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Pollution Abatement Equipments, Environmental Policies, and International Trade

by

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1. Introduction

In recent years, the environmental industry which supplies environmental goods and services attracts lots of attention. The global market of the industry is estimated to have the scale of about US$300 billion in 2000, and then is growing at 5.5% per year.[1] Environmental goods and services including pollution abatement equipments contribute pollution control and reduction, and natural resource conservation. The expansion of the environmental industry through international trade may contribute to the higher quality of environment in the world.

There are some theoretical papers which deal with the environmental industry under international trade.[2] In this standpoint, our work is related to Merrifield (1988), Copeland (1991), Chua (2003), and Sugiyama (2003), which incorporate the environmental industry that supplies the pollution abatement equipment or service. Merrifield (1988) analyzes the effects of equipment standards on trade of final goods and international capital movements. Copeland (1991) analyzes international trade of waste disposal services. Chua (2003) examines the effect of an emission tax on patterns of comparative advantage in three sector model including an abatement service industry, where the abatement service is a non-traded good. Sugiyama (2003) supposes two sectors which consist of sectors producing a final good and a pollution abatement equipment, and examines the effects of an emission tax and a subsidy to the purchase of the equipment.

International trade of pollution abatement equipments, however, has not incorporated in those papers. Merrifield (1988) assumes that pollution decreases the productivity of capital in the final

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[1] See OECD (1996, 2001) for detailed data with respect to the environmental industry.

[2] There are many theoretical studies on trade and the environment. See Rauscher (1997) and Copeland and Taylor (2003) for general discussion of this subject.

good's sector and the abatement equipment is not traded. In addition, Copeland (1991) and Sugiyama (2003) consider the traded abatement equipment or service under a small open economy.

The purpose of this paper is to investigate the formation of comparative advantages in the context of pollution abatement equipment and to examine the effects of environmental policies under the tradable pollution abatement equipment. The markets of pollution abatement equipments and services will grow in years to come, and then the prevalence of such goods and services through international trade may affect the quality of environment. We will set up a two country model with a final good and a pollution abatement equipment, and will consider a emission tax and a subsidy to purchase of the pollution abatement equipment as environmental policies.

The main results of our paper are as follows. First, the subsidy the subsidy to purchase the abatement equipment can be a substitute for the emission tax. That is, the government can impose the lower emission tax by raising the subsidy in order to achieve the first best allocation. Second, a raise in the emission tax decreases the relative price of the pollution abatement equipment while a raise in the subsidy to the purchase of the equipment increases the relative price. Hence, ceteris paribus, the country with a higher emission tax or a lower subsidy to the equipment purchase has a comparative advantage in the pollution abatement equipment. Third, the effects of the emission tax in one country on the amount of pollution and welfare depends on the specialization pattern under free trade.

The rest of the paper is organized as follows. In Section 2, we set up the basic framework of the model. Section 3 examines the effects of an emission tax and a subsidy to the pollution abatement equipment in autarky. In Section 4, we explore the structure of comparative advantage based on the international differences in the environmental policies, and the effects of these policies in international trade between two countries. Finally, Section 5 gives some concluding remarks.

2. Technology and Emission

There are two countries: H and F. Both countries can produce one final good and one pollution abatement equipment. For simplicity, we assume that technologies are identical between the two countries.

One final good is produced by using labor, and the production function in country i is given by

$$X^i = (1/a_X)L_X^i, \quad (1)$$

where X^i and L_X^i are the output of the final good and the input of labor for the final good production in country i respectively, and a_X is the unit labor requirement of the final good in both countries.

Production of the final good emits pollution. The total emission depends on the output of the final good and the input of an equipment to reduce pollution. The emission function is written as

$$E^i = h(X^i, M_D^i), \quad (2)$$

where E^i and M_D^i are the emission level and the amount of the pollution abatement equipment used in country i respectively. The emission function is increasing in X^i and decreasing in M_D^i, since more production of the final good generates more pollution but it can be alleviated by installing the pollution abatement equipment. We also assume that that the emission function is linearly homogeneous and $\partial^2 h/(\partial M_D^i)^2 > 0$. We assume that pollution is locally spread and there is no transnational pollution. Pollution generates disutility to the domestic consumers, and has no effect on the productivities of the goods.

The pollution abatement equipment is also produced only by use of labor. Its production function is given by

$$M_S^i = (1/a_M)L_M^i, \quad (3)$$

where M_S^i and L_M^i are the output of the pollution abatement equipment and the labor used for its production in country i respectively, and a_M is the unit labor requirement of the equipment in both countries.

The final good and the pollution abatement equipment are traded in perfectly competitive markets. However, no producer would demand or purchase the pollution abatement equipment if it were free to emit pollution. We assume, therefore, that a government of each country may impose an emission tax. We introduce a subsidy to purchase of the pollution abatement equipment as an environmental policy.[3] Suppose that the emission tax is $t^i \geq 0$, the subsidy rate is $s^i < 1$, and the price of the pollution abatement equipment is p^i in country i. Producers of the final good minimize the unit cost of emission tax payment and purchase of the pollution abatement equipment. So we can define the unit cost of the emission tax and the equipment in country i as

$$c(t^i, q^i) \equiv \min_{e^i, m^i} \left\{ t^i e^i + q^i m^i \,\middle|\, e^i = h(1, m^i) \right\}, \tag{4}$$

where $e^i \equiv E^i / X^i$, $m^i \equiv M_D^i / X^i$, and $q^i \equiv (1 - s^i) p^i$ is the demand price of the pollution abatement equipment in country i. This unit cost function is linearly homogeneous and concave in t^i and q^i. We assume that it is differentiable and the Shephard's lemma holds.

