Clean Development Mechanism in North-South Trade

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Abstract

Purpose- There is great conflict between some developed countries and developing countries (e.g., the U.S. vs. China) regarding attitudes toward reducing global warming. In this paper, I argue that open trade doesn't necessarily increase world pollution if Clean Development Mechanism (CDM) is generously undertaken and if the CDM devotes considerable real resources in transfers of the associate abatement technology.

Design/methodology/approach- The impacts of trade on environment can be decomposed into scale, technique and composition effects. In this paper, I incorporate abatement assets into Copeland and Taylor's (1994) model to argue that the technique effect stems from an increasing in pollution taxes and in international diffusion of abatement technology; however, the former is fully offset but the latter is facilitated by the CDM.

Finding- While world pollution is jointly determined by the composition and technique effects, in contrast to literature, open trade doesn't necessarily increase world pollution if CDM is generously undertaken with considerable real resources in abatement technology transfers.

Originality/values- Currently, there are more about one half of the CDM projects that allocate no real resources in technology transfers. This study addresses how voluntary investment of the CDM from the North (e.g., the U.S.) to the South (e.g., China) might reduce pollution on a global level only if having "generously" technology transfer.

Keywords Kyoto Protocol, Clean Development Mechanism, Pollution, Trade.

Paper Type Research paper

JEL Classification: F10, F15, F18.

1. Introduction

Copeland and Taylor (1994) applied the framework of Dornbusch, Fischer, and Samuelson (1977) to examine the linkage between trade and environment. In their model, open trade allows the principles of comparative advantage to determine the global pattern of trade and location of production, making the developed countries specialize in lower pollution goods while the developing countries specializes in higher pollution-intensive goods. The impacts of trade on environment can be decomposed into scale effect, technique effect and composition effect. In their model, open trade drives some marginal industries that are more pollution-intensive than the existing industries in the developed countries to the developing countries; however, these relocated industries are less pollution-intensive than the existing industries in the developing countries. As a result, the average pollution intensity in the developed countries decreases while that in the developing countries increases with the open trade, which is so called the composition effect.[1] Copeland and Taylor (1994) argue that the composition effect, driven by foreign direct investment (FDI) due to open trade, always dominates while the rest are fully offset, leading to a higher level world

[1] The scale effect measures the increase in pollution created by an increase in the aggregate incomes and consumption, holding constant the techniques of production and the composition of final output. The technique effect reflects the reduction in aggregate pollution arising from a switch to less pollution-intensive production techniques (e.g., driven by an increase in pollution taxes), holding constant income and the range of goods produced (Copeland and Taylor, 1994).

pollution in the aggregate.

However, although open trade leads to an increase in aggregate production and consumption (income effect) and shifts the pollution-intensive industries from the developed to the developing countries (composition effect), it is feasible to argue that the open trade does not necessarily increase world pollution if the developed countries are generously devoting resources in the transfer of advanced technology in pollution abatement associated with the increase in trade and investment (technique effect). Therefore, I apply the technology transfer scheme to Copeland and Taylor's (1994) model to address, in what circumstances, the technique effect may dominate the income and composition effects regarding to pollution abatement.

Global warming, which is largely due to the human pollution of greenhouse gas emissions, has received great attention in the media recently. For the sake of climate protection, the majority of the world reached an international agreement on reduction in greenhouse gases, the Kyoto Protocol. As part of this agreement, industrialized countries promised to reduce their collective emissions of greenhouse gases by 5.2% compared to 1990, with the commitment period specified from 2008 to 2012. Unfortunately, the domestic compliance costs (payment for emission reduction permits and carbon credits) are substantially high compared to the benefits of pollution abatement, and climate protection efforts lead to the voluntarily provision of a global public good to free riders (e.g., unconstrained countries and countries outside the Kyoto agreement),[2] hindering most developed countries from achieving their self-imposed emission targets such that the Kyoto Protocol has little effect (van Kooten, 2003; Böhringer and Vogt, 2006; Barrett, 2009).

Furthermore, there is great conflict between some developed countries and developing countries (e.g., the U.S. vs. China) regarding attitudes toward reducing global warming. At the heart of the current conflict between the U.S. and China in regards to the issue of global warming is that those who polluted the world first (i.e., the developed countries) should take more responsibility for fixing the global warming issues until the developing countries catches up in terms of economic development. While developing countries (e.g., China and India) have little role in the historic emissions and need space for economic development, developed countries (e. g., the U.S.), are responsible, both historically and currently, for the majority of greenhouse gases emissions, are stressing that the developing countries should also presently take binding targets of emission cuts because of their rapid economic growth, leading to conflict.

