<u>Οικονομικό Πανεπιστήμιο Αθηνών</u>

<u>Σχολή Οικονομικών Επιστημών</u>

Τμήμα Οικονομικής Επιστήμης

International Trade, Natural Resources, and the Environment

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Διατριβή υποβληθείσα προς μερική εκπλήρωση των απαραίτητων προϋποθέσεων για την απόκτηση του Μεταπτυχιακού Διπλώματος Ειδίκευσης.

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Contents:

Abstract

In recent years, the conflict between environmental and trade interests has drawn much of researchers' attention, emerging as one of the most complex and debatable issues in international trade theory and policy. Many supporters of trade liberalization believe that abolishing trade barriers would allow countries across the world to use their resources more efficiently, without deteriorating environmental quality. Furthermore, positive income effects induced by trade liberalization would allow governments to protect environmental quality more effectively.

On the contrary, some environmental interest groups oppose the free trade argument, arguing that trade liberalization increases world's demand for natural resources, thus pushing natural resources towards depletion; and stimulates pollution intensive production sectors, thereby increasing world pollution. Therefore, from this point of view, setting trade barriers may be beneficial for the environment.

However, whether trade liberalization improves or worsens the environment is not that obvious. Moreover, the optimal way in which trade policy and environmental policy should be coordinated does not follow any general rule, and it depends on various factors. For example, many developing countries face a policy dilemma: should they become more open to trade to gain from the income effects of trade liberalization, or should they focus on reducing the damage on their vulnerable environment? Their pressing needs for increasing incomes, economic growth and exports raise important questions about how to balance environmental protection, economic development and trade.

This thesis presents the most important parts of recent literature that attempt to answer these questions and provide a theoretical context about the linkages between trade and environmental variables, including policy variables.

The thesis is organized into two parts. The first part focuses on the impact of trade liberalization on the environment. Trade liberalization may be beneficial or hazardous for the environment. Some countries have comparative advantage in

pollution intensive production sectors. Hence, free trade stimulates production in these sectors, thereby having a negative impact on those countries' environmental quality. Similarly, some countries have comparative advantage in production sectors that use nationally owned natural resources as inputs, and thus, free trade pushes those resources towards depletion, stimulating the production in such sectors. Moreover, since environmental policy is more stringent in some countries and weaker in other countries, there might be an incentive for firms in pollution intensive sectors, or sectors that use a natural resource intensively, to reallocate their production to those countries in which polluting, or causing resource depletion, is less costly. On the other hand, relatively richer countries can protect their environmental quality and prevent depletion of their nationally owned resources more easily and more effectively. Thus if those countries have comparative advantage in an environmentally harmful sector, free trade need not lead to environmental degradation.

The second part focuses on the linkages between trade policy and environmental policy. Trade policy instruments and environmental policy instruments depend on each other, given that governments maximize domestic welfares. Trade policy responds to environmental problems as long as environmental policy is not set optimally. In addition, environmental policy may be designed as a substitute of trade policy, targeting both environmental problems and terms of trade, in the case of free trade restrictions, implemented by trade agreements or customs unions. Finally, when pollution spills over international borders, the responsiveness of each country on the other countries' pollution alters the optimal coordination scheme of trade and environmental policy.

Part 1

Effects of Trade Liberalization on the Environment

The main issue in part 1 of the thesis is to examine the impact of trade liberalization on environmental quality. Environmental quality can be improved either by reducing pollution in a country, or by preventing the depletion of a nationally owned renewable natural resource. Therefore we focus on both those environmental factors: The first chapter, 1.1, presents an analysis of how pollution may respond to trade liberalization, depending on countries' comparative advantages, and other factors; and the second chapter, 1.2, focuses on natural resources.

1.1. Effects of Trade Liberalization on Pollution

We first need to present a framework for the subsequent analysis. This is presented in the first section of this chapter. The second section presents a useful decomposition of the effect of trade liberalization on pollution. The third section extends the context used in the previous sections, allowing for endogenously determined environmental policy. The final section focuses on the pollution haven hypothesis, which refers to the responsiveness of the international allocation of production due to differences in the stringency of environmental policy across countries.

1.1.1. Pollution in a Small Open Economy

In this section we present a simple general equilibrium model which is applied in all subsequent sections, as well as in the second part, regarding the effects of trade liberalization on pollution or the linkages between trade policy and environmental policy.

The model presented below is developed by Copeland and Taylor (2003: Chapter 2) and it builds on previous works. The structure of the model is closest to that of McGuire (1982). Other important works are discussed below.

The basic set of assumptions of the model is that there are two industries (one "dirty" and one "clean"), two primary factors of production and a government that regulates pollution. The presence of pollution regulation implies that there is an extra cost for production for polluting firms. Hence firms that produce the dirty output may have to employ a portion of their factors into abatement activity. Both factor endowments and pollution regulation play a role in determining a country's comparative advantage. The main goal of the model is to construct a general equilibrium pollution demand and supply system, which determines equilibrium pollution as a function of world prices, factor endowments, technology, preferences and pollution regulation.

Pollution is treated as an input in the production of commodities. In fact, pollution is an undesirable output. However, as proved below, the two approaches turn to be equivalent. Furthermore, since pollution is treated as a third input along with the two primary factors, we have a model with three inputs. To keep the model tractable we have to make two additional assumptions: first, we assume that abatement activity employs factors at the same proportion as the dirty industry does; and, secondly, we assume a specific form for the abatement production function.

Technology

Consider a small open economy which takes world prices as given. Assume that there is a dirty good X which generates pollution during production and a clean good Y. Let the dirty good's price be $P_x = p$ and the clean good's price be $P_y = 1$ (i.e., the clean good is assumed to be the numeraire good for simplicity). Suppose also that there are two inelastically supplied primary factors: capital K and labor L, and let the production of the dirty good be capital intensive[1] (and the clean one be labor intensive), i.e.:

$$\frac{K_x}{L_x} > \frac{K_y}{L_y} \tag{1.1.1}$$

Suppose that pollution harms consumers but it has no effect on productivity of other firms. Both goods are assumed to be produced with constant returns to scale technology. The production function of Y is:

$$y = H(K_y, L_y) \tag{1.1.2}$$

We assume H is increasing and strictly concave in inputs. In the X sector, a firm can allocate an endogenous fraction θ of its inputs to abatement activity. Thus it uses the rest $(1-\theta)$ in production. The joint production technology of a firm in the dirty industry is given by:

$$x = (1-\theta)F(K_x, L_x) \tag{1.1.3}$$

$$z = \varphi(\theta)F(K_x, L_x) \tag{1.1.4}$$

where F is increasing, concave and linearly homogeneous in inputs, $0 \leq \theta \leq 1$, $\varphi(0) = 1, \varphi(1) = 0 \; and \; \frac{d\varphi}{d\theta} < 0$.

Under no abatement activity ($\theta = 0$) we have:

$$x = F(K_x, L_x) \tag{1.1.5}$$

$$z = x \tag{1.1.6}$$

Each unit of production generates one unit of pollution. We can think of $F(K_x, L_x)$ as the potential output; this is the output of X that would be generated if there were no pollution abatement. If firms choose $\theta > 0$, then some resources are allocated into abatement. This leaves the firm with a net output $(1-\theta)F(K_x, L_x)$. It is convenient

[1] Polluting sector is the capital intensive sector. This is the case of industrial pollution.

to put a little more structure on (1.1.4); hence we adopt the following functional form for abatement:

$$\varphi(\theta) = (1-\theta)^{\frac{1}{\alpha}} \tag{1.1.7}$$

where $0 < a < 1$. Using (1.1.3), (1.1.4) and (1.1.7) we obtain:

$$x = z^{\alpha}[F(K_x, L_x)]^{1-a} \tag{1.1.8}$$

which is valid for $z \leq F$, since $\theta \geq 0$. Thus, although pollution is a joint output, we can equivalently treat it as an input into the dirty good's production.

The relationship between net output x, potential output F and the resources allocated to abatement can be illustrated in a Figure 1.1.1 using isoquants.

Notice that we have $z \leq F$, because $\varphi(\theta) \in [0, 1]$. As we move down along an isoquant, pollution falls because firms allocate resources to abatement. To maintain a constant level of x, the inputs into production as measured by F must increase as the pollution level falls.

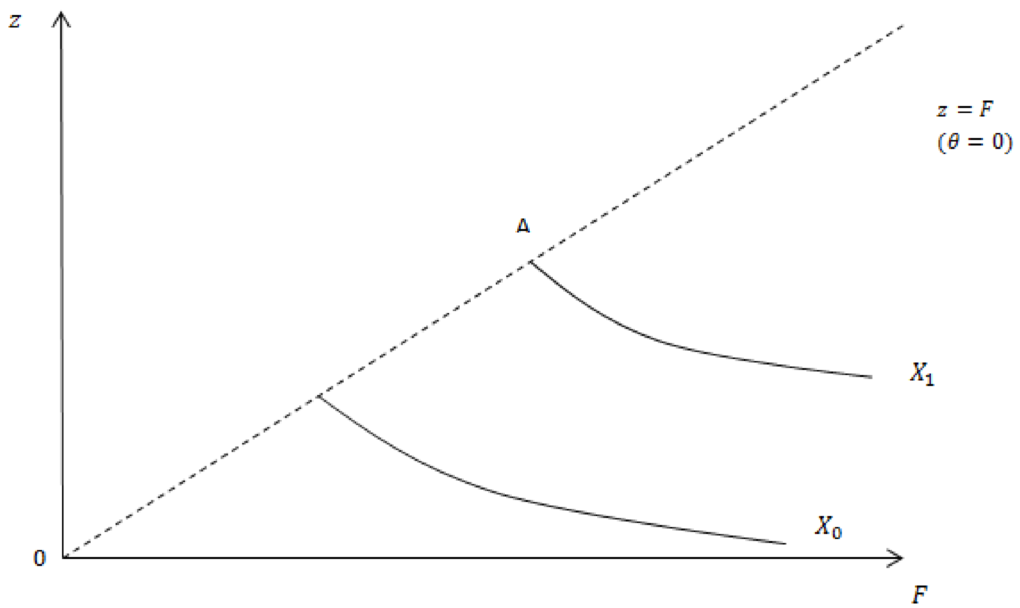

Figure 1.1.1

Cost Minimization

Assume that firms have to pay a fee τ for each unit of emissions they generate (τ can be either a pollution tax, or the price for a pollution permit). Because of the separability of our production function we can break the firm's problem into two steps: At first firms choose how much of each factor to use in order to minimize the cost of production of one unit of the potential output F; and then they minimize the total cost of production (cost of potential output and emissions payments) with respect to z and F, in order to find the most efficient way to combine potential output with environmental services to produce net output X. The unit cost function for F can be found by solving the following problem:

$$c^F(w,r) = \min_{\{k,l\}}\{rk + wl: F(k,l) = 1\} \tag{1.1.9}$$

The total cost of producing F units of potential output is $c^F(w,r)F$. Next, firms can determine how much abatement activity to undertake by finding the unit cost function for the net output. Formally, the firm solves the following cost minimization problem:

$$c^x(w,r,\tau) = \min_{\{z,F\}}\{\tau z + c^F(w,r)F: z^\alpha F^{1-a} = 1\} \tag{1.1.10}$$

The first order conditions for the problem (1.1.10) yield

$$\tau = \lambda\alpha z^{a-1}F^{1-a} \tag{1.1.11}$$

$$c^F = \lambda(1-\alpha)z^a F^{-a} \tag{1.1.12}$$

where λ is the Lagrange multiplier.

Dividing (1.1.11) and (1.1.12) by parts yields

$$\frac{z}{F}\cdot\frac{(1-\alpha)}{\alpha} = \frac{c^F}{\tau} \tag{1.1.13}$$

Moreover, since (1.1.8) is linearly homogeneous, we must also have:

$$px = c^F F + \tau z \tag{1.1.14}$$

Therefore, using (1.1.13) and (1.1.14) we can solve for pollution emissions per unit of net output (emission intensity), which we denote by e:

$$e \equiv \frac{z}{x} = \frac{\alpha p}{\tau} \tag{1.1.15}$$

Notice that emission intensity falls as pollution taxes (or emission permit prices) rise because pollution becomes more expensive. Furthermore, emission intensity rises as the price of the polluting good rises because the resources used in abatement have become more valuable. The solution described above is illustrated in Figure 1.1.2.

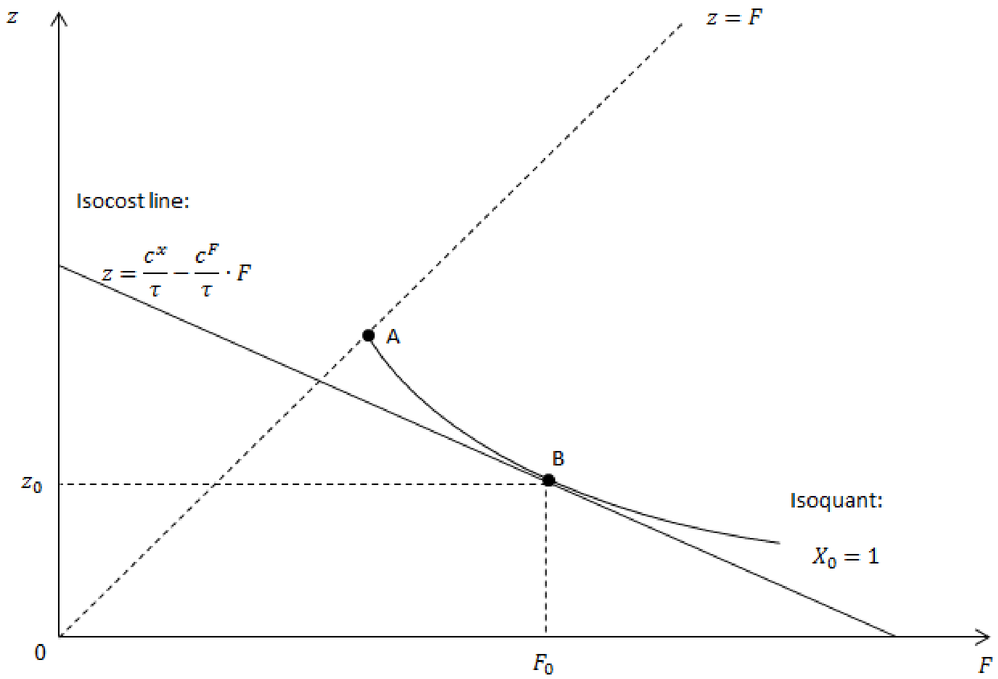

Figure 1.1.2

Point B in Figure 1.1.2 corresponds to the solution of the cost minimization problem described above. However, this is an interior solution; we may have a border solution instead. The isocost line becomes steeper as the emission tax falls, and thus for a sufficiently low emission tax the firm will find it optimal not to abate at all. To determine the conditions under whicsh a border solution occurs, define τ^* as the pollution tax that leaves a firm indifferent to abating or not. When there is no abatement, $z = x = F$ and $e = 1$. Thus, under no abatement, (1.1.15) yields

$$\tau^* = \alpha p \tag{1.1.16}$$

For any emission tax above τ^* the firm chooses to abate, and for any emission tax below τ^* it chooses not to abate at all.

Having derived emissions intensity, the economy's overall pollution emissions can be calculated as:

$$z = ex \tag{1.1.17}$$

Net and Potential Production Possibilities

The simplest way to illustrate the determination of output in a general equilibrium trade model is with the aid of the production frontier. However pollution is endogenous in our model, and thus the production possibility frontier must be three dimensional either if we treat pollution as an input or as a joint output along with X. Therefore we distinguish between net and potential production frontiers.

The *Potential Frontier* indicates the maximum amount of potential output F in the X industry that can be produced for any level of Y, given factor endowments and technology. That is, the potential output frontier illustrates the production possibilities for the economy if no abatement is undertaken.

The *Net Frontier* indicates the maximum amount of net output X that can be produced for any level of Y, given emission intensity e. All net frontiers lie inside the potential frontier because some sources are allocated into abatement activity, unless the economy is specialized in the production of Y.

For a given emission intensity e, we can derive the corresponding net frontier from the potential frontier substituting (1.1.17) into (1.1.8), which yields

$$x = e^{\frac{a}{1-a}} F(K_x, L_x) \tag{1.1.18}$$

Combining (1.1.18) with (1.1.3) we obtain a relation between the fraction of factors allocated into abatement activity θ and emission intensity e, which can be interpreted as a linkage between pollution abatement cost and emission intensity:

$$e = (1-\theta)^{\frac{1-\alpha}{\alpha}} \tag{1.1.19}$$

Notice that having a low emission intensity requires also having a high θ, or equivalently a high abatement cost.

Inverting (1.1.19) and using (1.1.15) we obtain the following expression for θ:

$$\theta = 1 - (\frac{\alpha p}{\tau})^{\frac{\alpha}{1-\alpha}} \tag{1.1.20}$$

Notice that the share of resources allocated to abatement increases as the pollution tax rises, since the opportunity cost of abatement has fell . Moreover, θ falls when the price of X rises, since the opportunity cost of abatement has increased. The net and potential production frontiers are shown graphically in Figure 1.1.3.

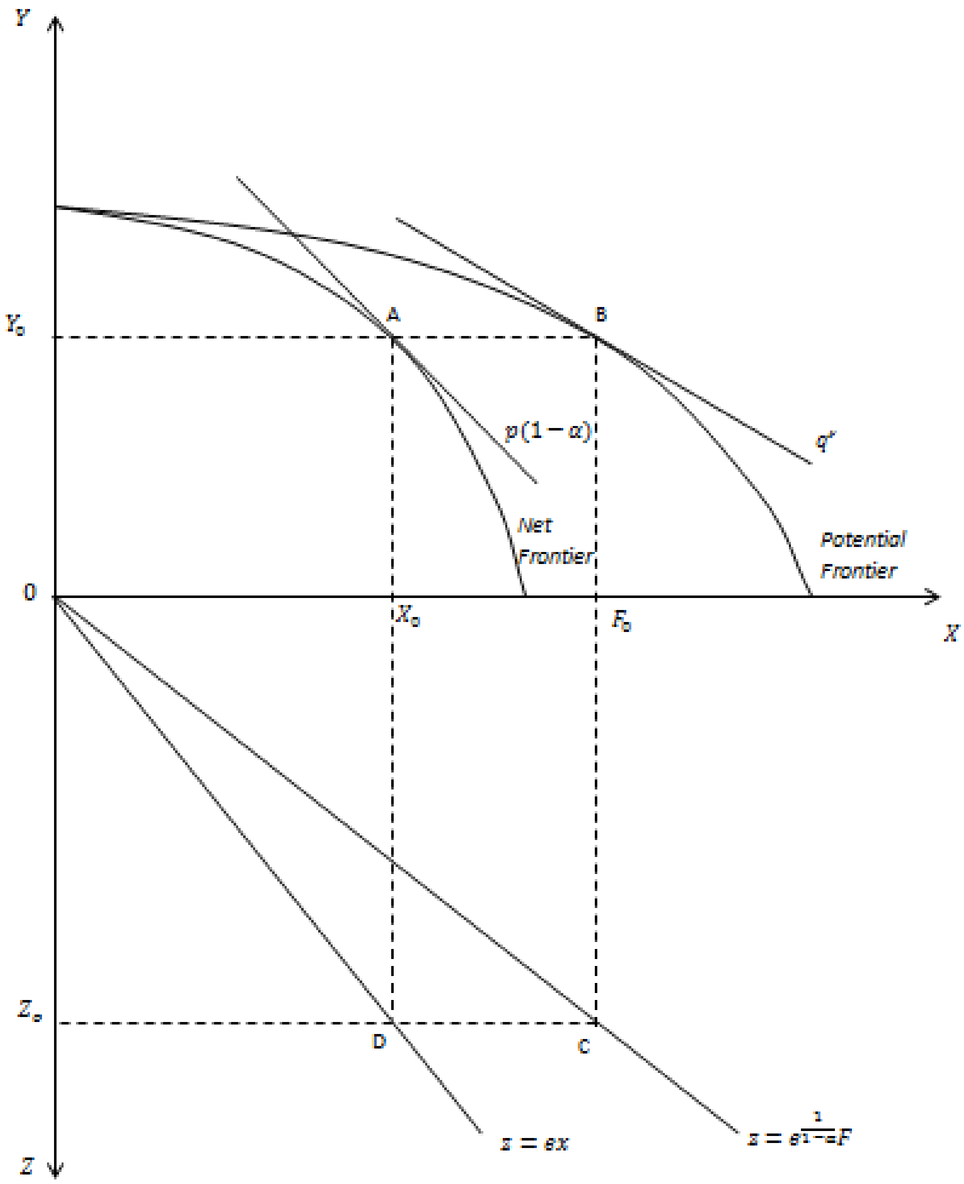

Figure 1.1.3

Equilibrium along the Net and Potential Production Frontiers

We can now exploit our production frontiers to illustrate the equilibrium levels of output and pollution for a given market goods price p and pollution emission fee τ[2]. We can use either the net or the potential frontier.

[2] We assume that τ is large enough so that firms in the X sector actively abate.

Using the Net Frontier:

Profits for a firm in the X sector are given by:

$$\pi^x = pX(K_x, L_x) - wL_x - rK_x - \tau z \tag{1.1.21}$$

Where, by (1.1.3), $X(K_x, L_x) = (1-\theta)F(K_x, L_x)$. Using (1.1.17) to replace z we obtain:

$$\pi^x = (p - \tau e)X(K_x, L_x) - wL_x - rK_x$$
$$\Leftrightarrow \pi^x = p(1-\alpha)X(K_x, L_x) - wL_x - rK_x - \tau z \tag{1.1.22}$$

Profits for a firm in the Y sector are given by:

$$\pi^y = H(K_y, L_y) - wL_y - rK_y{}^3 \tag{1.1.23}$$

The first order conditions for the profit maximization problem of the firms in each sector yields:

$$\begin{aligned} H_K &= p(1-\alpha)X_K = r \\ H_l &= p(1-\alpha)X_L = w \end{aligned} \tag{1.1.24}$$

Dividing by parts and rearranging yields

$$\frac{H_K}{X_K} = \frac{H_L}{X_L} = p(1-\alpha) \tag{1.1.25}$$

Notice that the slope of the net production frontier is given by[4]:

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[3] Recall that Y is assumed to be the numeraire good, and that Y is the clean good and thus firms in the Y sector do not have to pay a pollution emissions fee.

[4] The net production frontier is given algebraically by:

$Y(X) = \max\{ H(K_Y, L_Y): X = X(K_X, L_X), K_X + K_Y = K, L_X + L_Y = L \}$

$$\left.\frac{dY}{dX}\right|_{Net} = -\frac{H_K}{X_K} = -\frac{H_L}{X_L} \tag{1.1.26}$$

Combining (1.1.25) and (1.1.26) we get the equilibrium condition:

$$\left.\frac{dY}{dX}\right|_{Net} = -p(1-\alpha) \tag{1.1.27}$$

That is, in aggregate firms' behavior leads to a production point along the net frontier where the slope of the net frontier is equal to the producer price $q \equiv p(1-\alpha)$. This is point A in Figure 1.1.3. Pollution is determined at point D in the bottom half of the diagram.

<u>Using the Potential Frontier</u>:

We can rewrite the profits of a firm in the X sector, given by (1.1.21), as:

$$\pi^x = q^F F(K_x, L_x) - wL_x - rK_x \tag{1.1.28}$$

where q^F is the producer price a firm obtains for producing one unit of potential output F, given by:

$$q^F = p(1-\alpha)(1-\theta) \tag{1.1.29}$$

The producer price is less than p because only a fraction $(1-\theta)$ of output is available for sale (the rest is used for abatement), and of that only a fraction $(1-\alpha)$ remains after pollution taxes are paid.

Using the envelope theorem, the slope of the net production frontier is equal to the Lagrange multiplier for the constraint on X, which is denoted by λ. From the first order conditions of the maximization problem above we get:

$$\lambda = -\frac{H_K}{X_K} = -\frac{H_L}{X_L}$$

Working similarly we can obtain the slope of the potential production frontier:

$$\left.\frac{dY}{dX}\right|_{Potential} = -\frac{H_K}{F_K} = -\frac{H_L}{F_L}$$

The profits of a firm in the Y sector are given by (1.1.23). Combining the profit maximization conditions for firms in both sectors we get:

$$\frac{H_K}{F_K} = \frac{H_L}{F_L} = q^F \tag{1.1.30}$$

The slope of the potential frontier is given by:

$$\left.\frac{dY}{dX}\right|_{Potential} = -\frac{H_K}{F_K} = -\frac{H_L}{F_L} \tag{1.1.31}$$

Combining (1.1.30) with (1.1.31) we obtain the equilibrium condition:

$$\left.\frac{dY}{dX}\right|_{Potential} = q^F \tag{1.1.32}$$

At the equilibrium production point (point B in Figure 1.1.3), the absolute value of the slope of the potential frontier is equal to the relative producer price for potential output q^F. To illustrate equilibrium pollution, combine (1.1.17) and (1.1.18) to obtain:

$$z = e^{\frac{1}{1-a}}F \tag{1.1.33}$$

This is depicted at point C in the bottom half of Figure 1.1.3.

Finally, we can easily observe that:

$$\left.\frac{dY}{dX}\right|_{Potential} = (1-\theta)\left.\frac{dY}{dX}\right|_{Net} \tag{1.1.34}$$

and thus the two approaches (using the net or the potential frontier) are equivalent.

Equilibrium Using Algebra:

There are two sorts of equilibrium conditions: free entry (zero profit condition) and full employment condition. The unit cost function of the clean good is given by:

$$c^Y(\mathrm{w,r})=\min_{\{k,l\}}\{rk+wl: H(k,l)=1\} \tag{1.1.35}$$

The free entry conditions require that the unit cost of each good must be equal to its price:

(1.1.36)

$$c^F(w,r)=q^F$$

$$c^Y(w,r)=1 \tag{1.1.37}$$

The full employment conditions require that the demand of each factor (the sum of its demand for each sector) must be equal to its supply. To derive the factor demand functions we simply differentiate c^F and c^Y with respect to w and r:

$$a_{LF}(w,r)=\frac{\partial c^F(w,r)}{\partial w}$$

$$a_{KF}(w,r)=\frac{\partial c^F(w,r)}{\partial r}$$

$$a_{LY}(w,r)=\frac{\partial c^Y(w,r)}{\partial w}$$

$$a_{KY}(w,r)=\frac{\partial c^Y(w,r)}{\partial r}$$

Full Employment Conditions:

$$\underbrace{a_{LF}(w,r)F}+\underbrace{a_{LY}(w,r)Y}=\underbrace{L} \tag{1.1.38}$$

Labor Demand in the X Sector | Labor Demand in the Y Sector | Labor Supply

Total Labor Demand

$$\underbrace{\underbrace{a_{KF}(w,r)F}_{\text{Capital Demand in the X Sector}} + \underbrace{a_{KY}(w,r)Y}_{\text{Capital Demand in the Y Sector}}}_{\text{Total Capital Demand}} = \underbrace{K}_{\text{Capital Supply}} \qquad (1.1.39)$$

For a given emission price, we can solve (1.1.36) and (1.1.37) jointly to derive w and r. Also, for a given emission price we can solve (1.1.38) and (1.1.39) jointly to derive Y and F.