There are L^i identical consumers in country i, and each consumer owns one unit of labor. Welfare in each country is defined by a representative consumer's utility. The utility function is assumed to be identical in both countries, and is expressed as

$$u^i = u(y^i, E^i) \tag{5}$$

where u^i and y^i are the utility level and the consumption of the final good of a representative consumer in country i. Since the pollution is local, the domestic pollution affects the utility. We assume that $u_y^i \equiv \partial u(y^i, E^i) / \partial y^i > 0$ and $u_E^i \equiv \partial u(y^i, E^i) / \partial E^i < 0$.

3. Autarky

[3] This is not a production subsidy to the firms producing the pollution abatement equipment.

In this section, we will describe the autarkic equilibrium in each country and examine the effects of emission tax and the subsidy to the pollution abatement equipment.

3.1. The Equilibrium Conditions

All producers maximize their profit under the perfectly competitive markets. The final good is chosen as a numeraire, and its price is assumed to be 1. The profit conditions for the final good and the equipment to be produced in country i are

$$w^i a_X + c(t^i, q^i) = 1, \tag{6}$$

$$w^i a_M = p^i, \tag{7}$$

where w^i is the wage rate in country i.

Demand for labor arises from production of the final good and the pollution abatement equipment. We assume that the total supply of labor is fixed and labor is fully employed. The full-employment condition is

$$a_X X^i + a_M M_S^i = L^i. \tag{8}$$

Using the Shephard's lemma, we can derive the demand for the pollution abatement equipment.

$$c_q(t^i, q^i) X^i = M_D^i, \tag{9}$$

where $c_q(t^i, q^i) \equiv \partial c(t^i, q^i) / \partial q^i$ shows the demand for the pollution equipment per unit of the final good. The market clearing condition for the abatement equipment is

$$M_D^i = M_S^i \tag{10}$$

Each consumer receives labor income as well as a lump-sum transfer from the government. The government distributes its net revenue equally to the consumers. Then, a representative consumer's consumption of the final good in country i is

$$y^i = X^i / L^i . \tag{11}$$

Equations (5) to (11), together with (2), indicate the autarkic equilibrium conditions in country i. There are seven endogenous variables: w^i, p^i, X^i, M_D^i, M_S^i, E^i, y^i, and u^i. The set of the equations gives the solution for these variables, given t^i, s^i and the other exogenous variables.

3.2. The Relative Demand and Supply for the Abatement Equipment

First we will show how the price of the pollution abatement equipment is determined in autarky. Let us define

$$\theta(p^i;t^i,s^i) \equiv \{1-c(t^i,q^i)\}/p^i$$

for $t^i \geq 0$. Function $\theta(p^i;t^i,s^i)$ has the following properties for $t^i > 0$:

$$\theta_p^i \equiv \partial\theta/\partial p^i = -\{c_q^i q^i + w^i a_X\}/(p^i)^2 < 0,$$

$$\theta_t^i \equiv \partial\theta/\partial t^i = -c_t^i / p^i < 0,$$

$$\theta_s^i \equiv \partial\theta/\partial s^i = c_q^i > 0,$$

where $c_q^i \equiv c_q(t^i,q^i)$ and $c_t^i \equiv c_t(t^i,q^i)$. We also have $\theta(p^i;0,s^i) = 1/p^i$ since $c(0,s^i) = 0$. Let us define $\bar{p}^i \equiv \bar{p}(t^i,s^i)$ as the relative price of the abatement equipment satisfying

$$\theta(\bar{p}^i;t^i,s^i) = a_X / a_M . \tag{12}$$

Full-employment of labor (8) implies that either the final good or the abatement equipment must be produced by a positive amount. Then, using (6) and (7), we can easily show that in country i (i) the abatement equipment is not produced if $p^i < \bar{p}^i$, (ii) any combination of the final good and the abatement equipment satisfying (7) can be produced if $p^i = \overline{p}^i$, (iii) the final good is not produced $p^i > \overline{p}^i$. Thus, $\overline{p}^i \equiv \overline{p}(t^i, s^i)$ indicates *the relative supply price* of the abatement equipment when both goods are positively produced in country i. In Figure 1 RS^i shows the relative supply curve of the abatement equipment in country i. If $p^i < \overline{p}^i$, the relative supply of the abatement equipment is equal to zero. On the other hand, if $p^i > \overline{p}^i$, its relative supply becomes infinity.

Relative demand function for the abatement equipment can be obtained from the unit cost function (4). Using the Shephard's lemma, we have

$$c_q(t^i, q^i) = m^i. \tag{13}$$

Noticing that $c_{qq}^i \equiv \partial^2 c(t^i, q^i)/(\partial q^i)^2 < 0$, we can draw the *relative demand curve* with a downward slope like RD^i in Figure 1. If $t^i = 0$, the relative demand curve is identical to the vertical axis.

