustment always ensure both goods are produced in autarky. These adjustments in turn insulate the domestic economy from either very clean (all farming) or very dirty (all Smokestack) outcomes in autarky.

One impact of free trade is that a county has less control over the prices that it faces. In our small open economy case, world prices are entirely independent of production and consumption patterns in the domestic economy. As we will show, this basic implication of free trade can lead to large environmental consequences, because it forces policy adjustment to carry all of the burden when responding to the changed market conditions of international trade.

4. Free trade for a small open economy

Suppose we take our small open economy in its autarkic steady state and let it trade at a world relative price of S equal to p. Our derivation of pollution supply as a function of ρ remains the same as in autarky; however the derived demand for pollution must now reflect the fact that this small open economy can sell unlimited amounts of S at a constant world price. As a result, the derived demand for pollution is now obtained from the zero profit conditions Eq. 6 and Eq. 7, and is given by[11]

$$\rho = [p/aK^{\epsilon}]^{1/\alpha} \tag{15}$$

Not surprisingly, because the economy is small and open (with p fixed), the derived demand curve is perfectly elastic. As well, in contrast to the autarky case, when K rises, pollution demand now necessarily falls. An increase in K stimulates farming at the expense of S, thus reducing pollution demand. In autarky, the consequent reduction in S led to an increase in its relative price and an offsetting increase in pollution demand. In trade, domestic consumers now turn to imports to make up for the reduction in manufacturing output as K rises and product prices remain fixed. This absence of the price adjustment we had in autarky will prove critical to our results. Consequently, pollution demand is now a decreasing function of K.

Equating supply Eq. 9 and demand Eq. 15 yields:

$$Z = \frac{K}{\beta} - L(a/p)^{1/\alpha} K^{\epsilon/\alpha} \tag{16}$$

We refer to Eq. 16 as the *free trade pollution function* because it gives us this economy's temporary equilibrium flow of pollution forgiven levels of both K and the world relative price of manufactures, p. Equation 16 has been derived under the assumption that the economy produces both goods; below we will consider the possibility of specialization. Note that as long as the economy produces both goods, then from Eq. 16 we can tell that any increase in p raises pollution levels, as the economy's composition of output becomes more pollution intensive.

The free trade pollution function Eq. 16 differs from its autarky counterpart in three significant ways. First, note that for L sufficiently high, or p sufficiently low, Eq. 16 is negative: that is, over some range of parameter values the government does not allow any pollution, and Smokestack shuts down. Note that in autarky pollution was an 'essential' input and our autarky

---

[11] This calculation assumes both industries are active. We will subsequently amend the free trade pollution function to account for the possibility of specialization in manufacturing. Specialization in agriculture occurs whenever Eq. 16 is negative.

demand and supply for pollution always yielded an interior equilibrium with some pollution emitted. Therefore, in contrast to autarky, this economy can specialize in the 'clean' good.

Second, the free trade pollution function was constructed under the assumption that some of the agricultural good is produced in equilibrium. In autarky we could be assured of diversified production, but now specialization in the 'dirty' manufacturing good is now possible. If the relative price of manufactures is very high or if the environment's capital stock is very low, then the value of marginal product of labour in manufacturing may exceed that in Farming even with all of the economy's labour force in manufacturing. Consequently, the economy can specialize in Smokestack in trade, and we will amend Eq. 16 to take account of this possibility when the need arises.

Finally, the free trade pollution function is not a monotonic function of K as it was in autarky. The free trade pollution function is concave in K if $\epsilon > \alpha$, and convex in K if $\epsilon < \alpha$.

4.1. Benchmark Case: $p^{\mathrm{T}} = \mathrm{p}^{\mathrm{A}}$

To examine the effect of trade on our small open economy it is useful to begin with a benchmark case where the world relative price of manufactures equals the domestic autarky price. Under normal circumstances the equality of world and autarky prices would mean that there would be no basis for trade, no change in production levels, and no consequent change in either pollution or the long run level of the environment's capital stock. Opening up to international markets should have no effect, and indeed in some cases this will be true.