Comparative Statics

The model described above looks very much like the standard Heckscher-Ohlin model of international trade, with the only difference that the producer price q^F differs from the market price to take into account pollution taxes and abatement. Therefore, for given pollution taxes or emission intensities, the model inherits the standard properties of the Heckscher-Ohlin model.

<u>The Stolper-Samuelson Theorem:</u>
An increase in the producer price of a good increases the real return to the factor used intensively in the production of that good.

As it can be seen in Figure 1.1.4 below, an increase in the producer price of the polluting good would lead to an increase in the return to capital, which is the factor used intensively in the production of that good, and a decrease in the wage. Figure 1.1.4 depicts the isocost curves that correspond to the zero profit conditions (1.1.36) and (1.1.37) under prices: $p^Y = 1$ for the clean good and both prices q_0^F and q_1^F for the dirty good, where $q_0^F < q_1^F$.

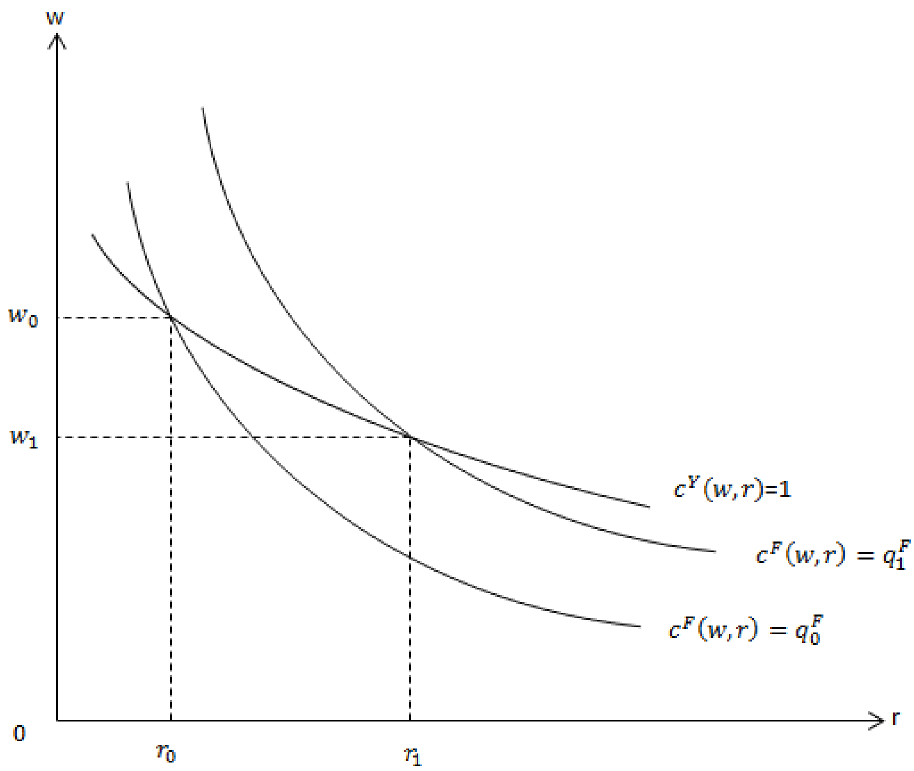

Figure 1.1.4

Similarly, an increase in the clean good's price would lead to an increase of w and a decrease of r.

<u>Rybczinski Theorem:</u>

For a given emission intensity, an increase in the endowment of one factor increases the output of the sector that uses this factor intensively, and reduces the output of the other sector, with no changes in factor prices.

As it can be seen in Figure 1.1.5 below, an increase in the endowment of capital would lead to an increase in the output of the polluting industry, which produces the capital intensive (dirty) good, and to a decrease in the output of the clean industry. Figure 1.1.5 depicts the curves that correspond to the full-employment conditions (1.1.38) and (1.1.39) for factor stocks: $L, K_0$and K_1, where $K_0 < K_1$.

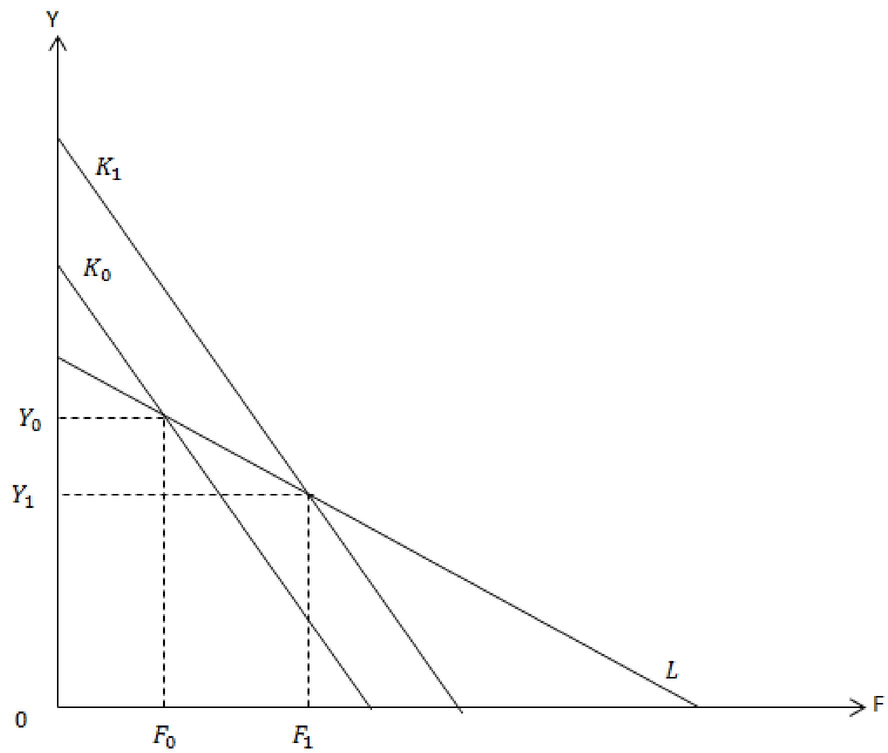

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Figure 1.1.5

Similarly, an increase in the labor stock L would lead to an increase in the output of the clean industry Y and to a decrease in the output of the dirty industry F or X. Reformulating the equilibrium conditions (1.1.36)-(1.1.39) in terms of net output we obtain:

$$\frac{c^F(w,r)}{(1-\theta)} = p(1-a) \tag{1.1.40}$$

$$c^Y(w,r) = 1 \tag{1.1.41}$$

$$a_{LX}(w,r)X + a_{LY}(w,r)Y = L \tag{1.1.42}$$

$$a_{KX}(w,r)X + a_{KY}(w,r)Y = K \tag{1.1.43}$$

Then we can solve the system (1.1.40)-(1.1.43) to obtain:

$$x = x(p,\tau,K,L) \tag{1.1.44}$$

$$y = y(p,\tau,K,L) \tag{1.1.45}$$

That is, outputs are determined by good prices, factor stocks and pollution policy. An important property of those functions is that both of them are homogeneous of degree 1 with respect to K and L. That means that if we multiply both factor stocks by the same positive number λ, then the new equilibrium outputs must be equal to the former ones multiplied by λ, i.e.:

$$x(p,\tau,\lambda K,\lambda L) = \lambda x(p,\tau,K,L)$$

$$y(p,\tau,\lambda K,\lambda L) = \lambda y(p,\tau,K,L)$$

To prove this, let a factor endowment vector be (K_0, L_0), and the equilibrium outputs that solve (1.1.42) and (1.1.43) jointly be x_0 and y_0. Then consider another factor endowment vector which is constructed multiplying the initial vector by λ, where $\lambda > 0$. Thus this vector is $(\lambda K_0, \lambda L_0)$. Firstly, recall that (1.1.40) and (1.1.41) can be solved jointly, independently of (1.1.42) and (1.1.43) and yield the equilibrium values of w and r. Hence the equilibrium w and r are the same under both factor endowment vectors. Lastly, it is obvious that since x_0 and y_0 solve the full employment conditions under (K_0, L_0), then λx_0 and λy_0 must solve the full employment conditions under$(\lambda K_0, \lambda L_0)$. Therefore, (1.1.44) and (1.1.45) are both homogeneous of degree 1.

Consumers

We assume there are N identical consumers in the economy. Their utility depends on both consumption of goods and environmental quality. For simplicity, we assume that preferences over consumption goods are homothetic and that the utility function is strongly separable with respect to consumption goods and environmental quality. The utility function of a typical consumer is given by:

$$U(x, y, z) = u(x, y) - h(z) \tag{1.1.46}$$

where $u(x, y)$ is increasing, homothetic and concave, and $h(z)$ is increasing and convex.

The "hate function" $h(z)$ must be increasing to justify that consumers dislike pollution, and it must be convex so that $U(x, y, z)$ be concave. The convexity of $h(z)$ means that consumers' "hate" of pollution depends directly and positively on the level of pollution. For high pollution levels consumers dislike an extra unit of emissions very much, but for low pollution levels and extra unit of emissions would slightly reduce consumers' utility.

The homotheticity assumption helps us in two ways: Firstly, we can write the indirect utility function as an increasing function of real income; and secondly, it ensures that the relative demand for goods is unaffected by income levels.

The strong separability assumption means that the marginal rate of substitution between x and y is not affected by the level of environmental quality.

Therefore, the indirect utility function of a typical consumer has the following form:

$$V(p, I, z) = v\left(\frac{I}{\beta(p)}\right) - h(z) \quad (1.1.47)$$

where $\frac{I}{\beta(p)}$ is the real per capita income which is constructed by dividing the nominal per capita income I with a price index $\beta(p)$, and $v(\cdot)$ is increasing and concave.

National Income Functions

In a perfectly competitive economy, profit maximizing firms maximize the value of national income. Thus a National Income Function is a maximum value function that can be written as:

$$G(p^x, p^y, K, L, z) = \max_{\{x,y\}}\{p^x x + p^y y : (x, y) \in T(K, L, z)\} \quad (1.1.48)$$

where $T(K, L, z)$ is a two-dimensional convex production possibility set with constant returns to scales.

<u>National Income Function Properties:</u>

Firstly, Hotelling's Lemma holds:

$$\frac{\partial G(p^x, p^y, K, L, z)}{\partial p^x} = x \quad (1.1.49)$$

$$\frac{\partial G(p^x, p^y, K, L, z)}{\partial p^y} = y \quad (1.1.50)$$

This follows from the Envelope Theorem.

Next, the returns to each factor can be found simply by differentiating with respect to the relevant factor endowment:

$$\frac{\partial G(p^x, p^y, K, L, z)}{\partial K} = r \quad (1.1.51)$$

$$\frac{\partial G(p^x, p^y, K, L, z)}{\partial L} = w \tag{1.1.52}$$

The derivative of the national income function with respect to the endowment of one factor gives us the value of the marginal product of this factor under equilibrium, and we have a perfectly competitive economy, this must be equal to the return to this factor. Another property is:

$$\frac{\partial G(p^x, p^y, K, L, z)}{\partial z} = \tau \tag{1.1.53}$$

In a perfectly competitive equilibrium, the price that firms would have to pay for one more unit of emissions would be equal to the value of the marginal product of emissions. The expression $\frac{\partial G(p^x, p^y, K, L, z)}{\partial z}$ can be interpreted as General Equilibrium Marginal Abatement Cost, since it measures the reduction of national income caused by a decrease in pollution emissions.

Given those properties, we can derive some additional properties of the National Income Function:

$$\frac{\partial^2 G(p^x, p^y, K, L, z)}{\partial (p^x)^2} = \frac{\partial x}{\partial p^x} \geq 0, \qquad \frac{\partial^2 G(p^x, p^y, K, L, z)}{\partial (p^y)^2} = \frac{\partial y}{\partial p^y} \geq 0$$

i.e. $G(p^x, p^y, K, L, z)$ is convex in prices. Moreover:

$$\frac{\partial^2 G(p^x, p^y, K, L, z)}{\partial K^2} = \frac{\partial r}{\partial K} \leq 0, \qquad \frac{\partial^2 G(p^x, p^y, K, L, z)}{\partial L^2} = \frac{\partial w}{\partial L} \leq 0$$

i.e. $G(p^x, p^y, K, L, z)$ is concave in endowments, and also:

$$\frac{\partial^2 G(p^x, p^y, K, L, z)}{\partial z^2} = \frac{\partial \tau}{\partial z} \leq 0$$

i.e. $G(p^x, p^y, K, L, z)$ is concave in pollution emissions, and the General Equilibrium Marginal Abatement Cost Curve is downward slopping.

Finally, because of the constant returns to scales, $G(p^x, p^y, K, L, z)$ is homogeneous of degree 1 in prices and homogeneous of degree 1 in factor endowments, i.e.:

$$G(\lambda p^x, \lambda p^y, K, L, z) = \lambda G(p^x, p^y, K, L, z)$$

$$G(p^x, p^y, \lambda K, \lambda L, \lambda z) = \lambda G(p^x, p^y, K, L, z)$$

In the National Income Function, as it is described above, we treat pollution as exogenous. This is consistent with an emission permit system. However, if there is no regulation on pollution, or if there is a fixed pollution tax in place, then z must be treated as endogenous. To do that, we have to define another maximum value function:

$$\tilde{G}(p^x, p^y, \tau, K, L) = \max_{\{x,y,z\}} \{p^x x + p^y y - \tau z \colon (x, y) \in T(K, L, z)\} \tag{1.1.54}$$

This is the maximum value of net revenue generated by the private sector. The relation between G and $\tilde{G}$ is:

$$G(p^x, p^y, K, L, z) = \tilde{G}(p^x, p^y, \tau, K, L) + \underbrace{\tau z}_{\text{Pollution Tax Revenue}}$$

Notice that $\tilde{G}(p^x, p^y, \tau, K, L)$ satisfies all the same properties as $G(p^x, p^y, K, L, z)$, with the exception of (1.1.53) because it is a function of τ instead of z. Instead of (1.1.53), applying the Hotelling's Lemma we get:

$$\frac{\partial \tilde{G}(p^x, p^y, \tau, K, L)}{\partial \tau} = -z(p, \tau, K, L) \tag{1.1.55}$$

and moreover:

$$\frac{\partial^2 \tilde{G}(p^x, p^y, K, L, z)}{\partial \tau^2} = -\frac{\partial z}{\partial \tau} \geq 0$$

Other Works

The model presented above is developed by Copeland and Taylor (2003: Chapter 2) builds on previous works.

McGuire(1982) developed a two-sector model with two primary factors of production which inherits all the standard properties of the Heckscher-Ohlin model, and it is the closest model to the one presented in this section. This model treats pollution exclusively as an input.

Pethig (1976) used a two-sector model with one primary factors of production which inherits the standard properties of the Ricardian trade model.

Markusen (1976) used a two-sector model with two primary factors of production, but did not allow for variable emissions intensity. This is the similar to the model developed above if we assume a constant θ. Because of this assumption, pollution would turn to be a constant percentage of the potential (or the net) output of the pollution sector, i.e.:

$$z = \varphi \cdot F(K_x, L_x)$$

More recent approaches often use more complex models. Copeland (1994) develops a general equilibrium model with many goods, many factors of production and many different pollutants.

Rauscher (1997, chapter 5) uses a two-sector model with one factor of production, like Pethig (1976), but he assumes that pollution harms producers as well as consumers, and he allows for consumption-generated pollution.

Copeland and Taylor(1994) develop a two-sector model with one primary factor of production, but they allow for a continuum of goods with different emission intensities.

However, Copeland and Taylor's(2003, Chapter 2) model provides an appropriate context for further analysis because although it is more complex than those of McGuire, Pethig and Markusen, it is simple enough to work on for theoretical analysis, unlike more recent models the complexity of which make them more precise but also more difficult to analyze.

1.1.2 Scale, Composition and Technique Effects

Because the linkages between the economy and the environment are subtle and complex, it is useful to decompose changes in pollution into three fundamental forces: scale, composition and technique effects. Copeland and Taylor (2003, Chapter 2) present and analyze this decomposition.

Grossman and Krueger(1993) used this approach in their study of the potential effects of NAFTA on the environment.

This decomposition is particularly useful in comparing the effects of different type of shocks to the economy. For example, both trade liberalization and capital accumulation tend to raise the productivity of the economy, but they may stimulate different types of economic activity.

To measure the scale of the economy we use the value of net output at world prices. Thus the scale of the economy, S, is defined as:

$$S = p^0 x + y \tag{1.1.56}$$

where p^0 denotes the world relative price of X prior to any shocks that we analyze.

To assure that scale will not change simply because of a change in valuation, i.e. a change in world prices, we will always construct S using the same (base year) world prices.

Recall from (1.1.15) that $e \equiv \frac{z}{x}$. Multiplying both the numerator and the denominator of this fraction by p^0, S and x, and defining the value share of net output of x in total output evaluated at world prices as $\varphi_\chi = \frac{p^0 x}{S}$, we obtain:

$$z = \frac{z}{x} \cdot \frac{p^0 x}{S} \cdot \frac{S}{p^0} = e\varphi_\chi \frac{S}{p^0} \tag{1.1.57}$$

Hence pollution emissions depend on the emissions intensity of production e, the importance of the dirty good industry in the economy φ_{χ}, and the scale of the economy S.

Taking logs in (1.1.57) and totally differentiating it yields[5]

$$\hat{z} = \hat{S} + \hat{\varphi}_x + \hat{e} \tag{1.1.58}$$

The first term of the right side of the equation (1.1.58) is the *scale effect*. It measures the increase in pollution that would be generated if the economy were simply scaled up, holding constant the mix of goods produced and production techniques. The scale effect a force that we might call an "income effect" on pollution.

The second term is the *composition effect.* If we hold the scale of the economy and emissions intensities constant, then an economy that devotes more of its resources to producing the polluting good will produce more.

The last term is the *technique effect.* Holding everything else constant, a reduction in the emissions intensity will reduce pollution.

<u>The Scale Effect:</u>

Assume that the emissions intensity is held fixed, and suppose we scale up the economy by increasing each of the endowments by an equal percentage. That is, denote the new factor endowment vector by $(\lambda K, \lambda L)$ and consider the effect of increasing λ. Differentiating (1.1.57) logarithmically with respect to λ yields an expression for the change in pollution decomposed into scale, composition and technique effects:

[5] For any variable$u$, let $\hat{u}$ denote u's growth rate, i.e.:

$$\hat{u} = \frac{du}{u}$$

$$\frac{\frac{dz}{d\lambda}}{z} = \frac{\frac{dx}{d\lambda} + \frac{dy}{d\lambda}}{S} + \frac{\frac{d\frac{x}{S}}{d\lambda}}{\varphi_{\chi}} + \frac{\frac{de}{d\lambda}}{e} \tag{1.1.58}$$

where we have imposed $p^0 = 1$.

Recall that $x(p, \tau, K, L)$ and $y(p, \tau, K, L)$ are homogeneous of degree 1 in K, L. This implies that:

$$\frac{\frac{dx}{d\lambda} + \frac{dy}{d\lambda}}{S} = \frac{x(p, \tau, K, L) + y(p, \tau, K, L)}{x(p, \tau, \lambda K, \lambda L) + y(p, \tau, \lambda K, \lambda L)} = \frac{1}{\lambda} > 0$$

The scale effect is positive. This is a pure scale effect, as both the composition and technique effects are zero. The linear homogeneity of x and y in endowments implies that $\frac{x}{S}$ is independent of λ. I.e. that:

$$\frac{d\frac{x}{S}}{d\lambda} = 0$$

Thus the composition effect is zero. Moreover, since both p and τ are fixed by assumption, we have that:

$$\frac{de}{d\lambda} = 0$$

i.e., the technique effect is also zero. Consequently, scaling up factor endowments in the presence of exogenous pollution taxes yields a pure scale effect:

$$\frac{\frac{dz}{d\lambda}}{z} = \frac{\frac{dx}{d\lambda} + \frac{dy}{d\lambda}}{S} = \frac{1}{\lambda} > 0$$

This is illustrated in Figure 1.1.6. Point A indicates the initial output point on the net frontier with producers receiving $q = p(1 - a)$ per unit of net output. A pollution emissions function $z = ex$ with a given fixed emission intensity e_0 is depicted in the lower panel in Figure 1.1.6.

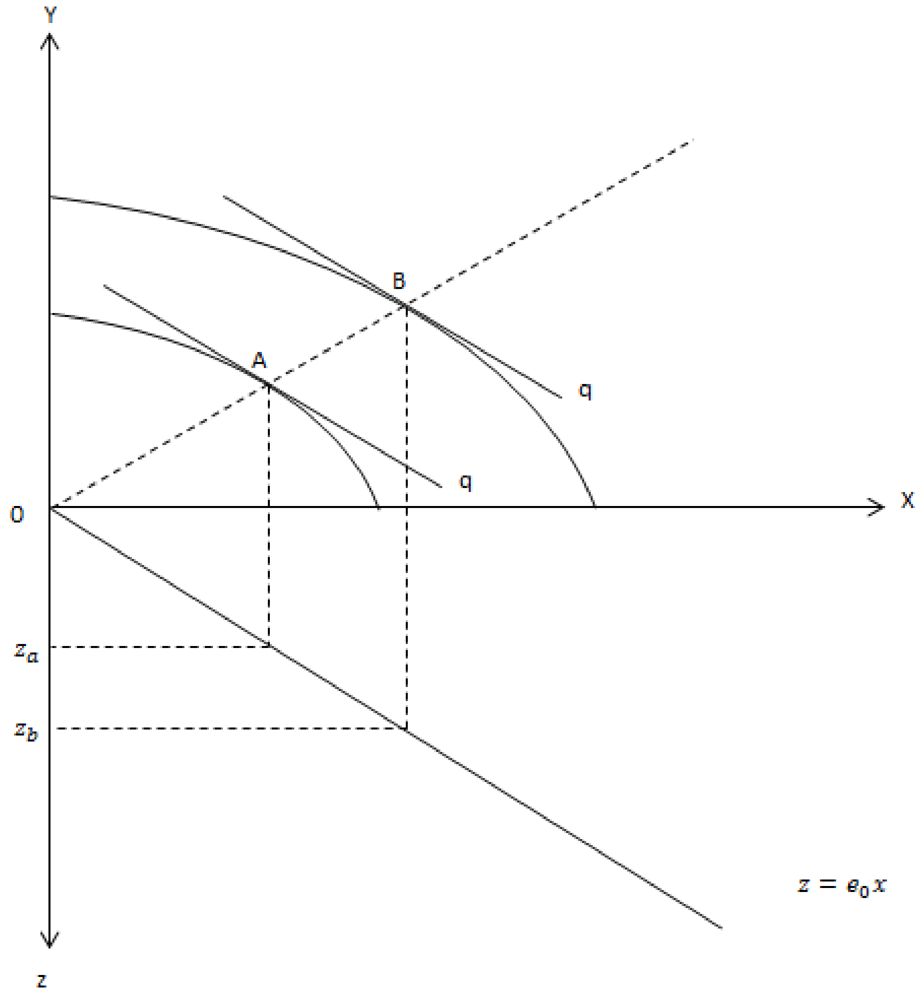

Figure 1.1.6

The initial level of pollution is z_a. After scaling up the economy, the new production frontier is just a radial expansion of the old one, because of constant returns to scale. The new production point is at point B, which is on the same ray through the origin as A. Pollution has increased to z_b. There is no technique effect because we have held emissions intensities and policy constant by assumption; and there is no composition effect since both the X and Y sectors expand equally.

The Composition Effect:

Assume again that the emissions intensity is held fixed, and now consider an increase in only the endowment of capital. Now the outward shift of the production frontier is skewed toward the X-axis, because industry X is capital intensive. This is depicted in Figure 1.1.7.

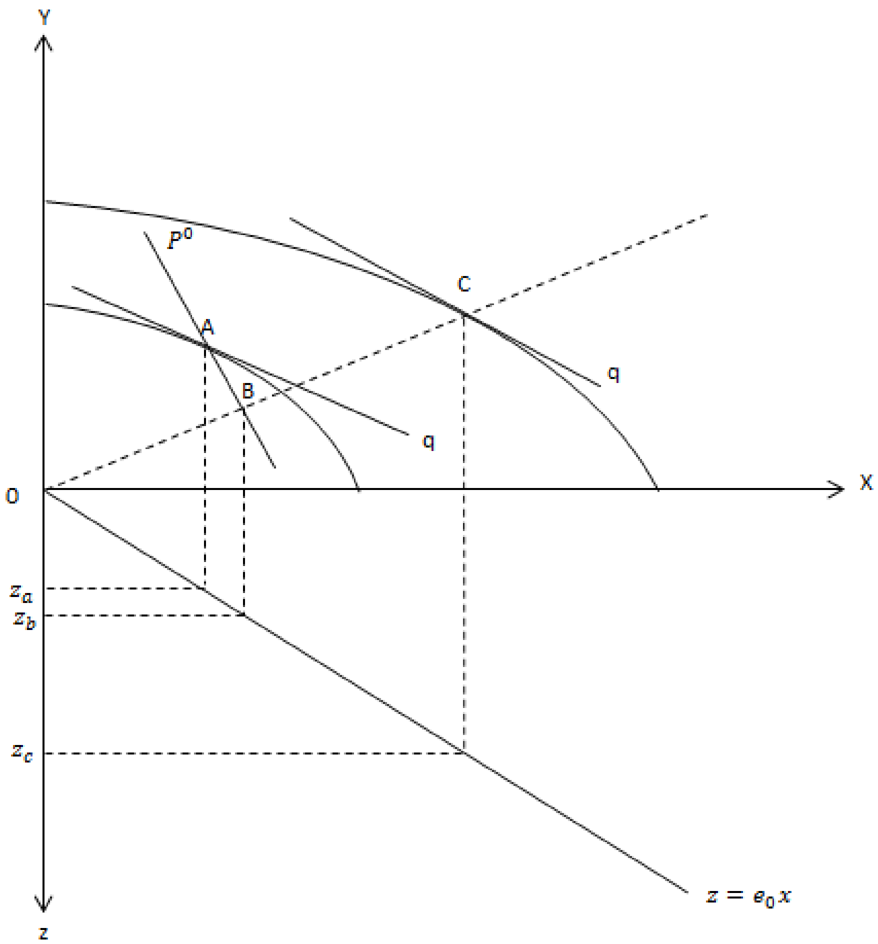

Figure 1.1.7

Notice that, consistently to the Rybczinski Theorem, capital accumulation leads to an increase of X and a decrease of Y in point C, compared to the initial point A._Both scale and composition effects are operative. The movement from point A to point C in Figure 1.1.7 can be decomposed into the movement from A to B, and the movement from B to C. The line denoted P_0 measures the value of the initial output at point A at our base-period world prices; this is the initial scale of the economy at point A. For any movement along P_0 the scale of the economy remains constant. The movement from A to B is a pure composition effect. This composition effect yields an increase in pollution from z_a to z_b. Next, the movement from B to C is the pure scale effect. This effect yields an increase in pollution from z_b to z_c.

