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Pollution Abatement Equipment and International Migration

1. Introduction

The importance of the environmental industry, which supplies environmental equipment and services, is steadily increasing given the drive to reduce pollution caused by smokestack industries and to preserve or improve the natural environment. Correspondingly, the global market of the environmental industry is also growing.

Several theoretical studies deal with environmental topics under the framework of the international trade model. With regard to the environmental industry, the pioneering work by Merrifield (1988) analyzes the effects of equipment standards on trade and capital mobility. Copeland (1991) studies the trade of waste disposal services. Chua (2003) examines the effects of an emission tax on the trade pattern in a three-sector model, one of which is the non-tradable pollution abatement service sector. Sugiyama (2003) also studies the effects of environmental policies in a two-sector model, one of which is the production sector of pollution abatement equipment. Abe and Sugiyama (2008) analyses the structure of comparative advantage 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.

There are several researches on the possibilities and effects of international migration in a two-country model considering the economic value of the natural environment. Tawada (2007) introduces the natural environment into the Harris and Todaro (1970) model, investigates the effect of an improvement in pollution abatement technology, and concludes that in case the urban area is capital intensive, the improvement in pollution abatement technology brings forth an increase in urban unemployment and a deterioration of the natural environment and national welfare. Kondoh (2006) analyzes the welfare effects of international migration in the presence of trans-boundary pollution by using a simplified version of the Copeland and Taylor (1999) model, in which the developed country's pollution abatement technology is superior to that of the developing country. In the absence of trade, workers will migrate from the developing country to the developed country. The developed home country will surely gain, but whether the host country will gain depends on parameters, abatement technology gap, and the magnitude of the coefficient of trans-boundary pollution. Kondoh (2007) is the extension study with two types of workers: unskilled workers, who contribute only to the production in the smokestack manufacturing industry, and skilled workers, who can contribute not only to the manufacturing production but also the reduction of pollution. However, it is noteworthy that in all of these studies about international migration, there is no consideration of environmental abatement equipment or service sector. Thus, both domestic and trans-boundary pollution will be reduced only by the decrease in the production of manufacturing good caused by international migration.

The purpose of this study is to investigate the wage gap between two countries, a developed domestic country and a developing foreign country, in the presence of pollution abatement equipment sector. We will set up a model with three good: smokestack manufacturing final good, environmentally sensitive agricultural final good, and pollution abatement equipment, which is supplied to the manufacturing industry by the public sector. We find that the real wage rate will be higher in the developed country with a higher productivity in the production of pollution abatement equipment or with superior pollution abatement technology. On the other hand, the effects on the real wage rate caused by environmental tax policies would not clear. Following permission for international migration, we can assert that in at least one of the two countries, migration will cause positive effects on the wage rate, stock of environment, and economic welfare of the representative worker. Moreover, under a certain simple condition, we show that both countries will be able to gain from international migration.

In Section 2, we set up the model and the effects on real wage caused by different abatement technologies or environmental policies in autarky are studied in Section 3. The effects of international migration on the wage rate, environmental capital stock, and economic welfare of each worker are analyzed in Section 4. Finally, Section 5 offers the concluding remarks.

2. The Model

We assume that the world comprises two countries H (home) and F (foreign) with three industries each. These industries include the smokestack manufacturing industry, which generates pollution; the environmentally sensitive agricultural industry, which suffers from the pollution; and the pollution abatement equipment industry, which is managed by the public sector. We consider this equipment is just like a filter, which helps to purify polluted air or water. With this equipment, the pollution abatement technology of the manufacturing industry could be improved. The two primary factors of production are labor and environmental capital; the latter is the specific factor in the production of the agricultural good.

The production functions of the manufacturing, agricultural and pollution abatement equipment industries in country H are

$$M = L_M , \tag{1a}$$

$$A = \sqrt{E} L_A , \tag{1b}$$

$$D = \beta L_D , \tag{1c}$$

where E is the stock of environmental capital; M and L_M are, respectively, the output and labor input in the manufacturing industry; A and L_A are those of the agricultural industry, D and L_D are those of the pollution abatement equipment industry; and β is the parameter that reflects the productivity of pollution abatement equipment. The output of both the manufacturing and pollution abatement equipment industries does not depend on the environmental capital stock, and one unit of output is produced by one and $1/\beta$ unit of labor, respectively. In contrast, the labor productivity of the agricultural industry depends on the level of the environmental capital stock: one unit of labor input produces $\sqrt{E}$ units of output in the agricultural industry.