The intersection of the relative supply and demand curves gives a autarkic equilibrium, E^i. In autarky, the relative price of the abatement equipment is determined by the relative supply price. That is, equation (12) determines the equilibrium relative price in autarky. If $t^i = 0$, we have $\overline{p}^i = a_M / a_X$ and any relative price lower than $\overline{p}^i$ can be an equilibrium price.

3.3. The Effects of Environmental Policies

We can derive the effects of the environmental policies on the relative price of the pollution abatement equipment by differentiating (12). We obtain

$$d\overline{p}^i / dt^i = -\theta_t^i / \theta_p^i = c_t^i / \theta_p^i p^i < 0, \tag{14}$$

$$d\overline{p}^i / ds^i = -\theta_s^i / \theta_p^i = -c_p^i / \theta_p^i > 0. \tag{15}$$

A raise in the emission tax reduces the relative price of the pollution abatement equipment while a raise in the subsidy increases its relative price. The emission tax increases the unit cost of the final good, so the relative price of the equipment must be lower for the final good to be produced. On the other hand, the subsidy to purchase of the pollution abatement equipment reduces the unit cost of the final good, so the relative price of equipment should be higher for the unit cost to be balanced to the price.

The effects of the two environmental policies on the relative demand for the abatement equipment are derived from differentiating (13) and using (14) and (15).

$$dm^i / dt^i = c^i_{qt} + (1-s^i)c^i_{qq}(d\overline{p}^i / dt^i) = c^i_{qt} /(c^i_q \overline{q}^i + w^i a_X) > 0 , \quad (16)$$

$$dm^i / ds^i = -\overline{p}^i c^i_{qq} + (1-s^i)c^i_{qq}(d\overline{p}^i / dt^i) = -w^i a_X \, \overline{p}^i c^i_{qq} /(c^i_q \overline{q}^i + w^i a_X) > 0 , \quad (17)$$

where $c^i_{qt} \equiv \partial^2 c(t^i, q^i) / \partial t^i \partial q^i > 0$ and $\overline{q}^i = (1-s^i)\overline{p}^i$. Both policies increase the relative demand for the abatement equipment to the final good although they have an opposite effect on the relative price of the abatement equipment. In the case of the subsidy to the purchase of equipment, the relative price increase gives a negative effect on the relative demand for the abatement equipment. But the direct effect of the subsidy outweighs this price effect.

Suppose that E^i_0 is the initial equilibrium in Figure 1. A raise in the emission tax or the subsidy makes the relative demand curve shift to the right like RD^i_1. By this demand effect, both polices would increase the relative supply for the abatement equipment, and the equilibrium moves from E^i_0 to F. In addition to this effect, the emission tax lowers the relative supply price of the equipment, and increases the relative demand for it. So the equilibrium moves further from F to E^i_t. On the other hand, the subsidy to the purchase of the equipment increases the relative supply price and decreases the relative demand for it. Thus, by this supply effect, the equilibrium moves from F to E^i_s. But the former effect is larger than the later effect, and the relative supply of the abatement equipment increases by the subsidy, too.

We can confirm these results of the comparative statics from the fact that the relative demand for the equipment depends on the relative price of the emission to the abatement equipment. Equation (13) can be written as $c_q(\tau^i, 1) = m^i$ where $\tau^i \equiv t^i / q^i$ from the homogeneity of the unit cost function.

Only τ^i affects the relative demand for the abatement equipment. Noticing that $c_{qt}(\tau^i,1) = q^i c_{qt}(t^i,q^i)$, we have

$$d\tau^i / d\gamma^i = (1/c_{qt}^i q^i)(dm^i / d\gamma^i), \tag{18}$$

where $\gamma = t$ and s. Since c_{qt}^i is positive, a rise in τ^i increases m^i. Using (14) and (15), we obtain

$$d\tau^i / dt^i = 1/\bar{q}^i(\bar{q}^i c_q^i + w^i a_X), \tag{19}$$

$$d\tau^i / ds^i = t^i w^i a_X /(1-s^i)\bar{q}^i(\bar{q}^i c_q^i + w^i a_X) > 0. \tag{20}$$

Therefore, both environmental policies increase the relative price of the emission to the abatement equipment, and make the final good producer use more abatement equipment and reduce the emission by a substitution effect.

Now substituting (9) and (10) into (8), we obtain

$$\{a_X + a_M c_q(\tau^i,1)\}X^i = L^i. \tag{21}$$

Differentiating (21), we have

$$dX^i / d\gamma^i = -\{a_X X^i \bar{q}^i c_{qt}^i /(a_X + a_M c_q^i)\}(d\tau^i / d\gamma^i) < 0, \tag{22}$$

where the sing of $d\tau^i / d\gamma^i$ is given by (19) or (20). Therefore, both environmental policies decrease the output of the final good and in turn increase the supply of the abatement equipment.

The emission in country i depends the output of the final good and the demand for the abatement equipment. But the demand for the abatement equipment must be equal to its supply, and it is expressed in term of the output of the final good by using the full-employment of labor. Differentiating (2) and utilizing the cost minimization and the full-employment conditions, we obtain

$$dE^i = (1/t^i)\{c^i + q^i(a_X / a_M)\}dX^i, \tag{23}$$

where $c^i \equiv c(t^i, q^i)$. Together with (22), we can conclude that both environmental policies decreases the total output of emission.