Using algebra, we can differentiate (1.1.57) logarithmically with respect to K and obtain:

$$\frac{\frac{dz}{dK}}{z} = \frac{\frac{dx}{dK} + \frac{dy}{dK}}{S} + \frac{\frac{d\frac{x}{S}}{dK}}{\varphi_{\chi}} + \frac{\frac{de}{dK}}{e} \tag{1.1.59}$$

Since we held pollution taxes constant by assumption, there is no technique effect. I.e., $\frac{\frac{de}{dK}}{e} = 0$.

Next consider the composition effect. Note that:

$$\frac{x}{S} = \frac{1}{1 + \frac{y}{x}}$$

From the Rybczinski Theorem, we have:

$$\frac{d\frac{y}{x}}{dK} < 0$$

Consequently, the composition effect is unambiguously positive:

$$\frac{\frac{d\frac{x}{S}}{dK}}{\varphi_\chi} > 0$$

For the scale effect, we can differentiate (1.1.54) with respect to K and obtain the expression:

$$\frac{dx}{dK} + \frac{dy}{dK} = r + a\frac{dx}{dK} > 0$$

Notice that a composition effect of labor accumulation would be negative, since the clean sector is labor intensive.

<u>The Technique Effect:</u>

Suppose there is an exogenous increase in the pollution emissions tax. That means that the emissions intensity will decrease. As a result, the net frontier must shift in as more resources are allocated to abatement. The effects of this exogenous policy change are illustrated in Figure 1.1.8:

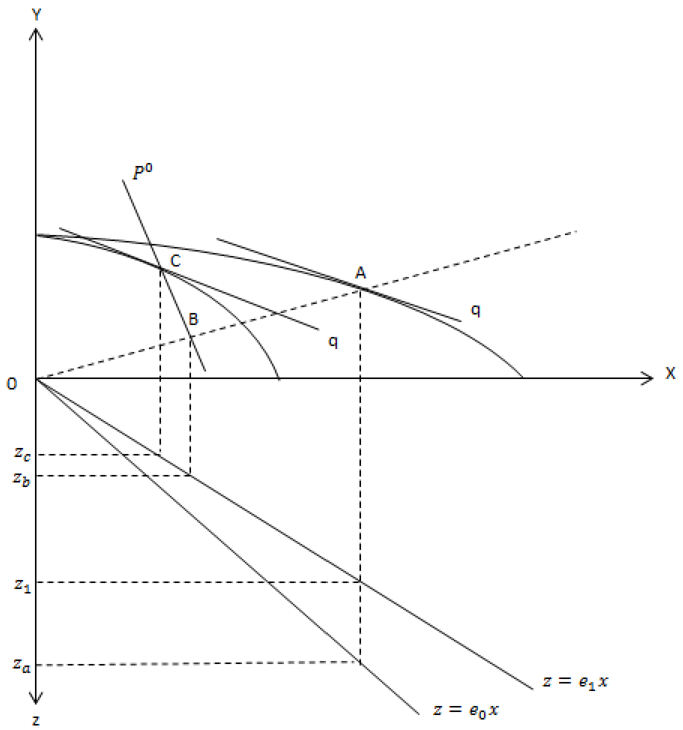

Figure 1.1.8

After the increase in pollution taxes and the subsequent decrease in emissions intensity from e_0 to e_1, and holding output at A, pollution falls from z_a to z_1. This is the technique effect: a higher pollution tax leads to cleaner production techniques because the opportunity cost of producing the polluting good is higher; and, holding the scale and composition of output fixed, this lowers pollution emissions. The movement from A to B is the scale effect, and the movement from B to C is the composition effect. Both the scale and the composition effects are negative and lead to a further drop in pollution, which eventually falls to z_c.

To confirm these results algebraically, differentiate (1.1.57) logarithmically with respect to τ to obtain:

$$\frac{\frac{dz}{d\tau}}{z} = \frac{\frac{dx}{d\tau} + \frac{dy}{d\tau}}{S} + \frac{\frac{d\frac{x}{S}}{d\tau}}{\varphi_\chi} + \frac{\frac{de}{d\tau}}{e} \tag{1.1.60}$$

Starting with the technique effect, we can derive from (1.1.15) that:

$$\frac{\frac{de}{d\tau}}{e} = -\frac{1}{\tau} < 0$$

The technique effect is negative. Higher taxes reduce the emissions intensity.
Next, the composition effect can be signed by noting:

$$\frac{d\frac{x}{S}}{d\tau} = \frac{d\frac{1}{1+\frac{y}{x}}}{d\tau} < 0$$

The sign follows from the fact that an increase in the pollution tax leads to a contraction of the X industry and an expansion of Y. Finally, the sign of the scale effect is determined by:

$$\frac{dx}{d\tau} + \frac{dy}{d\tau} = -z + a\frac{dx}{d\tau} < 0$$

Tightening up pollution policy therefore reduces pollution via three effects: cleaner techniques (technique effect), a shift in the composition of economic activity (composition effect) and a lower scale of output (scale effect).

Important uses of this approach

Except from Grossman and Krueger(1993) and their work on the effects of NAFTA on the environment, there are many other important works that apply this approach to analyze or estimate the effects of trade liberalization on environmental outcomes. Some of them are described below.

Cole, Rayner and Bates (1998) used this approach to analyze the effects of the Uruguay Round of Trade Liberalization on air pollution. Perroni and Wiggle (1994) ran various trade liberalization scenarios using a model benchmarked to 1986 data. Both of them found that the effect of trade liberalization on environmental outcomes is small.

Bohringer and Rutherford (2002) used a Computable General Equilibrium model to analyze the effects of agreements on climate change on trade and carbon leakage.
Antweiler, Copeland and Taylor (2001) estimated the scale, composition and technique effects for sulfur dioxide pollution using an international panel of data on ambient pollution. They found that increases in scale raise pollution; and that all else equal, increases in per capita income lower pollution (which they interpret as technique effect). Moreover, they found that the composition effect caused by capital accumulation is always positive, while the effects of trade on composition vary across countries, since their sign depends on whether a country is capital or labor abundant.

1.1.3. Endogenous Pollution Policy

In previous sections we treat pollution policy as exogenous. However, we expect it to be endogenous in fact. We expect, for example, that an increase in per capita income, which may be caused either by trade liberalization or economic growth, would lead to an increase in the demand for environmental quality, and thus to a tighter environmental regulation as a policy response. Introducing endogenous pollution policy will help us analyze the pollution haven hypothesis in the next section. The main sources of this section are Copeland and Taylor (2011), and Copeland and Taylor (2003, Chapter 2).

Demand for Pollution

The demand for pollution is a derived demand, as firms in the X sector derive benefits from securing the right to pollute. As discussed earlier, the pollution demand curve can be thought of as a general equilibrium marginal abatement cost curve. Recall from (1.1.53) that:

$$\tau = \frac{\partial G(p, K, L, z)}{\partial z} \tag{1.1.61}$$

This is the inverse demand for pollution. This function can be interpreted as a "marginal benefit of polluting" curve. From this relation we can define an implicit function $z = z(p, \tau, K, L)$, which is the demand function for pollution. Totally differentiating, and imposing $dp = dK = dL = 0$, we can solve for the slope of the pollution demand curve:

$$\frac{dz}{d\tau} = \frac{1}{G_{zz}} \leq 0 \tag{1.1.62}$$

The slope of the derived demand is non-positive since $G(\cdot)$ is concave in z.

Using (1.1.15) and (1.1.44) we can write demand for pollution as a function of the price of X, the pollution tax, and factor endowments:

$$z = e(p,\tau)x(p,\tau,K,L) \tag{1.1.63}$$

Thus the slope of the general equilibrium pollution demand is given by:

$$\frac{\partial z}{\partial \tau} = e_\tau x + e x_\tau < 0 \tag{1.1.64}$$

Notice that (1.1.64) identifies the two mechanisms at work in creating the negative slope of the demand for pollution. The first one is the technique effect: higher pollution taxes make abatement more profitable, thereby reducing the emissions intensity of production. The technique effect is the first term of (1.1.64), i.e. $e_\tau x < 0$. The second mechanism contains both the scale and the composition effect: with greater abatement efforts resources are drawn away from production of final goods and services, and this causes the output of x to fall as producers exit the x industry and move into the y industry. This mechanism is caught by the second term of (1.1.64), i.e. $e x_\tau < 0$.

Pollution demand shifts in response to changes in factor endowments and goods prices. To see how pollution demand depends on capital accumulation, differentiate (1.1.63) with respect to K:

$$\frac{dz}{dK} = e(p,\tau)\frac{dx(p,\tau,K,L)}{dK} > 0 \tag{1.1.65}$$

For a given pollution tax and for given goods prices, the emissions intensity is not affected by capital accumulation. Therefore, the shift of the demand for pollution is caused exclusively by the effect of capital accumulation on x, which is positive, as it is implied by the Rybczinski theorem. This shift is illustrated in Figure 1.1.9 (a).

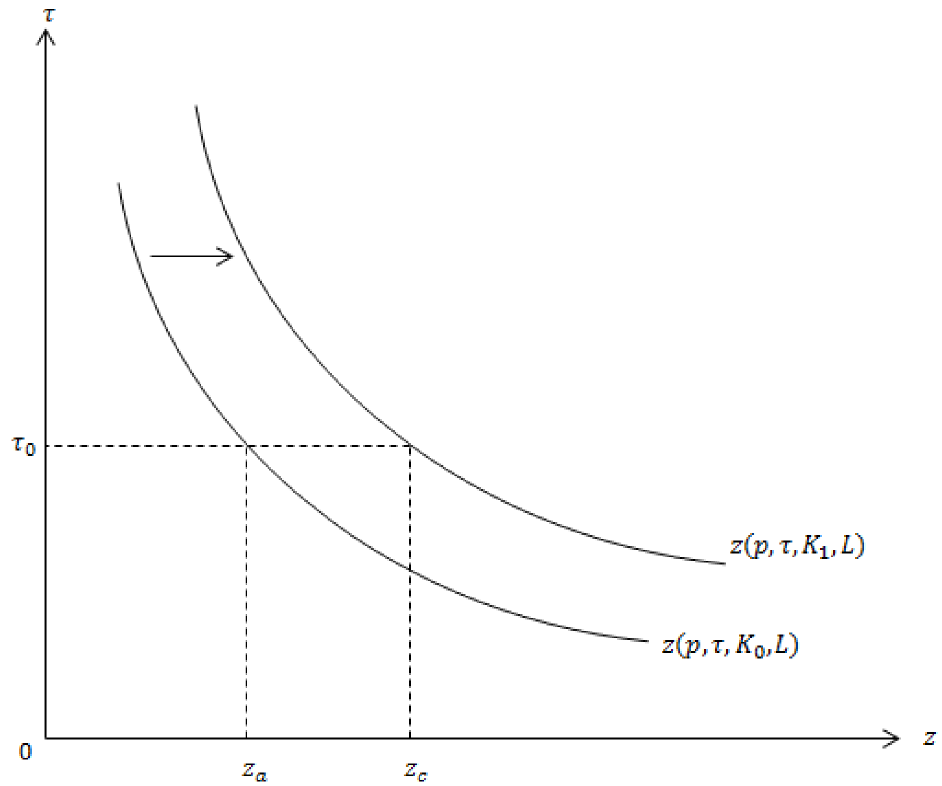

Figure 1.1.9(a)

Similarly, to see how pollution demand depends on labor accumulation, differentiate (1.1.63) with respect to L:

$$\frac{dz}{dL} = e(p,\tau)\frac{dx(p,\tau,K,L)}{dL} < 0 \qquad (1.1.66)$$

Again, for given τ and p, the emissions intensity is not affected by changes in L. Therefore, the effect of labor accumulation on the demand for pollution is caused exclusively from the response of x. Since the dirty sector is capital intensive, the effect of labor accumulation on the dirty output is negative, as it is implied by the Rybczinski theorem. This shift is illustrated in Figure 1.1.9 (b) below.

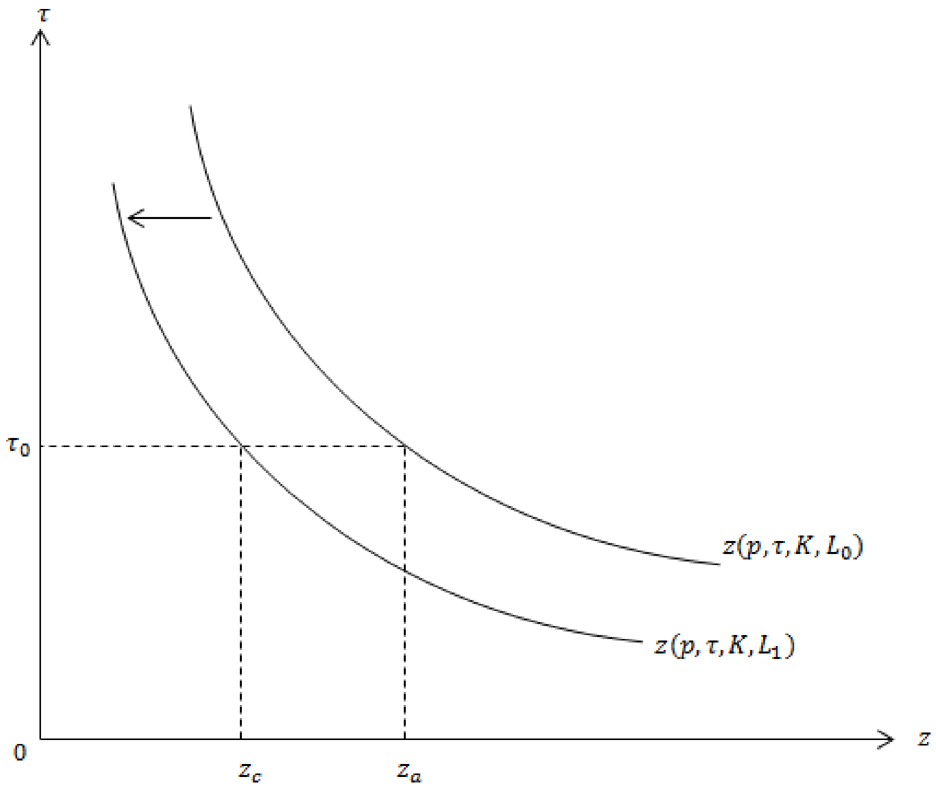

Figure 1.1.9(b)

Finally, we can differentiate (1.1.63) with respect to p to obtain:

$$\frac{dz}{dp} = x(p, \tau, K, L)\frac{de(p, \tau)}{dp} + e(p, \tau)\frac{dx(p, \tau, K, L)}{dp} > 0 \qquad (1.1.67)$$

(+) (+)

The intuition of this sign is that an increase in the price of the dirty good shifts the pollution demand to the right because abatement becomes more costly in terms of opportunity cost. This shift is the same as the one depicted in Figure 1.1.9 (a).

Supply of Pollution

The demand for pollution measures the marginal benefit of polluting. To determine the optimal pollution policy, we need to balance the marginal benefit of pollution against the marginal damage of polluting.

Since we have assumed all consumers are identical, the government's optimization problem is to maximize the utility of a representative consumer subject to production possibilities and private sector behavior. Thus the government's problem is:

$$\max_{\{z\}}\{ V(p, I, z), s.t. I = \frac{G(p, K, L, z)}{N}\}$$

The first order conditions for the solution of this problem yield

$$V_p \frac{dp}{dz} + V_I \frac{dI}{dz} + V_z = 0$$

In general, a change in the level of pollution will affect goods prices. However, since we work in a "Small Open Economy" context, changes in domestic pollution will have no effect on world prices, i.e., $\frac{dp}{dz} = 0$. Hence, we can solve for $\frac{dI}{dz}$ and obtain:

$$\frac{dI}{dz} = -\frac{V_z}{V_I} \quad (1.1.68)$$

Notice that the term $-\frac{V_z}{V_I}$ is the marginal rate of substitution between emissions and income. It reflects the typical consumer's willingness to pay for reduced emissions. In the environmental literature, this term is referred to as "marginal damage". We denote this by MD, and hence we define:

$$MD = -\frac{V_z}{V_I} \tag{1.1.69}$$

Using the constraint of the government's optimization problem, we have that:

$$\frac{dI}{dz} = \frac{G_z}{N} = \frac{\tau}{N} \tag{1.1.70}$$

Thus, using (1.1.69) and (1.1.70) we can rewrite (1.1.68) as:

$$\tau = N \cdot MD \tag{1.1.71}$$

This condition says that the optimal level of pollution is this level for which the emissions price faced by the producers is equal to aggregate marginal damage. In other words, (1.1.71) implies that for a small country which is open to international trade, the optimal pollution policy is to internalize the pollution externality. Since environmental quality is a pure public good, (1.1.71) is Simply the Samuelson rule for public goods provision[6].

[6] The Samuelson condition, authored by Paul Samuelson in the theory of public goods in economics, is a condition for the efficient provision of public goods. When satisfied, the Samuelson condition implies that further substituting private for public goods (or vice versa) would result in a decrease of social utility.

For an economy with n consumers the conditions reads as follows:

$$\sum_{I=1}^{N} MRS_i = MRT$$

MRS_i is individual i's marginal rate of substitution and MRT is the economy's marginal rate of transformation between the public good and an arbitrarily chosen private good.

If the private good is a numeraire good (the clean good in our model) then the Samuelson condition can be re-written as:

$$\sum_{i=1}^{N} MB_i = MC$$

where MB_i is the marginal benefit to each person of consuming one more unit of the public good, and MC is the marginal cost of providing that good. In other words, the public good should be

Recall the form of the indirect utility function of a typical consumer from (1.1.47) to derive:

$$MD = -\frac{V_z}{V_I} = \frac{\beta(p)h'(z)}{v'(R)} = MD(p, R, z) \tag{1.1.72}$$

i.e. the marginal damage function depends on goods prices, real income and pollution. Substituting real income with nominal income divided by the price index $\beta(p)$, and then substituting nominal income with the national income function divided by the number of consumers in the economy N, we can rewrite (1.1.71) as:

$$\tau = N \cdot MD(p, \frac{G(p, K, L, z)}{N}, z) \tag{1.1.71a}$$

This is the government's general equilibrium supply curve for pollution. It measures the country's willingness to allow pollution. Differentiating with respect to z we can get that the pollution supply curve is upward sloping[7]:

$$\frac{dMD}{dz} = MD_z + MD_R R_z = \frac{\tau}{N}(\frac{h''}{h'} - \frac{\tau v''}{v' N \beta}) \geq 0 \tag{1.1.73}$$

This sign is positive because of the convexity of $h(z)$ and the concavity of $v(R)$. Remember that both of them are increasing, and thus the first ratio is the parenthesis is positive, while the second is negative.

The pollution supply curve also shifts with changes in goods prices or real income. From (1.1.72) we can derive:

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provided as long as the overall benefits to consumers from that good are at least as great as the cost of providing it.

[7] We have used $G_z = \tau$.

$$MD_R = -\frac{v''}{v'} MD \geq 0 \tag{1.1.74}$$

Marginal damage is increasing in real income because environmental quality is a normal good. If $v(R)$ is linear, then real income gains have no effect on marginal damage. I.e. $MD_R = 0$.

Regulatory Equilibrium

The equilibrium level of pollution is determined by the interaction between the pollution demand curve and the pollution supply curve, i.e. the marginal benefit from pollution and the marginal damage of pollution.

$$G_z(p, K, L, z) = N \cdot MD(p, \frac{G(p, K, L, z)}{N\beta(p)}, z) \tag{1.1.75}$$

The efficient level of pollution z^* is determined by (1.1.75). To implement this efficient level of pollution, the government can employ either a pollution tax τ^* or issue z^* marketable permits that would yield an equilibrium permit price τ^*. Any equilibrium that can be implemented with a tax can also be implemented with a permit system. The equilibrium described above is depicted in Figure 1.1.10:

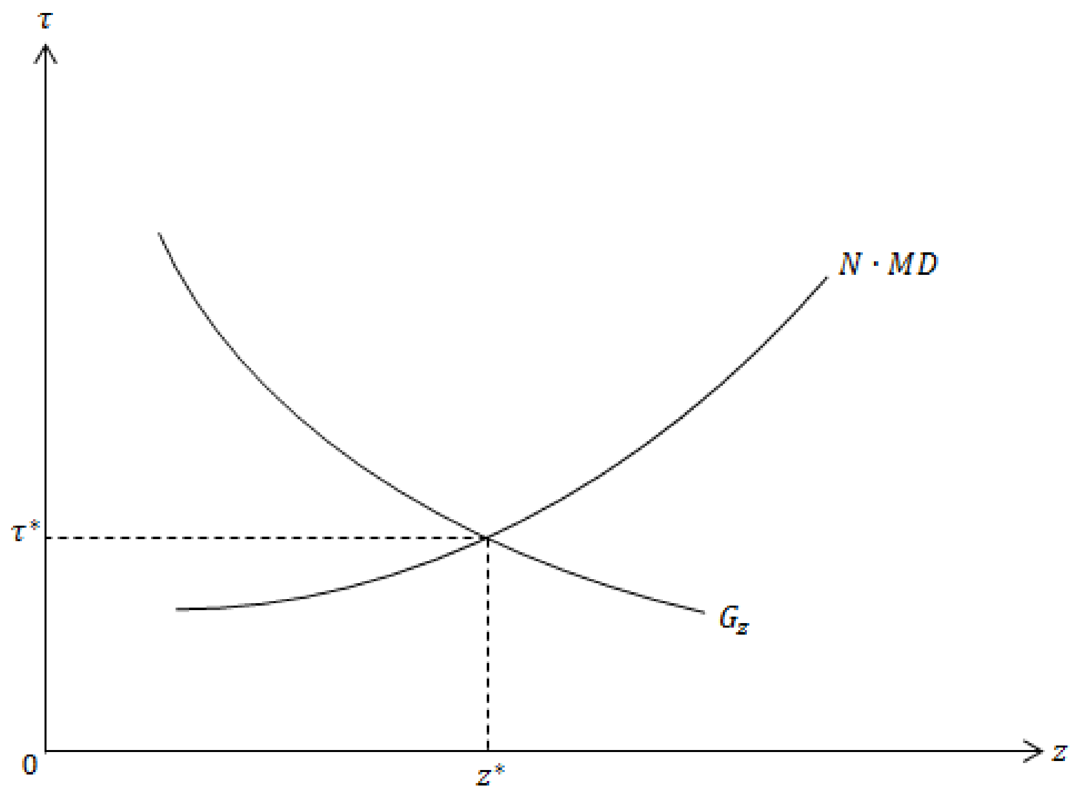

Figure 1.1.10

1.1.4. The Pollution Haven Hypothesis

A key issue in the trade and environment literature is the effect of domestic policy on international competitiveness of polluting industries. The pollution haven hypothesis is an important part of this issue. The main sources of this section are are Copeland and Taylor (2011), and Copeland and Taylor (2003, chapter 5).

The pollution haven hypothesis is that trade liberalization will cause polluting production to shift to countries with relatively weaker environmental regulation. The *competitiveness hypothesis* is that tighter environmental regulation reduces domestic competitiveness for firms in the pollution sector. This hypothesis is often referred to as a "pollution haven effect". If a pollution haven effect exists, and, in addition, weak environmental policy leads to a comparative advantage in polluting industry, then the pollution haven hypothesis is correct.

To see that the pollution haven hypothesis is different than the competitiveness hypothesis, suppose country A tightens up its environmental policy. If the competitiveness hypothesis is correct, then some pollution intensive production will shift out of the country. However, we cannot be sure whether that production will move to a country with weaker or tighter environmental policy. If a weak environmental policy does not necessarily assure a comparative advantage in polluting industry, then countries with skilled labour and infrastructure, but more stringent environmental policy, may attract the production that shifted out from country A.

The main alternative hypothesis to the competitiveness hypothesis is the Porter Hypothesis (Porter and van de Linde, 1995), which implies that tighter environmental regulation may actually increase competitiveness in the polluting sector. However, theoretical support for this hypothesis is weak.

Pethig's (1976) Ricardian trade model was the first to predict pollution havens. The only difference between the two countries in this model is that one has (exogenously) more stringent environmental policy. The model predicts that the country with weak environmental regulation will export the polluting good. Copeland and Taylor (1994) developed a pollution haven model with endogenous environmental policy, using a Dornbusch-Fischer-Samuelson (1977) framework with a continuum of goods with different pollution intensities. This is a typical North-South model, which is based on the assumption that North and South are two identical countries, except that North is richer than South. Since environmental quality is a normal good, and policy is assumed to be efficient, North chooses more stringent environmental policy than South. This model predicts that South will export the polluting good while North will import that good and export the clean good. Also, it is worth mentioning that this model predicts that trade liberalization increases world pollution via a global composition effect, because polluting industry shifts to countries with relatively weaker environmental policy. Those models isolate the effects of pollution policy differences on trade patterns. However, other factors affect trade patterns as well. Therefore, it is useful to work with models where the pollution haven effect interacts with other forces that determine trade patterns. Such models are developed by Copeland and Taylor (1997), Copeland and Taylor (2003, Chapter 4) and Richelle (1996). The Heckscher-Ohlin trade model developed by Copeland and Taylor (2003) is presented below.

Assume two primary factors of production K and L, and two goods: one polluting good X and one clean good Y (which is also assumed to be the numeraire good). The polluting sector is capital intensive, while the clean sector is labor intensive. Technology is given by (1.1.2) and (1.1.8):

$$x = z^{\alpha}[F(K_x, L_x)]^{1-a} \tag{1.1.8}$$

$$y = H(K_y, L_y) \tag{1.1.2}$$

In fact, we will just build on the model presented in section 1.1.1. Suppose there are two types of countries: North and South. The two countries are identical in terms of technology and preferences, but differ in that North is richer than South; for simplicity assume that populations are identical, but Northerners each owns more human and physical capital than Southerners. Since North is richer than South and environmental quality is assumed to be a normal good, if environmental regulation (which is assumed to be endogenous) is efficient, then North must have more stringent environmental policy than South. That is, South's marginal damage curve must be above South's, so that for any given level of pollution emissions z, North chooses a higher pollution tax τ than South. For example, assume the typical consumer's indirect utility function to be:

$$V(p, I, z) = \ln\left(\frac{I}{\beta(p)}\right) - \gamma z$$

In this case, the marginal damage is given by:

$$MD = -\frac{V_z}{V_I} = \gamma I$$

Since the two countries have the same preferences and population, and by (1.1.71) we have two equations:

$$\tau^N = \gamma N \cdot I^N \quad \text{(for North)}$$

$$\tau^S = \gamma N \cdot I^S \quad \text{(for South)}$$

which we can divide by parts and obtain:

$$\frac{\tau^N}{\tau^S} = \frac{I^N}{I^S} \qquad (1.1.76)$$

Since North is, by assumption, richer than South, we have that:

$$\tau^N > \tau^S$$

Thus the richer country chooses tighter environmental policy.

Next we will use relative demand and supply curves to illustrate the equilibrium. Since preferences over environmental quality are assumed to be strongly separable, and preferences over consumption goods are assumed to be homothetic and identical across the two countries, North's and South's relative demand curve is exactly the same.

