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Title	Recosideration of the Relationship between Environmental Regulation and Comparative Advantage : The Role of Environmental Externalities on the Production Side
Sub Title	
Author	YANASE, Akihiko
Publisher	Keio Economic Society, Keio University
Publication year	2004
Jtitle	Keio economic studies Vol.41, No.2 (2004.) ,p.77- 88
JaLC DOI	
Abstract	
Notes	
Genre	Journal Article
URL	https://koara.lib.keio.ac.jp/xoonips/modules/xoonips/detail.php?koara_id=AA00260492-20040002-0077

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KEIO ECONOMIC STUDIES 41(2), 77–88 (2004)

RECONSIDERATION OF THE RELATIONSHIP BETWEEN ENVIRONMENTAL REGULATION AND COMPARATIVE ADVANTAGE: THE ROLE OF ENVIRONMENTAL EXTERNALITIES ON THE PRODUCTION SIDE

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First version received June 2003; final version accepted December 2004

Abstract: The conventional view of the literature on trade and the environment is that tighter environmental policy leads to a country's comparative disadvantage in polluting goods. This paper re-examines such the relationship between environmental policy and comparative advantage by introducing negative externalities of pollution on the production side (productivity and/or factor endowments) into the standard Heckscher-Ohlin model. It is shown that, depending on the externality effects, tighter environmental policy may lead to a decrease in the autarky relative price of a pollution-intensive good.

Key words: Environmental Policy, Comparative Advantage, Pollution-intensity, Pollution Externality on the Production Side.

JEL Classification Number: F18, H23, Q28.

1. INTRODUCTION

Effects of the strictness of environmental policy on a country's comparative advantage and trade patterns have been analyzed theoretically since the 1970's. The standard observation is that the tighter environmental policy leads to a comparative disadvantage (advantage) in more (less) polluting goods, simply because a tighter environmental policy increases the production costs of polluting goods. A number of theoretical studies have been done in this line, from the pioneering works in the 70's, compiled in Siebert et al. (1980), to the researches of late such as Copeland and Taylor (1994, 1995) and Antweiler et al. (2001), who exercise richer models to investigate the effects of trade liberalization on the environmental quality.

Acknowledgements. I would like to thank an anonymous referee for valuable comments on an earlier version of the paper. Any remaining errors are, of course, mine.
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Recently, however, Chua (2003) develops a two-factor (labor and capital), three-good (two final goods and an abatement service) general equilibrium model and provides an example against this conventional view. Assuming that the level of emission is proportional to output, the author shows that the price of the good with higher pollution-output ratio may decrease in response to a higher pollution tax, or in other words, a country with tighter environmental policy may have a comparative advantage in the polluting good. This is because the pollution tax has two effects: on one hand it raises the price of the good with the higher tax burden; on the other hand it raises or lowers the relative wage-rental ratio depending on the factor intensity of the final goods. These two effects may work in opposite directions since it is assumed that the factor intensity is independent of the pollution intensity.

In this paper, I would like to provide a different explanation for the possibility that a country with the stringent environmental policy has a comparative advantage (disadvantage) in polluting (less polluting) goods. In distinction from Chua (2003) who formulates pollution as a by-product, I regard it as a factor of production, the total supply of which is determined by the government. A two-sector, competitive economy in which firms produce the goods by purchasing emission permits from the government as well as employing primary factor(s) of production is supposed. The model is essentially a traditional two-good general equilibrium one. In the model, the strictness of the environmental policy is signified by the level of the total permits[1]. Assuming that factors of production are freely mobile between sectors, by analogy with the Rybczynski theorem a country with tighter environmental policy has the less output of the pollution-intensive good[2], which leads to the higher autarky price of that good. When there are negative externalities of pollution on the production side, however, countervailing force against the Rybczynski theorem may exist and hence there may be a case where a tighter environmental policy lowers the relative price of polluting goods in the autarky equilibrium.

In most of the theoretical studies on trade and the environment, it has been assumed that pollution is harmful only to consumers whereas damages on the production side has been ignored. However, as Copeland and Taylor (1999) notes in the introductory part of their paper that develops a two-sector dynamic model of trade and pollution, the negative impacts of industrial pollution on fishing, agricultural yields, the value of standing forests, and tourism are not negligible. In this paper I would like to shed light on the effects of pollution on the productivity of goods and/or the total supply of primary factors of production, by examining two models that are variants of the standard Heckscher-Ohlin model. In the first model examined in Section 2, it is assumed that firms produce the goods employing "two factors" (one primary factor and the emission permit) and the negative externality of pollution on the productivity in each sector is present. It is shown that, depending on the elasticity of environmental externality in

[1] Environmental policy by pollution taxation is also considered, though briefly, in this paper. See Section 3.2.