Production activity in the manufacturing industry causes pollution, while with pollution abatement equipment, the pollution abatement technology of the manufacturing industry could be improved. We assume that the emission of pollutants, denoted by Z, is proportional to the manufacturing output:

$$Z = (\lambda - \mu D) L_M . \tag{2}$$

Here, λ is the pollution abatement technology without any equipment and μ is the efficiency of an equipment to improve the technology. We assume that pollution abatement technology can be improved proportionally with the number of introduced equipment.

We assume that the stock of environmental capital will be reduced by the amount equal to the level of emission, Z. Therefore, the total stock of environmental capital that remains after damages caused by emission have occurred is

$$E = \bar{E} - Z , \tag{3}$$

where $\bar{E}$ is the natural stock level of environmental capital before damages.

Regarding industry structure, we assume perfect competition with free entry both in the manufacturing and agricultural industries. Let π_M and π_A be the total profits of the manufacturing and agricultural industries, respectively, and those can be expressed as follows:

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$$\pi_M = p_M M - wL_M - tM \,, \tag{4}$$
$$\pi_A = A - wL_A \,, \tag{5}$$

where we take the agricultural good as the numeraire; p_M and w are, respectively, the price of manufactured good and the wage rate; and t is the rate of emission tax imposed by the government upon one unit of manufactured good. The government supplies pollution abatement equipment to the manufacturing industry free of charge. Thus there is no cost to introduce the equipment. Then, under the assumption that both goods are produced, profit maximizing conditions of each firm in the manufacturing and agricultural industries yield

$$\frac{\partial \pi_M}{\partial L_M} = p_M - w - t = 0 \,, \tag{6}$$
$$\frac{\partial \pi_A}{\partial L_A} = \sqrt{E} - w = 0 \,. \tag{7}$$

The full employment condition of country H is

$$L_M + L_A + L_D = L \,, \tag{8}$$

where L is the labor endowment of country *H*.

The pollution abatement equipment industry is managed by the government. The financial balance condition of the government is

$$wL_D = tM \,, \tag{9}$$

where the LHS of (9) is government spending which is just equal to the income of the workers employed in pollution abatement equipment industry, while RHS of (9) is government revenue, which is equal to the total tax revenue.

On the demand side, we specify the following social utility function of consumers:

$$U = (D_M)^{\alpha} (D_A)^{1-\alpha} \tag{10}$$

where both α and $1-\alpha$ are positive parameters, and D_M and D_A are, respectively, aggregate consumption levels of the manufactured and agricultural good. Because of the zero profit of each firm and balanced finance, the GDP of country H is equal to labor income, wL. Therefore the demand for each good is obtained by solving utility maximization problem, subject to the following budget constraint:

$$D_A + p_M D_M = wL. \tag{11}$$

Thus, we have

$$p_M D_M = \alpha wL, \tag{12a}$$
$$D_A = (1-\alpha)wL. \tag{12b}$$

3. Wage Difference in Autarkic Equilibrium

In autarky, as there is no international trade, the aggregate domestic demand of manufactured and agricultural good should be equal to the total domestic output. Thus, we have

$$D_M = M, \tag{13a}$$
$$D_A = A. \tag{13b}$$

From (5), (7), (12b), and (13b) we have

$$L_A = (1-\alpha)L, \tag{14}$$

and making use of (8) and (1c) we obtain

$$\beta(M - \alpha L) + D = 0. \tag{15}$$

On the other hand, from (6), (12a), and (13a) we have

$$\alpha wL - M(w+t) = 0. \tag{16}$$

Finally, from (2), (3), and (7) we have

$$\bar{E}-(\lambda-\mu D)M = w^2 . \qquad (17)$$

Now we have three equations (15), (16), and (17), which determine three endogenous variables, w, M, and D, when the exogenous variables $\bar{E}, \alpha, \beta, L, t, \mu$, and λ, are given[1].