Finally, we derive the effects of these policies on welfare. Differentiating the representative consumer's utility function, we obtain

$$du^i = \alpha^i [t^i / \{s^i c^i + (1 - s^i)\} - L^i (-u_E^i / u_y^i)] dX^i , \qquad (24)$$

where $\alpha^i \equiv u_y^i \{s^i c^i + (1 - s^i)\} / t^i L^i > 0$. Since both environmental policies decreases the output of the final good, a raise in the emission tax or the subsidy to the abatement equipment purchase increases (decreases) welfare if $t^i / \{s^i c^i + (1 - s^i)\} < (>) L^i (-u_E^i / u_y^i)$. The term $L^i (-u_E^i / u_y^i)$ is the sum of the marginal rate of substitution between the final good and the emission, and indicates the amount of the final good that must be compensated for a unit increase in the emission to keep the utility constant. In other words, it shows the social marginal cost of the emission.

We can derive the optimal tax or subsidy rule from (24):

$$t^i / \{s^i c^i + (1 - s^i)\} = L^i (-u_E^i / u_y^i) . \qquad (25)$$

If $s^i = 0$, the optimal emission tax must be the social marginal cost of the economy. Since $0 \le c^i < 1$, the value of the denominator must be between 0 and 1 if $s^i > 0$. Thus, the optimal emission tax should be lower if there is a positive subsidy to the equipment purchase. Notice that the emission tax must be positive for (25) must be satisfied, but the subsidy to the equipment purchase can be zero or positive.

We can also show that the optimal tax or subsidy rule shown by (25) leads the economy the first best allocation. Maximizing the representative consumer's utility, taking into consideration the production functions and the resource constraint, we obtain the first order condition for the first best allocation.

$$1 / \{h_X^i - (a_X / a_M) h_M^i\} = L^i (-u_E^i / u_y^i) \qquad (26)$$

The left hand side of (26) shows an increase in the final good production due to a unit increase in the emission, which indicates the social marginal benefit of the emission. Thus, equation (26) states that the social marginal benefit of the emission must be equalized to the sum of the each consumer's marginal benefit. It is basically the standard Samuelson rule for a public bad. If the producers maximize their profits under the competitive markets, we obtain

$$t^i / \{s^i c^i + (1-s^i)\} = 1/\{h_X^i - (a_X / a_M) h_M^i\} . \qquad (27)$$

Combining (25), (26), and (27), we have equation (26). It implies that we can attain the first best resource allocation by the optimal tax or subsidy rule under a competitive economy.

There are infinite number of the combination of t^i and s^i satisfying (25). The relationship between t^i and s^i satisfying (25) can be derived from the second order conditions for welfare maximization. Let us define $g(t^i, s^i) \equiv L^i(-u_E^i / u_y^i) - t^i / \{s^i c^i + (1-s^i)\}$ so that (25) is identical to $g(t^i, s^i) = 0$. Since t^i and s^i reduce the emission, the second order conditions for welfare maximization are $\partial g / \partial t^i \equiv g_t^i < 0$ and $\partial g / \partial s^i \equiv g_s^i < 0$. Then, totally differentiating (25), we have $ds^i / dt^i = -g_t^i / g_s^i < 0$. As long as the emission tax is positive, we can have the lower emission tax by raising the subsidy to the purchase of the abatement equipment to attain the first best allocation.

Summarizing the above discussion, we have

Proposition 1. *The emission tax or the subsidy to purchase of the pollution abatement equipment has the following effects in autarky.*

(i) *A raise in the emission tax decreases the relative price of the pollution abatement equipment while the raise in the subsidy to purchase of the abatement equipment increases its relative price.*

(ii) *A raise in the emission tax or the subsidy to purchase of the pollution abatement equipment increases the output of the abatement equipment, and reduces the output of the final good and the emission as well.*

(iii) *A raise in the emission tax or the subsidy to purchase of the pollution abatement equipment increases the welfare of the economy if* $t^i/\{s^i c^i + (1-s^i)\}$ *is lower than the sum of the marginal rate of substitution between the final good and the emission.*

(iv) *The first best resource allocation can be attained by the optimal tax or subsidy rule* (25).

4. International Trade

In this section we will examine the structure of comparative advantages and the effects of the environmental policies under international trade.

4.1. The Structure of Comparative Advantages

The final good and the pollution abatement equipment can be traded when both countries engage in international trade. There are some factors which affect the trade patterns. The standard Ricardo model focuses on the international differences in technologies as a determinant of trade structure. In this paper, on the other hand, we focus on the international differences in environmental policies, so we assume that the production technologies are identical in both countries.

The autarkic relative price of these goods determines the structure of comparative advantage. Each country will export the good whose autarkic relative price is lower than in the other country. As is shown in (12), the autarkic relative price depends on t^i and s^i.

We assume tentatively that $t^i > 0$ so that there is a positive demand for the pollution abatement equipment. Suppose that country H has the lower emission tax than country F but the two countries imposes the same level of subsidy to purchase of the pollution abatement equipment. Then, Proposition 1(i), or (14), implies that the autarkic relative price of the abatement equipment is higher in country H than in country F. In Figure 2, curves θ^H and θ^F indicate functions $\theta^H(p^H; t^H, s)$ and $\theta^F(p^F; t^F, s)$ respectively where s is the common subsidy rate to the equipment purchase in both countries. From the property of the function, curve θ^F must be drawn to the left of curve θ^H.

