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Abstract

This paper constructs a model of a small open economy in which Lindahl taxes are imposed on environmental degradation. The government provides a public input devoted to environmental preservation according to an Austrian point-input-point-output process. We identified the conditions under which international trade has a positive or an adverse effect on environmental quality.

1 Introduction

Linkages between trade and environment have grown to be one of the major concerns in the theory of international trade. The everlasting debate over protectionism vs. free trade remains in the veins of such environmental concerns. Although it is impossible to provide a comprehensive overview of the extensive literature on this subject, we can at least say that two strands of literature appears to have emerged: One looks at consequences of environmental policies on trade and the other investigates the effects of trade on environmental quality.

The former strand of literature is mainly concerned with the consequences of diversity in environmental standards among trading countries, as well as the effects of a particular environmental policy on trade. One of the key contributions in the context of international trade theory is that they showed the diversity in environmental standards alone can cause trade. Conventional trade models were extended to incorporate pollution or common property of environmental goods to show that trade occurs even among countries that are identical except for different environmental standards or property right systems. (Pethig (1976), Baumol and Oates (1988), Chichilnisky (1994)). It also led to the important discussion of whether environmental protection provides justification for interference with free trade. As in Bhagwati and Srinivasan (1996), the common perception that lower environmental standards in a particular country create a cost advantage over other countries with higher environmental standards and free trade only enhances so-called 'eco-dumping' is being scrutinized.

The latter strand of literature focuses on the question of whether trade liberalization leads to improvement in environmental quality. Conflicting views on this issue have not yet been resolved. Free trade advocates argue that trade liberalization brings about an increase in income and creates demand for environmental quality and incentives for new investment in pollution abatement. Protectionists, on the other hand, take an opposite view on the income effects on environment; an increase in income generated by trade liberalization only leads to more consumption and hence more pollution.[1] This paper falls into this category, for it examines the effects of trade liberalization on environment by constructing a simple model of a small open economy in which pollution abatement is carried out by the government.

The primary purpose of the paper is to highlight the following features of pollution (or environmental clean up) and analyze the effects of trade on pollution abatement. The first feature is that pollution abatement is a very time-consuming process. It is not too hard to imagine the examples; cleaning up the polluted water, contaminated air and soil; they all require long duration of time to recover the environmental quality. We follow Findlay (1978)'s excellent formalization of the 'Austrian' capital and consider pollution abatement process to be time-consuming, i.e., after employing input, say for building environmental clean up facilities, it requires periods of time until the environmental quality is recovered.[2] To my limited knowledge, time-consuming aspect of pollution abatement has

[1] See Copeland and Taylor (1994) for further discussion.

[2] Neo-Austrian capital theory follows the tradition of Jevons, Böhm-Bawerk, and Wicksell, and incorporated time into the production phase. For a survey of the neo-Austrian capital theory, see Burmeister (1974).

not been discussed in the literature.

The second feature is the fact that environmental quality is a public good.[3] Due to the free-rider problem associated with environmental clean up, the government is to provide environmental abatement to private sectors and charges Lindahl taxes to cover the cost. We abstain from discussing the informational and administrative difficulties associated with imposing Lindahl taxes and determining optimal level of pollution abatement.[4] Since our analysis is confined to a small open production economy, we follow Khan (1996) and formalize environmental quality as a non-traded public input in the model.[5] Pollution is hence perceived as an input rather than a byproduct of the production process. Pollution can alternatively be treated as a byproduct of a production process as in Copeland (1991) and Yu (1980). However, as Khan (1996) puts it; 'Pollution can generally be conceived either as a byproduct of the polluting industry or treated as an input rather than an output in the production process. There is no substantive difference between the two approaches.'[6]

The organization of the paper is as follows. Section 2 presents the model and the notion of equilibrium. Comparative static analysis of the model is carried out in Section 3 as a preliminary to our discussion of the relationship between trade and environment which is presented in Section 4. Section 5 closes the paper with some remarks.