[2] If there are sector-specific factors of production, the Rybczynski theorem may not hold in the short run. See, e.g., Jones and Neary (1984, Section 2.4) and Wong (1995, Section 2.6).

each sector, the autarky price of the pollution-intensive good may decrease in response to a tighter environmental policy[3]. In Section 3, the second model, in which there are "three factors" (two primary factors and the emission permit) and the total supply of each primary factor is affected by pollution, is developed. In this setup, more stringent environmental regulation may lead to a comparative advantage in polluting goods even if there are no direct productivity effects of pollution.

There have been a number of empirical studies testing the effects of environmental policy on patterns of trade as well. Some studies (e.g., Robison 1988; Low and Yeats 1992; Lucas et al. 1992) show the evidence in favor of the theoretical prediction, but others (e.g., Tobey 1990; Van Beers and van den Bergh 1997; Xu 1999) do not. The theoretical analysis in this paper, which suggests that even in a simple two-sector general equilibrium framework the relationship between the strictness of environmental policy and comparative advantage is not always self-evident, can be an explanation of the variation among empirical results as well as the gap between the theory and the evidence.

2. A MODEL WITH ONE PRIMARY FACTOR AND POLLUTION

Consider an economy producing two goods. Production of each good requires a primary input, labor, but generates pollution that deteriorates the environmental quality. To control the emission of pollution, the government issues pollution permits and firms must purchase them for producing goods. Total emissions E, the level of which is determined by the government, are regarded as public "bads" and may affect the productivity of each good, i.e., pollution may cause negative externality on production. These relationships can be written as a "production function" $X_j = F^j(E, L_j, E_j)$, $j = 1, 2$, where X_j, L_j and E_j denote output of good j, labor input for producing good j and emission generated by producing that good, respectively[4]. It is further assumed that $F^j(E, L_j, E_j)$ can be written as

$$F^j(E, L_j, E_j) = A_j(E)\, G^j(L_j, E_j), \quad j = 1, 2,$$

where $A_j(E)$ is decreasing in E and $G^j(L_j, E_j)$ exhibits constant returns to scale with diminishing marginal productivity to each factor. The negative externality on production is therefore modeled as a Hicks-neutral technical "regress" (i.e., negative progress)[5].

It is assumed that labor can be freely mobile between sectors and both sectors comply the environmental policy. Thus both sectors face the the same wage rate w and the same

[3] There has been substantial works that extend the standard Heckscher-Ohlin model by assuming that production technology exhibits variable returns to scale or there exist external economies of scale and re-examine the validity of the Stolper-Samuelson and the Rybczynski theorems. See, e.g., Wong (1995, Chapter 5) for a review. Although the source of externality is different, the present study is considered to be closely related to this research area.

[4] On the interpretation of pollution as an input, see, e.g., Siebert et al. (1980), López (1994) and Copeland and Taylor (1994, 1995).

[5] McGuire (1982) has derived a reduced form production function that depends on the level of an environmental policy parameter and discussed under what conditions environmental regulation is equivalent to neutral technical regress. The present analysis, by contrast, assumes the direct externality effect of pollution and hence a tighter environmental regulation reduces E and brings about the technical progress.

price of an emission permit τ. Both goods are produced by competitive, representative firms minimizing the unit production cost and hence the labor-output ratio a_{Lj} and permit-output ratio a_{Ej} of good j ($j = 1, 2$) are derived as functions of the relative factor price w/τ and the total emissions E.

Under perfect competition, firms producing positive outputs earn zero profit. Let p be the price of good 1 (good 2 is assumed to be numeraire). The zero profit conditions are therefore given by

$$a_{L1}(w/\tau, E)\, w + a_{E1}(w/\tau, E)\, \tau = p\,, \tag{1}$$

$$a_{L2}(w/\tau, E)\, w + a_{E2}(w/\tau, E)\, \tau = 1\,. \tag{2}$$

Let L be the total endowment of labor, assumed to be constant. The endowment of pollution permits $\bar{E}$ is exogenously determined by the government. Needless to say, $\bar{E}$ is equal to the total emissions of the economy E. The full employment conditions are then given by

$$a_{L1}(w/\tau, E)\, X_1 + a_{L2}(w/\tau, E)\, X_2 = L\,, \tag{3}$$

$$a_{E1}(w_1/\tau, E)\, X_1 + a_{E2}(w/\tau, E)\, X_2 = E\,. \tag{4}$$

2.1. Externality on Productivity and the Effect of Tighter Environmental Policy on Output

Let $\hat{z} \equiv dz/z$ denote the percent change of a variable z. Totally differentiating (1), (2), (3) and (4) and rearranging terms yield

$$\theta_{L1}(\hat{w} + \hat{a}_{L1}) + \theta_{E1}(\hat{\tau} + \hat{a}_{E1}) = \hat{p}\,, \tag{5}$$

$$\theta_{L2}(\hat{w} + \hat{a}_{L2}) + \theta_{E2}(\hat{\tau} + \hat{a}_{E2}) = 0\,, \tag{6}$$