Our purpose in adopting this benchmark is to isolate those factors determining whether trade has large or small environmental impacts. To start we wish to show that when our small open economy faces world prices equal to autarky prices, free trade can have large environmental consequences. We will then go on to show that trade has even larger environmental impacts when world prices are not equal to autarky prices.

4.1.1. Weak externality

Consider first the case when $\epsilon < \alpha$ and the free trade pollution function is strictly convex. In Fig. 3 we plot a free trade pollution function corresponding to Eq. 16 evaluated at a world price for manufactures equal to our small open economy's steady state autarky price. The solid line labeled $Z^{\mathrm{T}}(K;\, p^{\mathrm{A}})$ is the free trade pollution function when we assume $\epsilon < \alpha$ (ignore for the moment the dashed lines). Since $\alpha < 1$, this requires $\epsilon < 1$; i.e. improvements in the quality of the environment have diminishing effects in raising farming productivity. Moreover, since empirical work suggests that α is likely quite small, we will refer to this $\epsilon < \alpha$ case as one where the (inter-temporal) externality is weak.

Not surprisingly, it is straightforward to show that the free trade pollution function (evaluated at autarky prices) must go through the autarkic steady state as shown. Moreover, since the free trade pollution function cuts from below (as did the autarky pollution function), this new trading equilibrium is also stable. Consequently, if K were to differ from K_{SA} because of some shock to the system, then the economy would move monotonically back towards its autarkic steady state at K_{SA}. In short, just as we would expect, openness to international markets has no effect on the economy.

If we now allow this economy to trade at world prices just slightly above those in autarky, then the free trade pollution function shifts upwards and is represented by the dashed line labelled $Z^T(K;\ p^T > p^A)$. On impact, the flow of pollutants exceeds the environment's cleansing capacity and the capital stock starts to fall. A new equilibrium is eventually established to the left of K_{SA}. At the outset of trade this economy enjoys conventional gains from trade since with K momentarily fixed, and pollution being correctly internalized (for the short run), trade is welfare enhancing. Over time however, the

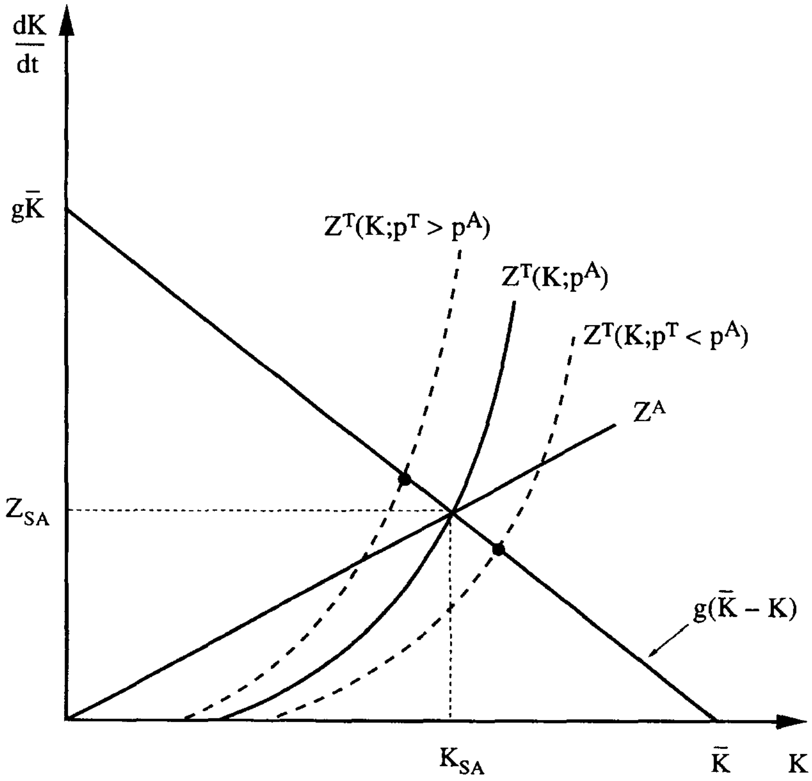

Fig. 3. Small open economy with $\epsilon < \alpha$.

reduction in the capital stock reduces these gains and at the new equilibrium it may have eliminated them completely.