2 The Model and the Notion of Equilibrium

Consider a small open economy in which government produces a non-traded intermediate good devoted to environmental preservation according to an Austrian point-input-point-output process. There are n internationally traded final goods, which are produced by using labor. Labor

[3] Environmental commodity is treated as a regional public good as opposed to a global public good in this paper. Treatment of environment as a regional public good can be found, for example, in Copeland and Taylor (1994) and Khan (1996). Global or trans-border pollution is analyzed, among others, in Chichilnisky (1994), Copeland and Taylor (1995).

[4] See Yukutake (1996).

[5] For the discussion of public inputs see Yukutake (1996) and references therein.

[6] See Khan (1996) and the references therein.

is assumed to be mobile intersectorally but not internationally. Perfect competition prevails in the markets.

Let G denote the amount of a composite commodity for environmental clean up. As mentioned earlier, pollution abatement is carried out according to an Austrian point-input-point-output process à la Findlay (1978). Therefore, there is a lag between the time when the cost for the environmental commodity is born and the time when the clean-up effect is realized. Labor is initially used, say, for building facilities for pollution abatement. As time elapses, the amount of pollution abatement increases at a diminishing rate. Production of a composite commodity for environmental clean up, hence requires labor and time as inputs. The output of an environmental commodity per unit of labor after time t has elapsed, g, is given by

$$g = g(t),\ g'(t) > 0,\ g''(t) \leq 0 \tag{1}$$

The total amount of environmental commodity is thus

$$G = L_g g \tag{2}$$

where L_g denotes the amount of labor used for environmental clean up.

Assuming the government to act competitively, the government chooses the optimal production period, t^*, for the environmental commodity. The government's problem, thus, is to maximize the discounted profit $qGe^{-\rho t} - wL_g$, where q is the marginal cost of the environmental commodity, ρ is the rate of interest and w is the wage rate. Maximizing the discounted profit with respect to t leads to

$$\frac{1}{g}\frac{dg}{dt} = \rho \tag{3}$$

It is useful to write down the solution to (3) as follows.

$$t^* = \tau(\rho) \tag{4}$$

The zero-profit condition gives us

$$g(t^*)e^{-\rho t^*} = \frac{w}{q} \tag{5}$$

The technology for the final good production is given by

$$X_i = F_i(L_i, G),\ i = 1, \cdots, n \tag{6}$$

where X_i denotes the output of final good i, L_i being the amounts of labor used in the production of commodity i. F_i is assumed to be continuously differentiable and exhibits constant returns to scale. Production of each final good uses the same amount of environmental commodity, i.e., pollution abatement is a public input. This reflects the fact that environmental degradation causes externality among industries. It should be noted that the constant returns to scale assumption imply that the environmental externalities are of what Meade calls the 'unpaid factors of production' type.[7]

The problem of a competitive producer in sector i is to maximize his profits by choosing L_i taking p_i's, the wage rate, w, and the supply of the environmental commodity G as given. The allocation of labor is thus determined through the marginal productivity pricing;

$$w = p_i F_{iL} \tag{7}$$

where $F_{iL} = \frac{\partial F_i}{\partial L_i}$.

The government imposes each industry a Lindahl tax (or a personalized price) for the environmental degradation. The rate of the Lindahl tax, equal to the marginal product the environmental commodity in each industry, is different across industries. Let q_i denote the Lindahl tax for sector i, then we can write

$$q_i = p_i F_{iG} \tag{8}$$

$$q = \sum_{i=1}^{n} q_i \tag{9}$$

[7]Mead (1952) distinguished two types of public inputs. He calls a public input an 'atmosphere' type if the final goods' production functions exhibit constant returns to scale with respect to private inputs alone, i.e. outputs can be doubled by doubling the amount of private inputs, while keeping the level of public input constant. The aggregate production functions exhibit increasing returns to scale. When public inputs are pure public goods, they fall into this type. As the benefits from public inputs become more rival and more excludable due to congestion or limited availability, the degree of returns to scale for final goods' production diminishes. When final goods' production functions exhibit constant returns to scale with respect to all inputs, the externalities associated with public inputs is what Meade calls the 'unpaid factors of production' type.

It is well known that when Lindahl taxes are applied to finance the cost of public inputs, the sum of the marginal rate of substitution between public input and labor is equal to the marginal cost of public input and the Pareto optimality is achieved.[8]

Assuming full employment of labor, the material balance equation is given by the following equation.

$$\sum_{i=1}^{n} L_i + L_g = \mathcal{L} \tag{10}$$

where $\mathcal{L}$ is the exogenously given amount of the working population.