$$\lambda_{L1}(\hat{a}_{L1} + \hat{X}_1) + \lambda_{L2}(\hat{a}_{L2} + \hat{X}_2) = 0\,, \tag{7}$$

$$\lambda_{E1}(\hat{a}_{E1} + \hat{X}_1) + \lambda_{E2}(\hat{a}_{E2} + \hat{X}_2) = \hat{E}\,, \tag{8}$$

where θ_{ij} is the distributive share of factor i in sector j and λ_{ij} is the fraction of factor i put in sector j ($i = L, E$, $j = 1, 2$). Clearly, $\theta_{Lj} + \theta_{Ej} = 1$, $j = 1, 2$ and $\lambda_{i1} + \lambda_{i2} = 1$, $i = L, E$ hold.

Totally differentiating the unit production function $A_j(E)\, G^j(a_{Lj}, a_{Ej}) = 1$ and using the cost minimization conditions $w = \lambda A_j G^j_L$ and $\tau = \lambda A_j G^j_E$, where λ is a Lagrange multiplier (which is in turn equal to the commodity price), it follows that

$$A'_j\, G\, dE + A_j\, G^j_L\, da_{Lj} + A_j\, G^j_E\, da_{Ej} = -\varepsilon_j\, \hat{E} + \theta_{Lj}\, \hat{a}_{Lj} + \theta_{Ej}\, \hat{a}_{Ej} = 0\,, \quad j = 1, 2\,,$$

where $\varepsilon_j \equiv -A'_j\, E/A_j$ is the elasticity of environmental externality effect on the productivity of good j ($j = 1, 2$). In light of the above expression, (5) and (6) can be rewritten as follows:

$$\theta_{L1}\, \hat{w} + \theta_{E1}\, \hat{\tau} = \hat{p} - \varepsilon_1\, \hat{E}\,, \tag{9}$$

$$\theta_{L2}\, \hat{w} + \theta_{E2}\, \hat{\tau} = -\varepsilon_2\, \hat{E}\,. \tag{10}$$

The elasticity of substitution between labor and emission permits in sector j can be defined as

$$\sigma_j \equiv -\frac{\hat{a}_{Lj} - \hat{a}_{Ej}}{\hat{w} - \hat{\tau}}, \quad j = 1, 2.$$

With this definition and the cost minimization condition $\theta_{Lj}\,\hat{a}_{Lj} + \theta_{Ej}\,\hat{a}_{Ej} = \varepsilon_j\,\hat{E}$, $\hat{a}_{ij}$ can be solved as

$$\hat{a}_{Lj} = \varepsilon_j\,\hat{E} - \theta_{Ej}\,\sigma_j(\hat{w} - \hat{\tau}), \quad \hat{a}_{Ej} = \varepsilon_j\,\hat{E} + \theta_{Lj}\,\sigma_j(\hat{w} - \hat{\tau}), \quad j = 1, 2.$$

In light of these expressions. (7) and (8) can be rewritten as follows:

$$\lambda_{L1}\,\hat{X}_1 + \lambda_{L2}\,\hat{X}_2 = \delta_L(\hat{w} - \hat{\tau}) - (\lambda_{L1}\,\varepsilon_1 + \lambda_{L2}\,\varepsilon_2)\hat{E}, \tag{11}$$

$$\lambda_{E1}\,\hat{X}_1 + \lambda_{E2}\,\hat{X}_2 = \hat{E} - \delta_E(\hat{w} - \hat{\tau}) - (\lambda_{E1}\,\varepsilon_1 + \lambda_{E2}\,\varepsilon_2)\hat{E}, \tag{12}$$

where $\delta_L \equiv \lambda_{L1}\,\theta_{E1}\,\sigma_1 + \lambda_{L2}\,\theta_{E2}\,\sigma_2$ and $\delta_E \equiv \lambda_{E1}\,\theta_{L1}\,\sigma_1 + \lambda_{E2}\,\theta_{L2}\,\sigma_2$. δ_i can be interpreted as the aggregate percentage saving in factor i ($i = L, E$) at unchanged outputs associated with a 1 percent fall in the relative wage (Jones 1965).