It is important to note that the fall in K created by trade is of the same order of magnitude as the change in prices brought about by trade — and hence we are back to the fundamental ambiguity mentioned in the introduction. Pollution is marginally higher in trade, the environment is marginally worse, but trade has also brought its conventional (and likewise marginal) consumption gains. In the new trading steady state, welfare may be higher or lower but this will depend quite sensitively on our specific model structure. Conversely, if we let this economy trade at world prices just below autarky prices then the environment improves and there are conventional gains from trade. (See the dashed line $Z^{\mathrm{T}}(K;\ p^{\mathrm{T}} < p^{\mathrm{A}})$. Hence if the externality is small, the introduction of production externalities per se does not necessarily change our standard intuition regarding the welfare implications of trade in distorted economies.

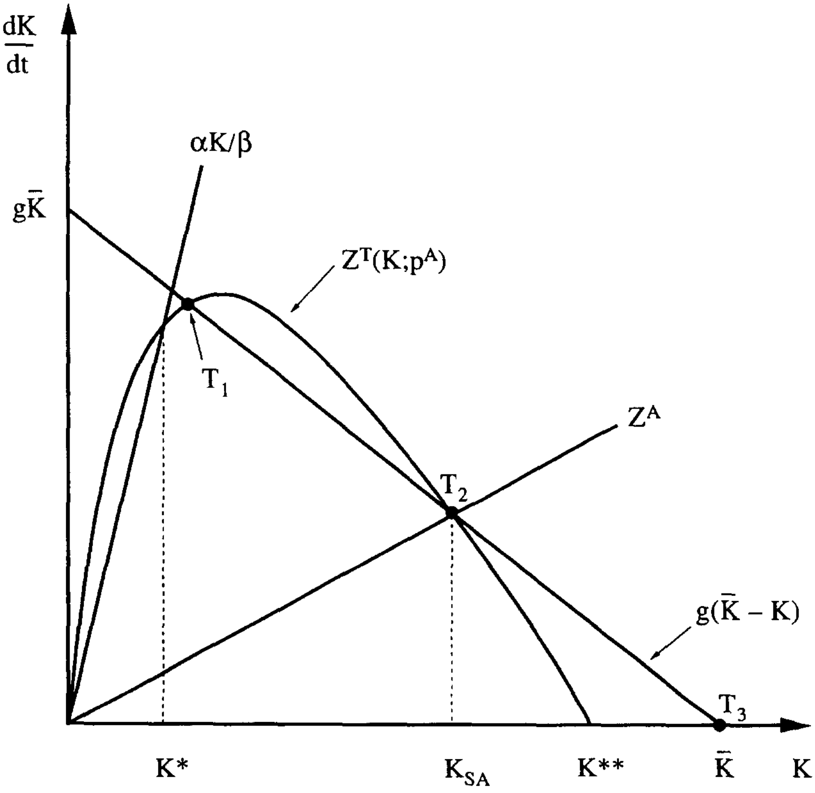

Fig. 4. Small open economy with $\epsilon > \alpha$ and world prices equal to Autarky prices.

4.1.2. Strong externality

Now consider the case when $\epsilon > \alpha$. In Fig. 4 we have drawn the free trade pollution function Eq. 16 evaluated at autarky prices when $\epsilon > \alpha$ and assuming that both industries are active. The free trade pollution function is strictly concave in this case. But even if the pollution function is strictly concave, it may cut the regeneration function from above or below at the autarkic steady state. If the intersection is from above (as depicted), then free trade at autarky prices is an unstable equilibrium. Conversely, if it is from below, then free trade at autarky prices is a stable equilibrium. More specifically, we find that instability requires a slightly more stringent condition than just $\epsilon > \alpha$; that is,

Proposition 1. Suppose free trade goods prices are equal to autarky prices. If $\epsilon > \alpha[1 + g\beta]/[1 - \alpha b_s]$ then the autarky production allocation is an unstable equilibrium. If $\epsilon < \alpha[1 + g\beta]/[1 - \alpha b_s]$ then the autarky production allocation is a stable equilibrium. *Proof.* See Appendix.