To derive the relative supply curves, recall (1.1.44) and (1.1.45), which imply that equilibrium outputs are functions of goods prices, the pollution tax and factor endowments. Remember, also, that these functions are both homogeneous of degree 1. The relative supply of a country is defined as the ratio of the two outputs. Notice that since (1.1.44) and (1.1.45) are linearly homogeneous, the relative supply of a country must be homogeneous of degree zero. Therefore, we can write the relative supplies of the two countries as:

$$RS^N = \frac{x^N(p, \tau^N, \frac{K^N}{L^N}, 1)}{y^N(p, \tau^N, \frac{K^N}{L^N}, 1)} \tag{1.1.77}$$

$$RS^S = \frac{x^S(p, \tau^S, \frac{K^S}{L^S}, 1)}{y^S(p, \tau^S, \frac{K^S}{L^S}, 1)} \tag{1.1.78}$$

We do not know whether North's relative supply curve is above or below South's. Figure 1.1.11 depicts all possible cases.

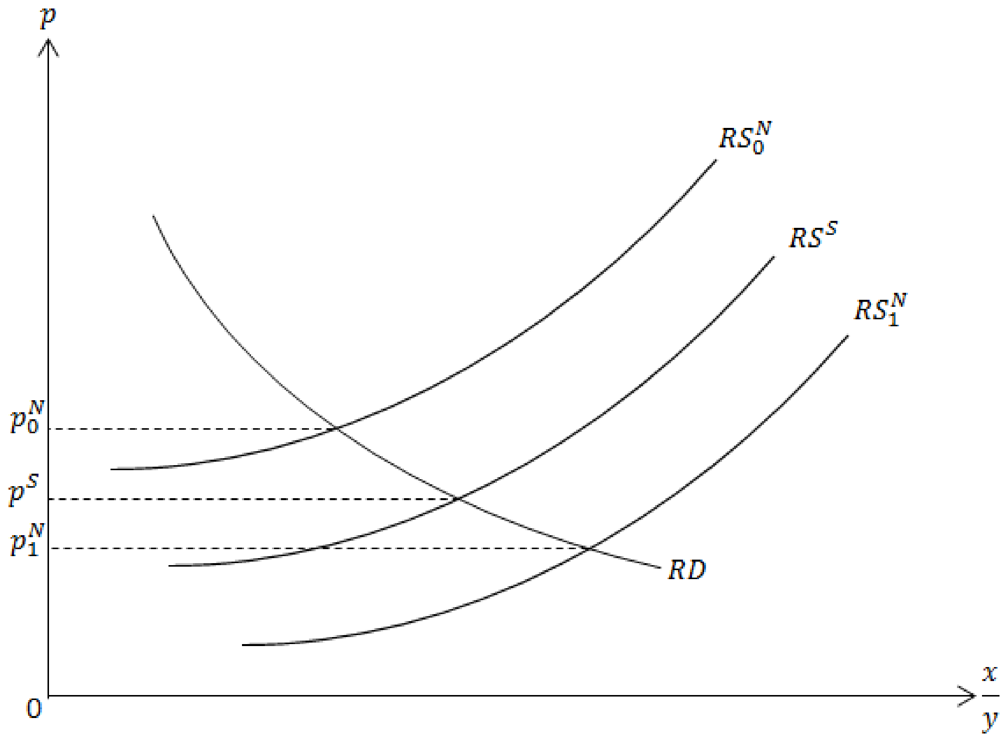

Figure 1.1.11

At first assume that the capital-labor ratios are equal across the two countries. Thus their relative supplies differ only because of the pollution taxes. Since North charges a higher emissions price than South, we must have that:

$$\frac{x^N}{y^N} < \frac{x^S}{y^S}$$

That is, North's relative supply curve must be above South's. Therefore, in the absence of trade, the relative price of the polluting good is higher in North than in South. Hence North will export the clean good, while South will export the dirty good. This is the pure pollution haven case of Copeland and Taylor (1994) because income-induced pollution policy differences are the only motive for trade.

Next assume that North is capital abundant. I.e.:

$$\frac{K^N}{L^N} > \frac{K^S}{L^S}$$

North’s richness and its more stringent environmental policy push its relative supply curve upward and to the left of South’s. However, North’s capital abundance favors the capital intensive sector and pushes its relative supply curve downward and to the right. The net effect depends on what is more important in determining relative costs: capital abundance or regulatory differences. If the effect of capital abundance is stronger, then North’s relative supply curve will be below South’s. Therefore the relative price of the polluting good will be higher in South than in North. Hence, although North has tighter environmental policy, it will export the polluting good, while South will export the clean good. If the effect of regulatory differences is stronger, this is again a case of a pollution haven effect, but not a pure one, since this time it was mitigated by the effect of capital abundance.

Finally, if North is labor abundant, the pollution haven hypothesis is incorrect. In this case, North’s relative supply curve will be below South’s, and thus North will export the polluting good.

This model focuses on the role of factor endowment differences on pollution havens. However, there are more factors that may also determine trade patterns. Ederington, Levinson and Minier (2004) and Zeng and Zhao (2009) developed models that agglomeration economies may limit the mobility of polluting firms: if the benefits of agglomeration outweigh the costs of relative stringent policy, a firm may prefer to remain in the jurisdiction with tighter pollution regulation.

1.2. Effects of Trade Liberalization on Natural Resources

In this chapter we focus on natural resources. In the first section we consider that type of externalities which affects the sector in which it is generated, while the second section focuses on cross-sectoral externalities.

1.2.1 Renewable Resources

Models that try to analyze international trade in renewable resources incorporate negative externalities that are internal to the industry but external to the producer. That is, production in one sector affects negatively on the productivity in the same sector. Such approaches are introduced in Brander and Taylor(1997a,b), Chichilnisky (1994), McCrae (1978), Kemp and Long (1984), Bulte and Barbier (2005) and Fischer (2010).

This section presents the model developed by Brander and Taylor, which combines the Ricardian trade model with the Schaeffer fisheries model. We begin with the description of the basic structure of renewable resource growth. Assume an open-access economic regime. The earliest work that analyzes the open-access case has been conducted by Gordon(1954). He found that harvesting occurs up to the point at which the current return to a representative harvester is equal to the harvester's current cost. Since we have assumed an open-access resource, no harvester has any incentive to delay harvesting, because of the expectation that someone else will harvest the whole stock instead. Let the resource stock be denoted by $S(t)$, and its natural growth rate denoted by $G(S(t))$. If $H(t)$ is the harvest rate of this resource, then the change in the resource stock at time t is given by:

$$\frac{dS(t)}{dt} = G\big(S(t)\big) - H(t) \tag{1.2.1}$$

For simplicity, assume that the resource stock growth function has the form of the logistic function[8]:

$$G(S) = rS(1 - \frac{S}{K}) \tag{1.2.2}$$

where K is the carrying capacity of the resource, i.e. the highest possible value for S.

Notice that when the resource stock is equal to its carrying capacity, then its growth rate is zero. r is the "intrinsic" or "uncongested" growth rate. That is, if the resource's carrying capacity was very large relatively to its current stock, the proportional growth rate $\frac{G(S)}{S}$ would be equal to r. The functional form of the harvest rate $H(t)$ depends on the economic incentives of harvesters.

Closed Economy

Now we will present the autarkic general equilibrium setting of the model. Assume a country with a nationally owned open-access renewable resource.

<u>Production:</u>

Assume that there are two goods: H, which is the harvest from the renewable resource, and M, which is some other good. Below we will refer to M as "manufactures". As stated above, the model has a Ricardian basis. Thus there is only one primary factor of production (Labor, denoted as L) along with the resource stock. M is produced using labor only; for simplicity assume that one unit of L produces one unit of M. Hence:

$$MP_L^M = 1$$

[8] The logistic function is often used in biology as a form of a population or a resource stock growth function. It implies that when the resource stock is relatively low, its growth rate is increasing and the stock function is convex, and when the resource stock is relatively high, its growth rate is decreasing and the stock function is concave. For very high values of the resource stock its growth rate converges to zero and the stock function converges to a horizontal line at the level of its carrying capacity.

Assume also that M is the numeraire good. Hence, assuming a competitive labor market (so that the wage for one unit of labor w is equal to the value of its marginal product) we have:

$$w = VMP_L^M = P \cdot MP_L^M = 1$$

Next, assume that H is produced according to the Schaeffer production function[9]:

$$H^P = aSL_H \tag{1.2.3}$$

where a is a positive productivity parameter, and L_H is the amount of labor used in H. The superscript P stands for production. The production function for M is simply $M^P = L_M$.

Since L_H units of labor produce H^P units of H, and given the constant returns to scale in labor in the production of the harvesting good, for one unit of H, the amount of labor that is required is given by:

$$a_{LH}(S) = \frac{L_H}{H^P} = \frac{1}{aS} \tag{1.2.4}$$

Notice that:

$$\frac{da_{LH}(S)}{dS} < 0$$

That is, the largest the resource stock, the less the unit labor requirements in the resource sector.

[9] The Schaefer harvesting function has been extensively applied to fishing. This functional form yields constant returns to scales in labor input, which is empirically plausible, and it facilitates the analysis.

Assuming that firms in both sectors are profit maximizers in a competitive environment, the harvesting good's price must be equal to the unit cost of production. I.e.:

$$p = w \cdot a_{LH} = \frac{w}{aS} \tag{1.2.5}$$

Equation (1.2.5) implies that labor costs are the only explicit costs of production. This holds because of the open access to the resource.

Assuming that labor is freely mobile, w must be the same in both sectors. Thus $w = 1$. Hence (1.2.5) becomes:

$$p = \frac{1}{aS} \tag{2.2.6}$$

Consumption:

Assume that a representative consumer is endowed with one unit of labor, and has a Cobb-Douglass utility function:

$$u = h^{\beta} m^{1-\beta} \tag{1.2.7}$$

where $\beta \in (0,1)$ is a taste parameter, h is the individual consumption of *H*, and m is the individual consumption of *M*.

Consumers maximize utility subject to the budget constraint[10]:

$$p \cdot h + m = L \tag{1.2.8}$$

Maximizing (1.2.7) subject to (1.2.8) and solving the first order conditions jointly, we get:

[10] Remember that *M* is the numeraire good, and that consumers have one unit of labor to supply for a wage of $w = 1$, and this is their only source of income. Therefore a representative consumer's income is equal to *L*.

$$h = \frac{w\beta}{p}$$
$$m = w(1-\beta) \tag{1.2.9}$$

(1.2.9) shows a representative consumer's demand for each good. We can derive aggregate demands just multiplying by L:

$$H^C = \frac{w\beta L}{p} \tag{1.2.10}$$

$$M^C = w(1-\beta)L \tag{1.2.11}$$

The superscript C stands for consumption.

Finally, the inverse demand function of the harvesting good can be derived directly from (1.2.10):

$$p = \frac{w\beta L}{H^C} \tag{1.2.12}$$

Temporary Equilibrium:

At a given moment, the resource stock is fixed. We can derive a temporary equilibrium for a given level of the resource stock. As discussed below, this equilibrium will change as the resource stock adjusts to its steady state level.

Because of the competitive market assumption, a full employment condition must be satisfied. This condition is:

$$H^P a_{LH}(S) + M = L \tag{1.2.13}$$

Substituting (1.2.4) in (1.2.13) and solving for H^P yields:

$$H^P = aLS - aSM \tag{1.2.14}$$

(1.2.14) is the economy's production possibility frontier.

The temporary equilibrium can be derived just equating the supply price given by (1.2.6) to the demand price given by (1.2.12):

$$\frac{1}{aS} = \frac{\beta L}{H}$$
$$\Leftrightarrow H = \alpha\beta LS \tag{1.2.15}$$

(1.2.15) gives the equilibrium harvest for any given level of the resource stock, and it is referred to as the "harvest schedule". Substituting (1.2.15) in (1.2.13) we can derive the equilibrium output of *M*:

$$M = (1-\beta)L \tag{1.2.16}$$

Notice that (1.2.16) implies what fraction of *L* that is employed in each sector at any temporary equilibrium. *β* in *H* and *1-β* in *M*.

<u>Transition to the Steady State:</u>

At the steady state we have:

$$\frac{dS(t)}{dt} = 0$$
$$\Leftrightarrow G(S) = H(S)$$

Thus, to solve for the steady state, we combine the resource stock growth function given by (1.2.2) with the harvest schedule function given by (1.2.15). Let the autarky steady state level of the resource stock be denoted by S_A. Solving (1.2.2) and (1.2.15) jointly yields two solutions:

$$S_A = K(1 - \frac{\alpha\beta L}{r}) \tag{1.2.17}$$

and $S = 0$.

Notice that $S = 0$ is a corner solution that corresponds to a steady state at which the resource is completely depleted. Notice also that an interior solution S_A exists only if

$\frac{r}{L} > \alpha\beta$. That is, the slope of the resource stock natural growth function at $S = 0$ must be lower than the slope of the harvesting schedule function, so that they intersect at a point where S is positive.

Figure 1.2.1 depicts the steady state of the resource stock. S_0 is the initial stock of the resource. Since S_0 is to the right of S_A, at this level harvest is higher than the natural growth rate of the stock, and, consequently, the stock shrinks to S_A. If the initial stock S_0 was to the left of S_A, that would lead to a harvest that is lower than the natural growth rate of the resource, and thus the stock would rise until it reaches S_A. It is worth mentioning that even if the initial stock was to the left of the maximum sustainable yield (MSY), which is the stock level that corresponds to the peak point of the natural growth curve, the transition to the steady state would be similar to the process discussed above. Finally, although $S = 0$ is a steady state stock level, the stock does not converge to this point for any level of S_0.

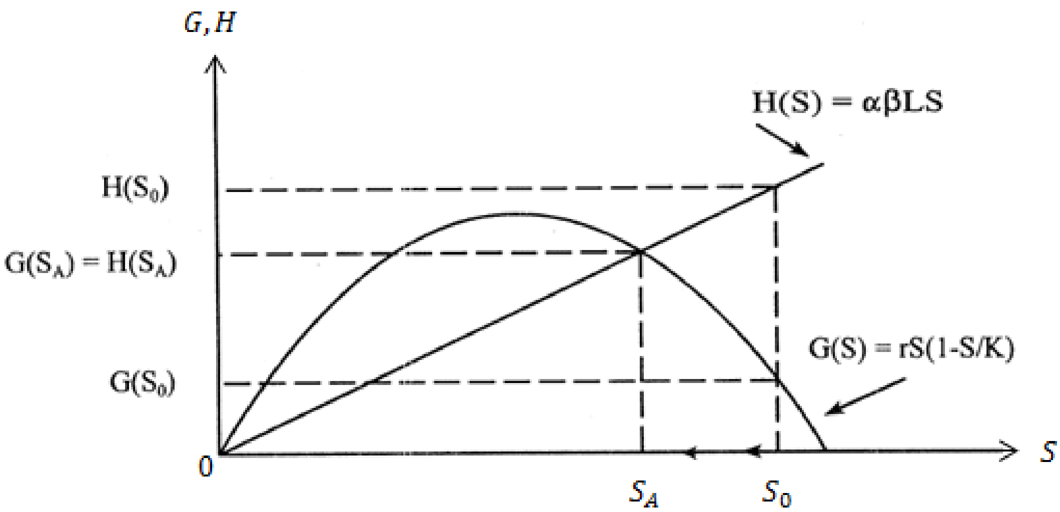

Figure 1.2.1

At the steady state, the temporary equilibrium price and harvest can be derived by substituting (1.2.17) into (1.2.6) and (1.2.15) respectively:

$$p^A = \frac{1}{S^A} = \frac{1}{\alpha K(1 - \frac{\alpha\beta L}{r})} \qquad (1.2.18)$$

$$H^A = \alpha\beta LK(1 - \frac{\alpha\beta L}{r}) \qquad (1.2.19)$$

As the resource stock shrinks towards its steady state level, the production possibility frontier pivots inward. Figure 1.2.2 illustrates the transition of the temporary equilibrium towards the autarkic steady state equilibrium.

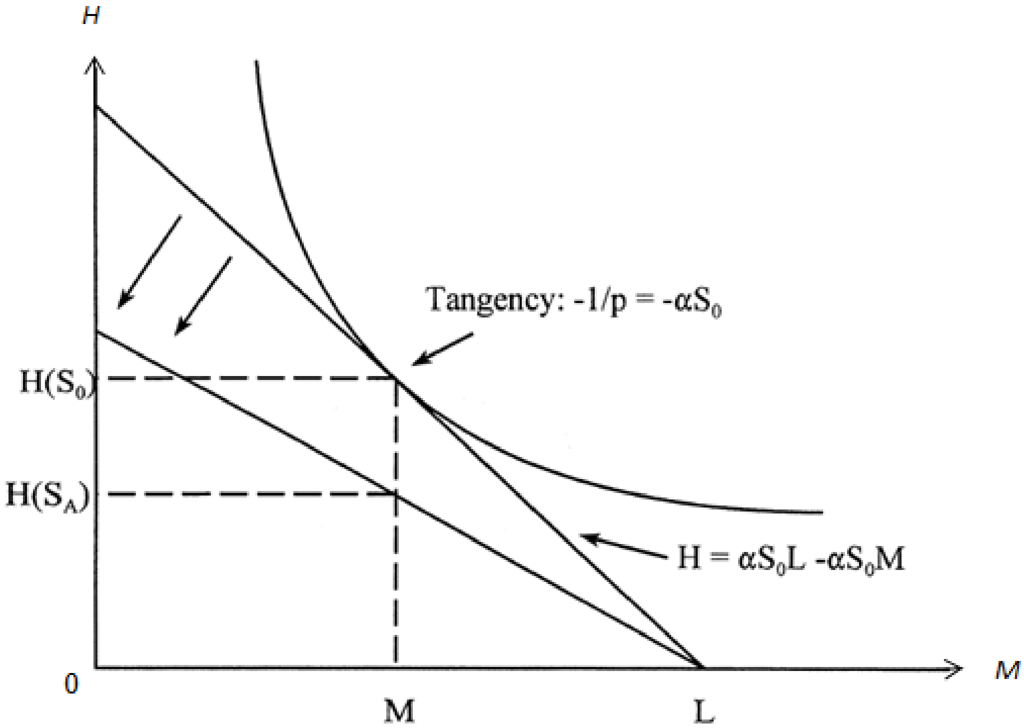

Figure 1.2.2

The next question that arises is how does a change in the value of a variable or a parameter of the model affects the autarkic steady state resource stock, harvest and price levels. Differentiating (1.2.17), (1.2.18) and (1.2.19) with respect to *r* and *K* we observe that an increase in the intrinsic growth rate or the carrying capacity of the resource would increase the resource stock and the harvest levels at the steady state, and decrease the price of the resource good. I.e.:

$$\frac{\partial S^A}{\partial r} > 0 \qquad \frac{\partial H^A}{\partial r} > 0 \qquad \frac{\partial p^A}{\partial r} < 0$$

$$\frac{\partial S^A}{\partial K} > 0 \qquad \frac{\partial H^A}{\partial K} > 0 \qquad \frac{\partial p^A}{\partial K} < 0$$

Next, differentiating (1.2.17), (1.2.18) and (1.2.19) with respect to *L*, *α* and *β* we get that:

$$\frac{\partial S^A}{\partial L} < 0 \qquad \frac{\partial H^A}{\partial L} = \alpha\beta K(1 - \frac{2\alpha\beta L}{r}) \qquad \frac{\partial p^A}{\partial L} > 0$$

$$\frac{\partial S^A}{\partial \alpha} < 0 \qquad \frac{\partial H^A}{\partial \alpha} = \beta L K(1 - \frac{2\alpha\beta L}{r}) \qquad \frac{\partial p^A}{\partial \alpha} = \frac{1 - \frac{2\alpha\beta L}{r}}{a^2 K(1 - \frac{\alpha\beta L}{r})^2}$$

$$\frac{\partial S^A}{\partial \beta} < 0 \qquad \frac{\partial H^A}{\partial \beta} = \alpha L K(1 - \frac{2\alpha\beta L}{r}) \qquad \frac{\partial p^A}{\partial \beta} > 0$$

That is, an increase in the amount of labor *L*, the productivity parameter *α* or the taste parameter *β* would unambiguously decrease the resource stock steady state level S^A. Also, an increase in *L* or *β* would increase the price of the resource good p^A. The effect of *α* on p^A is more complicated, as well as the effects of *L*, *α* and *β* on H^A. An increase in *α* would lead to an increase in H^A and p^A if $\frac{r}{L} > 2\alpha\beta$, and to a decrease in H^A and p^A if $\frac{r}{L} < 2\alpha\beta$. Similarly, an increase in *L* or *β* would lead to an increase in H^A if $\frac{r}{L} > 2\alpha\beta$, and to a decrease in H^A if $\frac{r}{L} < 2\alpha\beta$.

Notice that for a sufficiently large increase in *L*, *α* or *β*, the condition for the existence of an interior steady state point, $\frac{r}{L} > \alpha\beta$, may be violated, and the unique steady state point would be at $S = 0$. Hence, a large increase in *L*, *α* or *β* may cause extinction of the resource. Notice also that an equipropotionate increase in L and r would not affect on S^A, H^A or p^A, and it would not lead to violation of the condition $\frac{r}{L} > \alpha\beta$.

Open Economy

Now suppose that the economy turns from autarkic to open to trade. Assume that the economy we study is small, in the sense that it takes the international relative price of the resource good p^* as given. When trade opens, the value of the marginal product of labor in the harvesting sector becomes $p^* MP_L^H = p^* \alpha S_A$, and this is also the new wage in the resource sector. If this wage exceeds the wage in the manufacturing sector, which is equal to 1, then all workers move to the resource sector. Similarly, if the new wage in the resource sector is lower than 1, then all workers move to the manufacturing sector. Thus, if $p^* \alpha S_A > 1 \iff p^* > p^A$, then the economy has a comparative advantage in *H* and specializes in the resource sector, while if $p^* \alpha S_A < 1 \iff p^* < p^A$, then the economy has a comparative advantage in *M* specializes in the manufacturing sector. If $p^* \alpha S_A = 1 \Leftrightarrow p^* = p^A$, then the initial temporary equilibrium pattern of production is indeterminate, since workers are indifferent between the two sectors.

<u>The Case of a Resource Abundant Country ($p^* > p^A$):</u>

When trade opens, a resource abundant country will immediately specialize in the resource good. That is, the whole labor force will move to the resource sector. Hence, at the temporary equilibrium, $M = 0$, and consequently from (1.2.14) $H^P = \alpha L S_A$. The country exports *H* and imports *M*, domestic consumers consume the resource good at a lower quantity than H^P and a positive quantity of the manufacturing good, and their utility increases temporarily because of international trade. However, since the amount of labor employed in the resource sector increased, the harvest rate also increased. This could be depicted in Figure 1.2.2 by a new harvest rate curve with higher slope. Hence, in the temporary equilibrium, harvest occurs at a rate higher than the natural growth rate of the resource, and, therefore, the resource stock shrinks to a new steady state level:

$$S_D = \frac{1}{\alpha p^*} \qquad (1.2.20)$$

But then $H^P = \alpha LS_A$ and $M = 0$ is not a possible production bundle. At $M = 0$, the higher feasible quantity to produce is $\alpha LS_D < \alpha LS_A$. That could be depicted by a fall in the vertical intercept of the production possibility frontier. The final production and consumption points depend on the slope of the free trade budget line.

If the free trade budget line's slope is equal to that of the new production possibility frontier, then the economy will be driven at a diversified steady state equilibrium, where both goods are produced. Such a case is depicted in Figure 1.2.3.

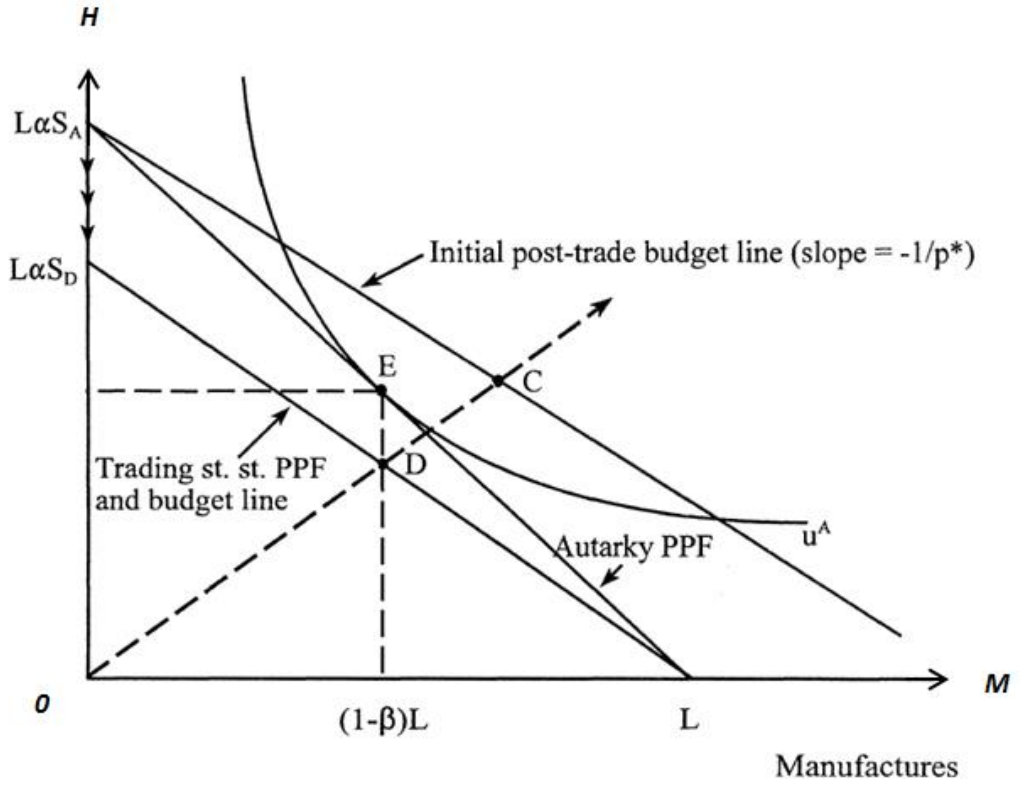

Figure 1.2.3

Initially, the autarkic equilibrium production and consumption point is point E. When the country becomes open to trade, an immediate specialization in the production of the resource good follows. The country produces $H^P = \alpha LS_A$ and $M = 0$ and consumes the quantities that correspond to point C, which are higher than those of point E, and they lead to higher utility than the autarkic equilibrium utility. Then the resource starts to shrink until either the value of the marginal product of labor in the resource sector becomes 1, or the resource stock stabilizes at a level that corresponds to a wage higher than 1. We first focus on the first case which is consistent to a diversified equilibrium. The second case is consistent to a specialized equilibrium.

As the resource stock shrinks towards S_D, the production possibility frontier's intercept falls to $\alpha L S_D$. The new free trade budget line coincides with the new production possibility frontier, and hence the production pattern is indeterminate. The new consumption point is point D, which lies on the same ray through the origin as point C[11]. Furthermore, the quantity consumed at point D is equal to the one consumed at the autarkic equilibrium point E[12]. Notice that point D corresponds to lower utility than point E, which means that free trade has led social welfare to decline. This happens because steady state consumption possibilities are dominated by those in autarky.