The Lindahl equilibrium studied in this paper is summarized in the following definition.

Definition 1 *An equilibrium is constituted by a tuple* (w^*, q^*) *and by a strictly positive tuple* $((X_i^*, L_i^*, q_i^*)_{i=1}^n,\ (G^*, L_g^*, t^*))$ *such that for all* $i = 1, \cdots, n$

(i) L_i^* *maximizes* $p_i F_i(L_i, G^*) - w^* L_i - q_i^* G$,

(ii) (L_g^*, t^*) *maximizes* $q^* g(t) L_g e^{\rho t} - w^* L_g$,

(iii) $X_i^* = F_i(L_i^*, G^*)$,

(iv) $G^* = L_g^*\ g(t^*)$,

(v) $\sum_{i=1}^n L_i^* + L_g^* = \mathcal{L}$,

(vi) $q_i^* = p_i F_{iG}(L_i^*, G^*)$,

(vii) $\sum_{i=1}^n q_i^* = q^*$

The above system of equations determine endogenous variables which are labor allocation between the n final good industries and the environmental sector, factor prices including Lindahl taxes for the environmental clean-up and the optimal production period for the environmental commodity. Once we make an analogy of a public input as a specific factor,

[8]The optimal condition for public input provision is derived in Kaizuka (1964) and Sandmo (1974).

the structure of the model with one primary factors of production and constant returns to technology can be seen as the conventional Ricardo-Viner model. However, it departs from the Ricardo-Viner model because the model is equipped with the decomposition property, i.e., the wage rate and the Lindahl taxes are determined independent of factor endowments. Factor price equalization as well as Lindahl tax equalization hold in the model. Also note that equation (3) implies the optimal production period depends solely on the exogenously given interest rate. Taking the decomposition property into account, the model can be decomposed to three subsystems, which are going to be analyzed separately in turn in the following section.

3 Mechanics of the Model

3.1 Choice of Technique for the Environmental Commodity

From equations (4) and (5), the cost function for the environmental good can be written as

$$q = \sum_{i=1}^{n} q_i = wg(\tau(\rho))e^{-\rho\tau(\rho)} = C_g(w, \rho) \tag{11}$$

Note that under the Austrian point-input-point-output process for the production of the environmental good, substitution between two inputs, labor and time does not occur. This is why the cost function described above is not homogeneous with respect to factor prices, w and ρ. Once t^* is determined, the production technology for the environmental good furnishes the characteristics of the Ricardian technology in the sense that the labor requirement per unit output is independent of the wage rate.

Upon totally differentiating equation (4), we obtain

$$\hat{t^*} = a\hat{\rho} \tag{12}$$

$$a = (1+\rho)\frac{\tau'}{\tau} \tag{13}$$

where $\hat{t^*} = \frac{dt^*}{t^*}$, $\hat{\rho} = \frac{d\rho}{1+\rho}$, and $\tau' = \frac{\partial\tau}{\partial\rho}$. It is easy to see that from equation (3) and the fact that function g is a concave function, $\tau' < 0$. We can thus write

Lemma 1 *The optimal production period for the environmental commodity, t^*, is inversely related to the interest rate, ρ.*

The intuition for this result is clear. An increase in the interest rate implies an increase in the cost of time, hence less time will be used for the production of the environmental commodity.

For the later analysis, we examine the changes in the choice of technique for the production of the environmental commodity. Let $a_g = \frac{1}{g(\tau(\rho))}$ be the labor requirement per unit of the environmental commodity.

$$\hat{a}_g = -\frac{g'}{g}\tau' d\rho = -a\tau\rho\hat{\rho} \tag{14}$$

where $\hat{x} = \frac{dx}{x}$. Lemma 1 implies that $a < 0$.

3.2 The Price Cost Equations

Due to the decomposition property of the model, factor prices, w and q_i, are determined solely by p_i and ρ. We can thus analyze the changes in factor prices by looking at the subsystem of the model consisting of price equals unit-cost equations.