We now turn to the economy of country *F*. Variables relating to this country are marked with asterisk. Since our focus is on the international difference in the effects of pollution abatement equipment on the level of abatement technology, the productivity of the pollution abatement equipment industry or the emission tax rate imposed by the government, we assume that country *F* is exactly the same as country *H* except for one of the exogenous variables μ, β or t. In other words, we assume $L = L^*, \alpha = \alpha^*, \bar{E} = \bar{E}^*$ and $\lambda = \lambda^*$ in deriving all our results.

Totally differentiating the equations (15), (16), and (17) yields the following matrix:

$$\begin{bmatrix} 0 & \beta & 1 \\ \alpha L - M & -(w+t) & 0 \\ 2w & \lambda - \mu D & -M\mu \end{bmatrix} \begin{bmatrix} dw \\ dM \\ dD \end{bmatrix} = \begin{bmatrix} \alpha L - M \\ 0 \\ 0 \end{bmatrix} d\beta + \begin{bmatrix} \alpha\beta \\ -\alpha w \\ 0 \end{bmatrix} dL$$

$$+ \begin{bmatrix} 0 \\ M \\ 0 \end{bmatrix} dt + \begin{bmatrix} 0 \\ 0 \\ DM \end{bmatrix} d\mu . \qquad (18)$$

The determinant of the matrix is,

$$\Delta = (\alpha L - M)(\lambda - \mu D + M\mu\beta) + 2w(w+t) > 0 , \qquad (19)$$

where from (2) and (15), the positive sign of Δ is guaranteed.

3.1 The international difference in the effects of pollution abatement

[1] It might be necessary to remark that from (15) and (16), we easily can derive (9). In usual case, the government intends to determine tax rate, t to maximize social utility, U. But in our analysis, because of strong resistance by the manufacturing industry, we assume that the tax rate is lower than optimal level and exogenously given. Moreover to satisfy (17), we implicitly assume that $\lambda - \mu D > 0$.

equipment on the level of abatement technology

First, let us consider the case $\mu > \mu^*$, which implies that the effect of the marginal increase in the number of pollution abatement equipment on the level of abatement technology is higher in country *H* than that in country *F*. This assumption is valid if we consider that country *H* is developed and the quality of the pollution abatement equipment is better, that is, the filter used to reduce the emission of polluted air or water is of a superior quality. In this case, we also assume that country *F* is exactly the same as country *H* except on this point. Therefore, we assume $\beta = \beta^*$ and $t = t^*$.

From (18), simple calculations yield

$$\frac{dw}{d\mu} = \frac{1}{\Delta} DM(w+t) > 0, \tag{20}$$

which implies $w > w^*$. From (6), as $dp_M = dw$ under constant tax rate, t, we can assert that real income of a worker in country *H* is higher than that in country *F*. Therefore, if international migration is permitted, workers tend to migrate from country *F* to country *H*.

3.2 The international difference in the productivity of the pollution abatement equipment industry

Second, let us consider the case $\beta > \beta^*$, which implies that the productivity of the pollution abatement equipment industry is higher in country *H* than that in country *F*. This assumption is valid if we consider that the technology of country *H* is more advanced. Even though there is no difference in the quality of both labor and produced good and labor input is just the same in each country, the output of country *H* is larger in quantities. We also assume that country *F* is exactly the same as country *H* except on this point. Therefore we assume $\mu = \mu^*$ and $t = t^*$.

From (18), simple calculations yield

$$\frac{dw}{d\beta} = \frac{1}{\Delta}(\alpha L - M)\mu(w+t)M > 0, \tag{21}$$

which implies $w > w^*$. Similar to the former case, from (6), as $dp_M = dw$ under constant tax rate, t, we can assert that the real income of a worker in country *H* is higher than that in country *F*. Therefore, if international migration is permitted, workers tend to migrate from country *F* to country *D*[2].

3.3 The international difference in the emission tax rate

Finally let us consider the case that $t > t^*$, which implies that the emission tax rate imposed by country *H*'s government is higher than that by country *F*'s government. This assumption is also valid and reasonable because the developed country *H* is more sensitive to preserve the environmental capital stock than the developing country *F*. In this case, we also assume that country *F* is exactly the same as country *H* except on this point. Therefore, we assume $\beta = \beta^*$ and $\mu = \mu^*$.