For the moment take for granted the intersection from above as depicted in Fig. 4, and consider the implications of free trade when $\epsilon > \alpha[1 + g\beta]/[1 - \alpha b_s]$. Because the free trade equilibrium is unstable, specialization in either manufacturing or in Farming is now a distinct possibility and we will now need to amend equation Eq. 16. Since we have fixed world prices, specialization depends only on the relative productivities in Farming and manufacturing. Specialization in Farming is already captured in Fig. 4 and occurs when the pollution function cuts the horizontal axis. If K ever exceeds K^{**}, national income is so high that the price of a pollution permit is too high to permit production of any manufactures. Consequently, the manufacturing industry shuts down and the environmental capital stock grows to $\bar{K}$. The free trade pollution function with specialization in farming (i.e., for $K > K^{**}$) lies along the horizontal axis.

Specialization in manufacturing occurs whenever the environment's capital stock falls to a level such that the value of marginal product in manufacturing exceeds that in Farming even with all labour in manufacturing. When Farming shuts down, the free trade pollution function is independent of p and must just reflect market clearing in labour and pollution markets. Hence, following our construction of pollution demand and supply in autarky, when specialized in manufacturing the demand for pollution is just:

$$Z^{\mathrm{D}} = [\alpha/(1 - \alpha)]\bar{L}/\rho$$

and combining this with the supply for pollution given in Eq. 9 we find the free trade pollution function, when specialized in manufacturing is just:

$$Z = [\alpha/\beta]K \tag{17}$$

In Fig. 4 the straight line emanating from the origin represents the free trade pollution function when specialized in manufacturing, so that the complete pollution function is now represented by the straight line for K less than K^*, the hill shaped line for $K > K^*$, and then the horizontal axis for $K > K^{**}$. That is:

Proposition 2. Suppose $\epsilon > \alpha$. At free trade prices equal to autarky prices, the free trade pollution function is given by:

(i)

$$Z = [\alpha/\beta]K \quad \text{for } K \leq K^*$$

(ii)

$$Z = \frac{K}{\beta} - L(a/p)^{1/\alpha} K^{\epsilon/\alpha} \text{ for } K^{**} \geq K \geq K^*$$

(iii)

$$Z = 0 \text{ for } K \geq K^{**}$$

Proof. See Appendix.

With this complete characterization in hand, we can now consider the effects of trade.

Several results are immediately apparent from Fig. 4. As shown, there are now three possible steady state equilibria in trade even when this small open economy trades at a world price equal to its autarky price. These possible equilibria are labeled T_1, T_2 and T_3. In addition to the multiplicity of equilibria, it is also apparent that the previous autarky equilibrium at T_2 is now unstable in free trade, whereas it was unique and globally stable in autarky. Finally, while the equilibria at T_1 and T_3 are both locally stable, they have very different welfare consequences.[12]

Perhaps the most surprising result is the instability of the previous autarky equilibrium at T_2. If we open this economy to trade at a world price equal to its autarky price, then any small perturbation to the system would move the economy to either one of the other two equilibria. If the economy moves to the high utility — low pollution equilibrium at T_3 then trade, even at autarky prices, is welfare improving. Conversely, if the economy moves to the low utility — high pollution equilibria at T_1 then trade, even at autarky prices, can reduce welfare significantly. These welfare results necessarily follow because at T_1, Z/K is higher and hence the disutility cost of pollution is higher; K is lower so production possibilities are a subset of what they were in autarky; and finally the relative price $p = p^A$ is the same in both trade and autarky. By a similar argument, moving to the low pollution outcome at T_3 is necessarily welfare improving. Hence we have shown:

---

[12] Fig. 4 is drawn under the assumption that at T_1 both industries are active, but T_1 could instead have the economy specialized in Smokestack.