In order to mitigate the conflict and to reduce greenhouse gas emissions

[2] For example, van Kooten (2003) estimated that the annual compliance cost for Canada ranges conservatively from $2.9 billion to about $6.2 billion, while the cost for Japan ranges from $17.5 billion to about $412.2 billion, and the cost for the Netherlands ranges from $900 million to about $2.44 billion. However, alternatively, these countries can generously transfer their clean and advanced technology to the developing countries, and then purchase the associated emission reduction credits. In this way, for example, Canada can save $0.6~2.3 billion annually.

corporately, the Clean Development Mechanism (CDM) was designed to allow the developed countries (called Annex 1 countries) to invest in projects that reduce pollution emissions in the developing countries. This is an alternative to more expensive pollution reductions in their own countries, thereby providing a cost-effective alternative to the binding commitments. For example, if the voluntary measures (e.g., CDM) are successfully undertaken by Japan, the total compliance costs would be reduced by about 13% in comparison to relying solely on domestic measures (van Kooten, 2003). Most importantly, the aim of this specific design is to encourage investment and technology transfer from the developed countries to assist the developing countries in achieving sustainable economic development by enabling necessary economic growth, while also contributing to the stabilization of greenhouse gas pollution in the atmosphere by the technique effect (Willis et al., 2006; Ellis et al., 2007).

The CDM projects have increased substantially from 64 projects and about 100k tons in expected certified emissions reductions (CERs) by 2012 in January 2005 to 2647 projects and about 2300 Million tons in expected certified emissions reductions in November 2009 (Schneider et al., 2008). The soaring increase in the CDM projects can, contrary to initial doubts about its potential, be a key pillar on a future regime to combat climate change while the CDM allows the less developed countries access to existing low-carbon technologies for the reduction of emissions while having sustainable economic development (UNFCCC, 2007; Capoor and Ambrosi, 2007; Schneider et al., 2008).

Moreover, Seres et al. (2009) have examined 3,296 registered and proposed CDM projects, and have found that roughly 36% of the projects involve technology transfer. They further have found that 53% of the projects claim both equipment and knowledge transfers, while about 32% of the projects that claim technology transfer involve only equipment imports, and 15% of the projects involve transfers of knowledge alone. The transfer of abatement technology, in terms of equipment and knowledge, accounts for a significant share of emission reductions.

In real practice, Chinese government's policy has a priority is to obtain advanced technology from Annex 1 countries, however, this orientation conflicts with the interest of foreign technology transfer who favor selling their own equipment to maximum profits. As a result, China has undertaken the greatest number of projects and reported the largest emission reduction on the global CDM market, while the CDM projects involving technology transfer in China is still small (Wang, 2009). Therefore, in this current model, I only refer the intangible knowledge, which is non-rival goods, to abatement assets.

The purpose of this article is not to solve any of the fundamental incentive problems inherent to the Kyoto Protocol, which requires the developed countries to voluntarily provide climate protection as a global good, but to address how voluntary investment with corresponding technology transfer might reduce pollution on a global level. Therefore, I develop a simple model by incorporating abatement assets into Copeland and Taylor's (1994) model, where the developed countries (i.e., the North) voluntarily transfers clean technology to the developing countries (i.e., the South) in order to fulfill the commitment to environmental protection. On one hand, the composition effect after open trade increases pollution levels in the South, but on the other hand, the technique effect due to the transfer of clean technology reduces pollution levels there. In aggregate, the net impact of the two effects on pollution levels in the developing countries is ambiguous, and may lead to an aggregate reduction in world pollution if the technique effect dominates. Note that, in Copeland and Taylor's (1994) model, the composition effect due to open trade always dominates such that the world pollution in the aggregate has to increase with an increase in trade and FDI. However, in this current paper, I argue that it is not necessary for world pollution to increase with an increase in trade and investment if technology transfer is generously undertaken.

The paper is organized as follows. In Section 2, I revisit Copeland and Taylor's (1994) model by adding abatement assets, while equilibrium is illustrated in Section 3.

Section 4 demonstrates how technique effect due to CDM transfers affects world pollution after open trade. Section 5 concludes.

2. **The Model**

In a world where the North is highly developed and the South is less developed, there is a continuum of private consumption goods, indexed by $z \in [0,1]$. The output of a consumption good z is a function of pollution discharge (d) and labor input (l) . In the following analysis, the Southern variables are indicated by an asterisk.

Copeland and Taylor (1994) first define the production function as $y(z) = \lambda^{\alpha(z)} l_y(z)$, where $\lambda > 0$ is a constant factor and $\alpha(z)$ is a parameter with a limitation of $0 < \underline{\alpha} \le \alpha(z) \le \overline{\alpha} < 1$. The total labor supply is exogenously given and is allocated into either production or pollution abatement in each sector z as $l(z) = l_y(z) + l_a(z)$, where l_y is the amount of effective labor assigned to production and l_a is the amount of effective labor assigned to abatement. The unconstrained level of pollution is defined as $d_0(z) = \lambda^{(1-\alpha)} y(z) = \lambda l_y(z)$, which determines the amount of pollution generated in the absence of any abatement activity. Particularly, they design an abatement technology as $A[l_a, d_0(y)] = d_0(y) - [\frac{\lambda^{\alpha-1} d_0(y)}{[d_0(y)/\lambda + l_a]^{1-\alpha}}]^{1/\alpha}$, which reflects diminishing returns to abatement activity while the $A[l_a, d_0(y)]$ is concave in l_a and is asymptotic to $d_0(y)$. With $A[0, d_0(y)] = 0$, the abatement function indicates that there is no abatement unless dedicated labor is allocated to it.