Although production pattern is indeterminate, there is only one division of labor across the two sectors that is consistent to a steady state equilibrium. Labor must be divided so that the current harvest is equal to the natural growth rate of the resource. Otherwise, the resource stock, and, consequently the value of the marginal product of labor in the resource sector would either increase or decrease, leading labor force either to enter or to exit the resource sector.

Although it is not obvious in the diagram, we can prove algebraically that the country still exports *H* and imports *M* after the transition from the temporary equilibrium to the stable steady state. It suffices to prove that at the new equilibrium point, the supply for the resource good exceeds the demand. Using (1.2.3), (1.2.10), (1.2.18) and (1.2.20) we obtain:

$$H^P - H^C = \frac{r}{ap^*}\left(1 - \frac{1}{ap^*K}\right) - \frac{\beta L}{ap^*} = \frac{r}{\alpha^2 K p^*}\left(\frac{1}{p^*} - \frac{1}{p^A}\right) > 0 \qquad (1.2.21)$$

[11] This follows from the assumption of homothetic preferences.

[12] This holds because national income measured in terms of *M* is equal in the two cases, and preferences are homothetic.

Thus the resource good is the exported good and the manufacturing good is the imported good.

In the diversified equilibrium, the country experiences temporary gains from trade which are eroded over time. Thus, for a sufficiently low discount rate, free trade leads the present value of utility to decline.

The second case is the specialized equilibrium. In this case, the free trade budget line has a vertical intercept is between αLS_A and αLS_D, and its horizontal intercept is higher than L. That means that steady state consumption possibilities are not necessarily dominated by those in autarky. Again, the country exports the resource good and imports the manufacturing good.

Denote the specialized equilibrium resource stock level as S_Z. Now the wage in the resource sector is:

$$w = \alpha p^* S_Z$$

We can solve for S_Z equating the current harvest with the natural growth rate of the resource under relative price p^*:

$$\alpha LS_Z = rS_Z(1 - \frac{S_Z}{K})$$
$$\Rightarrow S_Z = K(1 - \frac{aL}{r})$$

It is worth mentioning that a strong taste for the manufacturing good (i.e. a low value of the taste parameter *β*) leads to gains from free trade. Moreover, for a sufficiently high value of p^*, free trade leads to an increase in both steady state utility and the present value of future utility, while if p^* is not sufficiently high, then free trade leads to a decrease in steady state utility, but the present value of future utility may either increase or decrease, depending on the discount rate[13].

The Case of a Resource Poor Country ($p^* < p^A$):

When trade opens, a resource poor country will immediately specialize in the manufactured good. The temporary equilibrium point yields $H^P = 0$, $M^P = L$, and a consumption point on the free trade budget line which lies above the autarky consumption point. This implies that the country will export the manufactured good, import the resource good, and experience temporary gains from trade.

Since the economy specializes in the production of *M*, the whole workforce moves to the manufacturing sector. That means that current harvest decreases to zero; thus the natural growth rate of the resource exceeds harvesting rate at S_A, and the resource stock grows towards:

$$S_D = K \tag{1.2.22}$$

As the stock increases, the potential labor productivity in the resource sector also increases. The stock can either reach $S_D = K$ leading to a specialized equilibrium, or grow until the marginal product of labor in the resource sector reaches 1, leading to a diversified equilibrium. Figure 1.2.4 depicts the latter case. The free trade budget line is coincident with the steady state production possibility frontier, and thus the production pattern remains indeterminate. However, there is only one division of labor across the two sectors that is consistent to a steady state, in which:

$$G(S) = H^P(S)$$

[13] This can be proved by using the Cobb Douglass utility function to solve the inequality which states that utility is higher at the steady state equilibrium than in autarky. This yields:

$$u^T > u^A$$

$$\Leftrightarrow S_Z(\alpha\, p^*)^{1-\beta} > {S_A}^{\beta}$$

Thus a low value of β or a high value of p^* may lead to welfare improvement. In the case of welfare deterioration, since the country initially experiences gains from free trade, whether the present value of utility increases or increases depends again on the discount rate.

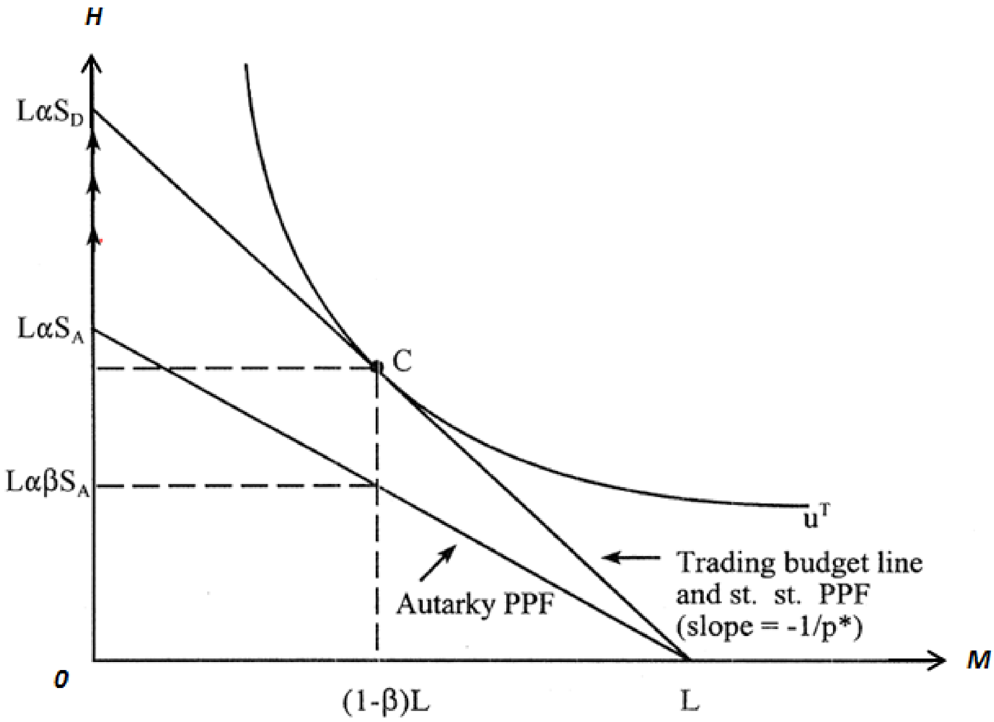

Figure 1.2.4

To prove that in the diversified equilibrium the resource poor country will export the manufactured good and import the resource good, it suffices to show that demand for the resource good exceeds supply. It follows directly from (1.2.21) that the country will export the resource good in a diversified equilibrium if $p^* < p^A$, and it will import the resource good if $p^* > p^A$.

The other case is the one of a specialized equilibrium. In this case, the free trade budget line's vertical intercept is above $L\alpha K$, and the economy remains specialized in the production of the manufactured good in steady state. The resource stock reaches its carrying capacity *K*. It is obvious that the resource good is the imported good and the manufactured good is the exported good.

In both cases, steady state utility is higher under trade than under autarky. Hence, gains from free trade are experienced everywhere along the transition path, and, consequently, it can be inferred that the present value of future utility increases because of trade liberalization.

<u>The Steady State Pattern of Production:</u>

Now we will state the conditions under which a diversified or a specialized equilibrium occurs.

The small open economy will specialize in M if the value of the marginal product of labor in the resource sector is less than unit, even if the resource stock reaches its highest possible value (K). That is:

$$VMP_L^H\big|_{S=K} \leq 1$$
$$\Leftrightarrow p^*\alpha K \leq 1$$
$$\Leftrightarrow p^* \leq \frac{1}{\alpha K} \tag{1.2.23}$$

If this holds, then the resource sector will attract no labor.

Similarly, the country will specialize in H if the value of the marginal product of labor in the resource sector exceeds 1 at S_Z. That is:

$$VMP_L^H\big|_{S=\,S_Z} \geq 1$$
$$\Leftrightarrow p^*\alpha\, S_Z \leq 1$$
$$\Leftrightarrow \frac{L}{r} \leq \frac{1}{\alpha}\left(1 - \frac{1}{p^*\alpha K}\right)$$

or

$$p^* \geq \frac{1}{\alpha K}\left(1 - \frac{\alpha L}{r}\right) \tag{1.2.24}$$

where $S_Z = K(1 - \frac{\alpha L}{r})$. Notice that, regardless of the world price, if $\frac{r}{L} < \alpha$, the country cannot specialize in the resource good, because employing its full labor force in the resource sector would lead to extinction of the resource.

(1.2.23) and (1.2.24) provide the conditions under which the small open economy specializes in the manufactured good and the resource good respectively. The condition that implies a diversified equilibrium is simply that neither (1.2.23) nor (1.2.24) hold. That is:

$$\frac{1}{\alpha K} \leq p^* \leq \frac{1}{\alpha K}\left(1 - \frac{\alpha L}{r}\right) \tag{1.2.25}$$

Now, (1.2.23), (1.2.24) and (1.2.25) together present the steady state production pattern of the small open economy as a function of world prices, provided that $\frac{r}{L} > \alpha$.

Denoting $\underline{p} = \frac{1}{\alpha K}$ and $\overline{p} = \frac{1}{\alpha K}\left(1 - \frac{\alpha L}{r}\right)$ we can write (1.2.23)-(1.2.25) and the patterns of production that each of them imply as:

$p^* \leq \underline{p}$	Specialization in M	(1.2.23)
$p^* \geq \overline{p}$	Specialization in H	(1.2.24)
$\underline{p} \leq p^* \leq \overline{p}$	Diversified Production	(1.2.25)

A major result of the above analysis is illustrated in Figure 1.2.5.

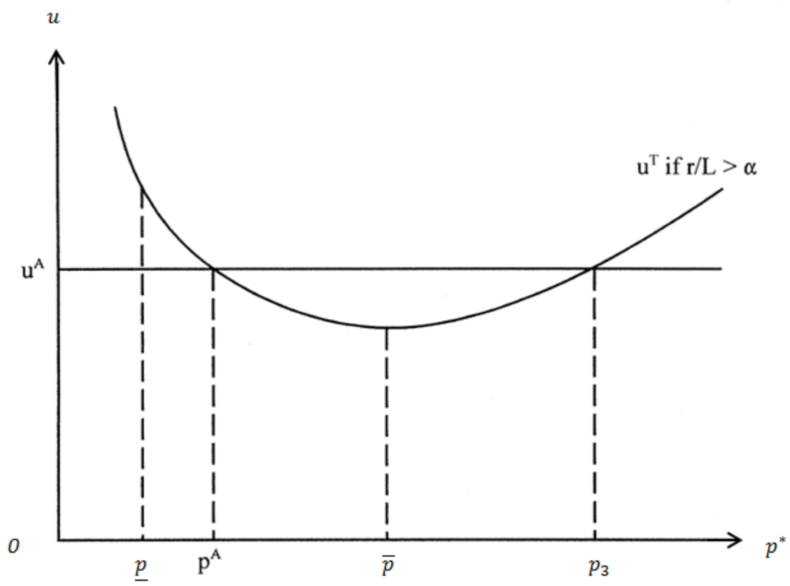

Figure 1.2.5

u^A is an identical consumer's utility under autarky, which of course is independent of the world prices, and u^T is an identical consumer's utility under free international trade. Assume that that $\frac{r}{L} > \alpha$. For a world price level below $\underline{p}$, the small closed economy specializes in the production of the manufactured good and there are gains from free international trade. After $\underline{p}$, but before p^A, the economy still exports *M* and experiences gains from international trade but the production is diversified. After p^A but before $\overline{p}$ the production remains diversified. The economy now exports the resource good, and experiences welfare losses from trade, which increase with improvements in terms of trade. Utility under free trade reaches its lower bound at $\overline{p}$. Right after this point the economy specializes in *H*, and it still experiences losses from trade. However, there is some price p_3, above which the economy remains specialized in *H*, but international trade is welfare improving, and gains from trade increase with improvements in terms of trade. If, on the other hand, that $\frac{r}{L} < \alpha$, then, as stated below, the economy cannot specialize in the resource good. The value of the marginal product of labor in the resource sector declines to 1 as the resource stock diminishes, and thus the economy must diversify its production and reduce its harvest rate.

The Analogue of the Pollution Haven Hypothesis

The next issue to consider is whether international trade puts increased pressure on resources with weak management regime. To discuss this, Chichilnisky(1994) developed a North-South model, where North and South's only difference was their resource access regime. She assumed fully enforced property rights in the North, and an open access resource regime in the South. South's weak management gives it a comparative advantage in the resource sector. This leads to excessive harvesting and trade-induced welfare losses in the South, while the North experiences gains from international trade. However, Brander and Taylor (1997b) state that this need not be the case; North and South may both gain from international trade. This is illustrated in Figure 1.2.6, which depicts North's and South's long run relative demand and supply curves. There are presented two cases for relative demand: low and high demand for the resource good.

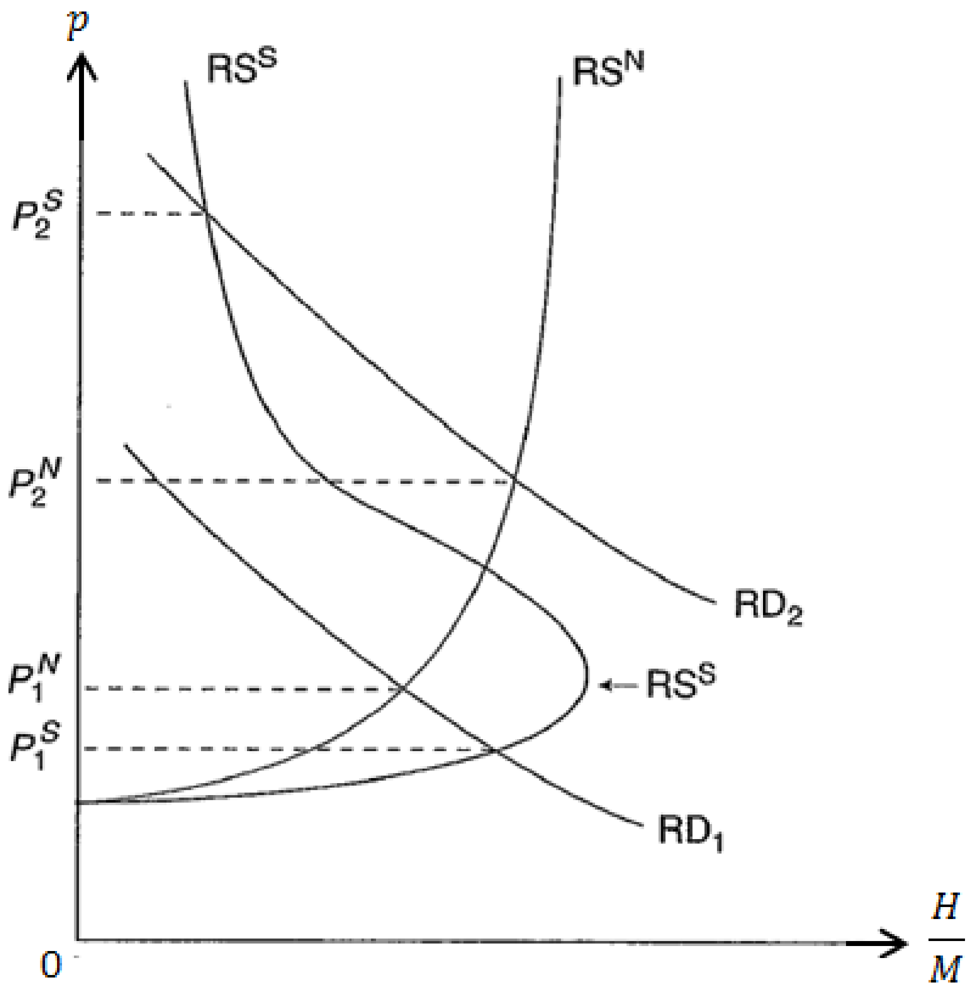

Figure 1.2.6

Since preferences are homothetic and identical across countries, relative demand curves must be identical across countries as well, downward sloping and independent of income. Relative supply curves depend on the resource access regime in each country. North's relative supply curve must be upward sloping, approaching asymptotically the maximum sustainably yield from the resource stock. Since North restricts harvesting, as the price of the resource good rises, harvesting becomes more profitable and attracts more producers. On the other hand, South's relative supply curve must be backward bending. At low price levels, harvesting is not very attractive to producers and the resource stock remains high. As the relative price of the harvesting good rises, the resource sector attracts more producers to enter and the relative supply curve is upward sloping. However, for a sufficiently high relative price of the resource good, the problem of excessive harvesting arises. Then, the effects of stock depletion dominate those of increased harvesting effort and, hence, the sustained level of harvesting falls as the price rises.

First consider the low-demand case, where the relative demand curve is RD_1 in Figure 1.2.6. The autarky relative prices in the two countries are p_1^N in the North and p_1^S in the South, where $p_1^N > p_1^S$. Hence South exports the resource good while North exports the manufactured good. This is the case analyzed by Chichilnisky(1994), where trade leads to resource depletion, and long-run consumption declines in South. This result is analogous to the pollution haven hypothesis.

Next consider the high-demand case, where the relative demand curve is RD_2 in Figure 1.2.6. Now the autarky relative prices in the two countries are p_2^N in the North and p_2^S in the South, and $p_2^S > p_2^N$. Hence, in this case, although South's resource access management is weak, South exports the manufactured good and North exports the resource good. North gains from trade because the externality is fully internalized. South also gains from trade, because labor is reallocated from the resource to the manufacturing production sector, thereby preserving the resource stock from depletion.

1.2.2 Environmental Capital:

In the previous section we presented the case of renewable natural resources, where production in the resource sector lowers the stock of the resource. In this section we present the case of cross-sectoral production externalities. There is a stock of environmental capital N which is used in the production of a good, say agriculture (A), and there is another sector, say manufactures (M), which does not use N in production, but it generates pollution which causes the stock of environmental capital to deplete. The model presented below is developed by Copeland and Taylor (1999).

Assume there are two primary factors of production: Labor (L) and Environmental (or Natural) Capital (N). N is assumed to be constant at any moment time, but it can either be degraded or enhanced over time. The change in the environmental capital stock at time t is given by:

$$\frac{dN}{dt} = r(\bar{N} - N) - \lambda M \tag{1.2.26}$$

where r measures the recovery rate of the environment, $\bar{N}$ is the natural level of the environmental capital stock and λ measures the units of pollution generated by one unit of production of the manufactured good.

The term $-\lambda M$ in (1.2.26) denotes the degradation of the environmental capital stock caused by pollution in the manufacturing sector. In other words, we could define a pollution generating function as: $Z = \lambda M$.

Notice that in the absence of pollution (i.e. for $M = 0$), the steady state level of the environmental capital stock would be equal to $\bar{N}$. For any positive produced quantity of the manufactured good the steady state level of N is lower than $\bar{N}$.
Furthermore, assume that the production function each sector is:

$$M = L_M \qquad (1.2.27)$$

$$A = \alpha N^{\beta} L_A \qquad (1.2.28)$$

where L_M and L_A are the amounts of labor employed in each sector, α is a labor productivity in agriculture parameter and $\beta \in (0,1)$.

Moreover, assume Cobb Douglass preferences. I.e. a typical consumer's utility function is given by[14]:

$$u = M^s A^{1-s} \qquad (1.2.29)$$

where s is the share of spending on the manufactured good, and, consequently, $1 - s$ is the share of spending on the agricultural good.

Autarky:

First we will derive the steady state level of the environmental capital stock. Assuming that both goods are essential for the economy (i.e. both goods must be consumed), the steady state level of *N* should be lower than $\overline{N}$. To derive the steady state level of N, denoted by N_{ss}, we simply use (1.2.26) to solve the equation $\frac{dN}{dt} = 0$ with respect to *N*. This yields

$$N_{ss} = \overline{N} - \frac{\lambda}{r} M \qquad (1.2.30)$$

(1.2.30) gives the steady state level of *N* provided that $\overline{N} - \frac{\lambda}{r} M > 0$. That is, specialization in *M* cannot lead to complete environmental capital depletion.

[14] Copeland and Taylor (1999) use Mill-Graham preferences instead of Cobb-Douglass preferences. That is, a typical consumer's utility function is given by:

$$u = b_m lnM + b_a lnA$$

where $b_m$and b_a are the shares of spending on each good. As we see, the Mill-Graham utility function is a positive monotonic transformation of the Cobb-Douglass utility function. Moreover, since there exist only two goods, *A* and *M,* we must have that: $b_m + b_a = 1$. Thus developing the model using the utility function given by (2.2.29) must lead to similar results.

To derive the autarkic steady state equilibrium, we will need a full employment and a zero profit condition. As always, the full employment condition has a form of $L = L_M + L_A$. Using (1.2.27) and a rearranged form of (1.2.28) to replace L_M and L_A we obtain:

$$L = L_M + L_A = M + \frac{A}{\alpha N^{\beta}} \tag{1.2.31}$$

(1.2.31) gives the short-run production possibility frontier of the economy which is linear. However, the steady state production frontier (or the long-run production frontier) is strictly convex. To see this, substitute (1.2.30) in (1.2.31). This yields

$$A = \alpha(L - M)(\bar{N} - \frac{\lambda}{r}M)^{\beta} \tag{1.2.32}$$

This function is strictly convex. The intuition for this is that as M and L_M increase more pollution is generated, and this leads to further degradation of the environmental capital, thereby causing labor productivity in agriculture to fall. Notice that an increase in M causes productivity in the manufacturing sector relatively to agriculture to rise. This result is similar to increasing returns to scale.

Figure 1.2.7 depicts both the short-run and the long run production frontier of the economy.

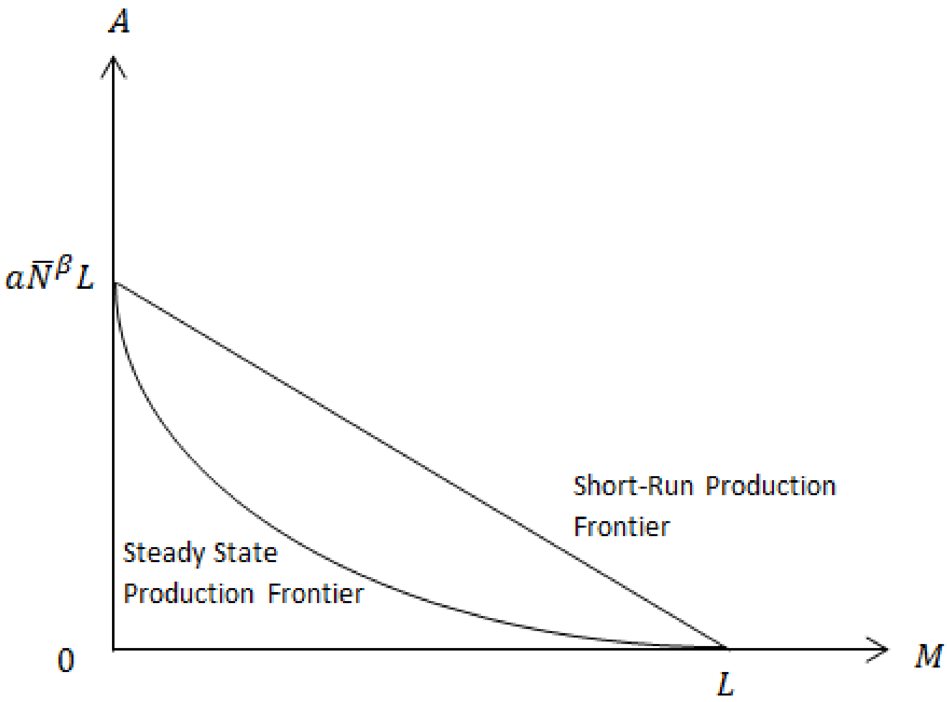

Figure 1.2.7

The zero profit condition requires that the return to labor must be equal to the value of its marginal product in each sector. That is:

$$p_M = w \tag{1.2.33}$$

$$p_A \alpha N^{\beta} = w \tag{1.2.34}$$

Dividing (1.2.33) and (1.2.34) by parts, and defining the relative price $p \equiv \frac{p_M}{p_A}$, we obtain:

$$p = \alpha N^{\beta} \tag{1.2.35}$$

which implies that relative prices depend on the environmental capital stock. Consequently, provided that both goods are produced in steady state, we can replace N in (1.2.35) by its steady state level, given by (1.2.30) and obtain:

$$p = \alpha(\overline{N} - \frac{\lambda}{r}M)^{\beta} \qquad (1.2.36)$$

When (1.2.36) is violated, then it is profitable to shift labor from one sector to the other. (1.2.36) gives the supply curve for M when $p \in (\alpha\left(\overline{N} - \frac{\lambda}{r}M\right)^{\beta}, \alpha\overline{N}^{\beta})$. For this range of prices, the supply curve for M is downward sloping. The intuition for this is that as M increases, the steady state level of N falls along with labor productivity in agriculture. This leads to lower demand for labor in agriculture, and thus and thus to a fall in the minimum price required to support the increased supply. If $p > \alpha\left(\overline{N} - \frac{\lambda}{r}M\right)^{\beta}$, then $M = L$ and if $p < \alpha\overline{N}^{\beta}$, then $M = 0$.

Moreover, the solution of consumers' utility maximization problem with Cobb-Douglass preferences yields a vertical demand function for M[15]:

$$D_M = \frac{swL}{p_M} = sL \qquad (1.2.37)$$

The supply-demand system described by (1.2.36) and (1.2.37) is depicted in Figure 1.2.8.

[15] We have made use of (2.2.33) to substitute w with p_M and simplify.