Proposition 3. Suppose $\epsilon > \alpha[1 + g\beta]/[1 - \alpha b_s]$. Trade at autarky prices will lower welfare if equilibrium T_1 is reached with trade. Trade at autarky prices will raise welfare if equilibrium T_3 is reached.

4.2. Free trade prices different from autarky prices

When the externality is strong and the economy trades at autarky prices we cannot tell which of the two very disparate outcomes it enjoys (or endures), but trade at a world price just above the autarky price gives us a determinate result. In Fig. 5, we depict a free trade pollution function for the home economy when it trades at a world price p^T just slightly above that in autarky. It is easy to show that an increase in p shifts the free trade pollution function up and alters the specialization regions as expected. At the outset of trade the economy releases a flow of pollutants Z_1 that exceeds the environment's cleansing capacity at the old steady state. Consequently, the capital stock

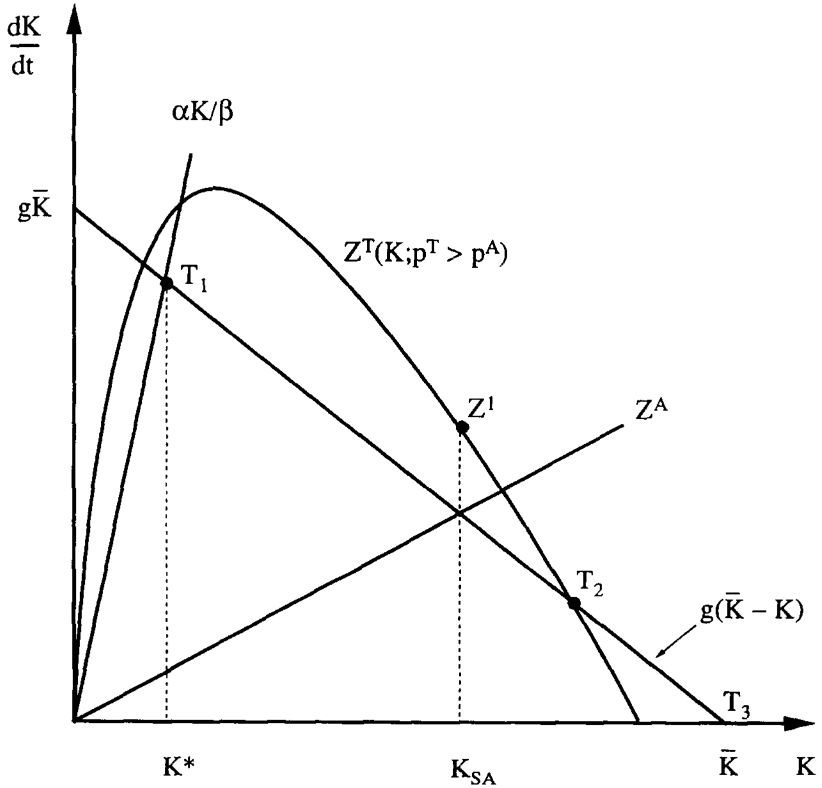

Fig. 5. Small open economy with $\epsilon > \alpha$ and world prices greater than Autarky prices.

starts to fall and we move to a new steady state in the neighborhood of T_1. At the outset of trade this economy enjoys conventional gains from trade because K is fixed, and the instantaneous disutility costs of pollution are correctly internalized. However, if the world price is only just higher than the autarky price, these gains must be correspondingly small. Moreover, over time there is a discrete welfare loss as the economy proceeds to the high pollution equilibria near T_1. As a result,

Proposition 4. If this economy trades at world prices $p^T = p^A + \delta$, with $\delta > 0$ small, then the movement from autarky to free trade creates immediate welfare gains, but lowers steady state utility. For some positive discount rates, overall welfare must necessarily fall with trade.