Combining these above set-ups, the pollution discharge by a representative firm is given by $d(y,l_a,z) = d_0(y(z)) - A[l_a, d_0(y(z))] = [\frac{y}{(l_a + l_y)^{1-\alpha}}]^{1/\alpha}$, which reduces in labor assigned to abatement (i.e., l_a) but increases in output of goods (i.e., y). Rearrange the pollution discharge equation, Copeland and Taylor (1994) obtain their output function: $y(d,l;z) = l^{1-\alpha(z)} d^{\alpha(z)}$ if $d \le \lambda l$, but $y(d,l,z) = 0$ otherwise.[3]

I extend Copeland and Taylor's (1994) model by introducing abatement assets. In this extension, each country is endowed with a stock of abatement assets that can be freely allocated across all production sectors as $H = \int_0^{\tilde{z}} h(z)dz$ and $H^* = \int_{\tilde{z}}^1 h^*(z)dz$ for the North and South, respectively. Here, $h(z)$ is the sector abatement asset in sector z, and the North possesses much more abundant abatement assets compared to the South, that is, $H >> H^*$. In order to employ the endowed abatement assets in a specific sector, I rewrite the abatement technology in Copeland and Taylor's (1994) model:

$$A_e[l_a, h; d_0(y(z))] = d_0 - [\frac{(\lambda^{\alpha-1} d_0)^{1/\alpha}}{(d_0/\lambda + l_a)^{1/\alpha - 1}}]^{\frac{1}{s}} h^{1-\frac{1}{s}}, \qquad (1)$$

where $0 < s < 1$. Intuitively, a country that is endowed with a greater stock of abatement assets should present a higher efficiency in any sector abatement technology if the abatement assets generate positive knowledge externalities to other

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[3] Copeland and Taylor (1994) assumed $y = d^{\alpha} l^{1-\alpha} = \lambda^{\alpha} l_y$. With $l_y \ge 0$ and $l_a \ge 0$, we must have $y = d^{\alpha} l^{1-\alpha} = \lambda^{\alpha} l_y \le \lambda^{\alpha} l$, indicating that the production function is valid only if $d \le \lambda l$.

sectors. Here, I apply the term $\frac{1}{s}$ to represent the impact of the externalities generated by the aggregate abatement assets, which is increasing diminishingly in the aggregate abatement assets (i.e., $s'(H) < 0$ and $s''(H) > 0$), but is irrelevant to a sector abatement asset h. This is a key assumption in this model, which will be discussed in more detail below. Furthermore, as implied in (1), the abatement function is concave in l_a and h, reflecting an assumption of diminishing returns to abatement activity: $\frac{\partial A_e}{\partial l_a} > 0$, $\frac{\partial^2 A_e}{\partial l_a{}^2} < 0$ and $\frac{\partial A_e}{\partial h} > 0$, $\frac{\partial^2 A_e}{\partial h^2} < 0$. We also have $A_e[0, h; d_0(y)] = 0$ and $A_e[l_a, 0; d_0(y)] = 0$ if no dedicated labor or sector assets are allocated to abatement.

With the assumptions of $y(z) = \lambda^{\alpha(z)} l_y(z)$ and $d_0(z) = \lambda^{(1-\alpha)} y(z) = \lambda l_y(z)$ that are made by Copeland and Taylor (1994), equation (1) can be rewritten as $A_e[l_a, h; d_0(y(z))] = d_0 - [(\frac{y}{l^{1-\alpha}})^{\frac{1}{\alpha}}]^{\frac{1}{s}} h^{1-\frac{1}{s}}$. In order to show the presence of positive abatement asset externalities, we must have $\frac{\partial A_e}{\partial H} = \frac{\partial A_e}{\partial s}\frac{\partial s}{\partial H} > 0$, which requires $\frac{\partial A_e}{\partial s} < 0$ while we already have $s'(H) < 0$. With $1 > s > 0$, the inequality $\frac{\partial A_e}{\partial s} < 0$ holds if $d < h$.[4] Thus, in this paper, I assume $d < h$ to ensure positive knowledge externalities exist in the abatement technology, leading to $\frac{\partial A_e}{\partial H} > 0$. It is also reasonable to argue that the efficiency of abatement technology improves

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[4] The equation (1) can be rewritten as $A_e = d_0 - h(\frac{y}{l^{1-\alpha} h^{\alpha}})^{\frac{1}{\alpha s}}$. The inequality $\frac{\partial A_e}{\partial s} < 0$ holds if $\frac{y}{l^{1-\alpha} h^{\alpha}} < 1$. In (2), we have $y = (d^s h^{1-s})^{\alpha} l^{1-\alpha} < h^{\alpha} l^{1-\alpha}$, implying $d < h$.

diminishingly with an increase in the abatement assets as $\frac{\partial^2 A_e}{\partial H^2} < 0$, which echoing with the key assumption of $s'(H) < 0$ and $s''(H) > 0$.