Given constant return to scale technology, we can write down the cost functions of the final goods as follows.

$$p_i = C_i(w, q_i),\ i = 1, \cdots, n \tag{15}$$

In order to conduct a comparative static analysis for the changes in output prices, we totally differentiate equations (15) and (11),

$$\begin{bmatrix} \hat{p}_1 \\ \vdots \\ \hat{p}_n \\ -b\hat{\rho} \end{bmatrix} = \begin{bmatrix} \theta_{1G} & 0 & \cdots & \theta_{1L} \\ \vdots & & & \vdots \\ 0 & \cdots & \theta_{nG} & \theta_{nL} \\ -\mu_1 & \cdots & -\mu_n & 1 \end{bmatrix} \begin{bmatrix} \hat{q}_1 \\ \vdots \\ \hat{q}_n \\ \hat{w} \end{bmatrix} \tag{16}$$

where θ_{ij} represents the share of the jth factor payment in the production of ith good,[9] $\mu_i = \frac{q_i}{q}$, and $b = (1 + \rho)t^*$.

[9]By definitioin, we have $\theta_{iL} + \theta_{iG} = 1$.

Solving the above subsystem of price-cost equations yields

$$\begin{bmatrix} \hat{q_1} \\ \vdots \\ \hat{q_n} \\ \hat{w} \end{bmatrix} = \begin{bmatrix} \frac{1-\beta_1\theta_{1L}}{\theta_{1G}} & \cdots & \frac{-\beta_n\theta_{1L}}{\theta_{1G}} & -\frac{l_1}{\mu_1} \\ \vdots & & & \vdots \\ \frac{-\beta_1\theta_{nL}}{\theta_{nG}} & \cdots & \frac{1-\beta_n\theta_{nL}}{\theta_{nG}} & -\frac{l_n}{\mu_n} \\ \beta_1 & \cdots & \beta_n & \frac{qG}{w\mathcal{L}} \end{bmatrix} \begin{bmatrix} \hat{p_1} \\ \vdots \\ \hat{p_n} \\ -b\hat{\rho} \end{bmatrix} \tag{17}$$

where $\beta_i = \frac{p_i X_i}{\sum_i p_i X_i}, 0 < \beta_i < 1$ is the GDP share of commodity i, $l_i = \frac{L_i}{\mathcal{L}}$ is the share of labor allocation to sector i.

The changes in the international prices and interest rate, thus, have the following effects on factor prices;

$$\hat{q_i} = \frac{1-\beta_i\theta_{iL}}{\theta_{iG}}\hat{p_i} - \sum_{j\neq i}\frac{\beta_j\theta_{iL}}{\theta_{iG}}\hat{p_j} + \frac{bl_i}{\mu_i}\hat{\rho} \tag{18}$$

$$\hat{w} = \sum_i \beta_i\hat{p_i} - \frac{bqG}{w\mathcal{L}}\hat{\rho} \tag{19}$$

It should be noted that β_i is the elasticity of w with respect to p_i, i.e., one percent increase in p_i increases wage by β_i percent. Hence the greater β_i is, an increase in p_i brings about the greater increase in w.

We can deduce an analogue of the Stolper-Samuelson theorem.

Proposition 1 [*Khan*(1984)] *An increase in the international price of the ith output leads to*
1) an increase in the wage rate,
2) an increase in Lindahl tax of the ith sector, and
3) a reduction in Lindahl tax of the jth sector ($j \neq i$).

The above result pertaining to the changes in the international output prices can be found in Khan (1984). The results are rather straightforward extensions of the Ricardo-Viner model. An increase in the price of an output, say p_i, holding the other prices constant increases factor prices of that sector, w and q_i. In the other sector whose output price is fixed, an increase in the wage rate reduces the Lindahl tax for the other sector, q_j ($j \neq i$).

Since the environmental commodity is an 'Austrian' capital, we can go beyond the conventional results of the Ricardian model and of the Ricardo-Lindahl model in Khan (1984). In particular, we can obtain some results pertaining to the effects of the changes in the interest rate.

Proposition 2 *When international output prices are fixed, an increase in the interest rate leads to*
1) a reduction in the wage rate,
2) an increase in Lindahl taxes for every sector.