From (9) and (10), it follows that

$$\hat{w} - \hat{\tau} = \frac{\hat{p} + (\varepsilon_2 - \varepsilon_1)\hat{E}}{|\theta|}, \tag{13}$$

where $|\theta| \equiv \theta_{L1}\,\theta_{E2} - \theta_{L2}\,\theta_{E1} = \theta_{E2} - \theta_{E1}$. The relative factor price is affected by the total emission permits via negative impacts of pollution on the productivity of goods. Substituting (13) into (11) and (12) and solving them for $\hat{X}_1$ and $\hat{X}_2$ to get

$$\hat{X}_1 = \frac{1}{|\lambda|}\left[\frac{\lambda_{E2}\,\delta_L + \lambda_{L2}\,\delta_E}{|\theta|}\hat{p} + \left\{-\lambda_{L2} + \frac{(\lambda_{E2}\,\delta_L + \lambda_{L2}\,\delta_E)(\varepsilon_2 - \varepsilon_1)}{|\theta|} - |\lambda|\,\varepsilon_1\right\}\hat{E}\right], \tag{14a}$$

$$\hat{X}_2 = \frac{1}{|\lambda|}\left[-\frac{\lambda_{E1}\,\delta_L + \lambda_{L1}\,\delta_E}{|\theta|}\hat{p} + \left\{\lambda_{L1} - \frac{(\lambda_{E1}\,\delta_L + \lambda_{L1}\,\delta_E)(\varepsilon_2 - \varepsilon_1)}{|\theta|} - |\lambda|\,\varepsilon_2\right\}\hat{E}\right], \tag{14b}$$

where $|\lambda| \equiv \lambda_{L1}\,\lambda_{E2} - \lambda_{E1}\,\lambda_{L2} = \lambda_{E2} - \lambda_{E1}$. The coefficient of $\hat{E}$ in (14) consists of three terms. The first term is the *magnification effect*, i.e., the effect of a change in the total permits on outputs in line with the Rybczynski theorem: a reduction in E increases (decreases) the output of the labor-intensive (pollution-intensive) good. The second stems from a change in the relative factor price, i.e.. the *indirect effect* due to the environmental externality on productivity. The direction of this effect depends on the factor intensity and the pollution elasticity of each sector. The third term is the *direct productivity effect* of pollution: a reduction in E increases outputs of both sectors because of an improvement of the productivity.

From (14). the rate of change of the relative output X_1/X_2 can be derived as follows:

$$\hat{X}_1 - \hat{X}_2 = \frac{\delta_L + \delta_E}{|\lambda|\,|\theta|}\hat{p} + \frac{1}{|\lambda|}\left\{-1 + \left(\frac{\delta_L + \delta_E}{|\theta|} + |\lambda|\right)(\varepsilon_2 - \varepsilon_1)\right\}\hat{E}\,. \tag{15}$$

The coefficient of $\hat{E}$ becomes positive provided that sector 1 (sector 2) is more pollution-intensive, i.e., $|\lambda| < 0$ and $|\theta| < 0$ ($|\lambda| > 0$ and $|\theta| > 0$), *and* $\varepsilon_1 \leq (\geq)\varepsilon_2$. Hence *tighter environmental policy (i.e., a reduction in E) decreases the relative output of the pollution-intensive good if the pollution-intensive sector suffers the productivity loss from pollution not more than the labor-intensive sector.* In such a case, the direct and indirect productivity effects reinforce the magnification effect. If, however, the pollution-intensive sector suffers from pollution more than the labor-intensive sector, the magnification and the productivity effects work in the opposite direction.

2.2. Environmental Policy and Autarky Equilibrium Price

The possibility that tighter environmental policy can increase the relative output of the pollution-intensive good may revise the conventional wisdom on comparative advantage as well. To see this, let us consider the demand side of the economy and derive the autarky equilibrium price. Denote the demand for good j by x_j ($j = 1, 2$). Assuming that the preference of a representative consumer is homothetic in consumption, the relative demand x_1/x_2 is dependent on the relative price p and (possibly) the total emission E:

$$\frac{x_1}{x_2} = f(p, E)\,.$$

The dependence of x_1/x_2 on E reflects the negative externality of pollution on the representative consumer's utility[6]. The rate of change of x_1/x_2 is given by

$$\hat{x}_1 - \hat{x}_2 = -\sigma_d\,\hat{p} - \varepsilon_d\,\hat{E}\,. \tag{16}$$

where

$$\sigma_d \equiv -\frac{\partial \log (x_1/x_2)}{\partial \log p} \quad \text{and} \quad \varepsilon_d \equiv -\frac{\partial \log (x_1/x_2)}{\partial \log E}$$

are the elasticity of substitution between the two goods on the demand side and the pollution elasticity of relative demand, respectively.

In the autarky equilibrium, the relative price p_A is determined so that the relative supply X_1/X_2 and the relative demand x_1/x_2 are equalized. From (15) and (16), it follows that

$$\hat{p}_A = \frac{-\varepsilon_d - \dfrac{1}{|\lambda|}\left\{-1 + \left(\dfrac{\delta_L + \delta_E}{|\theta|} + |\lambda|\right)(\varepsilon_2 - \varepsilon_1)\right\}}{\dfrac{\delta_L + \delta_E}{|\lambda|\,|\theta|} + \sigma_d}\hat{E}\,. \tag{17}$$

It is clear that a tighter environmental policy (reduction in the total permit E) raises the autarky relative price of good 1 if the second term in the numerator of (17) is positive. As discussed in the previous subsection, however, the sign of this term becomes