The pollution discharged after abatement is given by $d = d_0 - A_e$. Incorporating the pollution emission d into equation (2), we obtain the production function as

$$y = (d^s h^{1-s})^{\alpha(z)} (l)^{1-\alpha(z)} \quad \text{if} \quad \lambda l > d \,, \tag{2}$$

but $y(d,l,z) = 0$ otherwise.[5] The labor/pollution combination that minimizes costs for a firm satisfies

$$\frac{s\alpha(z)}{1-\alpha(z)} = \frac{\tau d}{wl}, \tag{3}$$

where τ is the pollution tax in the North and is larger than the South's pollution tax as $\tau > \tau^*$. Here, w is the wage rate. Implication in (3), the share of pollution charges in the cost of producing good z is always $\alpha(z)$, where $\alpha'(z) > 0$ is to order the goods in terms of increasing pollution intensity. [6]

Being derived from (2), the abatement asset and pollution combination that minimizes costs satisfies

$$\frac{s}{1-s} = \frac{\tau d}{rh}, \quad \forall z \,. \tag{4}$$

The total cost of pollution handling for a firm consists of a tax payment for pollution discharges (i.e., τd) and the costs of employing abatement assets (i.e., rh). The

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[5] The relation $y = (d^s h^{1-s})^{\alpha} l^{1-\alpha} = \lambda l_y \le \lambda l$ leads to a limitation of $\lambda \ge \frac{d^s h^{1-s}}{l}$. On the other hand, we already assume $d < h$ to ensure that positive knowledge externalities exist. The intersection of the two inequality is $\lambda l > d$.

[6] Copeland and Taylor (1994) assumed that $\alpha(z)$ is strictly increasing in z.

share of pollution charges in the total cost of handling pollution is always s for all z, that is, s is irrelevant to z. Here, r is the return to the abatement assets, which is the same for all sector while we have already assumed that the abatement assets are freely allocated across all production sectors. That is, r is determined by a country's aggregate abatement assets while the individual industry just takes the price of abatement assets as given. Considering that the pollution tax rates τ and the returns to abatement assets r are uniform within a nation, the equilibrium in (4) then implies that

$$\frac{s}{1-s} = \frac{\tau\int_0^{\tilde{z}} d(z)dz}{r\int_0^{\tilde{z}} h(z)dz} = \frac{\tau D}{rH}, \tag{5}$$

where $D = \int_0^{\tilde{z}} d(z)dz$ denotes aggregate pollution in the North. An implication of (5) is that, *ceteris paribus*, the more a country is endowed with abatement assets, the less the aggregate pollution, and the smaller the share of abatement costs in the total cost of handling pollution, as indicated by $s'(H) < 0$. It echo our key assumption that the s captures the impact of positive externalities generated by a country's aggregate abatement assets, and pollution supposedly reduce with an increase in the aggregate abatement assets diminishingly.

3. Equilibrium

Directly following Copeland and Taylor's (1994) methodology, I derive the optimal pollution tax and aggregate pollution as follows. Assume identical utility functions among consumers of both the North and South, where the share of spending on each good is constant, as in the model of Dornbusch, Fischer, and Samuelson (1977). The utility function specified by Copeland and Taylor (1994) is then given by

$$U = \int_0^1 b(z)\ln[x(z)]dz - \frac{\beta D^{\gamma}}{\gamma}, \tag{6}$$

where $x(z)$ is the consumption of good z, $b(z)$ is the continuum counterpart to the many-commodity budget share, and $\int_0^1 b(z)dz = 1$. Here D denotes total pollution discharged in this country, and $\gamma > 1$ denotes that the marginal wiliness to pay for pollution reduction is a non-decreasing function of pollution levels. To simplify matters, both the North and South are identical in size and in population density, and pollution has only a local effect, so that the damage caused by pollution has similar effects in both countries, as indicated by $\beta = \beta^* > 0$.

Maximizing a consumer's utility function with the consumer's budget constraint leads to an indirect utility function of a consumer:

$$V = \int_0^1 b(z)\ln[b(z)]dz - \int_0^1 b(z)\ln[p(z)]dz + \ln(\frac{I}{L}) - \frac{\beta D^{\gamma}}{\gamma}, \tag{7}$$

where $p(z)$ is price of good z, I denotes national income of the North, and L represents total labor supply in the North. The North's government chooses its pollution tax τ by taking consumer and producer behaviors as given by maximizing the indirect utility with respect to τ:

$$\tau = -LV_D / V_I = \beta D^{\gamma-1} I, \tag{8}$$

where Copeland and Taylor (1994) assume the prices $p(z)$ as given while choosing the pollution tax. Equation (8) shows that “pollution taxes are increasing in income since environmental quality is a normal good, and nondecreasing in the aggregate pollution level since the marginal rate of substitution between consumption and pollution is nondecreasing.” (Copeland and Taylor, 1994). Similarly, the pollution tax in the South is given by $\tau^* = \beta D^{*\gamma-1} I^*$. With $D < D^*$, $I > I^*$ and $\gamma \geq 1$, Copeland and Taylor argue $\tau > \tau^*$ in equilibrium.