From (18), simple calculations yield

$$\frac{dw}{dt} = \frac{1}{\Delta} M(\beta M \mu + \lambda - \mu D) > 0, \tag{22}$$

which implies $w > w^*$ in this case. But different from the former two cases, from (6), we have $dp_M/dt = dw/dt + 1$, which implies $dp_M/dt > dw/dt > 0$. Therefore, in this case we can conclude $p_M/p_M^* > w/w^* > 1$ or $w^*/p_M^* > w/p_M$. Now the real income of country *H* is not always higher than that of country *F*. In case α is sufficiently large (small), which means that the consumers' preference is toward the manufactured (agricultural) good, country *F* (*H*) will be the host country for the international immigration.

Now we can offer the following proposition:

PROPOSITION 1

(1) The international difference in the effects of pollution abatement equipment on the level of abatement technology or the productivity of the pollution abatement equipment industry would cause international migration from the developing country to the developed country.

(2) The international difference in the emission tax rate imposed by the governments would also cause international migration but the direction depends on the parameter of the preference of consumption.

3.4 The international difference in the effect of pollution abatement equipment

[2] Because of the simple setting of our model, the effects caused by an increase in μ and β are quite the same.

From (18), simple calculations yield

$$\frac{d(\mu D)}{d\beta}=\mu\frac{dD}{d\beta}=\frac{\mu}{\Delta}(\alpha L-M)(\lambda-\mu D)+2w(w+t)>0\,, \tag{23}$$

$$\frac{d(\mu D)}{d\mu}=\mu\frac{dD}{d\mu}+D=\frac{D}{\Delta}(\alpha L-M)(\lambda-\mu D)+2w(w+t)>0\,. \tag{24}$$

Therefore, we have $\mu D>\mu^*D^*$ in the case of $\beta>\beta^*$ or $\mu>\mu^*$, which implies that pollution abatement equipment is more effective in country *H*.

4. International Migration and Welfare

From Section 3, we can conclude that developed country *H* whose technology is more advanced and suitable for producing high-quality pollution abatement equipment will be the host country for immigration, if it is permitted. Moreover, if each worker strongly prefers to consume agricultural good, country *H* with higher environmental tax rate will also be the host country. Now let us investigate the effects of immigration on the wage rate, production of both manufactured and agricultural goods, environmental capital stock, and socioeconomic welfare.

4.1 The effects on wage rate

From (18), applying (9), simple calculations yield

$$\frac{dw}{dL}=-\frac{\alpha w}{\Delta}(\lambda-2\mu D)\,, \tag{25}$$

which implies $dw/dL>(<)0$ in case that $\lambda<(>)2\mu D$. Therefore, applying (23) and (24), we have three cases.

The first case is that pollution abatement equipment is sufficiently effective and can reduce more than half of the original emission of pollution by the manufacturing industry in each country. In this case both $\lambda<2\mu D$ and $\lambda^*<2\mu D^*$ are satisfied and international immigration will enhance the wage rate in country *H*. On the other hand, the wage rate in country *F* will decrease by the outflow of workers. Thus, international migration expands the wage gap between the two countries and the incentive of migration will continue. But even these two inequalities can hold initially, they cannot continue to hold for a long time. Eventually, as workers migrate to country

H, there are very few workers left in country *F*, so $2\mu^* D^*$ will eventually be smaller than λ^*. Let us call this Case 1.

The second case is that the pollution abatement equipment is not sufficiently effective and it can reduce less than half of the original emission of pollution by the manufacturing industry in each country. In this case both $\lambda > 2\mu D$ and $\lambda^* > 2\mu D^*$ are satisfied and international migration will reduce the wage rate of country *H*, enhance the wage rate of country *F*, and therefore reduce the gap between the two countries. In this case, after several episodes of migration, an equilibrium state, in which no wage gap and no motivation for migration anymore, may emerge. Let us call this Case 2.