[6] In Copeland and Taylor (1994, 1995), the utility function is assumed to be additively separable and in Chua (2003), it is multiplicatively separable. In both cases, the relative demand is solely dependent on the relative price.

ambiguous *if the productivity effects are so large that they outweigh the magnification effect.* In such the case, *a country with a tighter environmental regulation may have a comparative advantage in the pollution-intensive good.*

3. A MODEL WITH TWO PRIMARY FACTORS AND POLLUTION

In this section I present an alternative model, with two primary factors of production, labor and capital. I also assume that the negative externality of pollution emerges as a reduction in effective supply of the primary factors, not as a decrease in productivity of each good[7]. Pollutants such as SO_x and NO_x have negative effects on human health (e.g., asthma and bronchial infection) and may reduce the endowment of effective labor. They also react with cloud water to form acid rain, which accelerates the decay of building materials and paints as well as damages on forests and soils. In other words, such pollutants may accelerate depletion of productive capital. These facts would support validity of the present setup.

The economy is characterized by the following system of equations:

$$a_{L1}(w/\tau, r/\tau)\, w + a_{K1}(w/\tau, r/\tau)\, r + a_{E1}(w/\tau, r/\tau)\, \tau = p\,, \tag{18}$$

$$a_{L2}(w/\tau, r/\tau)\, w + a_{K2}(w/\tau, r/\tau)\, r + a_{E2}(w/\tau, r/\tau)\, \tau = 1\,, \tag{19}$$

$$a_{L1}(w/\tau, r/\tau)\, X_1 + a_{L2}(w/\tau, r/\tau)\, X_2 = L(E)\,. \tag{20}$$

$$a_{K1}(w/\tau, r/\tau)\, X_1 + a_{K2}(w/\tau, r/\tau)\, X_2 = K(E)\,, \tag{21}$$

$$a_{E1}(w/\tau, r/\tau)\, X_1 + a_{E2}(w/\tau, r/\tau)\, X_2 = E\,, \tag{22}$$

where a_{Kj} denotes the unit capital requirement in sector j ($j = 1, 2$), r the price of capital and K the capital endowment. The other variables are defined in the same way as in the previous section.

(18) and (19) are zero profit conditions for good 1 and 2, respectively. (20) and (21) are full employment conditions for labor and capital, respectively. As in the previous model, I assume that the environmental policy takes the form of tradable emission permits. Under this assumption, τ is an endogenous variable that depends on E, which is solved from the equilibrium condition for the emission market (22)[8]. Alternatively, environmental policy can take the form of emission taxes. If it is assumed that the government levies tax on emission of pollution, τ is a policy parameter whereas E, the total level of pollution in the economy, is endogenously determined by (22). I will discuss the effect of tighter environmental policy on comparative advantage in the case of emission tax policy later on.

3.1. *Effects of Tighter Environmental Policy*

Totally differentiating the zero profit conditions (18) and (19) and using the cost minimization condition, it follows that

[7] Or equivalently, it can be explained that we assume that the productivity effects of pollution in both sectors are of equal size.

[8] w and r are endogenously determined from (18) and (19) as functions of p and τ, while X_1 and X_2 are solved from (20) and (21).

$$\theta_{L1}\,\hat{w} + \theta_{K1}\,\hat{r} + \theta_{E1}\,\hat{\tau} = \hat{p}\,, \tag{23}$$

$$\theta_{L2}\,\hat{w} + \theta_{K2}\,\hat{r} + \theta_{E2}\,\hat{\tau} = 0\,. \tag{24}$$

Solving (23) and (24) for $\hat{w}$ and $\hat{r}$, I obtain

$$\hat{w} = \frac{\theta_{K2}\,\hat{p} + (\theta_{K1}\,\theta_{E2} - \theta_{E1}\,\theta_{K2})\,\hat{\tau}}{|\theta|}\,, \quad \hat{r} = \frac{-\theta_{L2}\,\hat{p} + (\theta_{E1}\,\theta_{L2} - \theta_{L1}\,\theta_{E2})\hat{\tau}}{|\theta|}\,, \tag{25}$$

where $|\theta|$ is defined here as $|\theta| \equiv \theta_{L1}\,\theta_{K2} - \theta_{K1}\,\theta_{L2}$. (25) states that, for given τ, if good 1 is labor-intensive and good 2 is capital-intensive (i.e., $a_{L1}/a_{K1} > a_{L2}/a_{K2}$), $|\theta| > 0$ holds and hence w is increasing and r is decreasing in τ, respectively, and vice versa.