Following a standard methodology, we can derive the unit cost function from equations (2) and (3) as

$$c(w,\tau,h;z) = \kappa(s,z) h^{\frac{\alpha(z)(1-s)}{1-\alpha(z)(1-s)}} \tau^{\frac{\alpha(z)}{1-\alpha(z)(1-s)}} (w/A)^{\frac{1-\alpha(z)}{1-\alpha(z)(1-s)}}, \qquad (9)$$

where $\kappa(s,z) = [((\frac{\alpha s}{1-\alpha})^{-\alpha s} + (\frac{\alpha s}{1-\alpha})^{1-\alpha}) s^{-\alpha s}]^{\frac{1}{1-\alpha(1-s)}}$ and A denotes the productivity in the North and the South’s productivity is given by A^*. In (9), the unit product cost of a good is increasing in the country’s wage rate and pollution tax rate, but is decreasing in the country’s productivity and abatement assets. An industry that is endowed with greater stock of abatement assets, *ceteris paribus*, tends to have cost advantage in that sector.

Similarly, the unit cost function in the South is given by $c(w^*, \tau^*, h^*; z)$. For given wage and tax rates in each country, good z will be produced in the North if $c(w,\tau,h;z) \leq c(w^*,\tau^*,h^*;z)$, implying

$$\omega \equiv \frac{w}{w^*} \leq \frac{A}{A^*} \frac{\tilde{c}(\kappa, h, \tau; z)}{\tilde{c}(\kappa^*, h^*, \tau^*; z)} \equiv C(\tilde{z}), \qquad (10)$$

where $\tilde{c}(\kappa, h, \tau; z) = \frac{A}{w} c(w, \tau, h; z)$ and $\tilde{c}(\kappa^*, h^*, \tau^*; z) = \frac{A^*}{w^*} c(w^*, \tau^*, h^*; z)$. The term $\frac{\tilde{c}(\kappa, h, \tau)}{\tilde{c}(\kappa^*, h^*, \tau^*)}$ in (10) decreases in $\frac{\tau}{\tau^*}$ and increases in $\frac{h}{h^*}$, but varies with $\frac{\kappa}{\kappa^*}$.

By simulating $\kappa(s, z)$ with respect to s and $\alpha(z)$, Figure 1 shows that values of $\kappa(s, z)$ changes with pollution intensity of goods in different level of s. Here, we have $\alpha'(z) > 0$ to denote that pollution intensity increases with z. We also have $s'(H) < 0$ to denote that a smaller value of s corresponds to a greater stock of abatement assets. The North, which is bountiful in the aggregate abatement assets compared to the South, should have a smaller s than the South. As illustrated in Figure 1, a country endowed with a greater stock of abatement assets (e.g., $s = 0.3$) slightly has cost advantage than a country with a lower stock of abatement assets (e.g., $s = 0.8$) in producing the low pollution-intensity goods (i.e., $\alpha(z) <\approx 0.3$) as indicated by $\kappa(s(H), z) < \kappa(s(H^*), z)$. To the contrary, the country that is endowed with a greater stock of abatement asset has largely cost disadvantage in producing high pollution-intensive goods as indicated by $\kappa(s(H), z) > \kappa(s(H^*), z)$ when $\alpha(z)$ is larger than 0.3.

With the simulation of $\kappa(s, z)$ in Figure 1 and with $A > A^*$ and $h > h^*$, I argue that the North has the comparative advantage in producing the low pollution goods while comparative disadvantage in producing high pollution goods compared to the

South. As a result, there exist a $\tilde{z}$ to equal the inequality (10). We can illustrate (10) as a downward sloping curve with respect to z as in Figure 2.

Note as above, $b(z)$ is the continuum counterpart to the many-commodity budget share and $\alpha(z)$ is the share of output returns to labor for each good production. Therefore, we can obtain the balance of trade schedule as

$$\omega = \frac{\int_0^{\tilde{z}} b(z)[1-\alpha(z)]dz}{\int_{\tilde{z}}^1 b(z)[1-\alpha(z)]dz} \equiv B(\tilde{z}), \tag{11}$$

which shows a upward sloping curve with respect to z as in Figure 2. In equilibrium, the North has cost advantages in producing goods along $[0,\tilde{z}]$, and the South has cost advantages in producing goods along $[\tilde{z},1]$.

4. Pollution, CDM, and Technology Transfer

The goods along $[\tilde{z},1]$ are produced in the South, with the remaining goods produced in the North. Balanced trade leads to:

$$I = \varphi(\tilde{z})(I + I^*), \tag{12}$$

where $\varphi(\tilde{z}) = \int_0^{\tilde{z}} b(z)dz$ denotes the share of world spending on Northern goods.

