Management for a Variety of Environmental Pollution and North-South Trade

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Management for a Variety of Environmental Pollution and North-South Trade

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Abstract

A simple static model incorporating a variety of environmental pollution is developed. An autarky model shows that a developing country regulates fewer types of pollution by income-induced environmental policy. As income grows, the types of regulated pollution increase and also introduced regulations become tougher. Then the model incorporates international trade between a developed country and a developing country. The model gives a new interpretation for the pollution haven hypothesis. Some types of pollution abated with inefficient technology are emitted more in a developing country but other types necessarily increase in a developed country in order to meet the trade balance.

Keywords: pollution, trade, a developing country
JEL classification: F11, O11, Q25

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The Institute of Developing Economies (IDE) is a semigovernmental, nonpartisan, nonprofit research institute, founded in 1958. The Institute merged with the Japan External Trade Organization (JETRO) on July 1, 1998. The Institute conducts basic and comprehensive studies on economic and related affairs in all developing countries and regions, including Asia, Middle East, Africa, Latin America, Oceania, and East Europe.

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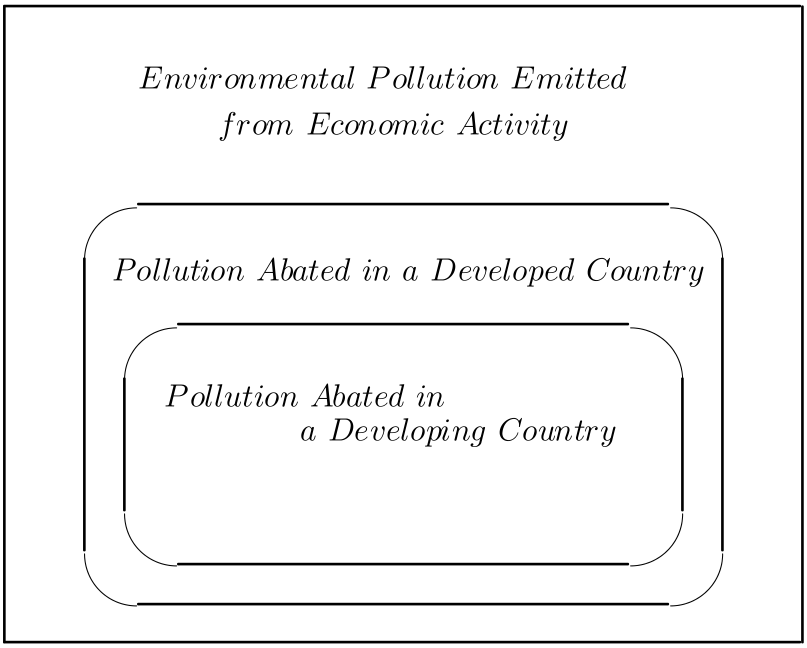
1 Introduction