Totally differentiating the full employment conditions for the primary factors (20) and (21), it follows that

$$\lambda_{L1}\,\hat{X}_1 + \lambda_{L2}\,\hat{X}_2 = -\varepsilon_L\,\hat{E} - \lambda_{L1}\,\hat{a}_{L1} - \lambda_{L2}\,\hat{a}_{L2}\,, \tag{26}$$

$$\lambda_{K1}\,\hat{X}_1 + \lambda_{K2}\,\hat{X}_2 = -\varepsilon_K\,\hat{E} - \lambda_{K1}\,\hat{a}_{K1} - \lambda_{K2}\,\hat{a}_{K2}\,, \tag{27}$$

where $\varepsilon_L \equiv -L'E/L$ and $\varepsilon_K \equiv -K'E/K$ are elasticities of environmental externality on total amounts of labor and capital, respectively, in the economy. I assume for simplicity that the elasticities of substitution between factors of production are equal to unity, implying that the production functions of both sectors are of the Cobb-Douglas type:

$$-\frac{\hat{a}_{Lj} - \hat{a}_{Ej}}{\hat{w} - \hat{\tau}} = -\frac{\hat{a}_{Kj} - \hat{a}_{Ej}}{\hat{r} - \hat{\tau}} = 1\,, \quad j = 1, 2\,.$$

Then, with the condition $\theta_{Lj}\,\hat{a}_{Lj} + \theta_{Kj}\,\hat{a}_{Kj} + \theta_{Ej}\,\hat{a}_{Ej} = 0$, $\hat{a}_{Lj}$ and $\hat{a}_{Kj}$ are solved as follows:

$$\hat{a}_{Lj} = -\left(1 - \theta_{Lj}\right)\left(\hat{w} - \hat{\tau}\right) + \theta_{Kj}\left(\hat{r} - \hat{\tau}\right)\,, \tag{28a}$$

$$\hat{a}_{Kj} = \theta_{Lj}\left(\hat{w} - \hat{\tau}\right) - \left(1 - \theta_{Kj}\right)\left(\hat{r} - \hat{\tau}\right)\,, \tag{28b}$$

for $j = 1, 2$. Solving (26) and (27) for $\hat{X}_1$ and $\hat{X}_2$, it follows that

$$\hat{X}_1 = \frac{(\lambda_{L2}\,\varepsilon_K - \lambda_{K2}\,\varepsilon_L)\,\hat{E} + \lambda_{L2}\left(\lambda_{K1}\,\hat{a}_{K1} + \lambda_{K2}\,\hat{a}_{K2}\right) - \lambda_{K2}\left(\lambda_{L1}\,\hat{a}_{L1} + \lambda_{L2}\,\hat{a}_{L2}\right)}{|\lambda|}\,, \tag{29a}$$

$$\hat{X}_2 = \frac{(\lambda_{K1}\,\varepsilon_L - \lambda_{L1}\,\varepsilon_K)\,\hat{E} + \lambda_{K1}\left(\lambda_{L1}\,\hat{a}_{L1} + \lambda_{L2}\,\hat{a}_{L2}\right) - \lambda_{L1}\left(\lambda_{K1}\,\hat{a}_{K1} + \lambda_{K2}\,\hat{a}_{K2}\right)}{|\lambda|}\,, \tag{29b}$$

where $|\lambda| \equiv \lambda_{L1}\,\lambda_{K2} - \lambda_{K1}\,\lambda_{L2} = \lambda_{L1} - \lambda_{K1}$. Then, with (25) and (28), the rate of change in the relative output X_1/X_2 for given τ can be derived as follows:

$$\hat{X}_1 - \hat{X}_2 = \frac{\varepsilon_K - \varepsilon_L}{|\lambda|}\hat{E} + \frac{\theta_{E2} - \theta_{E1}}{|\lambda|\,|\theta|}\hat{\tau} + \frac{\{1 + (\lambda_{K1} - \lambda_{L1})\,\theta_{L1}\}\,\theta_{K2} + \{1 + (\lambda_{L1} - \lambda_{K1})\,\theta_{K1}\}\,\theta_{L2}}{|\lambda|\,|\theta|}\hat{p}\,. \tag{30}$$

To close the model, we must take into account the equilibrium condition for the market of emission permits (22). Totally differentiating (22) and substituting (25), (28) and (29) into them, the relationship between the total supply of permits E and the permit price τ can be derived as

$$\frac{\Phi}{|\lambda|\,|\theta|}\hat{\tau} = \left\{1 - \frac{(\lambda_{E1}-\lambda_{L1})\,\varepsilon_K - (\lambda_{E1}-\lambda_{K1})\,\varepsilon_L}{|\lambda|}\right\}\hat{E} - \frac{(\lambda_{E1}-\lambda_{K1})\,\theta_{K2} + (\lambda_{E1}-\lambda_{L1})\,\theta_{L2}}{|\lambda|\,|\theta|}\hat{p}\,, \tag{31}$$

where

$$\Phi \equiv (\lambda_{E1}-\lambda_{K1})\,(\theta_{K1}\,\theta_{E2}-\theta_{E1}\,\theta_{K2}) + (\lambda_{L1}-\lambda_{E1})\,(\theta_{E1}\,\theta_{L2}-\theta_{L1}\,\theta_{E2}) + (\lambda_{K1}-\lambda_{L1})\,(\theta_{L1}\,\theta_{K2}-\theta_{K1}\,\theta_{L2})$$