The aggregate pollution of the North is the sum of pollution generated by the production of Northern output:

$$D = \int_0^{\tilde{z}} d(z)dz = \int_0^{\tilde{z}} \frac{s(H)\alpha(z)p(z)y(z)}{\tau} dz = \int_0^{\tilde{z}} \frac{s(H)\alpha(z)b(z)(I+I^*)}{\tau} dz . \tag{13}$$

Incorporating (12) into (13), and doing the same for the South, we obtain

$$D = s(H)I\theta(\tilde{z})/\tau\varphi(\tilde{z}) \quad \text{and} \quad D^* = s(H^*)I^*\theta^*(\tilde{z})/\tau^*\varphi^*(\tilde{z}), \tag{14}$$

where $\theta(\tilde{z}) = \int_0^{\tilde{z}} \alpha(z)b(z)dz$ is the share of Northern pollution charges in world income. The next step is plugging the optimal pollution tax in (8) into (14) to get expressions for pollution in the two economies:

$$D = (\frac{s(H)\theta(\tilde{z})}{\beta\varphi(\tilde{z})})^{\frac{1}{\gamma}} \text{ and } D^* = (\frac{s(H^*)\theta^*(\tilde{z})}{\beta\varphi^*(\tilde{z})})^{\frac{1}{\gamma}}. \quad (15)$$

Rewriting (12) in percent change notation (e.g., $\hat{D} = \frac{dD}{D}$) yields:

$$\hat{D} = \frac{1}{\gamma}(\hat{s} + \hat{\theta} - \hat{\varphi}) \text{ and } \hat{D}^* = \frac{1}{\gamma}(\hat{s}^* + \hat{\theta}^* - \hat{\varphi}^*), \quad (16)$$

where $\hat{\theta} - \hat{\varphi}$ denotes the composition effect and $\hat{s}$ denotes the technique effect. Open trade changes the goods produced in each country (a composition effect), increases real income (a scale effect), and creates incentives for governments to adjust their pollution taxes (a technique effect). After opening up trade from autarky, relatively clean industries are relocated in the North while pollution-intensive industries are relocated in the South. Copeland and Taylor (1994) argue that composition effect dominates the other two effects and conclude that open trade always lowers the pollution level in the North, increases the pollution level in the South, and increases worldwide pollution if the conditions $\tau > \tau^*$ and $\frac{A}{A^*} > \frac{w}{w^*} > 1$ hold.[7] However, in this model, international spillovers of intangible abatement technology also contributes to the technique effect, such that pollution is not only determined by the composition effect but also by the technique effect, and only the

[7] The presumption of $\tau > \tau^*$ and $\frac{A}{A^*} > \frac{w}{w^*} > 1$ are taken as given in my extended model.

scale effect is fully offset after open trade.

It has been well documented that openness to trade brings up gains from trade, including specialization according to comparative advantage and the realization of economies scale, suggesting that open economy will enjoy higher levels of income and consumption than in autarky. Additionally, among others, Grossman and Helpman (1991) argued that trade in goods facilitates the exchange of intangible ideas, leading to international knowledge spillovers, accelerating the growth of the economy.[8] Thus, in this current model, the technique effect comes from two sources: one arises from an increase in pollution taxes that leads to adoption of cleaner production method. However, this type of technique effect is fully offset as argued in Copeland and Taylor's (1994) model. The other technique effect arises from gains from trades due to international knowledge spillovers that is separated from the above one, so that we have $\hat{s}(H^*) < 0$ after open trade in (16). The intangible assets are non-rival, so that the international knowledge spillovers will not reduce the abatement assets in the North as $\hat{s}(H) = 0$.

Adding the two items in (16) together, we obtain the world pollution as:

$$\hat{D} + \hat{D}^* = \frac{1}{\gamma}(\hat{s} + \hat{s}^*) + \frac{1}{\gamma}[(\hat{\theta}^* - \hat{\varphi}^*) + (\theta^* - \varphi^*)]. \tag{17}$$

The first brackets in (17) indicate that the net technique effect is negative while we

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[8] Reasonably, the countries in trade should also enjoy higher level of abatement assets, since which should increase correspondingly to the increase in consumption and income along the balanced path in equilibrium.

already argued on the above that $\hat{s}^* < \hat{s} = 0$. The second brackets in (17) indicate the net composition effect that is positive as argued already by Copeland and Taylor (1994). The overall world pollution emissions reflect the relative strength of the composition effect and the technique effect.

Proposition 1: *The technique effect stems from not only the rising pollution taxes but also the international diffusion of abatement technology, and only the former is fully offset by the composition effect. Thus, the overall world pollution emissions reflect the relative strength of the composition effect and the technique effect.*

CDM as an Instrument of Technology Transfer

Currently, the Kyoto Protocol is an international agreement under which the North has promised to reduce its greenhouse gas emissions to a certain level. The CDM, a part of the Kyoto Protocol, provides a flexible way to reach the emission reduction target, which allows the North to invest in CDM projects that reduce emissions in the South as a way to earn emission reduction credits without hindering its economic development. My model provides a channel for the CDM to play a role in reducing world pollution, in which the CDM can help buster the technique effect such that world pollution may become lower.