Remembering that we have $\mu D > \mu^* D^*$ in the case of $\beta > \beta^*$ or $\mu > \mu^*$, there is a possible third case which satisfies $2\mu D > \lambda = \lambda^* > 2\mu^* D^*$. In this case, from (25), we can conclude that migration from country *F* to country *H* will enhance the wage rates of both countries. Let us call this Case 3.

4.2 The effects on production and environmental capital

From (18), simple calculations yield

$$\frac{dM}{dL} = \frac{1}{\Delta}\alpha[2w^2 + \beta\mu M(\alpha L - M)] > 0, \tag{26}$$

$$\frac{dD}{dL} = \frac{1}{\Delta}\alpha\beta[(\alpha L - M)(\lambda - \mu D) + 2wt] > 0. \tag{27}$$

The abovementioned results show that because of international migration, the production of both the manufacturing and pollution abatement equipment industries in country *H* (*F*) will increase (decrease).

Regarding the effect on the environmental capital stock, we have the following relationship from (7),

$$\operatorname{sgn}\frac{dw}{dL} = \operatorname{sgn}\frac{dE}{dL}, \tag{28}$$

which implies that the level of the environmental capital stock of country *H* will increase (decrease) after migration in Case 1 and 3 (Case 2), and that of country *F* will increase (decrease) in Case 2 and 3 (Case 1), respectively[3].

[3] We could obtain the same results from the following equation:

4.3 The effect on socioeconomic welfare

Next let us consider the effect on socioeconomic welfare. In this model, as there is no profit of the competitive firms in the manufacturing industry, the socioeconomic welfare will be equal to the economic welfare of the workers. From (10), domestic utility function of a representative worker could be defined as

$$u = u(m,a) = m^{\alpha} a^{1-\alpha}, \tag{29}$$

where m and a are, respectively, per capita consumption of manufactured and agricultural good in country *H*. Thus, without international trade, $m = M/L$ and $a = A/L$ must be satisfied in equilibrium. Totally differentiating (29) yields

$$du = u(\frac{\alpha}{m} dm + \frac{1-\alpha}{a} da). \tag{30}$$

From the definition of m and a, we can apply the following equations to (30):

$$dm = \frac{1}{L} dM - \frac{M}{L^2} dL, \tag{31a}$$

$$da = \frac{1}{L} dA - \frac{A}{L^2} dL. \tag{31b}$$

Moreover, we also have the following equation from (12b) and (13b):

$$dA = (1-\alpha) L dw + (1-\alpha) w dL. \tag{32}$$

By calculation, we can obtain

$$\frac{du}{dL} = -\frac{\alpha u}{\Delta} [\frac{D}{\alpha\beta} + (1-\alpha)](\lambda - 2\mu D), \tag{33}$$

and therefore, in case of $\lambda < (>) 2\mu D$, we can conclude $du/dL > (<) 0$, respectively, which implies that socioeconomic welfare in country *H* will increase (decrease) after

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$\frac{dE}{dL} = -(\lambda - \mu D)\frac{dM}{dL} + \mu M \frac{dD}{dL}$, by applying (2) and (3).

migration in Case 1 and 3 (Case 2), and that of country F will increase (decrease) in Case 2 and 3 (Case 1), respectively[4]. Now we establish the following proposition:

PROPOSITION 2

(1) If pollution abatement equipment is sufficiently effective and can reduce more than half of the original emission of pollution by the manufacturing industry in each country, international migration will enhance (reduce) the wage rate, environmental capital stock and socioeconomic welfare of the host (source) country.

(2) If pollution abatement equipment is not sufficiently effective and can reduce less than half of the original emission of pollution by the manufacturing industry in each country, international migration will reduce (enhance) the wage rate, environmental capital stock and socioeconomic welfare of the host (source) country.

(3) If pollution abatement equipment is sufficiently effective (not sufficiently effective) and it can reduce more (less) than half of the original emission of pollution by the manufacturing industry in the developed (developing) country, international migration will cause global gain, that is, enhance the wage rate, environmental capital stock, and socioeconomic welfare of both the countries.