Equation (11) implies that an increase in the interest rate, by shortening the production period for the environmental commodity, brings about a decrease in the real wage rate valued in terms of the environmental commodity, $\frac{w}{q}$. Since the output prices are fixed, a decline in $\frac{w}{q}$ implies a reduction in w and an increase in q_i for all i.

3.3 Material Balance Equations

Again, the decomposition property of the model allows us to analyze the effects of the changes in the factor endowment on the outputs independent of prices. Toward this end, we totally differentiate the following material balance equations.

$$a_{iG}X_i = G \tag{20}$$

$$\sum_{i=1}^{n} a_{iL}X_i + a_g G = \mathcal{L} \tag{21}$$

where $a_{iG} = \frac{\partial C_i}{\partial q_i}$ is the demand for environmental good per unit of output i, $a_{iL} = \frac{\partial C_i}{\partial w}$ is the demand for labor per unit of output i. We then obtain the following:

$$\begin{bmatrix} 1 & 0 & \cdots & -1 \\ 0 & 1 & 0 & \vdots \\ \vdots & \cdots & \cdots & -1 \\ l_1 & \cdots & l_n & l_g \end{bmatrix} \begin{bmatrix} \hat{X}_1 \\ \vdots \\ \hat{X}_n \\ \hat{G} \end{bmatrix} = \begin{bmatrix} -\hat{a}_{1G} \\ \vdots \\ -\hat{a}_{nG} \\ \hat{\mathcal{L}} - \sum_i l_i \hat{a}_{iL} - l_g \hat{a}_g \end{bmatrix} \tag{22}$$

By assuming $dp_i = d\rho = 0$, we have $\hat{a}_{iL} = \hat{a}_{iG} = 0$ for all i and $\hat{a}_g = 0$. The subsystem reduces to nothing but the Ricardo-Lindahl model discussed in Khan (1984). This is not surprising because the optimal production period as well as factor prices are determined solely by the international output prices and interest rate and do not depend on output levels. Although we can resort to Khan (1984) for the results on the effects of the changes in the factor endowment and no further analysis is necessary, we spell out the solution of the subsystem and reiterate the result below for the purpose of our later analysis.

Solving the above subsystem yields

$$\begin{bmatrix} \hat{X}_1 \\ \vdots \\ \hat{X}_n \\ \hat{G} \end{bmatrix} = \begin{bmatrix} 1-l_i & -l_2 & \cdots & -l_n & 1 \\ -l_1 & 1-l_2 & \cdots & -l_n & 1 \\ \vdots & \vdots & \cdots & 1-l_n & \vdots \\ -l_1 & -l_2 & \cdots & -l_n & 1 \end{bmatrix} \begin{bmatrix} -\hat{a}_{1G} \\ \vdots \\ -\hat{a}_{nG} \\ \hat{\mathcal{L}} - \sum_i l_i \hat{a}_{iL} - l_g \hat{a}_g \end{bmatrix} \tag{23}$$

which gives us the following expression.

$$\begin{aligned} \hat{X}_i &= \hat{\mathcal{L}} - \sum_i l_i \hat{a}_{iL} - l_g \hat{a}_g - (1-l_i)\hat{a}_{iG} + \sum_{j \neq i} l_j \hat{a}_{jG} \\ \hat{G} &= \hat{\mathcal{L}} - \sum_i l_i \hat{a}_{iL} - l_g \hat{a}_g + \sum_i l_i \hat{a}_{iG} \end{aligned} \tag{24}$$

Clearly, the above formulae indicate that an increase in the labor endowment brings about a proportional increase in final good's outputs and environmental commodity.

Proposition 3 : [*Khan*(1984)] *If international prices and interest rate are fixed, an increase in the labor endowment leads proportional increase in final goods' outputs and the environmental commodity. The output response in each commodity, including the environmental commodity, is identical.*

This is an analogue of the well-known property of the Ricardian model.

Unfortunately, the price-output response, to which we proceed in the next section, is less trivial because of the time-consuming production process of the environmental good.