is negative[9]. Substituting (31) into (30), the percentage change in the relative output X_1/X_2 can be obtained as follows:

$$\hat{X}_1 - \hat{X}_2 = \left[\frac{\varepsilon_K-\varepsilon_L}{|\lambda|} + \frac{\theta_{E2}-\theta_{E1}}{\Phi}\left\{1 - \frac{(\lambda_{E1}-\lambda_{L1})\,\varepsilon_K - (\lambda_{E1}-\lambda_{K1})\,\varepsilon_L}{|\lambda|}\right\}\right]\hat{E} + \frac{\Psi}{|\lambda|\,|\theta|}\hat{p}\,, \tag{32}$$

where

$$\Psi \equiv \{1+(\lambda_{K1}-\lambda_{L1})\,\theta_{L1}\}\,\theta_{K2} + \{1+(\lambda_{L1}-\lambda_{K1})\,\theta_{K1}\}\,\theta_{L2} - \frac{\theta_{E2}-\theta_{E1}}{\Phi}\{(\lambda_{E1}-\lambda_{K1})\,\theta_{K2} + (\lambda_{E1}-\lambda_{L1})\,\theta_{L2}\}\,.$$

The coefficient of $\hat{E}$ consists of terms that present three effects. The first term in the square bracket, $(\varepsilon_K-\varepsilon_L)/|\lambda|$, is the *direct externality effect*: a change in the total level of pollution affects the endowment of labor and/or capital and hence the output of each good. The second term can be further decomposed into two effects. The first one, $(\theta_{E2}-\theta_{E1})/\Phi$, is the *endowment effect*, which corresponds to the magnification effect in the model with one primary factor. The second one, $-\{(\theta_{E2}-\theta_{E1})/\Phi\}\cdot\{(\lambda_{E1}-\lambda_{L1})\,\varepsilon_K-(\lambda_{E1}-\lambda_{K1})\,\varepsilon_L\}/|\lambda|$, refers to the *indirect externality effect*, which stems from a change in factor prices.

In the absence of externality effects (i.e., $\varepsilon_K=\varepsilon_L=0$), the coefficient of $\hat{E}$ in (32) is reduced to $(\theta_{E2}-\theta_{E1})/\Phi$. We can say that *sector 1 is more (less) pollution-intensive than sector 2* if $\theta_{E1}>\theta_{E2}$ ($\theta_{E1}<\theta_{E2}$) holds. This definition of pollution intensity can be justified by the following grounds. First, in a substantial number of empirical studies, pollution-intensive sectors are identified as those which have incurred high levels of abatement expenditure per unit of output in the US and other OECD economies (e.g.,

[9] For $h, i = L, K, E, h \neq i$, it holds that

$$\text{sign}\,(\lambda_{h1}-\lambda_{i1}) = \text{sign}\,(\lambda_{h1}\lambda_{i2}-\lambda_{i1}\lambda_{h2}) = \text{sign}\,(\theta_{h1}\theta_{i2}-\theta_{i1}\theta_{h2})\,.$$

Robison 1988; Tobey 1990; Low and Yeats 1992)[10]. Second, when we regard the emission of pollution as a factor of production as well as labor and capital, the pollution intensity should be identified from the viewpoint of each primary factor. In other words, good 1 (good 2) is said to be pollution-intensive "in terms of labor" relative to good 2 (good 1) if $a_{E1}/a_{L1} > (<) a_{E2}/a_{L2}$ and analogously, it is said to be pollution-intensive "in terms of capital" relative to good 2 (good 1) if $a_{E1}/a_{K1} > (<) a_{E2}/a_{K2}$. However, since

$$\theta_{E2} - \theta_{E1} = (\theta_{E2}\theta_{L1} - \theta_{E1}\theta_{L2}) + (\theta_{E2}\theta_{K1} - \theta_{E1}\theta_{K2}) ,$$

$\theta_{E1} > \theta_{E2}$ holds if sector 1 is pollution intensive in terms of both labor and capital. Therefore it is reasonable to distinguish the pollution intensity by comparing the share of pollution permits (construed as pollution abatement cost) θ_{Ej}. Based on this definition of pollution intensity, it follows that *a tighter environmental policy reduces the relative output of the pollution-intensive good if there are no externality effects on the supply of primary factors.*

Next consider the situation in which the externality effects of pollution on factor endowments are present. Suppose that sector 1 is capital-intensive (i.e., $|\lambda| < 0$). In addition, it is normally assumed that dirty goods are capital-intensive (see, e.g., Antweiler et al. 2001) and hence suppose sector 1 is also pollution-intensive (i.e., $\theta_{E1} > \theta_{E2}$). Then, the coefficient of $\hat{E}$ in (32) is positive if $\varepsilon_K < \varepsilon_L$ holds. In other words, *if the labor supply is more severely damaged by pollution than the capital supply, tighter environmental policy (reduction in E) unambiguously reduces the relative output of the capital-intensive, dirty good.* This is because the direct and indirect externality effects reinforce the endowment effect of a change in the supply of emission permits. If, however, the negative externality of pollution on the capital endowment is larger (in the elasticity form) than on the labor endowment, the externality effects and the endowment effect work in the opposite direction and hence the sign of $\hat{E}$ becomes ambiguous. Hence tighter environmental regulation may increase the relative output of the pollution-intensive good.