Kondoh (2006) studies the case without the pollution abatement equipment industry and from Theorem 1 of this study, we can easily conclude that with difference in pollution abatement technology and without trans-boundary pollution, the developed country will surely lose from international immigration. On the other hand, the developing country will surely gain. But in this study, by introducing the public-managed industry of pollution abatement equipment, the inflow of labor will expand the production of the equipment industry, which will contribute to the welfare of the developed country. Therefore, unlike Kondoh (2006), we have a special possibility that both the countries can gain from the international migration.

5. Concluding Remarks

We introduced the environmental industry, which supplies pollution abatement equipment, into the Copeland and Taylor (1999) model. We found that the real wage rate will be higher in the developed country with a higher productivity in the production of pollution abatement equipment or with a superior pollution abatement technology. On the other hand, the effects on the real wage rate caused by environmental tax

[4] See Appendix for derivation of (33).

policies would not clear. After the permission for international migration, we could assert that at least in one of the two countries, migration will cause positive effects on the wage rate, stock of environment, and economic welfare of the representative worker. Moreover, under a certain simple condition, we showed that both the countries will be able to gain from international migration.

In this model, we compared the case after the permission of international migration was granted with the case of autarky. But instead of international migration, international trade might occur. Because in autarky, under the condition of $\beta > \beta *$ or $\mu > \mu *$, the relative price of the manufactured good is higher in the developed country, namely, $p_M > p_M *$. Therefore, because of the comparative advantage, if it is permitted, country H will start to export the agricultural good and import the manufactured good. This trade pattern is reflected in the case considered in Kondoh (2006). A future research topic can be the possibility and effects of international migration under free international trade. In this case, we might consider the possible cases that one of the two countries does not produce all three goods.

In modifying Copeland and Taylor's (1999) model to allow for migration, we simplified some aspects of that model following Kondoh (2006), for example, the dynamic aspect relating to the natural recovery of environmental capital. A worthwhile extension of our research would be to analyze international migration taking into account the dynamic specification of the original Copeland and Taylor model.

Appendix

This appendix deals with the derivation of (33). From (29) we have

$$du = u(\frac{\alpha}{m} dm + \frac{1-\alpha}{a} da) . \tag{A1}$$

Substituting (31a) and (31b), (A1) yields

$$\frac{1}{u_2} du = \frac{\alpha}{mL} dM + \frac{1-\alpha}{aL} dA - \frac{1}{L} dL . \tag{A2}$$

Again applying (32), we have

$$\frac{1}{u}du = \frac{\alpha}{mL}dM + \frac{(1-\alpha)^2}{a}dw + [\frac{(1-\alpha)^2 w - a}{aL}]dL$$

$$= \frac{\alpha}{mL}dM + \frac{(1-\alpha)^2}{a}dw - \frac{\alpha}{L}dL , \qquad \text{(A3)}$$

and therefore the effects on sub-utility u_2 caused by an increase in labor endowment can be expressed as

$$\frac{1}{u}\frac{du}{dL} = \frac{\alpha}{mL}\frac{dM}{dL} + \frac{(1-\alpha)^2}{a}\frac{dw}{dL} - \frac{\alpha}{L} . \qquad \text{(A4)}$$

Now let us investigate the sign of the sum of the first and third terms of the RHS of (A4). We can calculate as follows:

$$\Theta \equiv \frac{\alpha}{mL}\frac{du}{dL} - \frac{\alpha}{L} = \frac{\alpha}{mL}(\frac{dM}{dL} - \frac{M}{L}) = \frac{\alpha}{L}(\frac{dM}{dL}\frac{L}{M} - 1)$$

$$= \frac{1}{\Delta}[2\alpha w^2 + \alpha\beta\mu M(aL - M)]\frac{L}{M} - 1$$

$$= \frac{\alpha L}{\Delta M}(2w^2 + \mu MD) - 1$$

$$= \frac{1}{\Delta w}[(w+t)(2w^2 + \mu MD) - w\{(2w(w+t) + \frac{D}{\beta}(\lambda - \mu D) + DM\mu\}]$$

$$= \frac{1}{\Delta w}[t\mu MD - \frac{Dw}{\beta}(\lambda - \mu D)] = -\frac{D}{\Delta\beta}(\lambda - 2\mu D) . \qquad \text{(A5)}$$

Thus, applying (25) and (A5) to (A4), we finally obtain (33).

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