The interaction between income and the environment on a macro level has undergone intensive examinations since 1990s[Grossman and Krueger(1992), World Bank(1992)]. The common approach among the empirical studies is to look at different pollution indicators one by one and to examine their correlations with income along with other variables. It clips a single type of pollution from a variety of pollution and regresses each on these variables independently. Among the empirically shown, are found monotonically increasing/decreasing or inverted-U-curve relationships between income and various types of pollution. The last relationship is frequently referred as the Environmental Kuznetz Curve(EKC). The clipping-a-single-pollution approach is adopted partly because the departure of these studies is to find out if a certain relationship and a turning point exists for each pollution, moreover, if it is robust. And it is also because these studies depend on reduced forms where each pollution level is endogenously determined by income leaving its mechanism unknown. An EKC relationship attracts attentions to draw policy lessons how to curb increasing pollution and to predict when to have a turning point. Following the clipping approach in the empirical studies, theoretical studies attempt to show mechanisms for EKC[Selden and Song(1995), John and Pecchenino(1994), Stokey(1998)]. They replicate the EKC relationship for a single representative pollution indicator. This paper argues that this clipping-a-single-pollution approach may lead to narrowing the scope of the interaction between a variety of pollution as a whole and income. Looking at various pollution indicators at a certain level of income, there are some indicators starting to improve while others still deteriorating. Improvement of environmental quality through abatement is achieved by environmental regulations and their enforcement. Shafik(1994) argues pollution without local impacts such as carbon dioxide hasn't been regulated, while pollutants with obvious and local impacts such as sulfur have been subject to regulation. The different relationships between various pollution and income has been explained as such. On the other hand, even for pollution with local impacts, there are some that are not yet effectively regulated at certain levels of income. Panayotou(1995), Selden and Song(1994) and Cole et al.(1997) find a common pattern for turning-point income levels for the pollution with inverted-U curves although their estimated levels vary. Turning points for sulfur dioxide are observed at lowest income levels, then those for small particulate matters and nitrogen oxide as next. The result shows that as income increases, more types of pollution pass turning-points and enter decrease phases. Obviously, regulations are not enforced uniformly across various pollution. It is of our interest at which level of income regulation for a given type of pollution start to be enforced and how the regulation relates to those for the other types. By comparing the pollution problems in developing and developed country, the following observation can be made. Developing countries face many types of pollution problems as in developed countries. A list of pollutants starts from conventional pollution of air and water to newly created toxic chemicals and to pollution causing damage beyond national borders. There are pressing needs to abate various types of environmental pollution in order to achieve sustainable development. Both developed and developing countries have adopted more or less similar ambient or emission standards following the standards recommended by, for example, WHO[WHO(1999)] with health consideration. However it is often observed that regulations are not well enforced in developing countries[ADB(1993)]. Accordingly, health problems and damages for production sectors heavily depending on the environment occur due to illegal release of pollution more frequently in developing countries. Some pollution is loosely regulated and others are left unregulated on an effective basis. From the observation, it can be hypothesized that the number of effectively regulated types of pollution is positively correlated with income levels. Figure 1 shows this relationship between a variety of effectively regulated and therefore abated pollution in a developing country and a developed country.



(Figure 1)

How the environmental regulations for a variety of pollution are set as income increases has not directly tested empirically. However an evidence for our hypothesis can be found in Dasgupta et al.(2001). They investigate the relationship between income and implementation of regulations for various environmental indicators by using 31 countries' data. They show regulations are implemented firstly for natural resource, then water pollution and finally air pollution. It implies more types of environmental indicators enter the regulatory framework. They also show that the regulations are tightened as income increases.

By focusing on a single type of pollution, a mechanism is not shown why some pollution worsen while others improve, moreover, how they relate to each other. This paper attempts to look at the environment-income relationship from a different perspective from previous theoretical studies. We will show that by facing various pollution problems, an economy decides which types of pollution to be abated and which types not to be abated depending on their effects on utility and their abatement costs for firms at each level of income.

The first goal of this paper is to present a simple static model consistent with those evidence and to investigate their determinants. How regulatory frameworks for various pollution evolve as income increases are also examined. For previous theoretical studies dealing with the environment and income, it is common to use a representative or a composite environmental indicator. Differences and correlations among various pollution haven't attracted much attentions. In section 2, we attempt to develop a static model for an economy in autarky to show how an economy allocates resources among abatement of various pollution as income increases. We also examine factors affecting emission levels for various pollutants. Consumers' and firms' behavior can explain the observed phenomenon. A consumer is eager to have regulations on pollution with serious impacts on people's lives as long as the amount by consumption that need to be sacrificed is affordable. They prefer to abate pollution with less impacts after dealing with more serious problems and being afford to treat other problems. Regulating pollution benefits consumers. The benefits differ depending on types of pollution since each pollution has a different emission scale as well as different toxicity. Consumers gain significantly by abating highly toxic pollutants with larger emission scales. On the other hand, the same regulations burden firms as they need to reallocate the resource from goods production to pollution abatement. Firms are pressured to start abating pollution by society. Since various types of pollution are emitted from diversified production processes for a variety of goods, firms' abatement costs vary among the types of pollution. Upon deciding how much burden firms can share to abate various pollution, abatement costs that are different among various pollution matter. The government faces trade-offs between benefits and costs that evolve as income rises and chooses to either unregulate or regulate each type of pollution. For regulated pollution, it decides the strictness of regulation. These factors create the differences in regulating various pollution depending on income levels.