The autarkic relative price is p^{HA} in country H, which is higher than p^{FA} in country F. Therefore, country H has a comparative advantage in the final good, and country F has a comparative advantage in the pollution abatement equipment.

The international differences in the subsidy rate to the equipment purchase also affect the structure of comparative advantages. Its subsidy has an opposite effect on the value of θ, so the country with a higher subsidy rate will have a comparative advantage in the final good. Thus , we have

Proposition 2. *Suppose that both countries have identical technologies and the emission tax is positive.*

(i) *The country with a lower emission tax has a comparative advantage in the final good and the other country has a comparative advantage in the pollution abatement equipment if the subsidy rate to the purchase of the abatement equipment is the same in both countries.*

(ii) *The country with a higher subsidy rate to the purchase of the abatement equipment has a comparative advantage in the final good and the other country has a comparative advantage in the pollution abatement equipment if the emission tax is the same in both countries.*

4.2. The Trade Equilibrium

Let us consider the case where the source of comparative advantages stems only from the international differences in the emission tax. For simplicity, we assume that both countries give the same rate subsidy to the equipment purchase. Suppose that country H has a lower emission tax than country F, and has a comparative advantage in the final good production. Since we assume that $t^H < t^F$, we must have $\overline{p}^H > \overline{p}^F$. If country H increases the emission tax, given the emission tax in country F, $\overline{p}^H$ decreases and approaches to $\overline{p}^F$. The equilibrium relative price under free trade, p^T, should be between $\overline{p}^F$ and $\overline{p}^H$.

The equilibrium relative price under international trade must be such that the demand and supply is equalized at the world market. That is,

$$M_D^H + M_D^F = M_S^H + M_S^F \tag{28}$$

The equilibrium can be also expressed by using the relative demand and supply for the abatement equipment. Its relative demand, m, is defined as

$$m \equiv \{c_q(t^H, q)X^H + c_q(t^F, q)X^F\}/(X^H + X^F), \tag{29}$$

where $q = (1-s)p$ and $X^i \equiv L^i / \{c_q(t^i, q)a_M + a_X\}$. Then, we obtain the properties of the relative demand function.

$$\partial m / \partial p = X^{-2}[(c_{qq}^H X^H + c_{qq}^F X^F)X - M_D\{(\partial X^H / \partial p) + (\partial X^F / \partial p)\}] < 0, \tag{30}$$

$$\partial m / \partial t^H = X^{-2}\{c_{qt}^H X^H X - M_D(\partial X^H / \partial t^H)\} > 0, \tag{31}$$

where $X \equiv X^H + X^F$ and $M_D \equiv M_D^H + M_D^F$. Since $\partial X^i / \partial p = -(1-s)a_M (X^i)^2 c_{qq}^i / L^i > 0$ and $\partial X^i / \partial t^i = -a_M (X^i)^2 c_{qt}^i / L^i < 0$. Therefore, the relative demand curve has a downward slope. As the emission tax in country H is raised, it shifts to the right like RD_0, RD_1 and RD_2 in Figure 3

We must also notice that there are three possible specialization patterns. If $p = \overline{p}^F$, country H completely specializes in the final good production but country F produces both goods. If $\overline{p}^F < p < \overline{p}^H$, country H completely specializes in the final good and country F completely specializes in the abatement equipment. If $p = \overline{p}^H$, country H produces both goods but country F completely specializes in the abatement equipment. The relative supply curve of the equipment in the world market, RS_j, is drawn in Figure 2. If $t^H = 0$, $\overline{p}^H = a_M / a_X$. The value of $\overline{p}^H$ becomes smaller as t^H increases. So the relative supply curve shifts down like RS_0, RS_1 and RS_2 in Figure 3 as the emission tax in country H increases.

If t^H is small, the equilibrium relative price will be $\overline{p}^F$ under free trade. For example, if $t^H = 0$, there is no demand for the abatement equipment in country H and no actual trade will occur. The abatement equipment is not used in country H. It is produced and purchased domestically in country F. The relative demand curve in this case is shown by a curve like RD_0, and the trade equilibrium is shown by point A in Figure 3. As long as the demand for the equipment in country H is so small that country F can export the abatement equipment at $\overline{p}^F$, country F produces both good. Let us call this situation Case *I*.

When t^H becomes higher, the relative demand for the abatement equipment increases so that country F completely specializes in the production of the abatement equipment. Let us call this situation Case *II*. For example, if the relative demand curve is RD_1 and the relative supply curve is RS_1 in Figure 3, the trade equilibrium is shown by point B where country H completely specializes in the final good and country F completely specializes in the abatement equipment.

The emission tax in country H may become so high that the amount of the abatement equipment produces in country F cannot satisfy its total demand. Then, country H produces the abatement equipment as well as the final good. Let us call this situation Case *III*. This case will happen when the relative demand curve is RD_2 and the relative supply curve is RS_2 in figure 3. The trade equilibrium is shown by point C.

Irrespective of what specialization pattern occurs at the trade equilibrium, the amount of final good consumption must satisfy a trade balance condition but is not constrained by the domestic supply of the final good. The trade balance condition is

$$y^i L^i - X^i = p(M_S^i - M_D^i). \qquad (32)$$

The consumption level under international trade will be determined by (32) while it is determined by (11) in autarky.