The same mechanism behind the negative results of Proposition 4 can, however,work in reverse to give the economy large gains from trade. If this economy trades at a world price just below its autarky price, the pollution function shifts down (not shown in the figure) and the economy moves to an equilibrium at T_3. Trade induces the economy to specialize in F and eliminates all pollution. Consequently, we have shown:

Proposition 5. If this economy trades at world prices $p^T < p^A$, a movement from autarky to free trade will create both immediate and long run welfare gains. Even if p^T differs only marginally from p^A, the welfare gains from trade will be very significant.

Propositions 3, 4 and 5 indicate that under some circumstances free trade can create large environmental consequences and that these consequences in turn lead to significant changes in utility levels. Free trade at world prices just marginally different from those in autarky need not create only marginally different environmental or welfare outcomes.

Proposition 4 in particular appears to fit the trade-induced degradation hypothesis that we sketched in the introduction. At the outset of trade (because world prices exceed autarky prices) the output of Smokestack rises slightly and the value marginal product of pollution as an input rises as well. Pollution emissions rise. Over time the environment worsens and K falls. Because of the reduction in environmental capital, the supply curve for pollution shifts back to reflect the now higher marginal damage of emissions. At the same time however labour moves into Smokestack because the productivity of labour in the clean industry falls. Consequently, this reallocation of labour (created by the fall in K) raises the physical marginal product of pollution, in turn raises the demand for pollution, and in equilibrium raises the flow of pollution emitted. The environment worsens further. And like Alice in *Through the Looking Glass* the faster this economy moves into Smokestack the farther its welfare level falls behindits autarky value.

5. When can free trade bring about large consequences?

Thus far we have taken as given the 'intersection from above' as depicted in Fig. 4 and Fig. 5. However it is important to understand the driving force behind our result. It is apparent from Fig. 4 that a negatively sloped free trade pollution function is necessary for trade to create large effects, and a pollution function that cuts the regeneration function from above is sufficient. It is straightforward to show that the free trade pollution function is negatively sloped at the point of intersection with the autarkic steady state if $\epsilon > \alpha/[1-\alpha b_s]$. And the pollution function 'cuts from above' if a slightly more stringent condition is met: $\epsilon > \alpha[1+g\beta]/[1-\alpha b_s]$.

Our 'large consequences' results from Propositions 3–5 depend on only five parameters. To understand how they interact, start in a trading equilibrium at T_2 in Fig. 4 and suppose K decreases. On impact, the decrease in K lowers labor's value of marginal product in Farming and labour moves into manufacturing. With more labour in manufacturing, the temporary equilibrium demand for pollution rises. At the same time, because K falls, the environment worsens and the government responds by lowering the temporary equilibrium supply of pollution. The relative strength of these two opposing effects determines whether emissions rise or fall with a change in K; i.e. they determine whether the free trade pollution function in Fig. 4 is positively or negatively sloped. If the demand side dominates, the pollution function is negatively sloped at T_2.

Our necessary condition tells us that the demand side is more likely to dominate if ϵ is larger. This is because the larger is ϵ, the greater is the fall in Farming's marginal product when the environment worsens. Consequently, the greater is the movement of labour into manufacturing, and the greater is the increase in the marginal product of pollution in manufacturing. As a result, the more sensitive is Farming to changes in the natural environment, the more likely is trade to create large environmental consequences.

As well, our necessary condition also tells us that the larger is labour's share (or the smaller is pollution's share α) in the value of manufacturing, the more likely is our result. Suppose labor's share in manufacturing is large and K falls from K_{SA}. Then labour moves into manufacturing from Farming, and because labour is such an important input the resulting increase in pollution's marginal product in manufacturing is also large. Therefore, manufacturing does not need to be very pollution intensive for our 'large consequences' result to hold.