For the second goal, international trade between two countries, namely a developed and a developing country, is incorporated. When both countries emit the same set of pollution, how will their composition change through trade and relocation of firms? One argument about trade and the environment is upon opening up an economy to join free trade, dirty industries may move out of developed countries that set tougher environmental regulations to developing countries. This argument claiming free trade increases pollution in developing countries is often called the pollution haven hypothesis. Another argument follows the comparative advantage theory and suggests that capital intensive industries often categorized as dirtier industries move from labor-abundant developing countries to capital-abundant developed countries. This argument instead claims pollution increase in developed countries. Empirical studies have not drawn a conclusion about which of these arguments apply. Grossman and Krueger(1993) shows that joining NAFTA decrease the levels of pollution through a rise in income. On the other hand, Jaffe et al.(1995)

concludes that environmental regulations don't have much effects on competitiveness for industries. In these empirical studies, any available pollutants are picked and tested if they increased after trade liberalization. The trade model with a variety of pollution developed in this paper suggests that the direction of shifts in various pollution isn't a one way from a developed country to a developing country but it is two ways depending on the types of pollution.

The model with a variety of pollution in section 2 is extended to incorporate trade between developed and developing countries in section 3. A developing country becomes a pollution haven through income-induced trade in Copeland and Taylor(1994) where a single type of pollution matters. When a variety of goods emit different types of pollution, free trade affect not only pollution levels but also the composition of various pollution. Two-country trade model enables us to investigate factors affecting firms' decision where to locate and hence how to create a change in pollution composition. It will be shown that some types of pollution are emitted more in a developed country rather than a developing country. The pollution haven hypothesis occurs in a sense that those types of goods emitting pollution that requires costly abatement technology move to a developing country but others rather move to a developed country.

Analysis in this paper is confined to pollution that causes damage within the boundary of country. Pollution is assumed to be dispersed in a short-term and it is treated as flow. It is also assumed that developed and developing countries have the common variety of industries as well as the common variety of pollution. There are no enforcement problems so that all the firms comply with the environmental regulations. Both section 2 and 3, we focus on income-induced changes in environmental regulations and other parameters related to technology or tastes are assumed same between developed and developing countries.

2 Income and a Variety of Pollution

2.1 The Closed-Economy Model

A static model for a closed economy is developed. The purpose of this model is to show the relationship between income and income-induced endogenous regulations for a variety of pollution. It is derived as an outcome of rational behaviors by economic agents and it is consistent with what was described above. Factors affecting the level of various pollution are also examined. An important feature of this model is to consider various types of pollution that have different impacts on utility and also require different abatement technology because they are emitted from various production processes.

There are a variety in consumption goods indexed by $z = 1 \sim Z$ and a single factor of production, labor. The economy has L population. Goods for each industry is manufactured by labor with a common constant returns-to-scale technology. Different industries produce different goods with different technology. Various types of pollution are emitted from production of goods, hence, there are a variety of pollution. We assume only one type of pollution that is unique to each industry is emitted to simplify matters[1]. Therefore, our model has as many types of pollution as a variety of goods. Accordingly,

[1] This assumption may be too restrictive as generally multiple types of pollutants are emitted from a single production process.

pollution is indexed by $z = 1 \sim Z$.

$$y_z = \lambda_z l_z v_z \tag{1}$$

y_z is output of goods z produced by effective labor l_z. Effective labor is a measure of workers on effectiveness basis. Each worker has effectiveness A where $A > 0$ and total effective labor for the economy is AL. λ_z is productivity which varies across goods. A firm can undertake two distinct activities, which are production of a single type of goods and abatement of pollution emitted from its production process. Firm z is endowed with technology or a set of available techniques $v_z \in [0, 1]$ for all z. By choosing techniques, levels for both production and pollution abatement are determined. v_z closer to zero means more pollution abatement and less production of goods. v_z closer to one is more production but less abatement. Let output when all the effective labor is allocated to producing goods as potential output. When a dirty technique $v_z = 1$ is used, potential output $\hat{y}_z = \lambda_z l_z$ is produced and no pollution abatement is conducted given the level of effective labor. d_z is pollution emitted from goods z production.