4.3. The Effects of Emission Tax under International Trade

Let us first consider the effect of the environmental policies in Case *I*. Since country H completely specializes in the final good, all amount of labor is used in the final good production. Thus, we have $X^H = L^H / a_X$, which is constant. The abatement equipment is imported from country F, and its amount is $M_D^H = c_q(t^H, \bar{q}^H)(L^H / a_X)$. Since the emission tax increases the purchase of the abatement equipment and the output of the final good is constant, the emission tax in country H reduces the emission level in country H.

From the trade balance condition, (32), we obtain the final good consumption of a representative consumer: $y^H = (X^H - \bar{p}^F M_D^H) / L^H$. Since the emission tax in country H does not change the output of the final good and the relative price of the abatement equipment but increases the import of the abatement equipment, it reduces the consumption of a representative consumer in country H. The amount of emission in country H is given by equation (2). Taking these equations into consideration, and differentiating the representative consumer's utility function with respect to t^H, we obtain

$$du^H / dt^H = (u_y^H c_{qt}^H h_M^H / a_X)\{t^H /(1-s) - L^H(-u_E^H / u_y^H)\}, \tag{33}$$

where $dM_D^H / dt^H = c_{qt}^H (L^H / a_X) > 0$. Thus, welfare in country H will increase (decrease) if $t^H /(1-s) < (>) L^H(-u_E^H / u_y^H)$. In addition, as long as we assume this specialization pattern, the optimal tax rule is

$$t^H /(1-s) = L^H(-u_E^H / u_y^H). \tag{34}$$

If the government of the country H employed the optimal rule under the autarky, (25), equation (33) could be written as $du^H / dt^H = (u_y^H c_{qt}^H h_M^H / a_X)[sc^H t^H /(1-s)\{sc^H + (1-s)\}] \geq 0$, where equality holds only if $s = 0$. If there is a positive subsidy to the purchase of the equipment, The optimal emission tax under free trade should be higher than that derived from the optimal tax rule under autarky.[4]

Next let us examine the welfare change in country F. In Case *I*, Equation (28) can be explicitly written as $c_q(t^F, \bar{q}^F)X^F + c_q(t^H, \bar{q}^F)X^H = (L^F - a_X X^F)/a_M$, which yields

$$dX^F / dt^H = -c_{qt}^H X^H / \{c_q^F + (a_X / a_M)\} < 0 . \qquad (35)$$

The emission tax in country H increases the demand for the abatement equipment produced in country F, and then the production of the final good decreases in country F. From the trade balance condition (32), we obtain

$$dy^F / dt^H = (N^F / X^F L^F)(dX^F / dt^H) , \qquad (36)$$

Where $N^F \equiv t^F E^F - spM_D^F$ indicates the net government revenue in country F. Thus, per capita consumption in country F is increased (decreased) by the emission tax in country H if the net government surplus is negative (positive). Finally, from the utility function in country F, we have

$$du^F / dt^H = u_y^F (dy^F / dt^H) + u_E^F c_t^F (dX^F / dt^H) . \qquad (37)$$

From (37), together with (35) and (36), the emission tax in country H increases the welfare of country F if the initial net government surplus in country F is non-positive.

Summarizing the above discussion in Case *I*, we obtain

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[4] Notice that we do not compare the level of the optimal emission tax under free trade and under autarky. We state that if the autarkic optimal tax rule were initially applied under free trade, raising the emission tax would increase the welfare of country H.

Proposition 3. *Suppose that country H completely specializes in the final good while country F produces both goods.*

(i) *The emission tax in country H reduces the amount of emission in country H and it also reduces the per capita consumption in country H. A raise in the emission tax in country H increases (decreases) the welfare of country H if* $t^H/(1-s)$ *is lower (higher) than the sum of the marginal rate of substitution between the final good and the emission. The optimal emission tax rule is given by* (32).

(ii) *A raise in the emission tax in country H increases the production of the abatement equipment in country F. It also increases the welfare of country F if the initial net government surplus in country F is non-positive.*

Next let us consider Case *II* where countries H and F completely specializes in the final good and the abatement equipment respectively. The amount of the final good produced by country H is L^H / a_X, while the amount of the abatement equipment country F produces is L^F / a_M. Since country F does not produces the final good, the abatement equipment is demanded only by the final good producer in country H. The market clearing condition for the abatement equipment is expressed as

$$c_q(t^H, q)L^H / a_X = L^F / a_M . \tag{38}$$

Equation (38) determines the relative price of the abatement equipment under free trade. Since $c_{qq}^H < 0$, equation (38) gives an unique solution of p, which depends on t^H, s, and the other exogenous variables. Differentiating (38), we obtain

$$dp / dt^H = -c_{qt}^H / c_{qq}^H (1-s) > 0 . \tag{39}$$

The inequality in (39) shows a contrasting result to that obtained under autarky. The emission tax increases the relative price of the abatement equipment under free trade while it decreases the relative price under autarky.

Obviously the outputs of the final good and the abatement equipment do not change due to the environmental policies as long as both countries completely specialize in their production.

Country F exports all of the abatement equipment since the final good is not produced domestically and so there is no demand for the abatement equipment in country F. The amount of the abatement equipment purchased by the final good producer in country H is L^F / a_M , which is constant. In addition, the amount of the final good produced in country H is L^H / a_X , which is also constant. Therefore, the amount of emission in country H remains constant, too. The utility level of a representative consumer in both countries is affected only by a change in the consumption of the final good.