4 Trade and Environment

In this section, building on the preliminary results obtained in the previous section, we are going to investigate the relationship between trade and environment by examining the output responses of final goods and the environmental commodity to the changes in the international prices of final goods and the interest rate. Toward this end, we need to incorporate the changes in the choice of production technique brought about by the changes in the international output prices and interest rate, and deduce the price-output relationships in the model.

4.1 Price Output Responses

We first investigate the changes in the choice of technique for the production of final goods. To begin with, we utilize the definition of an elasticity of factor substitution, σ_i^{LG},

$$\sigma_i^{LG}(\hat{q}_i - \hat{w}) = \hat{a}_{iL} - \hat{a}_{iG} \tag{25}$$

The cost minimization via the envelope theorem gives us

$$\theta_{iL}\hat{a}_{iL} + \theta_{iG}\hat{a}_{iG} = 0 \tag{26}$$

The routine Jone's-type manipulation of combining it with equation (25), we obtain

$$\hat{a}_{iL} = \theta_{iG}(\hat{q}_i - \hat{w})\sigma_i^{LG} \tag{27}$$

$$\hat{a}_{iG} = -\theta_{iL}(\hat{q}_i - \hat{w})\sigma_i^{LG} \tag{28}$$

From the subsystem of price-cost equations, we can reduce the following relationship between factor prices and output prices.

$$\hat{q}_i - \hat{w} = \frac{1-\beta_i}{\theta_{iG}}\hat{p}_i - \sum_{j \neq i} \frac{\beta_j}{\theta_{iG}}\hat{p}_j + \frac{\beta_i}{\mu_i} b\hat{\rho} \tag{29}$$

Substituting equations (14), (27) and (29) into equation (24), we are ready to present the following formulae.

$$\begin{aligned}
\hat{G} &= \hat{\mathcal{L}} - l_g\hat{a}_g - \sum_i l_i\sigma_i^{LG}(\hat{q}_i - \hat{w}) \\
&= \hat{\mathcal{L}} + \sum_i (l_i\gamma_{Li} - \beta_i \sum_{k=1}^{n} l_k\gamma_{Lk})\hat{p}_i \\
&\quad -(b\sum_i l_i\sigma_i^{LG}\frac{\beta_i}{\mu_i} - l_g a\tau\rho)\hat{\rho} \qquad (30) \\
\hat{X}_i &= \hat{G} + \theta_{iL}\sigma_i^{LG}(\hat{q}_i - \hat{w}) \\
&= \hat{G} + \theta_{iL}\gamma_{Li}(1-\beta_i)\hat{p}_i - \theta_{iL}\gamma_{Li}\sum_{j\neq i}\beta_j\hat{p}_j + \frac{\theta_{iL}\sigma_i^{LG}}{\mu_i}\beta_i b\hat{\rho} \qquad (31) \\
\gamma_{Li} &\equiv -\frac{\sigma_i^{LG}(\hat{q}_i - \hat{w})}{\hat{w} - \hat{p}_i} = \frac{\sigma_i^{LG}}{\theta_{iG}}
\end{aligned}$$

where γ_{Li} defined above is the elasticity of marginal product of labor in sector i.

In order to proceed, we need the following concept.

Definition 2 *The elasticity of wage with respect to p_i when $\hat{\mathcal{L}} = \hat{a}_g = \hat{G} = 0$ is called the elasticity of wage respect to p_i within the final good sector.*

We can now make the following observation.

Lemma 2 *The elasticity of wage with respect to p_i within the final good sector is equal to $\frac{l_i\gamma_{Li}}{\gamma}$, where $\gamma \equiv \sum_{i=1}^{n} l_i\gamma_{Li}$.*

Proof. By substituting equation (20) into (21) and upon totally differentiating, we obtain

$$\sum_{i=1}^{n} l_i(\hat{a}_{iL} - \hat{a}_{iG}) + l_g(\hat{a}_g + \hat{G}) = \hat{\mathcal{L}} \qquad (32)$$

Using equation (32) and after some manipulation, we can rewrite the above expression as

$$\hat{w} = \sum_{i=1}^{n} \frac{l_i\gamma_{Li}}{\gamma}\hat{p}_i - \frac{1}{\gamma}(\hat{\mathcal{L}} - l_g(\hat{a}_g + \hat{G})) \qquad (33)$$