$$d_z = l_z \phi_z(v_z) = \frac{\hat{y}_z \phi_z(v_z)}{\lambda_z} \tag{2}$$

ϕ_z has a different functional form for each z. Assume $\phi_z(0) = 0$, and $\phi_z'(0) = 0$. For $v_z > 0$, $\phi_z'(v_z) > 0$ and $\phi_z''(v_z) > 0$. d_z is increasing in v_z. For $v_z = 1$, $\phi_z(1) = 1$ then $\phi_z'(1) = \gamma_z < \infty$ for all z. The pollution function is specified as follows.

$$d_z = \frac{\hat{y}_z v_z^{\gamma_z}}{\lambda_z} \tag{3}$$

γ_z is an abatement efficiency coefficient where $1 < \gamma_z < \infty$. Larger γ_z means the abatement technology for pollution z is more efficient.

If firms are unregulated, they do not have an incentive to abate pollution and they would always set $v_z = 1$. We assume that a benevolent government chooses a level of regulation for pollutant z in order to maximize social welfare and requires firm z to apply a production technique v_z. We also assume there are no enforcement problems so that all the firms comply with the government regulations. Under this circumstance, firm z maximizes profits given v_z for all z. This model with multiple products and multiple types of pollution can be viewed as an extension of Stokey(1998) as well as Copeland and Taylor(1994)[2].

There are L consumers indexed by i where $i = 1 \sim L$. Each consumer is endowed with 1 unit of labor or A unit of effective labor. All the consumers have the same utility function.

$$\sum_{z=1}^{Z} u_z(x_{zi}) - \sum_{z=1}^{Z} h_z(d_z) \tag{4}$$

4 is a utility function for a representative consumer. Assume utility function is strongly separable with respect to consumption and pollution. A consumer gains utility from consuming Z different types of goods and suffers from disutility from Z different types of pollution. For utility from consuming goods u_z, assume $u_z'(x) > 0$, $u_z''(x) < 0$, $\lim_{x \to 0} u_z' = \infty$. For disutility from pollution h_z, assume $h_z'(d_z) > 0$, $h_z''(d_z) > 0$ and $\lim_{d_z \to 0} h_z'(d_z) = 0$.

Each type of pollution and consumption goods has a different impact on consumer's utility through $u_z(x_{zi})$ and $h_z(d_z)$ respectively. Note that consumption

[2] In Copeland and Taylor(1994), each good is produced with labor and pollution as inputs by joint-production function.

goods x_{zi} is private goods and pollution d_z is public goods.

$$\sum_{z=1}^{Z} \beta_z \ln(x_{zi}) - \sum_{z=1}^{Z} \frac{d_z^{\alpha_z}}{\alpha_z} \tag{5}$$

where

$$\sum_{z=1}^{Z} \beta_z = 1 \tag{6}$$

A consumer i where $i = 1 \sim L$ maximizes utility in terms of variety of consumption goods under an income constraint given prices of goods and wage. Each consumer is endowed with a unit of labor or A effective labor. Wage for effective labor is ω and wage for labor is W where $W = A\omega$. The level of pollution is public goods and each consumer cannot choose pollution levels by themselves. Therefore, a consumer maximizes utility by choosing a consumption bundle under a budget constraint given by $I_i = A\omega \geq \sum_{z=1}^{Z} x_{iz} p_z$ for all i. By adding the consumption bundles over L consumers by $x_z = \sum_{i=1}^{L} x_{iz}$, demand for goods z of a country is obtained. $\beta_z AL$ effective labor is allocated for goods z. Output for goods z is,

$$x_z = \hat{y}_z v_z = \lambda_z \beta_z A L v_z \tag{7}$$

The potential output is,

$$\hat{y}_z = \lambda_z \beta_z A L \tag{8}$$

2.2 Endogenous Environmental Regulations for a Variety of Pollution

Given consumers' and firms' behavior, a government as social planner maximizes social welfare by choosing pollution abatement level v_z for all z.