From (32), the consumption of a representative consumer in country H is $y^H = (\bar{X}^H - p\bar{M}_D^H)/L^H$, where $\bar{X}^H = L^H / a_X$ and $\bar{M}_D^H = L^F / a_M$. Using (5), we have

$$du^H / dt^H = -(u_y \bar{M}_D^H / L^H)(dp / t^H) < 0 , \qquad (40)$$

where the inequality holds due to (39). On the other hand, the consumption of a representative consumer in country F is given by $y^F = p / a_M$. Then, we obtain

$$du^F / dt^H = (u_y / a_M)(dp / dt^H) > 0 , \qquad (41)$$

where the inequality holds due to (39).

Proposition 4. *Suppose that country H completely specializes in the final good while country F completely specializes in the abatement equipment. The emission tax in country H does not change the output of the final good and the abatement equipment and the emission level, but it increases the relative price of the abatement equipment. A raise in the emission tax in country H decreases the welfare of country H while it increases the welfare of country F.*

Finally, let us consider Case *III*. The abatement equipment is demanded only in country H, but it is produced in both countries. Since country H produces both goods, the relative price of the abatement equipment is determined by (6) and (7), and the equilibrium relative price under free trade is identical to the autarkic relative price in country H, i.e., $p = \bar{p}^H$. Thus, from (14), we have $dp/dt^H = d\bar{p}^H/dt^H < 0$.

The market will clear under the condition that $M_D^H = M_S^H + M_S^F$, where $\bar{M}_S^F = L^F/a_M$. Substituting $M_D^H = c_q(t^H, \bar{q}^H)X^H$ into the condition and using (8), we have

$$\{a_X + a_M c_q(\tau^H, 1)\}X^H = L^H + a_M \bar{M}_S^F. \tag{42}$$

Equation (42) is identical to (21) except that $a_M \bar{M}_S^F$ appears in the right hand side. Since $a_M \bar{M}_S^F$ is constant, we obtain equation (22), which shows the effects of the environmental policies on the output of the final good. That is, $dX^H/dt^H < 0$.

The per capita consumption in country H is given by $y^H = (X^H - p\bar{M}_S^F)/L^H$. Substituting this equation into the utility function, and differentiating it, we obtain

$$du^H/dt^H = \alpha^H[t^H/\{sc^H + (1-s)\} - L^H(-u_E^H/u_y^H)](dX^H/dt^H) - (u_y^H \bar{M}_S^F/L^H)(dp/dt^H). \tag{43}$$

The first term in (43) is identical to the welfare effect under autarky, and the second term shows the terms of trade effect. The emission tax in country H reduces the relative price of the abatement equipment, so the terms of trade for country H improves. Thus the second term in (43) is positive. If the autarkic optimal rule were initially applied under free trade, the higher emission tax would increase the welfare of country H since the first term disappears.

The per capita consumption in country F is given by $y^F = p/a_M$, and there is no local emission. Thus, we have

$$du^F/dt^H = (u_y^F/a_M)(dp/dt^H) < 0. \tag{44}$$

The emission tax in country H has a negative effect on the welfare of country F through the terms of trade effect. Therefore we obtain

Proposition 5. *Suppose that country H produces both goods but country F completely specializes in the abatement equipment. The emission tax in country H reduces the output of the final good, the amount of emission, and the per capita consumption in country H. The optimal emission tax for country H is higher than the emission tax derived from the autarkic optimal emission tax rule under free trade. A raise in the emission tax in country H always reduces the welfare of country F.*

5. Concluding Remarks

This paper analyses the structure of comparative advantages generated by the international differences in environmental policies in a model with the pollution abatement equipment and examines the effects of the environmental policy under the open economy. The effects of the environmental policy depend on the specialization pattern under free trade, so the trade pattern is shown to be very important to evaluate the policy.

[To be filled.]

Appendix 1.

We will derive (23) in this appendix. The condition for the cost minimization gives us

$$-h_M^i = t^i / q_M^i .$$

From the market clearing and full-employment conditions, we also have

$$dM_D^i = dM_S^i = -(a_X / a_M) dX^i .$$

Differentiating the emission function, applying the homogeneity of the function, and substituting these equalities, we obtain

$$dE^i = h_X^i dX^i + h_M^i dM_D^i$$

$$= \{(h^i / X^i) - h_M^i (M_D^i / X^i)\} dX^i + h_M^i dM_D^i$$

$$= (1/t^i)\{c^i - q^i (a_X / a_M)\} dX^i$$

Appendix 2.

We will derive (24) in this appendix. Since the per capita consumption of the final good is given by X^i / L^i, we have $dy^i = (1/L^i) dX^i$. Then we obtain

$$du^i = (u_y^i / L^i) dX^i + u_E^i dE^i$$

$$= [u_y^i \{c^i + q^i (a_X / a_M)\} / t^i L^i][t^i / \{c^i + q^i (a_X / a_M)\} - L^i (-u_E^i / u_y^i)] .$$

Since $c^i + q^i (a_X / a_M) = c^i + q^i (1 - c^i) / p^i = s^i c^i + (1 - s^i)$ from (6) and (7), we have (24).

Appendix 3.