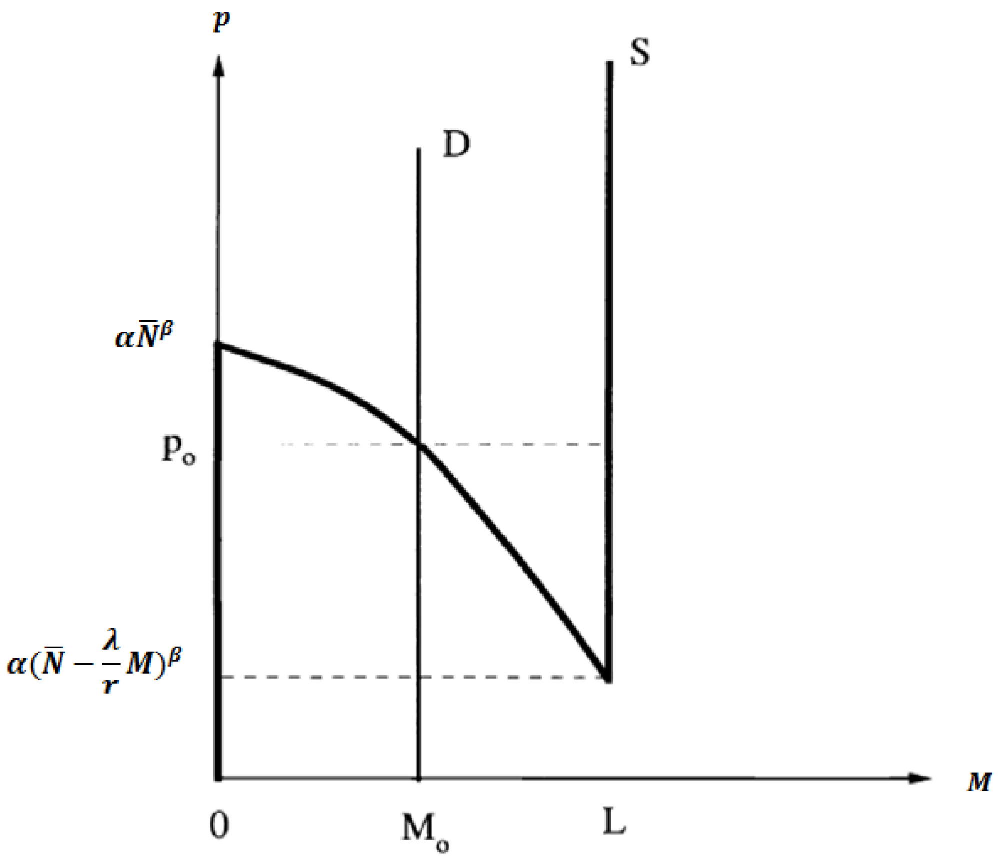

Figure 1.2.8

The solution of the supply-demand system yields a steady state solution at the point (M_0, p_0) in Figure 1.2.8.

Using (1.2.37) to substitute for *M* in (1.2.26) yields a first order linear differential equation, the solution of which implies that the autarkic steady state is unique, globally stable and convergence to the steady state point is monotonic[16].

[16] The general solution of this differential equation is:

$$N(t) = N_{ss} + [N_{(t=0)} - N_{ss}]e^{-rt}$$

which implies that:
$\frac{dN}{dt} > 0$ if $N_{(t=0)} < N_{ss}$, and
$\frac{dN}{dt} < 0$ if $N_{(t=0)} > N_{ss}$.

Free Trade

We assume a small open economy. First consider the case in which the world price equals the domestic price under autarky. In this case there are three possible equilibria: Specialization in M ($M = L$), specialization in A ($M = 0$) and the autarkic allocation of production ($M = M_0$). However, the last one is not stable. Starting at $M = M_0$, a slight increase in M would cause N to deplete and labor productivity in agriculture to fall, making agriculture less competitive and thus creating a comparative advantage in M. Therefore, the economy would specialize in M. Similarly, a slight decrease in M would lead the economy to specialize in A. Moreover, if $p^* > p_A$, then the economy specializes in M, while if $p^* < p_A$, the economy specializes in A.

Now assume that there exist two identical countries: Home (H) and Foreign (F)[17]. The increasing returns to scale effect that arises from the existence of cross-sectoral externalities creates an incentive for an industry to concentrate in one location in order to reap the benefits of positive external economies. For this reason, trade can emerge between two identical economies. Moreover, since the two countries are identical, the autarkic steady state equilibrium will be a free trade equilibrium as well; however, an unstable equilibrium. We will examine two possible cases:

<u>1. High Demand for the Polluting Good ($s > 0.5$):</u>

Notice that world demand for the manufactured good is given by:

$$\frac{s(wL + w^*L^*)}{p_M} = \frac{sL(w + w^*)}{p_M} > L$$

This inequality implies that world demand for M exceeds the maximum amount of this good that can be supplied from one country's industry solely. Therefore, both countries must produce the manufactured good. Nonetheless, the agricultural good

[17] Let the superscript * stand for denoting Foreign's variables.

must be produced as well. Hence, in this case, at the only steady state equilibrium F specializes in the production of M while H produces both goods.

Suppose that both countries start with an environmental capital stock of N_0 and then trade opens. Then, the autarkic equilibrium is not stable. The transition to the free trade equilibrium is illustrated in Figure 1.2.9.

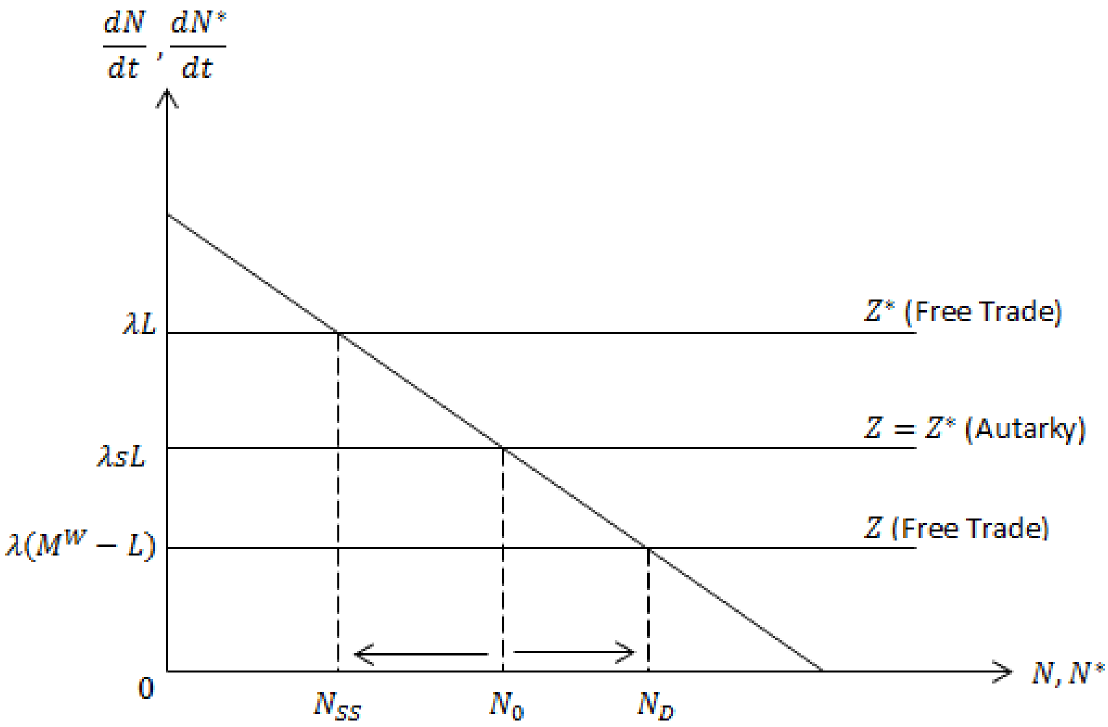

Figure 1.2.9

Suppose that, after trade opens, Foreign increases its production of M slightly. This causes Foreign's environmental capital stock to shrink, and creates a comparative advantage in M, which leads Foreign to specialize in the production of M (i.e. $M^F = L^*$). Thus pollution in F increases to λL^* and its environmental capital stock shrinks towards its specialized steady state level N_S^*.

In Home, imports of M increase and domestic production decreases. Notice that since M is produced in both countries, wages in the two economies must be equal; i.e. $w = w^* = p_M$. Thus world demand for the manufactured good can be written as:

$$M^W = \frac{sL(w + w^*)}{p_M} = 2sL$$

Remember that F specializes in M, i.e. $M^F = L^*$, and thus H covers the rest of the world demand:

$$M^H = M^W - L^*$$

and thus pollution in H must be:

$$Z = \lambda M^H = \lambda(M^W - L^*)$$

as it is shown at Figure 1.2.9. Notice that this level of pollution is lower than the pollution level under autarky, and thus environmental capital starts to recover, and grows towards its diversified steady state level N_D. Moreover, remember that the relative price of A is given by $\frac{p_A}{p_M} = \frac{1}{\alpha N^\beta}$. Hence, as the environmental capital stock increases, the relative price of A decreases. This result, combined with the consequent increase of labor productivity in Home and the decrease of labor productivity n Foreign, ensures that Foreign will increase its production of M slightly, and eventually specialize in M.

It is worth mentioning that, in the case of high demand for the dirty good, both countries gain from trade: Home gains from the expansion of its production possibilities caused by the environmental improvement, while Foreign's benefits arise from the Terms of Trade improvement, as its exported good, M, becomes relatively more expensive.

To see that both countries benefit from international trade, notice that purchasing power in terms of M, $\frac{w}{p_M} = 1$, is the same under trade or under autarky, while purchasing power in terms of A, $\frac{w}{p_A} = \alpha N^\beta$, rises as the environmental capital stock grows. Thus free international trade is mutually beneficial in the case of high demand for the polluting good.

2. High Demand for the Clean Good ($s < 0.5$):

In this case, two types of equilibria can emerge: Home specializes in A and Foreign diversifies (for sufficiently low s), or Home specializes in A and Foreign specializes in M (for intermediate values of s). Notice that in either case the manufactured good is produced only in one country, and hence wages in the two countries need not be equal.

Suppose that trade opens and F increases its M output slightly, thus generating additional pollution and reducing its environmental capital stock. This creates a comparative advantage in M for F and a comparative advantage in A for H. Home specialize in A; however Foreign cannot specialize completely in M, at least at the first stages of the transition to the trading equilibrium, because of the high demand for A. In the free trade steady state H will be specialized in A, while F can either be specialized in M or diversified.

First consider the case in which Foreign remains diversified in the free trade steady state. World demand for the manufactured good is given by $M^W = \frac{s(w^*L^*+wL)}{w^*}$. Since A is produced in both countries, unit production costs must be equal across countries. I.e.:

$$p_A = \frac{w}{\alpha N^\beta} = \frac{w^*}{\alpha N^{*\beta}}$$

Rearranging, we can substitute for w and w^* and obtain:

$$M^W = \frac{s(\alpha p_A N^{*\beta} + \alpha p_A N^\beta)}{\alpha N^{*\beta}} = s(L^* + L\frac{N^\beta}{N^{*\beta}}) \qquad (1.2.38)$$

Thus we can write total pollution emissions as a function of the environmental capital stocks of the two countries, as:

$$\Omega(N, N^*) = \lambda s(L^* + L\frac{N^\beta}{N^{*\beta}}) \tag{1.2.39}$$

Notice that for a given N, $\Omega(N^*; N)$ is convex and decreasing in N^*: as N^* falls, agricultural productivity in F falls too, and w increases so that unit costs remain equal across countries. Moreover, Home's demand for M ($\frac{swL}{w^*}$) increases, while Foreign's demand for M (sL^*) remains constant. Therefore, pollution in Foreign increases as a result to a decrease in its environmental capital stock.

Moreover, for a given N^*, $\Omega(N; N^*)$ is increasing in N: as N rises, w rises, and Home's demand for (and consequently Foreign's production of) M increase, thus increasing pollution in Foreign.

If Foreign is specialized in M in the free trade equilibrium, then its total pollution is λL^*. Thus pollution in F is given by:

$$Z^* = \min\{\lambda L^*, \Omega(N, N^*)\}$$

Transition to the free trade steady state is illustrated in Figure 1.2.10.

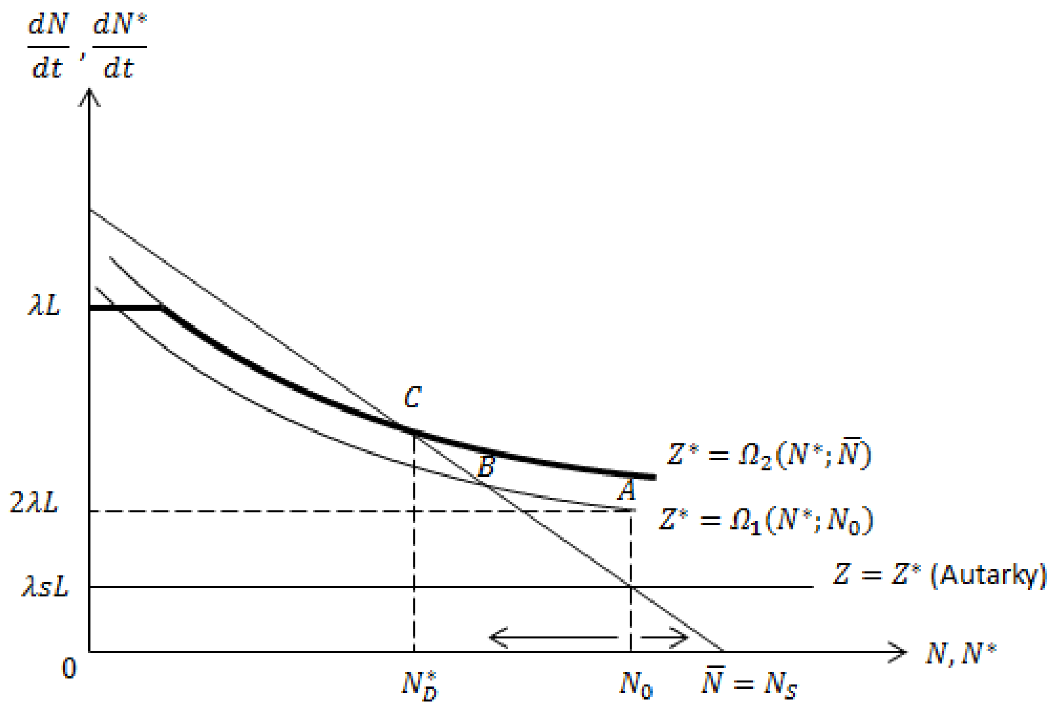

Figure 1.2.10

Suppose that both countries start with an environmental capital stock of N_0 in autarky. When trade opens, Home specializes in A and its pollution becomes zero. Its environmental capital stock starts to recover and approaches $\bar{N}$ over time. Foreign initially doubles its M output, and its pollution becomes $2\lambda L^*$. At point A foreign pollution exceeds environmental capital stock's natural regeneration rate, thus leading the stock to deplete until it reaches N_D^*. There are two reinforcing effects that cause foreign pollution to increase: firstly, as foreign environmental capital stock decreases, Home's terms of trade improve, thus increasing Home's demand for M, while Foreign's demand for M remains unchanged. Consequently, world demand for the manufactured good increases, leading Foreign to produce more M and generate more pollution. This corresponds to a movement along $\Omega_1(N^*; N_0)$ from point A to point B. Secondly, as Home's environmental capital recovers its real income increases[18], thus creating additional demand for (and, consequently

[18] As we prove below, Home's real income increases in terms of both goods.

additional foreign production of) M. This corresponds to a shift of $\Omega_1(N^*; N_0)$ upwards to $\Omega_2(N^*; \bar{N})$. Therefore the economy ends up to point C.

Notice that Home's terms of trade improve, while Foreign's terms of trade deteriorate due to the transition. Consequently, Home experiences welfare gains from international trade, while Foreign experiences welfare losses. To illustrate this, we can examine what happens to each country's purchasing power:

Home's Purchasing Power:

In terms of M
$$\frac{w}{p_M} = \frac{w}{w^*} = \left(\frac{N}{N^*}\right)^{\beta}$$

In terms of A
$$\frac{w}{p_A} = \alpha N^{\beta}$$

Foreign's Purchasing Power:

In terms of M
$$\frac{w^*}{p_M} = 1$$

In terms of A
$$\frac{w^*}{p_A} = \alpha N^{*\beta}$$

Remember that N recovers and N^* depletes during the transition to the free trade steady state. Thus purchasing power in Home increases in terms of both goods, while purchasing power in Foreign decreases in terms of the agricultural good, and it remains constant in terms of the manufactured good. Thus, in the case of high demand for the clean good and diversified equilibrium for Foreign, free trade is not mutually beneficial.

Now consider the case in which Foreign specializes in M. This happens for intermediate values of s (but still $s < 0$, i.e. demand for the clean good remains relatively high). The transition to the free trade steady state is illustrated in Figure 1.2.11.

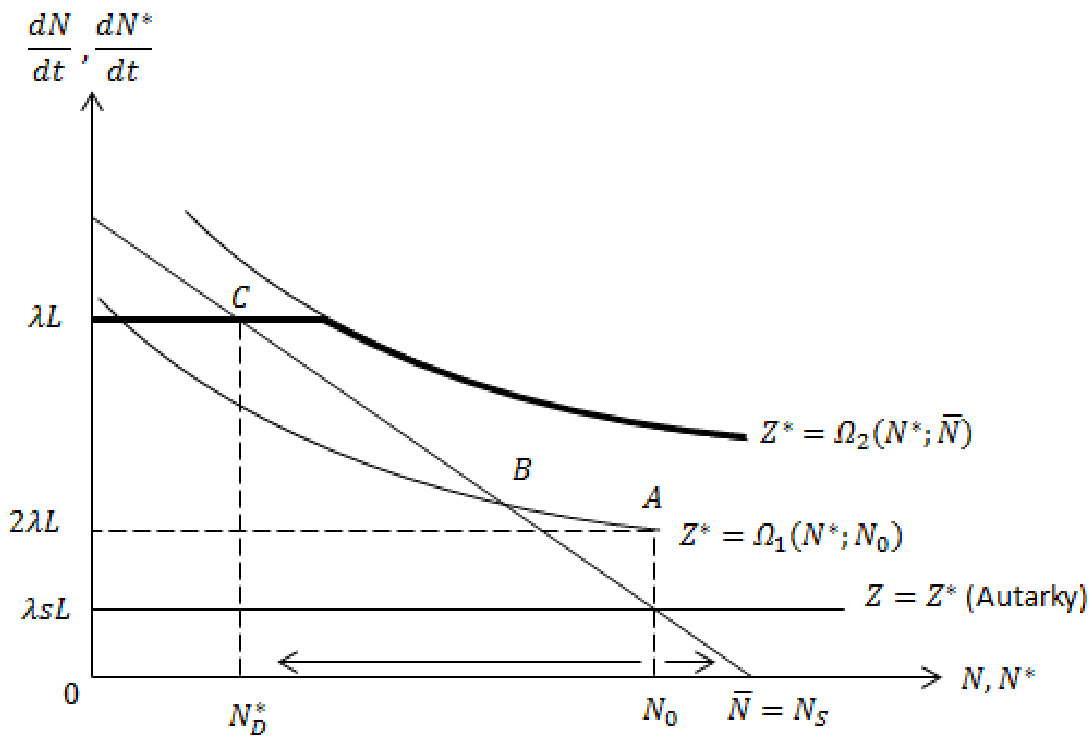

Figure 1.2.11

The free trade steady state point is point C, where Foreign is specialized in M. At early stages of the transition, Foreign's production is diversifies, and its welfare declines, as in the previous case. However, as F specializes in M, further depletion of its environmental capital stock becomes economically irrelevant. Once Foreign specializes in M, its terms of trade improve. Its purchasing power in terms of the manufactured good remains constant, while it increases in terms of the agricultural good. Therefore, the final welfare outcome for Foreign may be positive or negative. However, Home unambiguously gains from trade, as its purchasing power in terms of the manufactured good remains constant, while in increases in terms of the agricultural good.

Therefore, in the case of high demand for the clean good, and a specialized equilibrium in Foreign, free trade is unambiguously beneficial for Home, while Foreign's welfare initially declines but rises afterwards.

Non-Identical Countries

Now suppose that countries may differ in their regenerative capacity r, or in their population density L. We will examine whether trade allocates activities across countries efficiently.

Difference in the Regenerative Capacity:

Assume that Home environmental capital's natural regeneration rate is higher that Foreign's. That is $r > r^*$. Consequently, Home's environmental capital stock in autarky must be higher than Foreign's. Moreover, since environmental capital recovers faster in Home than in Foreign, Home can produce more A for any given level of M than Foreign. Therefore, it is logical that world production efficiency requires either that Home specializes in A and Foreign specializes in M, or Home diversifies and Foreign specializes in M. In other words, world production efficiency requires that all the demanded quantity of the clean good must be produced in the country with the highest natural regeneration rate. This is consistent to the case of high demand for the dirty good ($s > \frac{1}{2}$), and to the case of high (but not very strong) demand for the clean good ($s < \frac{1}{2}$, but sufficiently high). In these two cases, free trade allocates activities efficiently. However in the case of very strong demand for the clean good ($s < \frac{1}{2}$, and sufficiently low), Home specializes in A and Foreign produces both goods, which is inefficient, and thus the allocation of activities that emerged from trade liberalization is inefficient. In either case, Home gains from trade, while Foreign may loose if $s < \frac{1}{2}$.

Difference in the Population Density:

Now suppose that Foreign is more densely populated than Home, i.e. $L^* > L$. This leads to $N > N^*$ in autarky, and the less populated country has a comparative advantage in the production of the clean good. Hence, when trade opens, Home increases its A output, while Foreign increases its M output.

Efficiency requires that the most densely populated country always specializes. The logic is based on the fact that labor productivity in the clean sector declines because of pollution. For the allocation of activities to be efficient, the number of workers in agriculture who have their productivity reduced must be minimized. In the case of high demand for the dirty good ($s > \frac{1}{2}$) trade allocates activities across countries efficiently. To illustrate this, remember that both countries must produce M when $s > \frac{1}{2}$, and compare world farming output in the two extreme cases: when Foreign specializes in M, and when Home specializes in M. World demand for M is $s(L + L^*)$, and, thus, using (1.2.32) we can obtain world agricultural output. When Foreign specializes in M:

$$A^{*W} = (1 - s)\left[\overline{N} - \frac{\lambda}{r}(s(L + L^*) - L^*)\right]^{\beta}(L + L^*)$$

When Home specializes in M:

$$A^{W} = (1 - s)\left[\overline{N} - \frac{\lambda}{r}(s(L + L^*) - L)\right]^{\beta}(L + L^*)$$

It is clear that $A^{*W} > A^W$ if and only if $L^* > L$. Therefore, we can conclude that in the case of high demand for the dirty good, trade allocates activities across countries efficiently.

Now consider the case of low demand for the manufactured good. In this case, following the same logic as in the above case, efficiency requires all of the manufactured output to be produced in the less populated country. Assume world demand for M to be $L_m^* < L$. When Foreign specializes in A, world agricultural output is:

$$A^{*W} = \overline{N}^{\beta} L + \left(\overline{N} - \frac{\lambda}{r} L_m^*\right)^{\beta}(L - L_m^*)$$

When Home specializes in A, world agricultural output is:

$$A^W = \bar{N}^\beta L + \left(\bar{N} - \frac{\lambda}{r} L_m^*\right)^\beta (L^* - L_m^*)$$

Again, ${A^*}^W > A^W$ if and only if $L^* > L$. However, when demand for the clean good is high, the less densely populated country specializes in the production of A, and, hence, trade allocates activities across countries inefficiently.

Notice that the less densely populated country always gains from trade, while the most densely populated country may loose from trade if demand for the clean good is sufficiently high.

Other Works

Smulders, van Soest and Withagen (2004) and Rus (2006) develop models with negative production externalities both within and across sectors. Benarroch and Thille (2001) and Unteroberdoerster (2001) use an extension of the model developed by Copeland and Taylor (1999) presented above, which allows for transboundary pollution. Zeng and Zhao (2009) also develop an extension of a simple cross-sectoral production externalities model, allowing for agglomeration effects in production.

Part 2
Trade Policy and Environmental Policy

In this part we focus on the linkages between trade and environmental policy. In the first chapter we present an analysis of how trade policy responds to the presence of environmental problems. In the second chapter we reverse this relation: we focus on how environmental policy depends on trade policy, and most significantly on trade liberalization via, for example, free trade agreements. In the third chapter we consider transboundary pollution, and how it affects the optimal choice environmental policy instruments under trade agreements.

2.1. Effects of Pollution on Trade Policy

In this section we present the analysis conducted by Copeland and Taylor (2001) on whether the possibility of environmental degradation should alter a country's stance towards trade policy. Standard theory implies that when all externalities are completely internalized, then optimal trade policy cannot deviate from free trade. That is, under optimal environmental policy ($\tau = N \cdot MD$, as it has been presented in section 1.1.3), an open economy's optimal trade policy is free trade ($t = 0$). However, if environmental policy is not set efficiently, then an open economy's second best optimal trade policy may differ from free trade. We will consider the cases of production generated pollution and consumption generated pollution.

2.1.1. Production Generated Pollution

Assume a perfectly competitive economy with no other distortions than pollution generated externalities and trade barriers, and suppose there are two goods: Y_1, which is assumed to be the imported good, and Y_2, which is assumed to be the exported good. We will consider both the cases where the imported or the exported good is the pollution generating good. Moreover assume a representative consumer[19].

The representative consumer's budget constraint is given by:

$$E(p+t,v,z,u) = G(p+t,v,z) + tM \qquad (2.1.1)$$

where t is a tariff on imports, M is imports and $E(p+t,v,z,u)$ is the expenditure function that can be calculated solving the representative consumer's expenditure minimization problem.

Equation (2.1.1) implies that representative consumer's expenditure must be equal to national income plus import payments.

Balanced trade requires that:

$$M(p,t,\tau) = X^*(p) \qquad (2.1.2)$$

Notice that demand for imports depends on world price, import tariff, and emissions tax.

Totally differentiating (2.1.1) we obtain[20]:

$$E_u du = (\tau - E_z)dz - Mdp + tdM \qquad (2.1.3)$$

To find the optimal choice of trade and environmental policy, choose the tariff t and t pollution tax τ to maximize representative consumer's utility u subject to (2.1.1). Setting $du = dp = dM = 0$ in (2.1.3) we obtain the optimal emissions tax:

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[19] That is, normalize $N = 1$, for simplicity, with no loss of generality.

[20] For this result we also used the expression $\frac{\partial G}{\partial(p+t)} - \frac{\partial E}{\partial(p+t)} = -M$, which follows from the definition of imports, i.e. Imported Quantity=Demanded Quantity-Produced Quantity. Demanded quantity is captured by $\frac{\partial E}{\partial(p+t)}$ and (domestically) produced quantity is captured by $\frac{\partial G}{\partial(p+t)}$.

$$\tau = E_z \tag{2.1.4}$$

Setting $du = dp = dz = 0$ we obtain the optimal tariff:

$$\frac{t}{p} = \frac{X^*}{pX_p^*} = \frac{1}{\varepsilon_{X^*p}} \tag{2.1.5}$$

where $\varepsilon_{X^*p} = \frac{\partial X^*}{\partial p}\frac{p}{X^*}$ is the price elasticity of foreign export supply.

Notice that (2.1.4) implies that the optimal pollution tax equals marginal damage, so that the pollution externality is fully internalized. Moreover, if the economy is small, in the sense that it faces exogenously determined world prices, then (2.1.5) yields $t = 0$[21]. That is, the optimal trade policy for a small open economy is to allow for free trade.

We have shown that the most efficient combination of trade and environmental policy for a small open economy is to choose an environmental tax that internalizes the pollution externality and abolish trade barriers. Hence, environmental problems are irrelevant to the choice of trade policy, as long as externalities are internalized. However, if environmental policy is not set optimally, then optimal trade policy may deviate from free trade. Suppose that pollution policy is too weak and (2.1.4) is violated. That is, $\tau < E_z$.

There are two effects of changes in trade policy on welfare: a volume of trade effect, and an indirect effect on pollution emissions. The effect on the volume of trade is given by[22]:

$$dM = -(G_{qq} - E_{qq})dt + (E_{qz} - G_{qz})dz + E_{qu}du \tag{2.1.6}$$

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[21] As a world price taker, a small economy faces a perfectly elastic foreign export supply curve. That is, $\varepsilon_{X^*p} = \infty$.