$$\sum_{z=1}^{Z} \beta_z \ln(\hat{y}_z v_z) - \sum_{z=1}^{Z} \frac{(\hat{y}_z v_z^{\gamma_z})^{\alpha_z}}{\alpha_z \lambda_z^{\alpha_z}} \tag{9}$$

If $v \in [0, 1)$, then regulations are introduced and pollution is abated. Otherwise, regulation is not introduced and no abatement activity is conducted by firms.

$$v_z = \begin{cases} \left[\frac{\beta_z^{1-\alpha_z}}{\gamma_z (AL)^{\alpha_z}}\right]^{\frac{1}{\alpha_z \gamma_z}} = \left[\frac{\beta_z \lambda_z^{\alpha_z}}{\gamma_z \hat{y}_z^{\alpha_z}}\right]^{\frac{1}{\alpha_z \gamma_z}} & if\ \hat{y}_z^{th} < \hat{y}_z \\ 1 & if\ \hat{y}_z \leq \hat{y}_z^{th} \end{cases} \tag{10}$$

$v \in [0, 1)$ is an interior solution and marginal utility from consuming goods z is equal to marginal disutility from pollution emitted from goods z. For $v = 1$, marginal utility from goods z is larger than disutility, therefore, regulation is not introduced and abatement is not conducted. v_z where $v_z < 1$ is a monotonically decreasing function of potential output $\hat{y}_z$ as $\frac{\partial v_z}{\partial \hat{y}_z} < 0$. The larger the potential output becomes, the severer the regulations are set. Let $v_z(\hat{y}_z^{th}) = 1$ where $\hat{y}_z^{th}$ is a threshold output for introducing regulation. $\hat{y}_z^{th} = \left[\frac{\beta_z \lambda_z^{\alpha_z}}{\gamma_z}\right]^{\frac{1}{\alpha_z}}$ is derived from our specification.

Given labor effectiveness A, it is optimal for the government to regulate the types of pollution whose levels of potential output exceeds the threshold output. After regulations are implemented where $v_z < 1$, from $\frac{\partial v_z}{\partial \beta_z} < 0$, the higher the budget share allocated to a type of goods, the severer the regulation for pollution from the goods' industry is set.

Now suppose there are a developed country(with asterisk $*$) and a developing country. They have the same size of population $L = L^*$ and are endowed with the same preference and production technology. Only difference is the level of effectiveness of labor A where $A^* > A$. $\frac{\partial v_z}{\partial A} < 0$ for $v \in [0, 1)$ shows that regulation is severer in a developed country. Following proposition is about comparison of the number of regulations introduced for a developing country and a developed country.

Proposition 1 *The types of abated pollution are fewer in a developing country than in a developed country.*

PROOF. Let denote a developed country and a developing country with and without asterisk, respectively. Let S^* and S be a set for types of products manufactured by production technology accompanied by pollution abatement. $S = \{z; 0 \leq v_z < 1\}$ for a developing country and $S^* = \{z; 0 \leq v_z^* < 1\}$ for a developed country. From 10, we know for $z \in S$, v_z and v_z^* is a monotonically decreasing function of a potential output for a developing country $\hat{y}_z$ as $\frac{\partial v_z}{\partial \hat{y}_z} < 0$ and for a developed country $\frac{\partial v_z^*}{\partial \hat{y}_z^*} < 0$ for all z. This also enables us to write $S = \{z; \hat{y}_z^l < \hat{y}_z\}$ and $S^* = \{z; \hat{y}_z^l < \hat{y}_z^*\}$ where $\hat{y}_z^l$ is a threshold for the lowest level of potential output to start pollution abatement in industry z and it is common for both countries. From 8, $A < A^*$ implies $\hat{y}_z < \hat{y}_z^*$ for all z. In order to show that the number of types of goods whose production process is regulated are more in a developed country, we will show when $A < A^*$, then $S \subset S^*$ by contradiction. Suppose $S^* \subseteq S$ then there exists z' such that $z' \in S$ and $z' \notin S^*$. This implies that $\hat{y}_{z'}^l < \hat{y}_{z'}$ and $\hat{y}_{z'}^* < \hat{y}_{z'}^l$, therefore, $\hat{y}_{z'}^* < \hat{y}_{z'}$. By definition, $\hat{y}_{z'}^* > \hat{y}_{z'}$.QED