From (32), we have $y^i = \{X^i + p(M_S^i - M_D^i)\} / L^i$. Differentiating it with respect to t^H, we obtain

$$dy^F / dt^H = [dX^F / dt^H + p\{d(M_S^F - M_D^F) / dt^H\}] / L^F$$

$$= [1 - p\{(a_X / a_M) + c_q^F\}](1/L^F)(dX^F / dt^H)] .$$

$$= [X^F + p(M_S^F - M_D^F) - (p/a_M)L^F](1/L^F X^F)(dX^F/dt^H)$$

$$= (y^F - w^F)(1/X^F)(dX^F/dt^H).$$

In addition, using (6), (7), (8), (32) for country F, we have

$$(y^F - w^F)L^F = t^F E^F - spM_D^F.$$

Then, we obtain (36) in the text.

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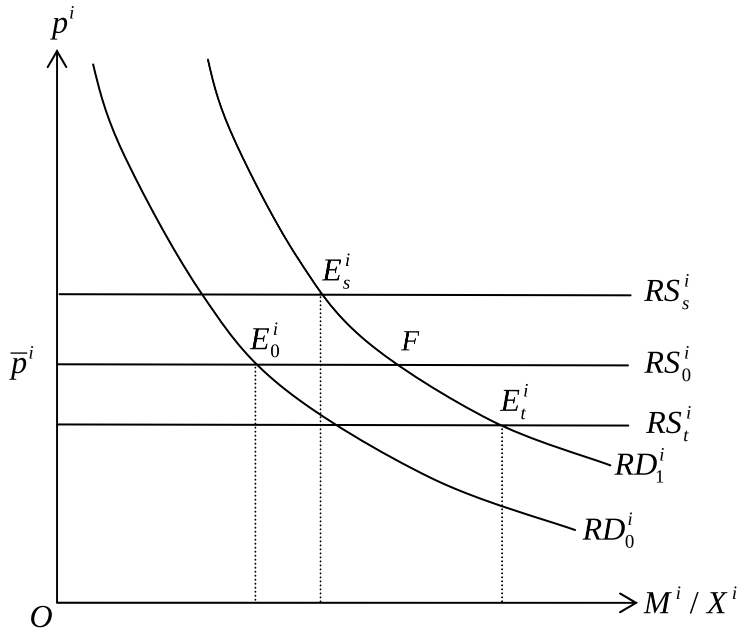

Figure 1

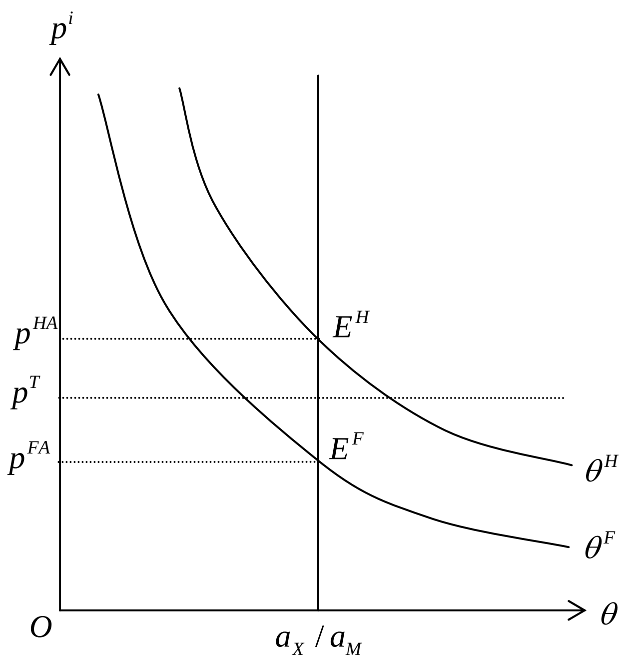

Figure 2

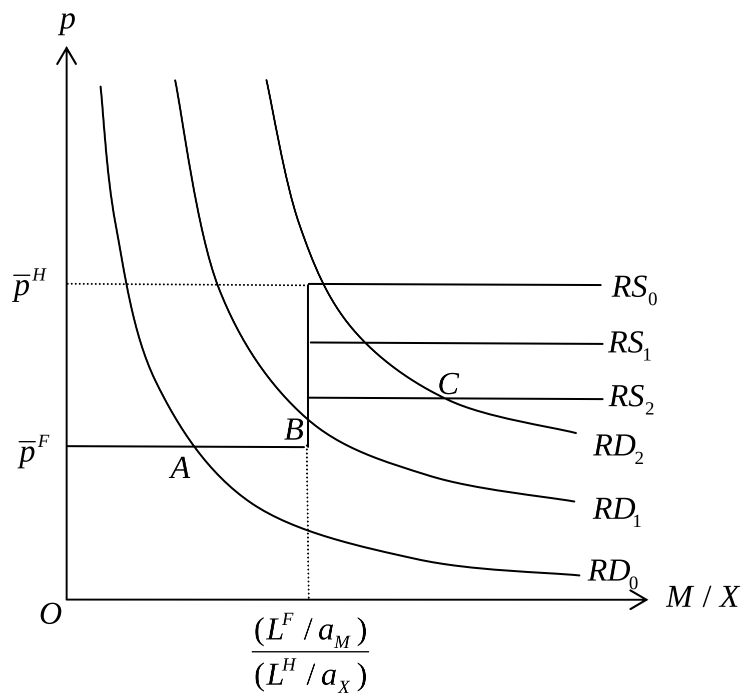

Figure 3