Our results are also more likely to hold the smaller is the share of manufactures in consumption. Since the share of manufactures does not appear in either the free trade pollution function or the regeneration function, we know that its relevance must come from pinning down the point (i.e. the autarky steady state) at which we evaluate the derivative of the pollution function. If the share of manufactures in consumption is small, then this economy has a relatively clean environment in autarky (K_{SA} is large). A fall in K away from the steady state then has a proportionately smaller effect in raising the disutility of pollution, and hence the temporary equilibrium pollution supply shifts less in response to the fall in K. As a result, the equilibrium level of pollution is more likely to rise when K falls. Consequently, our economy could be very clean and suffer relatively little from pollution prior to trade, but free trade could still create large environmental consequences.

Finally, our results depend on both the short and long run characteristics of industrial pollution. If pollution creates a significant amount of eyesore pollution (β large), but can be cleansed from the environment quite quickly (g large) then our 'large consequence' results are less likely to hold. Pollutants with significant immediate costs will be regulated more heavily and when K falls, the supply of permits will fall considerably. As well, if they can be cleansed from the environment quickly, as K falls the environment's rate of cleansing rises relatively more. Conversely, if the pollutant has a small short term disutility cost, but is very difficult to cleanse from the environment then our 'large consequences' result is more likely. A small short run cost implies a weak regulatory regime and a muted response to a fall in K. In addition, if the cleansing rate is small it is more likely that the increase in pollution created by the fall in K may easily overwhelm the environment's now faster (but still relatively small) rate of regeneration.

6. Conclusion

We presented a simple two sector dynamic model to examine the consequences of free trade when government pollution policy is myopic. We showed that free trade may have large environmental consequences but only in certain conditions. When free trade does have 'large consequences' the evolution of real income, pollution, and environmental quality appear to fit descriptive accounts of the trade-induced degradation hypothesis. While we find some support for the hypothesis, this support must be heavily qualified and much of the paper investigated the conditions under which it would obtain.

Trade can create 'large consequences' because in autarky both domestic price adjustment and endogenous policy responses worked to insulate the economy from extremely clean or extremely dirty equilibria. In free trade, domestic prices are linked to world prices and all of the burden of adjustment now falls on policy responses.

In some cases we find that adjustments in pollution policy alone can still carry the day and a trading economy is insulated from extreme environmental outcomes. In other cases however adjustments in pollution policy are overwhelmed by market driven changes in the composition of national output. As a result, free trade can set in motion a negatively reinforcing cycle of real income loss and environmental degradation that could not occur in autarky.

Although the government does not solve the full inter-temporal optimization problem in our model, we view this as a much more realistic assumption than full optimization. Moreover, provided pollution is not too high, the cost of ignoring the long run effects on environmental capital may well be small in autarky. As a result, the incentive for developing the institutions and knowledge needed to fully account for the long run costs of pollution are absent. This argument becomes all the stronger when we recall that our 'large consequences' result is most likely to arise in just those situations where the costs of pollution are small in the short run, large in the long run, and autarky is a relatively clean equilibrium.

7. Appendix

Proof of Proposition 1:

The autarky level of K will be an unstable equilibrium in free trade at $p = p^{\mathrm{A}}$ if and only if the free trade pollution function Eq. 16 intersects the regeneration function from above when evaluated at the autarky level of K and p. Differentiating (16) with respect to K and using Eq. 15, we have

$$\mathrm{d}z/\mathrm{d}K = 1/\beta - \epsilon L/(\alpha K \rho). \tag{A1}$$

At autarky prices, $\rho = \rho^{\mathrm{A}}$; hence using Eq. 14 in Eq. A1 yields

$$\left.\frac{dz}{dK}\right|_A = \frac{\alpha - \epsilon(1 - \alpha b_m)}{\alpha\beta} \tag{A2}$$

The slope of the regeneration function is $-g$, and therefore we require that the absolute value of $\mathrm{d}z/\mathrm{d}K$ be greater than g, or that $\epsilon > \alpha(1 + g\beta)/(1 - \alpha b_m)$.