An interior solution for v is shown in Figure 1. It is derived by using 9 and they are a marginal utility curve and a marginal disutility curve in terms

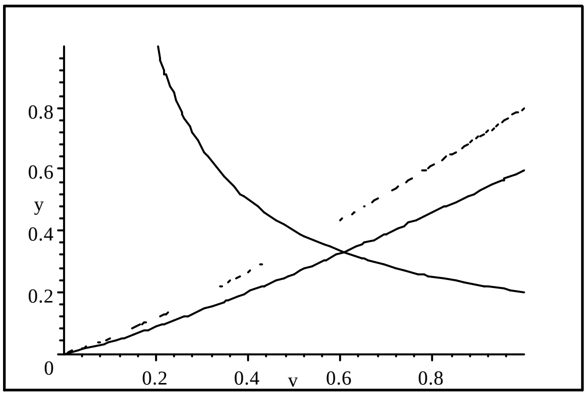


Fig. 1.

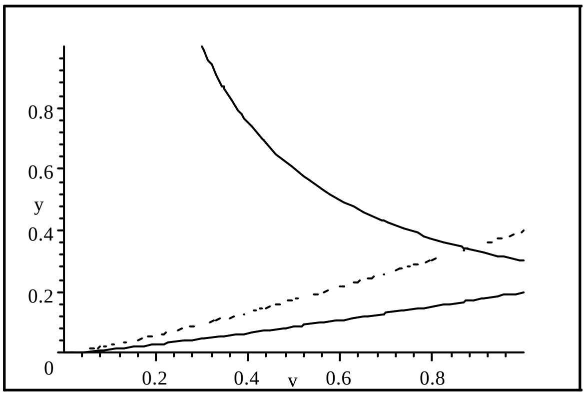


Fig. 2.

of v given fixed A. A downward curve with solid line is marginal utility for consumption and show marginal utility becomes lower by using dirtier technique. An upward curve with a dotted line is the marginal costs and shows marginal disutility becomes higher when applying dirtier techniques. A dotted line stands for the case of a rise in effectiveness of labor A. When A gets large, the marginal costs curve shift up and v declines. It should be noted that a change in A doesn't shift the marginal utility curve.

A corner solution is shown in Figure 2 with a solid line. After A increases, the marginal costs curve shift up and v becomes an interior solution meaning environmental regulation for the pollution is introduced. This graph intuitively shows more types of pollution enter regulatory framework by moving from corner solutions to interior solutions as income grows.

2.3 Changes in Composition of Pollution Emissions and Composition of Goods

After v_z is determined, optimal pollution emitted from industry z is derived as follows.

$$d_z = \begin{cases} \left(\frac{\beta_z}{\gamma_z}\right)^{\frac{1}{\alpha_z}} & if\ \hat{y}_z^{th} < \hat{y}_z \\ \beta_z AL & if\ \hat{y}_z \leq \hat{y}_z^{th} \end{cases} \tag{11}$$

Without regulations, all the types of pollution are emitted in proportion to effective labor allocated to the corresponding industries. Once regulations are introduced then abatement activities are conducted for some industries, the composition of pollution will change. With regulations, the levels of pollution emission are not affected by the size of economy. Comparative statics for regulated pollution suggests that optimal pollution levels are affected by abatement efficiency of technology, demand for the goods emitting the pollution and emission impacts on utility. From $\frac{\partial d_z}{\partial \gamma_z} < 0$, the optimal pollution emission from a industry treated with efficient abatement technology is lower. It suggests that abatement costs for the goods with higher γ_z is lower so that optimal pollution level is lower given other parameters are equal. According to $\frac{\partial d_z}{\partial \beta_z} > 0$, for any regulated pollution, the larger the budget share for goods z (larger β_z), the more pollution is emitted from goods z. For any regulated pollution z, when disutility of pollution z gets bigger(larger α_z), the pollution emission from goods z becomes lower.

$$x_z = \begin{cases} \hat{y}_z v_z & if\ \hat{y}_z^{th} < \hat{y}_z \\ \hat{y}_z & if\ \hat{y}_z \leq \hat{y}_z^{th} \end{cases} \tag{12}$$

At equilibrium, production of those goods emitting pollution that are regulated tightly decline. Therefore, demands for those goods are lower.