[22] This follows from totally differentiating the equation: $M = \frac{\partial E}{\partial (p+t)} - \frac{\partial G}{\partial (p+t)}$. Denote $q = p + t$.

We can use (2.1.6) to substitute for dM in (2.1.3) and obtain:

$$E_u\left(1-t\frac{E_{qu}}{E_u}\right)\frac{du}{dt}=-t\big(G_{qq}-E_{qq}\big)+\left[\tau-E_z+t\big(E_{qz}-G_{qz}\big)\right]\frac{dz}{dt} \tag{2.1.7}$$

Suppose that $1-t\frac{E_{qu}}{E_u}>0$[23]. First consider the case that the environmental policy instrument is a binding quota on imports. In this case, although the output of the polluting good may change as trade policy changes, overall pollution emissions are not affected by such changes, since they are held fixed because of the quota. Therefore, $\frac{dz}{dt}=0$, and thus (2.1.7) becomes:

$$E_u\left(1-t\frac{E_{qu}}{E_u}\right)\frac{du}{dt}=-t\big(G_{qq}-E_{qq}\big) \tag{2.1.8}$$

Since G is convex and E is concave in p, and also $E_u>0$ and, by assumption, $1-t\frac{E_{qu}}{E_u}>0$, solving (2.1.8) with respect to $\frac{du}{dt}$ we obtain:

$$\frac{du}{dt}=-\frac{t\big(G_{qq}-E_{qq}\big)}{E_u\left(1-t\frac{E_{qu}}{E_u}\right)}<0 \tag{2.1.9}$$

(2.1.9) implies that trade liberalization is welfare improving. Hence, in the case of binding emissions quotas as an instrument of environmental regulation, the second best optimal trade policy is still free trade[24]. Now suppose pollution regulation is imposed using a rigid emission tax as an environmental policy instrument. We treat the pollution tax as exogenous:

$$\tau=G_z(p+t,v,z) \tag{2.1.10}$$

[23] In fact, this is a necessary condition for stability (Neary and Ruane, 1988).

[24] Setting $\frac{du}{dt}=0$ yields $t=0$.

Totally differentiating (2.1.10) holding world prices and amounts of primary factors constant ($dp = dv = 0$) yields:

$$0 = G_{zq}dt + G_{zz}dz$$
$$\Leftrightarrow \frac{dz}{dt} = -\frac{G_{zq}}{G_{zz}} \qquad (2.1.11)$$

This is the indirect effect of a change in trade policy on pollution. Remember that G is concave in z, i.e. $G_{zz} < 0$. Moreover, notice that $G_{zq} = G_{qz} = \frac{\partial Y_1}{\partial z}$. If the imported good is the polluting good, then $\frac{\partial Y_1}{\partial z} \geq 0$ and thus $\frac{dz}{dt} \geq 0$. If the imported good is the clean good, then $\frac{\partial Y_1}{\partial z} \leq 0$, and, consequently $\frac{dz}{dt} \leq 0$. Therefore, the volume of trade effect of trade liberalization is unambiguously positive, but reducing t may either increase pollution (if the imported good is the clean good), or decrease pollution (if the imported good is the dirty good), and, hence, the sign of the effect of trade liberalization on welfare is uncertain. To derive the optimal tariff on imports solve (2.1.7) with respect to t:

$$t = \frac{(\tau - E_z)\frac{dz}{dt}}{-\frac{dM^C}{dt}} \qquad (2.1.12)$$

where M^C is the compensated import demand, and $\frac{dM^C}{dt} = E_{qq} - G_{qq} + (E_{qz} - G_{qz})\frac{dz}{dt}$ is its response to an increase in the import tariff, which is unambiguously negative if the effect of pollution on the demand, i.e. E_{qz}, is relatively small.

Therefore, we can conclude that:

- If the imported good is the polluting good, then $\frac{dz}{dt} \geq 0$, and thus $t \leq 0$. That is, second best optimal trade policy is to tax the import-competing sector, instead of setting a tariff on imports. Trade liberalization reduces both pollution and trade distortions.

- If the imported good is the clean good, then $\frac{dz}{dt} \leq 0$, and, consequently, $t \geq 0$. The second best optimal tariff on imports is positive. Trade liberalization is not welfare improving in this case. A reduction in trade distortions would exacerbate pollution distortions.

2.1.2. Consumption Generated Pollution

Now suppose that pollution is generated during consumption of the imported good Y_1, and no pollution is generated during production. Assume again a small open economy that takes world price p^* as given. Let the emissions per unit of consumption of domestically produced Y_1 be denoted by α, and the emissions per unit of consumption of imported Y_1 by α^*, and assume that consumption of an imported unit of output generates more pollution than consumption of a domestically produced unit. Let also τ and τ^* be the pollution taxes in Home and Foreign respectively, and t be the import tariff imposed by Home. The price that domestic consumers have to pay to consume a unit of imported Y_1 is given by:

$$p^d = p^* + \alpha^*\tau^* + t \tag{2.1.13}$$

That is, domestic consumers have to pay the international price p^*, the tariff t, and a pollution tax of $\alpha^*\tau^*$, since consuming a unit of imported Y_1 generates α^* units of pollution. Moreover, to consume a unit of domestically produced Y_1, consumers have to pay the domestic price and a pollution tax of τ per unit for α units of pollution; i.e. they face a price of $p + \alpha\tau$. For consumers to be indifferent between domestically produced and imported good, the two prices must be equal. That is:

$$p + \alpha\tau = p^* + \alpha^*\tau^* + t$$
$$\Leftrightarrow p = p^* + \alpha^*\tau^* - \alpha\tau + t \tag{2.1.14}$$

Letting y denote the domestic output of Y_1, we can write the representative consumer's budget constraint as:

$$E(p^* + \alpha^*\tau^* + t, z, u) = G(p^* + \alpha^*\tau^* - \alpha\tau + t) + tM + \tau^*\alpha^*M + \tau\alpha y \quad (2.1.15)$$

where $z = \alpha^*M + \alpha y$. Totally differentiating (2.1.15) yields:

$$E_u du = (\tau^* - E_z)\alpha^* dM + (\tau - E_z)\alpha dy + tdM \quad (2.1.16)$$

To find the first-best optimal trade and environmental policy, maximize u subject to (2.1.15). This yields

$$\tau = \tau^* = E_z \quad \text{and } t = 0 \quad (2.1.17)$$

Hence, as in the case where pollution was generated during production, despite the environmental problems, the most efficient combination of trade and environmental policy is to set a pollution tax that fully internalizes pollution externalities, and abolish trade barriers, allowing for free trade. However, if environmental policy is too weak, we can determine the optimal tariff solving (2.1.16) with respect to t, imposing $du = 0$. This yields:

$$t = -(\tau - E_z)\left(\alpha^* + \alpha\frac{\frac{dy}{dt}}{\frac{dM}{dt}}\right) \quad (2.1.18)$$

Notice that if the domestically produced good generates no pollution, i.e. $\alpha = 0$, then a tariff and a pollution tax are perfect substitutes: if there is no pollution tax, i.e. $\tau = 0$, then $t = E_z\alpha^*$, and the price of the imported good that consumers face is $p^* + E_z\alpha^*$, which is the same as in the case where the pollution externality is fully internalized and trade is liberalized. Hence, the second-best optimal policy requires that consumers substitute to the good that does not pollute, and thus domestic production rises. The presence of environmental problems does not affect on welfare.

However, if both goods pollute, i.e. $\alpha > 0$, then the optimal tariff does not internalize the pollution externality. For simplicity, assume that $\alpha = \alpha^*$. Then (2.1.18) becomes:

$$t = -\alpha(\tau - E_z)\left[1 + \frac{\frac{dy}{dt}}{\frac{dM}{dt}}\right] \quad (2.1.19)$$

Remember that G is convex in prices, and thus $\frac{dy}{dt} = G_{qq} > 0$. Moreover, assuming that effects of pollution changes on demand are relatively small, we get that $\frac{dM}{dt} < 0$. Therefore, when $\tau = 0$, we have $t = E_z\alpha^*$, and thus the price of the imported good is lower than what it would be in the first-best, and the tariff does not internalize the pollution externality.

2.2. Effects of Trade Liberalization on Environmental Policy

The part of the literature that is concerned with the effects of trade liberalization on environmental policy tries to determine how efficient environmental policy responds to freer trade. In general, the question is whether globalization puts pressure on countries to weaken their pollution policy. There are three major concerns on such issues:

1. Vulnerability of the environment: A country's environment may be more vulnerable in an open economy that in a closed one. For example, if an open economy has comparative advantage in a polluting sector, trade liberalization would cause an increase in the output of the exported good, and a subsequent pollution boom. Therefore, efficient environmental policy should respond to trade liberalization.

2. Policy substitution: Trade agreements usually ban export subsidies. Thus weak environmental policy could be thought as a substitute for export subsidies, since it stimulates the polluting sector.

3. Market access: Environmental policy can be designed and implemented in a way that restricts foreign access to local markets.

We will study all these issues below. In what follows, the main sources are Copeland and Taylor (2003), Copeland and Taylor (2011) and Rauscher (1997). Any other sources used in some specific sections will be also mentioned.

2.2.1. Vulnerability of the Environment

As we have seen in previous chapters, suboptimal environmental policy is costly in terms of an economy's welfare. However, these costs can be larger in an open economy than in a closed one. To illustrate this, we will compare the effect of weak environmental policy on an economy's welfare in two cases: when the economy is open to factor movements, and when it is open only in trade in commodities.

Open vs. Closed Economy

Assume a small economy where capital is freely mobile. The representative consumer's budget constraint is given by:

$$E(p,z,u) = \tilde{G}(p,\tau,v,k) - r\left(k - \bar{k}\right) + \tau z \tag{2.2.1}$$

where $\bar{k}$ is the domestically owned amount of capital, and k is the total amount of capital used domestically.

(2.2.1) implies that consumers' expenditure is equal to national income, capital payments or awards[25], and pollution emissions payments. Notice that we use the endogenous pollution formula for the national income function ($\tilde{G}$ instead of G). $\bar{k}$ can be determined solving:

$$r = \tilde{G}_k(p,\tau,v,k) \tag{2.2.2}$$

z can be determined solving:

[25] If $k > \bar{k}$, then capital payments is an outflow of r per unit of capital for $k - \bar{k}$ units, while if $k < \bar{k}$ then capital payments is an inflow of r per unit of capital for $\bar{k} - k$ units.

$$z = -\tilde{G}_{\tau}(p, \tau, v, k) \tag{2.2.3}$$

To derive the welfare effect of a change in pollution, we totally differentiate (2.2.1) imposing $dp = d\tau = dv = dk = d\bar{k} = 0$:

$$E_u du = (\tau - E_z)dz \tag{2.2.4}$$

We can derive the change in pollution caused by a change in the pollution tax totally differentiating (2.2.3):

$$dz = -(\tilde{G}_{\tau\tau}d\tau + \tilde{G}_{\tau k}dk) \tag{2.2.5}$$

Next, we can derive the change in capital caused by a change in the pollution tax totally differentiating (2.2.2):

$$0 = \tilde{G}_{k\tau}d\tau + \tilde{G}_{kk}dk$$

$$\Leftrightarrow dk = -\frac{\tilde{G}_{k\tau}}{\tilde{G}_{kk}}d\tau \tag{2.2.6}$$

Using (2.2.6) to substitute for dk in (2.2.5) we obtain:

$$dz = -(\tilde{G}_{\tau\tau}d\tau - \frac{\tilde{G}_{\tau k}\tilde{G}_{k\tau}}{\tilde{G}_{kk}}d\tau) \tag{2.2.7}$$

Finally, using (2.2.7) to substitute for dz in (2.2.4) we obtain:

$$E_u du = -(\tau - E_z)(\tilde{G}_{\tau\tau}d\tau - \frac{\tilde{G}_{\tau k}\tilde{G}_{k\tau}}{\tilde{G}_{kk}}d\tau)$$

$$E_u \frac{du}{d\tau} = (E_z - \tau)\tilde{G}_{\tau\tau} - (E_z - \tau)\frac{\tilde{G}_{\tau k}\tilde{G}_{k\tau}}{\tilde{G}_{kk}} \tag{2.2.8}$$

Equation (2.2.8) shows the total effect of a change in the pollution tax on welfare. This effect can be decomposed into two effects: a welfare effect of increasing the pollution tax, for a given supply of capital, which is captured by the first term in the right-hand part of (2.2.8) $(E_z - \tau)\tilde{G}_{\tau\tau}$, and a welfare effect due to the induced movement of capital, which is captured by the second term in the right-hand part of (2.2.8) $-(E_z - \tau)\frac{\tilde{G}_{\tau k}\tilde{G}_{k\tau}}{\tilde{G}_{kk}}$.

Remember that $\tilde{G}_{\tau\tau} > 0$ and $\tilde{G}_{kk} < 0$. If environmental regulation is weak, i.e. $E_z > \tau$, then both effects are positive, and, as we expected, an increase in the pollution tax is welfare improving ($\frac{du}{d\tau} > 0$).

Having not assumed capital mobility, the second term in (2.2.8) would be zero. That means that the cost of suboptimal pollution policy is higher for an economy open to capital mobility than for an economy open only to trade in commodities.

Efficient Response of Environmental Policy

Trade liberalization may lead to weaker environmental policy. This is not necessarily a sign of policy failure. When trade opens, weakening pollution regulation may be the efficient response of environmental policy.

Assume a small open economy with rigid import tariffs that charges a pollution tax per unit of emissions. The optimal second-best pollution tax is[26]:

$$\tau = E_z - t\frac{\frac{dM}{d\tau}}{\frac{dz}{d\tau}} \tag{2.2.9}$$

Recall that $\frac{dz}{dt} < 0$. Moreover, notice that if the import competing sector is the polluting sector, then an increase in the pollution tax reduces local production,

[26] This follows directly from the solution of the representative consumer's utility maximization problem. Recall the Budget Constraint $E(p+t, v, z, u) = G(p+t, v, z) + tM$. The result in (3.2.9) follows directly from totally differentiating the budget constraint, and solving with respect to τ.

thereby leading to an increase in imports. That is, $\frac{dM}{d\tau} > 0$. Hence, the optimal second-best pollution tax exceeds marginal damage, i.e. $\tau = E_z - t\frac{\frac{dM}{d\tau}}{\frac{dz}{d\tau}} < E_z$.

Notice that trade liberalization would lead to a fall in the pollution tax. That is, for $t = 0$, we get $\tau = E_z < E_z - t\frac{\frac{dM}{d\tau}}{\frac{dz}{d\tau}}$. Hence, if pollution policy is set optimally, then the efficient response to freer trade for a country which imports a polluting good is to weaken its environmental policy.

Even if environmental policy is not being explicitly used to try to undo the effects of trade policy as in (2.2.9), we can conclude that reducing the import tariff would lead to a reduction in the pollution tax, and thus to less stringent pollution regulation. This is illustrated in να.1. Reducing t shifts the demand for emissions inwards via a pure substitution effect[27], and also shifts the marginal damage curve upwards and to the left, via income and substitution effects[28].

Notice that the exact effect of reducing t on τ is ambiguous. However, assuming that the income effect on the marginal damage curve is sufficiently low, but still higher than the substitution effect, trade liberalization reduces both pollution and the optimal emissions tax.

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[27] Reducing the import tariff leads to increased competition in the import competing sector, making imports less expensive. This leads to an increase in imports of the polluting good, and to a decrease in local production; producers in the polluting sector shift to the clean sector after trade liberalization. Thus demand for pollution decreases. This is the substitution effect on the demand for pollution.

[28] Income effect: Trade liberalization raises real income, and environmental quality is a normal good. Hence the marginal damage curve shifts upwards and to the left due to the income effect. Substitution effect: The fall in the price of the imported good, induced by freer trade, shifts down the marginal damage curve. This is because consumption becomes cheaper relative to environmental quality, and thus consumers substitute environmental quality with consumption. However, in what follows we assume that the income effect is higher than the substitution effect, so that trade liberalization causes the marginal damage curve to shift upwards and to the left.

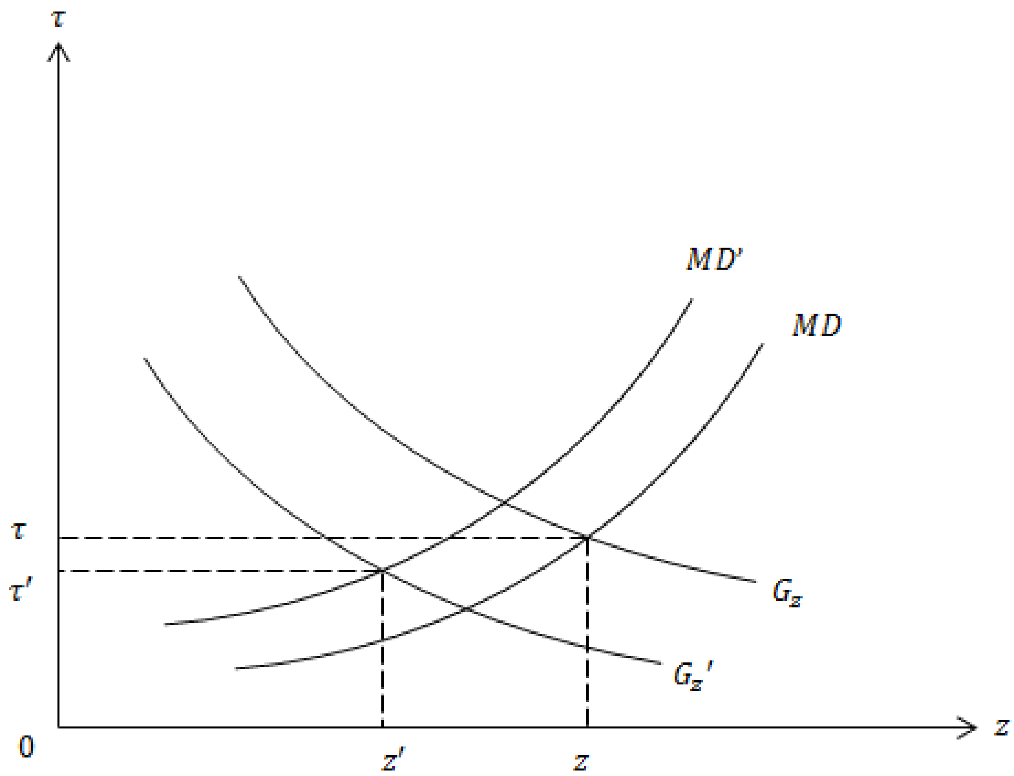

Figure 2.2.1

Conversely, if the exported good is the polluting good, trade liberalization would expand the export sector, thus increasing the demand for pollution. Consequently, trade liberalization in this case leads to a higher pollution tax. This is illustrated in Figure 2.2.2.

Notice that since τ is the price for pollution emissions (or equivalently, the price of environmental services), it can be perceived as analogous to a factor price. Since trade liberalization reduces the demand for pollution emissions if the import competing sector is the polluting sector, and raises the demand for pollution emissions if the exporting sector is the polluting sector, it is not surprising that, if environmental policy is set optimally, the efficient price of pollution emissions adjusts, having a change in the same direction as demand for emissions.

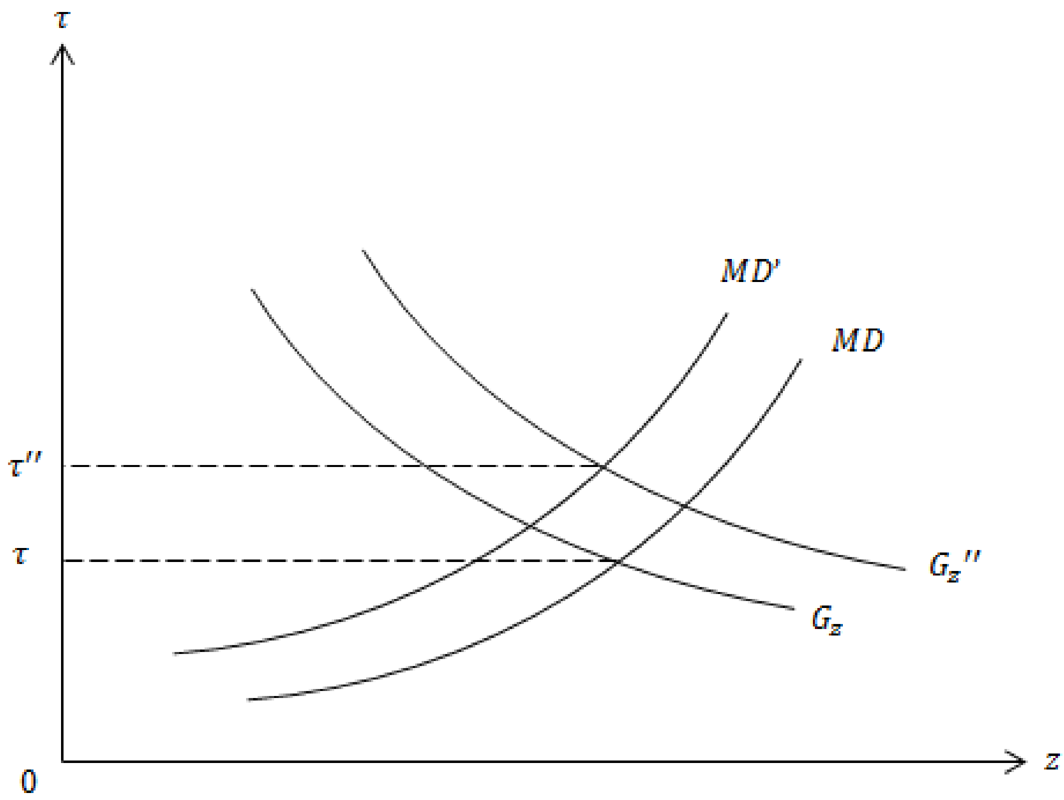

Figure 2.2.2

2.2.2. Policy Substitution

The policy substitution argument is that environmental policy may become weaker as a response to trade liberalization: as protection provided by trade barriers gets eliminated, governments may have an incentive to weaken environmental regulation, in order to protect domestic firms exposed to international competition. For instance, such instruments of protection may be eliminated because of a free trade agreement, or participation to a customs union. This argument is often referred to as “environmental dumping” or “ecological dumping”.

To analyze the policy substitution, we need models where governments have a motive to use trade policy in order to protect local industry. The literature is concerned mainly with two major types of motives of a country for protection: to improve its terms of trade; and to give domestic firms a strategic advantage over foreign firms.

Both of these will be analyzed below; however focusing a little more on strategic environmental policy, which has drawn the most attention among researchers.

Terms of Trade Motives for Protection

Consider a large country (Home), which can influence world prices, and suppose that a free trade agreement has been signed. Moreover suppose that Home imports the polluting good Y_1.

The second-best optimal pollution tax is given by[29]:

[29] This follows directly from the solution of the representative consumer’s utility maximization problem. Recall the Budget Constraint $E(p+t,v,z,u)=G(p+t,v,z)+tM$. Moreover, impose $t=0$, which is the condition of the free trade agreement. The result in (3.2.10) follows directly from totally differentiating the budget constraint, and solving with respect to τ.

$$\tau = E_z + M\frac{\frac{dp}{d\tau}}{\frac{dz}{d\tau}} \tag{2.2.10}$$

We expect that an increase in the pollution tax will increase the polluting good's price, and reduce pollution emissions. That is, $\frac{dp}{d\tau} > 0$ and $\frac{dz}{d\tau} < 0$. Therefore, the second-best optimal pollution tax is expected to be lower that marginal damage; i.e. $\tau = E_z + M\frac{\frac{dp}{d\tau}}{\frac{dz}{d\tau}} < E_z$. This implies that once trade policy is constrained by trade agreements, trade liberalization creates an incentive for governments to use pollution policy as a second-best trade policy instrument, aiming to subsidize domestic firms in the import competing sector. However, this does not illustrate whether the pollution emissions tax decreases or increases as the import tariff becomes zero. The path of the pollution tax need not be monotonic.

Furthermore, consider Foreign's (i.e. the exporter's of the polluting good) second-best optimal pollution tax:

$$\tau^* = E^*{}_{z^*} - X^*\frac{\frac{dp}{d\tau^*}}{\frac{dz^*}{d\tau^*}} > E^*{}_{z^*} \tag{2.2.11}$$

That is, free trade leads to more stringent pollution regulation for the exporting country of the pollution intensive good. This is because a country with market power in the polluting sector has a motive to implement an export tax in order to exploit its monopolistic power. However, if trade agreements do not allow for such taxes, environmental policy (or other domestic policies) may have a role as a second-best optimal policy.

Hence, this model predicts that trade liberalization may lead to weaker environmental policy in the import competing sector, but to a more stringent environmental policy in the exporting sector, which is a testable result. Another weakness of this model is that it is based on the assumption that the only policy instruments held by the government are trade policy and environmental policy. However, in reality, even if protecting local firms using trade policy instruments is impossible due to trade agreements or customs unions, it is unlikely that the next choice for a policy instrument would be environmental policy; governments can subsidize or tax firms implementing production subsidies, research and development subsidies, corporate taxes etc., which may be less distortionary and more efficient instruments than pollution regulation. Moreover, the terms of trade motive for protection does not explain why governments would subsidize local producers. However, this is explained by the strategic advantage motive for protection presented below.

Strategic Environmental Policy

Now instead of assuming that a country has monopolistic power over a production sector, assume that firms in countries have monopolistic power, and they compete each other strategically. Then governments have an incentive to use their policy instruments to give domestic firms a strategic advantage over foreign firms. In what follows we use the analysis conducted by Barrett (1994). He applies the simple export model developed by Brander and Spencer (1985) to the pollution regulation problem.

Assume two countries (Home and Foreign) and a local monopoly in each of them. Home firm produces x, and foreign firm produces x^*, which are homogeneous goods. There is no demand for these good in Home and Foreign; both countries export all of their outputs to a third country (Rest of the World, or RoW). Let $P(x + x^*)$ denote RoW's inverse demand function. Domestic firm's profits are given by:

$$\pi(x^*, \tau, s) = \max_{x,z}\{P(x + x^*)x - c(x, z) + sx - \tau z\} \quad (2.2.12)$$

where $c(x, z)$ is the domestic cost function, which is assumed to be increasing and convex in x, and decreasing in z. Moreover, s is an export subsidy, and τ is a pollution tax set by home government. The same variables with superscript * refer to foreign variables.

Foreign firm's profits are given by:

$$\pi^*(x,\tau^*) = \max_{x^*,z^*}\{P(x+x^*)x^* - c^*(x^*,z^*) - \tau^* z^*\} \tag{2.2.13}$$

Notice that, for simplicity, we have assumed that foreign government does not subsidize the foreign firm.

Maximizing (2.2.12) with respect to x and z, and (2.2.13) with respect to x^* and z^*, we obtain Home's and Foreign's best response functions, which are $br(x^*,\tau)$ and $br^*(x)$ respectively[30].