Proof of Proposition 2:

The economy specializes in M if the value of the marginal product of labour (evaluated at $\bar{L}$) is greater than labour productivity in sector F (given by Eq. 6):

$$p(1 - \alpha)(Z/\bar{L})^{\alpha} > K^{\epsilon} \tag{A3}$$

where Z is given by Eq. 16. Using Eq. 16 in Eq. A3 and rearranging yields the result that specialization in M occurs if

$$K < \left(B \frac{p^{1/\alpha}}{\beta L} \right)^{\alpha/(\epsilon - \alpha)} \tag{A4}$$

where B is a positive constant. Hence if $\epsilon > \alpha$, then for given p, there is some K^* such that the economy specializes in M for $K \leq K^*$. In this region, pollution is $Z = \alpha K/\beta$, as indicated in (Eq. 17). Pollution in the economy is always bounded above by the pollution generated if the economy specializes in M (given by (Eq. 17). Hence, as long as Manufacturing is active, the free trade pollution function is $Z = \min\,[\alpha K/\beta,\ K/\beta - L(a/p)^{1/\alpha}K^{\epsilon/\alpha}]$.

Finally, if $\epsilon > \alpha$, then there exists a K^{**} such that pollution in Eq. 16 falls to zero. If $K^{**} < \bar{K}$ (that is if K^{**} is in the range of feasible K) then further increases in K above K^{**} push up wages to such an extent that manufacturing becomes unprofitable at levels of ρ at which the country is willing to supply pollution. [That is, the ρ implied by Eq. 15 renders the supply of pollution given by Eq. 9 negative, and thus actual pollution supply falls to zero].

Acknowledgements

The authors thank SSHRC for funding this research, and a referee for helpful comments.

References

Bhagwati, J., 1993. The case for free trade. Scientific American 269, 41–49.

Copeland, B.R., 1994. International trade and the environment: Policy reform in a polluted small open economy. J. Environ. Economics Management 26, 44–65.

Copeland, B.R., Taylor, M.S., 1994. North-South trade and the environment. Quarterly J. Economics 109, 755–787.

Copeland, B.R., Taylor, M.S., 1995a. Trade and transboundary pollution. Amer. Economic Rev. 85, 716–737.

Copeland, B.R., Taylor, M.S., 1995b. Trade and the environment: a partial synthesis. Amer. J. Agricultural Economics 77, 765–771.

Copeland, B.R., Taylor, M.S., 1995c. Trade, spatial separation and the environment, NBER Working paper No. 5242.

Daly, H., 1993. The perils of free trade. Scientific American 269, 50–57.

Ethier, W., 1982. Decreasing costs in international trade and Frank Graham's argument for protection. Econometrica 50, 1243–1268.

Gillis, R.P., 1986. Rivers of sawdust: the battle over industrial pollution in Canada, 1865–1903. J. Canadian Studies 21, 84–103.

Grossman G.M., Krueger, A.B., 1993. Environmental impacts of a North American free trade agreement. In: Garber, P. (Ed.), The Mexico–U.S. Free Trade Agreement, MIT Press, Cambridge, MA.

Kjaergaard, T., 1994. The Danish revolution 1500–1800: An ecohistorical interpretation, Cambridge University Press, Cambridge.

Lopez, R., 1994. The environment as a factor of production: the effects of economic growth and trade liberalization. J. Environ. Economics Management 27, 163–184.

MacNeill, J., 1989. Strategies for sustainable economic development. Scientific American, 155–165.

Markusen, J.R., 1975. Cooperative control of international pollution and common property resources. Quarterly J. Economics 89, 618–632.

Markusen, J.R., 1976. International externalities and optimal tax structures. J. Int. Economics 5, 15–29.

Rauscher, M., 1991. National environmental policies and the effects of economic integration. Eur. J. Political Economy 7, 313–329.

Selden, T.M., Song, D., 1994. Environmental quality and development: Is there a Kuznets Curve for air pollution emissions? J. Environ. Economics 27, 147–162.

Woodland, A.D., 1982. International trade and resource allocation, North-Holland, Amsterdam.