The CDM is often associated with the transfer of technologies from the North to the South, and the number of CDM projects has soared, as well as the number of technologies transferred (de Coninck et al., 2007). It has been found that technology transfers occur in about 30% to 40% of the CDM projects, accounting for about 64% to 80% of the annual emission reductions (Haites et al., 2006; Glachant et al., 2007; Seres, 2007). Being a key means to boost technology transfer and diffusion, CDM consists of two forms of transfers: transfer of machinery and equipment and transfer of knowledge, skills, and know-how (Glachant et al., 2007). A host country imports the machinery and equipment from the North involves dedicated technology transfer costs; however, technology transfer may also occur costless through knowledge diffusion via CDM projects. All the tangible and intangible assets transfer occurs within the CDM projects contribute to the technique effect in reducing pollution. Note that these transfers increase not only the South's abatement asset but also the world's abatement assets as a whole with the intangible knowledge diffusion.

Supposed that there are some abatement assets $\Delta H = \Delta H_T + \Delta H_I$ have been transferred to the South from the North, where H_T and H_I denotes tangible and intangible abatement assets, respectively. The CDM transfers increases the South's abatement assets by ΔH but reducing the North's tangible assets by ΔH_T because the intangible assets are non-rival goods. For simplicity, let's assume all the intangible assets are costless diffused across national borders, although they are not in real practice. As a result, the abatement assets in the South increase with the CDM transfers, leading to a fall in pollution by $\hat{s}^* < 0$, but giving a rise to the pollution in the North by $\hat{s} > 0$. While the term s is decreasing diminishing with the abatement assets, accompanying with the assumption of $H >> H^*$ and $\Delta H > \Delta H_T$, we should observe a favorable technique effect on net as indicated by $|\hat{s}| < |\hat{s}^*|$. That is, the CDM transfer generates disproportionate impact on the abatement capability in each country, and is in favor of the South, reducing pollution in the aggregate for the world as a whole. Even if the CDM involves in no real resources of technology transfer (i.e., $\Delta H = \Delta H_I$), we should still observe a favorable technique effect on net because of the knowledge spillovers. However, the contribution of knowledge spillovers alone should be limited in reducing world pollution.

Proposition 2: *Open up trade may lead to a lower level of world pollution if CDM is generously undertaken. Conversely, world pollution likely grows with the open trade if the undertaken CDM involves in little or no dedicated clean technology transfer.*

Copeland and Taylor (2005) introduce a general equilibrium model to demonstrate that emission permit trade (a mechanism in the Kyoto Protocol) in a free trade world may increase world pollution and make the countries involved worse off. However, the clean technology transfer, highlighted in CDM scheme, is not addressed in their model and their equilibrium is non-cooperative. Instead, Yang (1999) addresses a dynamic general equilibrium model, which considers a unilateral technology transfer from the North to the South in order to mitigate pollution externalities. Yang shows that the unilateral technology transfer not only reduces global greenhouse gas emissions but also improves the welfare of the North, the South and the world as a whole if there is fully cooperation between the North and the South and if the transfers are restricted to ameliorating environmental externalities.[9] The Proposition 2 in this paper is in line with Copeland and Taylor (2005) when there is no clean technology transfer involved, and is in line with Yang (1999) when the dedicated clean technology transfer is generously undertaken.

Yang (1999) further shows in his simulation that the unilateral technological transfers represent only a tiny portion of the North's wealth. Therefore, no substantial financial obstacles should prevent such transfers. Take Yang's argument seriously, I also assume that the transferred assets contribute no substantial financial obstacles to the North in this current model. However, the welfare analysis is not addressed in this model.

5. **Conclusions**

I have incorporated abatement assets into Copeland and Taylor's (1994) model to show that pollution of greenhouse gas emissions is not only determined by the composition effect but also by the technique effect, and only the scale effect is fully

[9] Also see Aronsson et al. (2006), who developed a numerical general equilibrium model in a North-South world. Their simulations suggest that the technology transfer, driven by the CDM, may reduce the emissions and increase welfare at the global level.

offset. This model provides a channel for technology transfer mechanism to play a role in reducing world pollution, in which the developed countries can help facilitate the technique effect such that world pollution may become lower if not only the CDM but also all the FDI projects are generously undertaken with considerable advanced technology transfer. To the contrary, world pollution likely grows if the undertaken CDM (and FDI) involve in none or few dedicated advanced technology transfer.

The above argument finds indirect support from an empirical analysis of Zhang and Schoengold (2011) on the potential for emissions control policy in China. They examine the potential for emissions control within China’s power generation sector for which accounts for the majority of its carbon emissions. Zhang and Schoengold find out that the optimal emission tax rate is moderate when abatement technology allows removing at least 30 percent of newly generated emissions. That is, it implies that economic growth of a developing country can be achieved while still keeping the emission stock at a stable level provided that efficient abatement technology is available.

Unfortunately, Seres et al. (2009) argued that the CDM does not have an explicit technology transfer mandate, but it contributes to technology transfer by financing emission reduction projects that use technologies not available in the host countries. However, among the CDM projects that involve technology transfer, Seres et al.