The lemma follows from the coefficient of the first term on the right hand side of the equation.[10] It is easy to see $0 < \frac{l_i \gamma_{Li}}{\gamma} < 1$ and $\sum_i \frac{l_i \gamma_{Li}}{\gamma} = 1$. ∎

Recall that from equation (19), we know that β_i is the elasticity of wage with respect to p_i. We can present the following lemma

Lemma 3 *The elasticity of wage with respect to p_i is greater (less) than the elasticity of wage respect to p_i within the final good sector if and only if $l_i \gamma_{Li} - \beta_i \gamma < (>) 0$.*

Finally, we can present the following relationship between trade and environment.

Proposition 4 *An increase in the interest rate unambiguously reduces the supply of an environmental commodity. A reduction in the interest rate unambiguously increases the supply of an environmental commodity.*

As the interest rate increases, the cost of time for the production of the environmental commodity increases. This results in an increase in the Lindahl tax-wage ratio, and the labor demand in the final good sector increases. Therefore, labor shifts away from the environmental sector and the supply of the environmental commodity decreases. The implication of the proposition may be relevant to the developing countries. If a developing country with high interest rate can experience a decline in the interest rate by opening up its trade or liberalizing trade, the input cost of time in the production of the environmental commodity is reduced and results in an increase in the supply of an environmental commodity. However, if the interest rate increases, by the opposite reasoning, the supply of environmental commodity decreases. The direction of the changes in the interest rate is crucial for determining the effects of trade on environment.

Proposition 5 *An increase in the international price of commodity i increases the supply of an environmental commodity if the elasticity of wage respect to p_i within the final good sector exceeds the elasticity of wage with respect to p_i and reduces the supply of an environmental commodity if otherwise.*

[10]Notice also that one percent increase in the wage rate reduces the demand for labor in the final good sectors by γ percent.

We have now elucidated the conditions under which the output level of the environmental commodity increases. The output responses to price changes are less clear-cut as in the conventional Ricardo-Viner model. Trade liberalization is likely to increase the supply of an environmental commodity if the elasticity of marginal product of labor is high.

Our next concern is to examine whether trade liberalization expands the output of the polluting industry relative to the less-polluting industry. Using equation (31),

$$\begin{aligned}\hat{X}_i - \hat{X}_j &= (\theta_{iL}\gamma_{Li}(1-\beta_i) + \theta_{jL}\gamma_{Lj}\beta_i)(\hat{p}_i - \hat{p}_j) \\ &\quad +(\theta_{iL}\gamma_{Li} + \theta_{jL}\gamma_{Lj})\sum_{k\neq i,j}\beta_k(\hat{p}_j - \hat{p}_k) \\ &\quad -(\frac{\theta_{iL}\sigma_i^{LG}}{\mu_i}\beta_i - \frac{\theta_{jL}\sigma_j^{LG}}{\mu_j}\beta_j)\hat{\rho} \qquad (34)\end{aligned}$$

from which we can present the following.

Proposition 6 *1) An increases in the relative price of commodity i with respect to commodity j increases the output of commodity i relative to commodity j. A decrease in the relative price of commodity i with respect to commodity j decreases the output of commodity i relative to commodity j.*
2) An increase in the interest rate leads to an increase in the output of commodity i relative to commodity j if $\theta_{iL}\gamma_i - \theta_{jL}\gamma_j < 0$. A decrease in the interest rate leads to a decrease in the output of commodity i relative to commodity j if $\theta_{iL}\gamma_i - \theta_{jL}\gamma_j > 0$.

The first part of the proposition is a straightforward implication of having a concave production possibility frontier. The latter part of the proposition presents an interesting result on the changes in the composition of outputs caused by the changes in the interest rate. Let commodity i be the pollution-intensive good (interpreted as an industry with smaller θ_{iL}). Smaller the θ_{iL} is, an increase in the interest rate is more likely to expand the output of the pollution-intensive sector relative to the less-pollution intensive sector with greater θ_{jL} ($j \neq i$). Similarly, an increase in the interest rate is more likely to expand the output of the pollution-intensive sector relative to the less-pollution intensive sector if the elasticity of marginal product of labor for commodity i is small relative to commodity j.