Domestic welfare is given by domestic monopoly's profits plus tax revenues, minus subsidy payments and total pollution damage (which is denoted by $D(z)$):

$$W = \pi(x^*,\tau,s) - sx + \tau z - D(z) \tag{2.2.14}$$

Totally differentiating (2.2.14) we obtain[31]:

$$dW = \pi_{x^*}dx^* - sdx + (\tau - MD)dz \tag{2.2.15}$$

where $MD = \frac{\partial D(z)}{\partial z}$ is the marginal damage function.

Moreover, notice that totally differentiating the foreign firm's best response function we obtain $dx^* = \frac{\partial br^*}{\partial x}dx$. Using this to substitute for dx^* in (2.2.15) we get:

$$dW = \left(\pi_{x^*}\frac{\partial br^*}{\partial x} - s\right)dx + (\tau - MD)dz \tag{2.2.16}$$

[30] Assume that stability conditions hold. Those conditions ensure that best response functions intersect in the first quartile, so that the Nash Equilibrium corresponding quantities are positive.
[31] Notice that $\pi_s = x$, and $\pi_\tau = -z$.

Supposing that home government chooses the pollution tariff and the export subsidy aiming to maximize domestic welfare, then from (2.2.16) we can derive the solution of this maximization problem:

$$\tau = MD \tag{2.2.17}$$

$$s = \pi_{x^*} \frac{\partial br^*}{\partial x} \tag{2.2.18}$$

These imply that optimal environmental policy internalizes the pollution externality, while optimal trade policy promotes exports[32]. Notice that $\pi_{x^*} = P' \cdot x < 0$ and $\frac{\partial br^*}{\partial x} < 0$.

Now suppose that a trade agreement bans export subsidies. In this case, using (2.2.16), imposing $s = 0$, to calculate the second-best optimal pollution tax we obtain:

$$\tau = MD - \pi_{x^*} \frac{\partial br^*}{\partial x} \left(\frac{\frac{dx}{d\tau}}{\frac{dz}{d\tau}} \right) < MD \tag{2.2.19}$$

Notice that $\frac{\frac{dx}{d\tau}}{\frac{dz}{d\tau}} > 0$, and since $\pi_{x^*} \frac{\partial br^*}{\partial x} > 0$[33], the second-best optimal pollution emissions tax is lower that marginal damage. This follows from home government's incentive to subsidize the domestic monopoly.

Hence, using weak pollution policy as a substitute to export subsidies may increase a country's welfare. However, this result is very sensitive to market structure assumptions. To see this, suppose that instead of local monopolies, many firms

[32] This is the Brander and Spencer (1985) result, that in an international Cournot duopoly setting an export subsidy may be welfare improving, giving a strategic advantage to the domestic over the foreign firm. Subsidizing exports leads Home's best response function to shift out (that is, higher domestic production for any given level of foreign production), and this leads to a larger share in the export market for the domestic firm.

[33] That is, domestic and foreign quantities are strategic substitutes.

compete each other as well as they compete foreign firms. Assume that n identical firms are in Home. Denote a typical domestic firm's output by x, and the total output of their domestic $n-1$ rivals by $Y = (n-1)y$. A representative domestic firm's profits are given by:

$$\pi\big((n-1)y, x^*, \tau, s\big) = \max_{x,z}\{P(x + (n-1)y + x^*)x - c(x,z) + sx - \tau z\} \qquad (2.2.20)$$

Domestic welfare is given by total domestic firms' net profits (profits plus pollution tax revenues, minus subsidy payments), minus total pollution damage caused by n firms:

$$W = n(\pi - sx + \tau z) - D(nz) \qquad (2.2.21)$$

Suppose that a free trade agreement bans export subsidies, so that $s = 0$. Totally differentiating (2.2.21) yields

$$dW = n(\pi_Y(n-1)dy + \pi_{x^*}dx^* + \tau dz) - nMD \qquad (2.2.22)$$

From (2.2.22) we can find the solution to the domestic government's welfare maximization problem. The second-best optimal pollution tax is given by:

$$\tau = MD - \pi_{x^*}\frac{\frac{dx^*}{d\tau}}{\frac{dz}{d\tau}} - (n-1)\pi_Y\frac{\frac{dy}{d\tau}}{\frac{dz}{d\tau}} \qquad (2.2.23)$$

Notice that $\pi_{x^*} < 0, \frac{dx^*}{d\tau} > 0, \frac{dz}{d\tau} < 0, \pi_Y < 0,$ and $\frac{dy}{d\tau} < 0.$ It follows that $\pi_{x^*}\frac{\frac{dx^*}{d\tau}}{\frac{dz}{d\tau}} > 0,$ but $\pi_Y\frac{\frac{dy}{d\tau}}{\frac{dz}{d\tau}} < 0.$ Therefore, when there exists only one domestic producer (i.e. $n = 1$, domestic monopoly), the third term in the right hand side in (2.2.23) is zero, and the second-best optimal pollution tax is lower than marginal damage, and trade liberalization leads to weaker environmental regulation.

However, for $n > 1$ this term is positive, and thus whether the pollution tax will be higher or lower than marginal damage is uncertain.

When $n > 1$, domestic firms have an incentive to collude and act as a cartel and gain extra profits. However, cartels are usually illegal and firms have to compete each other a la Cournot, and the extra profits are dissipated. The government can tax domestic firms and push up the price, thereby pushing domestic output closer to the collusive level and exploiting the country's monopolistic power. This is why the second-best optimal pollution tax is higher when $n > 1$ than when $n = 1$.

Notice that government faces two conflicting motives: a motive to subsidize domestic firms to promote exports, and give them a strategic advantage over foreign firms; and tax exports to exploit the country's monopolistic power. Simulation models have shown that for a sufficiently low number of domestic producers, the tax motive is stronger than the subsidy motive, hence leading the second-best optimal pollution emissions tax to a level higher than marginal damage. Conversely, if n is too large, and thus monopolistic power is too weak, then the subsidy motive offsets the tax motive and the pollution tax is lower than marginal damage.

Another example that illustrates how the policy substitution result, as it is explained by the strategic advantage motive, is sensitive to the market structure assumption, is the case where firms compete internationally a la Bertrand. That is, firms' choice variable is prices instead of quantities, and, in this case, domestic and foreign prices are strategic complements.

Let $x(p, p^*)$ be the RoW's demand function for the home firm's output, where p is the domestic price and p^* is the foreign price. Domestic firm's profits are given by:

$$\tilde{\pi}(p^*, \tau, s) = \max_{p,z}\{px(p, p^*) - c(x(p, p^*), z) + sx(p, p^*) - \tau z\} \tag{2.2.24}$$

Domestic welfare is given by:

$$\widetilde{W} = \tilde{\pi} - sx + \tau z - D(z) \qquad (2.2.25)$$

Totally differentiating (2.2.25) yields:

$$d\widetilde{W} = \tilde{\pi}_{p^*} dp^* - sdx + \tau dz - MDdz = \left(\tilde{\pi}_{p^*}\frac{dp^*}{dp} - s\frac{dx}{dp}\right)dp + (\tau - MD)dz \qquad (2.2.26)$$

where $\frac{dp^*}{dp} > 0$, since prices are strategic substitutes, and $\frac{dx}{dp} = \frac{\partial x}{\partial p} + \frac{\partial x}{\partial p^*}\frac{dp^*}{dp}$.

From (2.2.26) we can derive the solution of the domestic government's welfare maximization problem. The first best optimal trade and environmental policies are:

$$\tau = MD \qquad (2.2.27)$$

$$s = \tilde{\pi}_{p^*}\frac{\frac{dp^*}{dp}}{\frac{dx}{dp}} \qquad (2.2.28)$$

(2.2.27) implies that environmental policy should internalize the pollution externality. As for trade policy, notice that $\tilde{\pi}_{p^*} > 0, \frac{dp^*}{dp} > 0$, and $\frac{dx}{dp} < 0$. It follows that $s = \tilde{\pi}_{p^*}\frac{\frac{dp^*}{dp}}{\frac{dx}{dp}} < 0$. That is, (2.2.28) implies that the first best optimal trade policy is an export tariff instead of an export subsidy. The home firm's profits would be higher if it could precommit to a higher price, and an export tax facilitates this.

Now suppose that a trade agreement that bans export subsidies has been signed. We can derive the second-best optimal pollution tax from (2.2.26) imposing $s = 0$:

$$\tau = MD - \tilde{\pi}_{p^*}\frac{dp^*}{dp}\left[\frac{\frac{dp}{d\tau}}{\frac{dz}{d\tau}}\right] \qquad (2.2.29)$$

Notice that $\tilde{\pi}_{p^*}\frac{dp^*}{dp}\left[\frac{\frac{dp}{d\tau}}{\frac{dz}{d\tau}}\right] < 0$, and thus $\tau = MD - \tilde{\pi}_{p^*}\frac{dp^*}{dp}\left[\frac{\frac{dp}{d\tau}}{\frac{dz}{d\tau}}\right] > MD$. That is, the second-best optimal pollution tax implied by (2.2.29) is higher than marginal damage.

Hence, in this case, freer trade has led to more stringent environmental policy, thus contradicting the policy substitution argument.

Monopolistic Competition:

Another approach to firm-level market power is to assume a monopolistically competitive market structure. A few important works have been conducted. Pfluger (2001) develops a model where firms produce a homogeneous polluting good, and are internationally mobile, but there is transportation cost, which introduces a home market effect. That is, consumers face a lower price for a good that is produced in their home country. Countries are identical. This is a case of horizontal differentiation. Countries have to weigh the benefits of attracting firm, which arise from the home market effect, against the costs of pollution. Two types of equilibria can emerge: first, countries may set too stringent pollution policy to chase firms out of the country and eschew the pollution costs; and second, countries may set weak pollution policy in order to attract firms and gain from the home market effect. The first case occurs when firms are very pollution intensive, and the latter case occurs when firms do not generate too much pollution.

Haupt (2006) develops a vertical differentiation model, where the number of varieties is endogenous, and there are no transportation costs (and hence no home market effect). In this model, more stringent environmental policy leads to fewer varieties. He predicts that trade liberalization would lead to more stringent environmental policy, because governments do not take into account the costs of a loss of product variety to foreign consumers.

Benarroch and Weder (2006) develop a model in which trade occurs in intermediate goods with different pollution intensities. Pollution policy in one country affects the relative supplies of clean and polluting goods, thereby altering environmental quality in the other country. They conclude that trade liberalization would lead either to a reduction in total pollution emissions in each country, or to a decrease in the pollution emissions per unit of output in at least one country. Furthermore, trade in intermediate product causes countries to import the environmental quality of their trading partners.

2.2.3. Market Access

Although trade agreements usually ban the use of policy induced trade barriers, governments still have the power to regulate local markets to protect health and safety, and to protect the environment. Therefore, governments may have an incentive to use environmental policy to restrict the access of foreign firms to domestic markets.

In this section, we will consider the effect of a trade agreement on such a motive of a government. The model presented above has been developed by Copeland and Taylor (2011), and it builds on the works of Fischer and Serra (2000), Gulati and Roy (2008), and Copeland (2008).

We assume two goods: Y_1 and Y_2. Y_1 is assumed to be the polluting good. Its price is p, and it is imported, but also produced domestically. We use a consumption generated pollution context, in which the consumption of a unit of Y_1 generates $\bar{e}$ units of pollution. However, the manufacturer can modify the pollution intensity and reduce it to $e < \bar{e}$, at a cost of $c(e)$, where $c(e)$ is assumed to be decreasing and convex in e[34]. Y_2 is assumed to be the clean good, and also the numeraire good. Pollution is regulated by a tax of τ per unit of emissions for the domestically produced good, and τ^* for the foreign produced good.

[34] That is, the cost of making the product relatively cleaner rises increasingly as the targeted pollution intensity falls.

Consumers face prices q and q^* for a unit of domestically and foreign produced good respectively. These prices are given by:

$$q = p + c(e) + \tau e \tag{2.2.30}$$

$$q^* = p^* + c^*(e^*) + \tau^* e^* + t \tag{2.2.31}$$

Arbitrage requires that $q = q^*$. Hence we can solve for the domestic producer price and obtain:

$$p = p^* + t + c^*(e^*) - c(e) + \tau^* e^* - \tau e \tag{2.2.32}$$

Competition leads domestic and foreign producers to minimize consumer prices, having e and e^* as choice variables. That is, domestic producers set:

$$c'(e) + \tau = 0 \tag{2.2.33}$$

while foreign producers set:

$$c^{*\prime}(e^*) + \tau^* = 0 \tag{2.2.34}$$

The budget constraint for the representative domestic consumer is given by:

$$E(q, z, u) = G(p, v) + \tau z^d + \tau^* z^M + tM \tag{2.2.35}$$

where z^d and z^M denote pollution generated by consuming the domestically and the foreign produced good respectively.

Total pollution is simply the sum of z^d and z^M, i.e.:

$$z = z^d + z^M = Y_1 e + M e^* \tag{2.2.36}$$

M denotes imports. Notice that, in a two-country world, domestic imports are equal to foreign exports. That is $M = X^*(p^*)$. Hence, totally differentiating (2.2.35) and rearranging, we obtain:

$$E_u du = (\tau - E_z)dz^d + (\tau^* - E_z)dz^M - (tX^*_{p^*} - X^*)dp^* \tag{2.2.37}$$

From (2.2.37) we can derive the solution of the government's welfare maximization problem. The first best trade and environmental policies are:

$$\tau = \tau^* = E_z \tag{2.2.38}$$

$$\frac{t}{p^*} = \frac{1}{\varepsilon^*} \tag{2.2.39}$$

Again, if import tariffs are allowed, then efficient environmental policy is used to internalize the pollution externality, and trade policy targets the terms of trade. ε^* denotes the price elasticity of the foreign export supply curve, and it is given by $\varepsilon^* = \frac{\partial X^*}{\partial p^*}\frac{p^*}{X^*}$.

Now suppose that a trade agreement bans import tariffs. Then the government has an incentive to restrict imports to improve home's terms of trade by implementing discriminatory pollution regulation. Consider the case where e^* is exogenous. Thus $dz^M = e^* dM = e^* dX^*$, and we can rewrite (2.2.37) as:

$$E_u du = (\tau - E_z)dz^d + ((\tau^* - E_z)e^* X^*_{p^*} + X^*)dp^* \tag{2.2.40}$$

In this case, optimal taxes are given by:

$$\tau = E_z \tag{2.2.41}$$

$$\tau^* = E_z + \frac{p^*}{\varepsilon^*} \tag{2.2.42}$$

The domestic emission tax internalizes the externality caused by domestically generated pollution. The emission tax on the foreign good, however, is equal to marginal damage increased by the first-best optimal import tariff. Therefore we can conclude that if discriminatory environmental policy is possible, then the emission tax on the imported good is used as an import tariff.

However, trade agreements respond to discriminatory environmental policy by imposing a National Treatment rule, which allows governments to choose their environmental policy as long as foreign firms are not treated less favorably than domestic firms.

Suppose that a National Treatment rule is in force in our model (i.e. $\tau = \tau^*$). We can solve for the second-best optimal pollution tax again using (2.2.37), and obtain:

$$\tau = E_z + X^* \frac{\frac{dp^*}{d\tau}}{\frac{dz}{d\tau}} > E_z \qquad (2.2.43)$$

Since there is an incentive to set an import tariff, the second-best optimal pollution tax is higher than marginal damage. Despite the National Treatment rule, the government retains the power to use its environmental policy to influence the terms of trade.

2.3. Transboundary Pollution

In this chapter we will focus on the effects of transboundary pollution an trade and environmental policy and trade agreements. The main source is Copeland and Taylor (2011).

First consider a case where pollution does not spill over international borders. Recall the 'two countries and two goods' context from the previous chapters. We will calculate the Pareto efficient solution of the regulation problem. Suppose that a social planer chooses an import tariff t for Home, an export tax t^* for Foreign[35], domestic and foreign pollution levels z and z^*, and a lump sum transfer T, to maximize a weighted value of domestic and foreign indirect utilities[36]:

$$\begin{aligned}&\lambda V(p+t, G(p+t, v, z)+tM-T, z)\\&+(1-\lambda)V^*(p-\ t^*, G^*(p-\ t^*)+t^*X^*+T, z^*)\end{aligned} \tag{2.3.1}$$

subject to the balanced trade constraint:

$$M(p,t,T,z)=X^*(p,t^*,T,z^*) \tag{2.3.2}$$

Because of the presence of lump sum transfers, the first-best optimal environmental policy can be obtained under free trade ($t=t^*=0$). Maximizing (2.3.1) subject to (2.3.2) yields:

$$\tau=MD \tag{2.3.3}$$

$$\tau^*=MD^* \tag{2.3.4}$$

and lump sum transfers are chosen so that weighted marginal utilities are equal across the two countries:

[35] By the Lerner Symmetry Theorem, setting a tax on the exported good is equivalent to setting a tariff on the imported good. We use trade taxes only on good 1 (imported for Home, exported for Foreign) to facilitate the analysis.

[36] Assume a welfare weighting parameter $\lambda \in (0,1)$.

$$\lambda V_I = (1-\lambda)V^*_{I^*} \tag{2.3.5}$$

Notice that the pollution taxes are independent of the income distribution across countries, and of the weighting parameter λ. As it will be shown later, this is because lump sum transfers are available. Notice also that efficiency requires that the shadow price of emissions be equal to marginal damage in each country, so that pollution externalities are internalized, but it does not require that environmental policy should be harmonized across countries. Hence if a trade agreement could constrain both environmental policy and trade policy, then governments would not be able to substitute trade policy instruments with pollution regulation instruments, and the first-best would be obtainable.

Now consider the case where transboundary pollution is present: pollution spills over international borders. Pollution affecting Home residents is given by:

$$z^A = z + \gamma z^* \tag{2.3.6}$$

Pollution affecting Foreign residents is given by:

$$z^{A^*} = z^* + \gamma^* z \tag{2.3.7}$$

where γ is a parameter that indicates the effect of pollution generated in Foreign on Home, and γ^* is a parameter that indicates the effect of pollution generated in Home on Foreign.

Consequently, marginal damage caused by pollution in a country affects marginal damage on the other country in the same way. That is, marginal damages caused by Home and Foreign are given by (2.3.8) and (2.3.9) respectively.

$$MD^A = MD + \gamma MD^* \tag{2.3.8}$$

$$MD^{A^*} = MD^* + \gamma^* MD \tag{2.3.9}$$

Again, suppose that a social planer chooses an import tariff t for Home, an export tax t^* for Foreign, domestic and foreign pollution levels z and z^*, and a lump sum transfer T, to maximize a weighted value of domestic and foreign indirect utilities:

$$\lambda V(p+t, G(p+t, v, z) + tM - T, z^A) \\ +(1-\lambda)V^*(p - t^*, G^*(p - t^*) + t^*X^* + T, z^{A^*}) \tag{2.3.10}$$

subject to the balanced trade constraint:

$$M(p, t, T, z) = X^*(p, t^*, T, z^*) \tag{2.3.11}$$

As in the previous case, the first-best is obtainable under free trade ($t = t^* = 0$). Maximizing (2.3.10) subject to (2.3.11) yields the first-best optimal pollution taxes:

$$\tau = MD + \gamma MD^* \tag{2.3.12}$$

$$\tau^* = MD^* + \gamma^* MD \tag{2.3.13}$$

And, again, lump sum transfers are chosen so that weighted marginal utilities are equal across the two countries:

$$\lambda V_I = (1-\lambda)V_{I^*}^* \tag{2.3.14}$$

Notice that (2.3.12) and (2.3.13) imply that optimal taxes follow the Samuelson rule: optimal taxes equal marginal damages for each country.

Notice also that, again, pollution taxes do not depend on the distribution of income across countries, neither on the weighting parameter λ. As it will become evident in the next case ($T = 0$ and free trade agreement), this is due to the availability of lump sum transfers. Assuming that Home is richer than Foreign, a welfare-maximizing international agent would choose a positive lump sum transfer from Home to Foreign, in order to equalize Home and Foreign's weighted marginal utilities of income, as (2.3.14) implies.

Now suppose that lump sum transfers are not available. Imposing $T = 0$, and solving the weighted welfare constrained maximization problem yields:

$$t = -t^* \tag{2.3.15}$$

and pollution policy is still determined by (2.3.12) and (2.3.13), targeting to internalize pollution externalities. Notice that (2.3.15) implies that Home, which is the richer country, should subsidize imports from Foreign, which is the poorer country, instead of setting an import tariff. That is, even if lump sum transfers are not available, the richer country can use an import subsidy to compensate the poorer country, as it would be the case in the presence of lump sum transfers. Moreover, (2.3.15) implies that domestic and foreign prices should be equal. Optimal environmental policy is independent of λ and the distribution of income, but now trade barriers are set.

Now extend the framework to include a free trade agreement, which bans trade taxes and subsidies. That is $t = t^* = 0$. In this case, environmental policy should deal both with environmental problems and international distribution of income. In this case, optimal pollution taxes are:

$$\tau = MD + \gamma\varphi MD^* - M(\varphi - 1)\frac{dp}{dz} \tag{2.3.16}$$

$$\tau^* = MD^* + \frac{\gamma^* MD}{\varphi} - X^*(1 - \frac{1}{\varphi})\frac{dp}{dz^*} \tag{2.3.17}$$

where $\varphi \equiv \frac{(1-\lambda)V_{I^*}^*}{\lambda V_I}$.

Notice that, because of decreasing marginal utilities, and since Home is richer than Foreign, the marginal utility of income is higher in Foreign than in Home, assuming a sufficiently low λ, it follows that $\varphi > 1$. Now optimal environmental policy depends on the distribution of income, and the welfare weighting parameter λ, and this illustrates why the presence of lump sum transfers (or equivalent instruments, as import subsidies used to compensate the poorer country) was the reason for environmental policy to be independent of those in former cases.

The second term on the right hand side in (2.3.16) and (2.3.17) is unambiguously positive. Ignoring the terms of trade effect, captured by the third term in each equation, (2.3.16) and (2.3.17) imply that Home (the richer country) puts a higher weight on the environmental impact of its pollution on Foreign than in the Samuelson rule, while Foreign puts a lower weight on the environmental impact of its pollution on Home than in the Samuelson rule. This leads to $\tau > \tau^*$, however not taking into account the terms of trade effect.

The terms of trade effect is captured by the last term in (2.3.16) and (2.3.17). Since we have assumed that Home imports the polluting good, we have $\frac{dp}{dz} < 0$. Therefore, it follows that $\tau > \tau^*$, and the terms of trade effect shift both taxes upwards. Hence, since environmental policy is more stringent in Home than in Foreign, the supply of foreign exports decreases, and foreign terms of trade improve.

Unilateral Policy

Now suppose that negotiation fails, and Home sets its trade and environmental policy unilaterally. The Home government maximizes indirect utility $V(p + t, (p + t, v, z) + tM, z^A)$ subject to the balanced trade constraint $M(p, t, \tau, z^*(p)) = X^*(p, z)$, and $z^* = z^*(p)$. This yields:

$$\tau = MD - tX_z^* = MD - \gamma^* tX_{zW}^* \tag{2.3.20}$$

$$\frac{t}{p} = \frac{1}{\varepsilon_{X^*p}}\left[1 + \gamma \frac{MDz^*}{pX^*} \varepsilon_{z^*p}\right] \tag{2.3.21}$$

where $\varepsilon_{X^*p} = \frac{dX^*}{dp} \cdot \frac{p}{X^*}$ is the price elasticity of Foreign's exports supply function.

(2.3.20) implies that there is an additional component to the standard marginal damage component. This additional term captures the direct effect of changes in

Home's pollution on foreign export supply. Suppose that $X_z^* < 0$, and, consequently, $\tau > MD$. Increasing the emission tax will cause Foreign's export supply curve to shift out, due to the decrease in domestic emissions. This will improve Home's terms of trade. Domestic environmental policy targets both the effects of pollution on the terms of trade, and on domestic pollution damage.

(2.3.21) implies that trade policy is used to target the terms of trade, as usually, and, furthermore, to influence foreign pollution. The optimal tariff follows the standard formula, plus an additional term which indicates the importance of foreign pollution relative to the value of Home's imports and the dependence of foreign pollution on Foreign's exported good price changes.

Trade in Pollution Emission Permits

If pollution in one country affects world welfare, the efficiency requires that emission prices should be equalized across countries. An alternative way, other than taxes, to achieve this is to allow free trade in emission permits. Theory predicts that a system of free tradable emission permits could lead to equalized emission prices across countries, and achieve efficiency. This unambiguously holds in the case of a domestic emission permit system: supposing that a country wants to reduce domestic pollution emissions, it might seem "fair" to force all polluting firms to reduce their emissions equally; however some firms would be willing to pay more for an extra unit of allowed emissions than others (in other words, marginal abatement costs differ across different firms), and thus this policy would not be efficient. A system of domestically tradable pollution permits would lead to equalized marginal abatement costs, achieving the efficient allocation of permits.

However, Copeland and Taylor (2005) show that this need not be the case in a system of internationally tradable emissions: they have shown that allowing for such a system could deteriorate welfare in some countries[37].

[37] Although allowing free trade for a formerly closed economy is predicted by international trade theory to be unambiguously welfare improving, this need not be the case when a country is already

Assume two polluting goods: Y_1 and Y_2, where Y_1 is Home's imported good, and it is more pollution intensive than Y_2. Let z^M and τ^M denote imported emission permits and their price respectively, and z^W denote world pollution emissions. Home's national income is given by:

$$I = G(p, v, z + z^M) - \tau^M z^M \quad (2.3.18)$$

Using (2.3.18) and totally differentiating the domestic welfare function, which in a representative consumer framework is given by the indirect utility function $V(p, I, z^W)$, and moreover imposing $z^M = 0$, yields the effect of importing permits for Home, starting from the position of no trade in permits:

$$\frac{1}{V_I}\frac{dV}{dz^M}\bigg|_{z^M=0} = (\tau - \tau^M) - M\frac{dp}{dz^M} - MD\frac{dz^W}{dz^M} \quad (2.3.19)$$

(2.3.19) implies that there are three effects on domestic welfare, each captured by each one of the three terms on the right hand side:

i. The first term, $(\tau - \tau^M)$, implies that Home gains from trade in permits if domestic price is higher than the price of an imported permit.

ii. The second term, $-M\frac{dp}{dz^M}$, captures the terms of trade effect. Since we have assumed that Home imports the more pollution intensive good, if free trade in emission permits causes the relative price of this good to rise, then Home's terms of trade deteriorate.

iii. The third term, $-MD\frac{dz^W}{dz^M}$, captures the effect of permit trade on global pollution. If permit trade leads to an increase in the price of the more pollution intensive good,

open to free trade in some markets, and it becomes open to one more market: Grossman (1984) shows that in a world with pre-existing free trade in commodities, introducing free capital mobility will alter prices of some goods, thereby yielding negative terms of trade effects for some countries. The case of free trade in emission permits is parallel to free capital mobility.

this will stimulate production of this good in countries which do not participate in free permit trade, thereby causing global pollution to rise.

Therefore, there are multiple scenarios in which allowing free trade in pollution emission permits may lead to welfare losses in some countries. This could be due to terms of trade deterioration, a global pollution boom, or both.

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