(2009) further found that 53% of the projects claim both equipment and knowledge transfers and 15% of the projects involve transfers of knowledge (i.e., intangible abatement assets) alone. They have also founded that technology transfer in the CDM projects is less likely occurring in the world's largest population countries, such as Brazil, China, and India. Consider that those projects that involve in technology transfer can account for the majority of the CERs, the CDM in its future modified form should encourage the CDM projects with technology transfers involved, but dispirit those with pure emission credits trading. Most important, compared to total FDI from developed countries to developing countries, the investment associated with CDM appears to be still small (de Coninck et al., 2007). Therefore, for the sake of world pollution reduction, the developed countries better render the developing countries advanced technology voluntarily when carrying out their FDI.

On the other hand, it takes real resources to successfully transfer clean technologies across national borders, which deters the technique effect.[10] If the technology transfer costs are taken into account, the success of the CDM/FDI is highly dependent on the technological capabilities in the host countries. In order to increase technology transfer under possible future clean development mechanisms,

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[10] While the Northern firms "encode" the relevant know-how, the Southern subsidiaries must "*decode*" the essential know-how to successfully adapt, digest, and integrate new technologies in local conditions (Buckley and Casson, 1976).

international and domestic policy makers need to complement the CDM/FDI by fostering host country's specific improvement in investment conditions, especially in their technological capabilities.

The simple extension described in this paper considers intangible technology transfer costs to be negligible and assume away cross-border pollution. A natural extension of this model is to endogenize the technology transfer costs and allow cross-border pollution, which will offer additional insights as to the role of technology transfer costs, clarifying the complex interactions between technology transfer, trade, and pollution. I hope to investigate these issues in future research.

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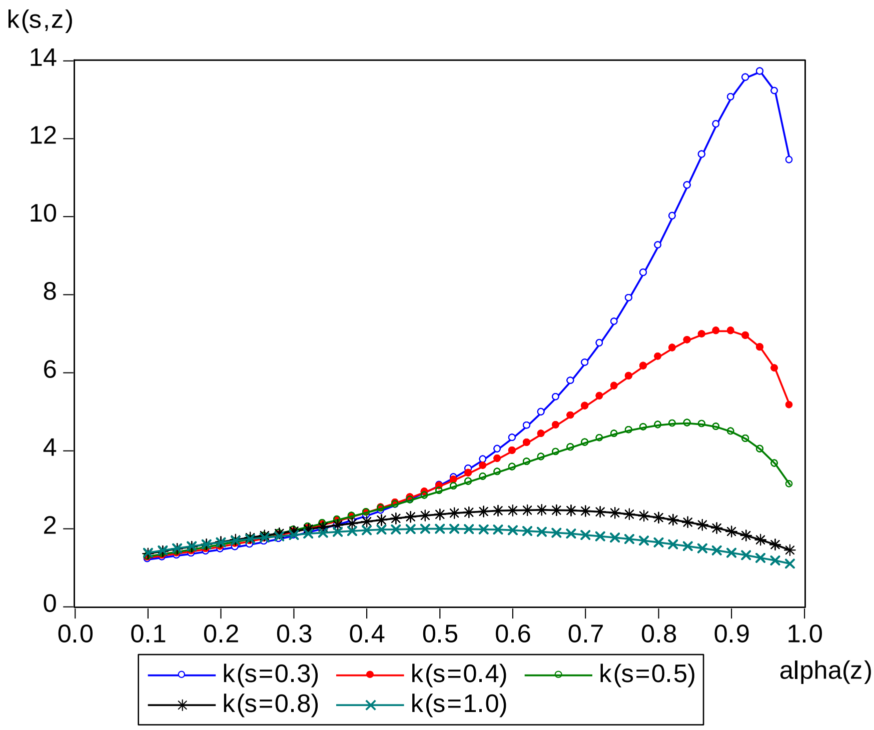

Figure 1 Stimulation of $\kappa(s,z)$ by different levels of s.

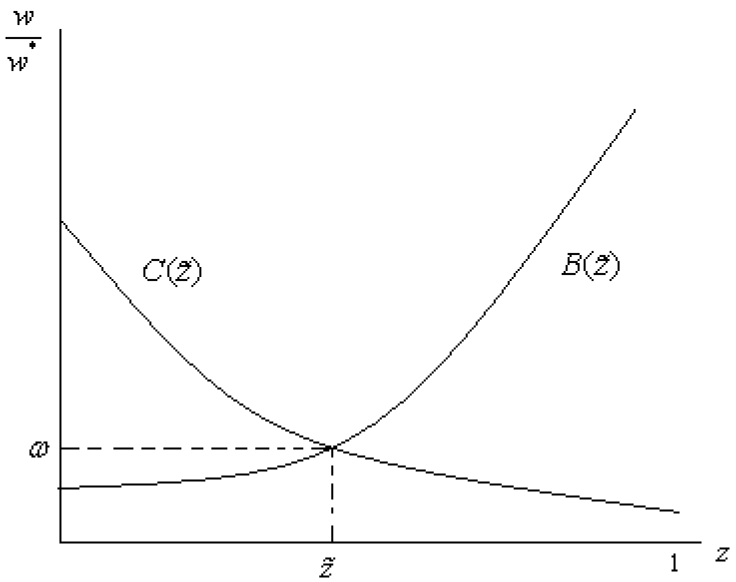

Figure 2 Equilibrium