4.2 The Stock Value of the Environmental Commodity in the Steady State

In the steady state, the stock value of the environmental commodity per unit of labor, K, is equal to the labor cost and the accumulated interest for the environmental goods under the maturity process. By taking integral of the instantaneous cost of the environmental good at time t, $\frac{w}{q}e^{\rho t}$, over the period 0 to t^*, we obtain

$$K = \int_0^{t^*} \frac{w}{q}e^{\rho t}dt = \frac{w}{q}\frac{1}{\rho}(e^{\rho t^*} - 1) \tag{35}$$

The total value of the stock of the environmental commodity, V, is

$$V = L_g K = a_g G K \tag{36}$$

Note that the value of the stock of the environmental commodity is proportional to L_g.

In order to investigate the effects of the changes in the international prices of final outputs and interest rate, we totally differentiate equations (35) and (36) by using (14) and (30);

$$\hat{K} = \frac{w}{q}e^{\rho t^*}t^*\hat{t^*} = \frac{w}{qK}e^{\rho\tau}a\hat{\rho} \tag{37}$$

$$\begin{aligned}\hat{V} &= \hat{a}_g + \hat{G} + \hat{K} \\ &= (\hat{\mathcal{L}} + \sum_i (l_i\gamma_{Li} - \beta_i \sum_{k=1}^{n} l_k\gamma_{Lk})\hat{p}_i \\ &\quad +(-(b\sum_i l_i\sigma_i^{LG}\frac{\beta_i}{\mu_i} - l_g a\tau\rho) + a\tau\rho\frac{1}{e^{\rho\tau}-1})\hat{\rho}\end{aligned} \tag{38}$$

We are ready to present the following.

Proposition 7 *The steady-state value of the stock of the environmental commodity increases (decreases) if*
1) the international interest rate decreases (increases),

2) the labor endowment increases (decreases),
3) the price of a commodity with respect to which the elasticity of wage within the final good sector is greater (less) than the elasticity of wage.

Since the changes in the labor endowment and the international prices of final outputs do not affect a_g nor K, it is not surprising that the response of the stock value of the environmental commodity to the price change is identical to that of G.

5 Conclusion

In this paper, we presented an 'Austrian' model of a small open economy with a environmental commodity. The environmental commodity characterized in this paper is a non-traded public input which requires production period to generate environmental quality. We identified conditions under which changes in the international commodity prices and changes in interest rate increases or decreases the output of the environmental commodity. An interesting result is that trade has a positive effect on environment if the interest rate interpreted as the cost of time for the production of environmental commodity decreases, but has an adverse effect on environment if the interest rate increases (Proposition 4). The elasticity of wage with respect to prices was shown to play an important role in determining the direction of the changes in the output of an environmental commodity due to the changes in the international price of final goods (Proposition 5). The stock value of the environmental commodity was found to be affected in the concerted manner as the flow output of the environmental commodity (Proposition 7).

This paper made a preliminary attempt to incorporate time-consuming aspect of pollution abatement, hence the structure of the model was kept to be as simple as possible to retain tractability of the analysis. However, the model may be too simple to analyze other important issues pertaining to the issue of environment and trade. Indeed, there are many possible ways of extending or modifying the model. For one, due to the assumption of a single factors of production, another important issue such as the effects of the influx of foreign capital on environment was beyond the scope of the paper.[11]

The virtue of Findlay (1978)'s analysis was that by incorporating 'Austrian' capital into the two country model of international trade, he interpreted the interest rate as the price of time as opposed to the rental price of capital and analyzed its determination of the equilibrium interest rate. In this paper, however, we confined our attention to a small open economy and the interest rate was assumed to be determined exogenously. Endogenously determining the interest rate by formulating a two-country model is another interesting venue to explore.

Finally, the model in this paper focused on a particular class of externality caused by an environmental commodity. Environmental quality was assumed to be a regional public good and constant returns to scale technology with respect to private factors of production and environmental commodity was assumed. This was to say that the environmental commodity is of the 'unpaid factors of production' type in Mead (1952)'s terminology. Analyzing the cases of a global public good as well as an 'atmosphere' type pure public inputs are warranted.

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