The autarky equilibrium condition $X_1/X_2 = x_1/x_2$ determines the equilibrium relative price, p_A. In light of (16) and (32), the rate of change in p_A is derived as follows:

$$\hat{p}_A = \frac{-\varepsilon_d - \left[\dfrac{\varepsilon_K - \varepsilon_L}{|\lambda|} + \dfrac{\theta_{E2} - \theta_{E1}}{\Phi}\left\{1 - \dfrac{(\lambda_{E1} - \lambda_{L1})\varepsilon_K - (\lambda_{E1} - \lambda_{K1})\varepsilon_L}{|\lambda|}\right\}\right]}{\dfrac{\Psi}{|\lambda|\,|\theta|} + \sigma_d}\hat{E} . \tag{33}$$

The autarky equilibrium is locally stable if $\Psi/(|\lambda|\,|\theta|) + \sigma_d > 0$. Assuming this condition holds, the relative equilibrium price of good 1 is negatively related to the total

[10] Some studies (e.g., Lucas et al. 1992) employ an alternative definition of the pollution intensity, based on emission levels per unit of output. Yet, despite variations in definitions, almost the same industries (pulp and paper, mining, iron and steel, primary nonferrous metals, and chemicals) are picked up as the pollution-intensive ones.

emission permits if the sign of the square bracket in (33) is positive. As discussed above, even if good 1 is a capital-intensive, dirty good, the sign is not always positive when $\varepsilon_K > \varepsilon_L$. In particular, the sign may be negative if in addition ε_d is close to zero[11] and the externality effects induced by environmental policy outweigh the endowment effect which is in line with the factor and pollution intensities. In other words, *a tighter environmental policy may result in comparative advantage in capital intensive, dirty goods if the effect of pollution on the relative demand is negligible, the capital supply is more severely damaged by pollution than the labor supply and the externality effects induced by environmental policy outweigh the endowment effect.*

3.2. *Choice of Policy Instruments*

It has been assumed so far in this paper that the government regulates the total level of emissions and makes firms trade the emission permits. However, except for a few studies (e.g., Copeland and Taylor 1995), existing models on trade and the environment have assumed pollution taxes rather than emission permits as environmental policy instruments. I would like to briefly discuss the relationships between environmental policy and comparative advantage for the case of emission tax.

The equilibrium relationship between the total emissions E and the payment of each firm for one unit of emission τ is given by (31). The coefficient of $\hat{E}$ in (31) consists of two terms. If there is no externality effect of pollution on the factor endowments ($\varepsilon_L = \varepsilon_K = 0$), the second term is deleted and hence the coefficient is reduced to 1, implying a negative relationship between E and τ. Even if the externality effects on the factor endowments are present and it works against the endowment effect, we can say that E and τ are negatively related as long as the indirect externality effect does not outweigh the endowment effect. In these cases, the analysis on the effect of tighter pollution permits policy (reduction in E) applies to that of tighter pollution tax policy (increase in τ).

4. CONCLUDING REMARKS

Using a two-good general equilibrium framework in which the emission of pollution is modeled as the input for production and the negative externality effects of pollution are present in the production side of the economy, this paper has discussed that tighter environmental regulations do not necessarily lead to a comparative disadvantage in pollution-intensive goods. This finding is contrary to the prevalent notion adopted in most of the theoretical works in trade and the environment. To show the possibilities of such the paradoxical result, I developed two models. In the first model, in which the productivity of each good is damaged by pollution, the paradox may arise under the assumption that the negative productivity effect of pollution is larger in the pollution-intensive sector. In the second model, in which the pollution affects the total supply of

[11] This assumption does not mean that the representative consumer's utility is barely independent on the level of pollution. See footnote 6.

primary factors, stringent environmental regulation may result in comparative advantage in the pollution-intensive good when the total supply of capital is more severely damaged than that of labor and the pollution-intensive sector is also capital-intensive.

It is an empirical question whether or not the above conditions are met since they depend on the production structure in each sector. As far as I know, there are few econometric models on trade and the environment but, e.g., López (1997) that allow for the environmental externality on productivity. Further empirical researches incorporating the richer elements of the production side would clarify why and how the theory and the evidence diverge.

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