3 Patterns of Industrial Location, Trade and Environmental Pollution

3.1 The model

We suppose the world is comprised with two countries, a developed country(with asterisk $*$) and a developing country. The purpose of this model is to see how income-induced regulations for types of pollutions affect location of firms then change trade and pollution patterns. Assume population between two countries are the same $L = L^*$ and no migration of labor is occurred. Also assume labor efficiency in a developed country is higher than in a developing country where $A^* > A$. Preferences over a variety of goods and pollutions are the same for two countries. Both countries are endowed with the same production technology for all types of goods. Assume all the goods are tradable and there are no transaction costs. In the previous section, we consider the problem whether a type of pollution is regulated or not by looking at whether interior solutions for v can be found or found corner solutions of $v = 1$. In this section we assume all the pollution are regulated and interior solutions can be found for both countries in order to avoid complexity arose by dealing with corner solutions.

The problem for a developing country is a reciprocal so that we present it in a developed country's case. A consumer decides the consumption bundles given wages and international goods' prices. Demand for goods z_z for a developed country is found to be $p_z x_z^* = \beta_z I^*$. Firms maximize profits given prices, wages and techniques regulated by the government. The government's problem is to choose production techniques v_z for all types of industries to maximize the following welfare function 13 taking as given consumer and producer behavior. The government treats international prices for a variety of goods as given.

$$\sum_{z=1}^{Z} \beta_z \ln\left(\frac{\beta_z I^*}{p_z}\right) - \sum_{z=1}^{Z} \frac{(l_z^* v_z^{*\gamma_z})^{\alpha_z}}{\alpha_z} \tag{13}$$

Where $I^* = W^* L^* = \sum_{z=1}^{Z} p_z \lambda_z l_z^* v_z^*$ and $W^* = A^* \omega^*$

By maximizing this indirect utility with respect to v_z, an optimal technique for production of goods z is determined by,

$$v_z^* = \left(\frac{\lambda_z \beta_z p_z l_z^{*1-\alpha_z}}{\gamma_z I^*}\right)^{\frac{1}{\alpha_z \gamma_z - 1}} \tag{14}$$

The government sets a production technique v_z by equalizing marginal utility loss from the lower consumption of goods z by using a cleaner technique and marginal utility gains from pollution reduction by using the technique. The marginal rate of substitution of good z for pollution z is decreasing so that optimal production technique v is not lowered as pollution z increases. Since all types of pollution are normal goods, production technique becomes cleaner as income rise.

3.2 Trade Equilibrium

Three types of equilibrium should be achieved for free trade between two countries. Firstly, a unit cost c_z between developed and developing countries will be equalized through trade. Secondly, the world demand for each goods must be met with the world supply. Finally, trade for both countries need to be balanced. Meeting these conditions yields an equilibrium wage ratio for two countries.

Firms move from one country to another in order to lower production costs until their relocation sufficiently raise costs in the country to stop the incentive to move. Therefore, a unit cost of production is equalized between two countries at equilibrium for all goods.

$$c_z^* = \frac{C_z^*}{y_z^*} = \frac{\omega^*}{\lambda_z v_z^*} \tag{15}$$

Or a firm in industry z sets price of goods equal to costs.

$$p_z = \frac{\omega}{\lambda_z v_z} \tag{16}$$

16 suggests that an increase in international prices of goods let a country to use cleaner production techniques.

Given an international price p_z, we obtain by taking ratio,

$$\frac{\omega}{v_z} = \frac{\omega^*}{v_z^*} \tag{17}$$

A tougher regulation that is equivalent to a lower v_z will raise costs of a unit effective labor allocated to production activities. If $\frac{\omega}{v_z} > \frac{\omega^*}{v_z^*}$ that implies regulatory costs in a developed country is lower, production of goods z will shift to a developed country. Conversely, firms producing goods z will shift its production process from a developed to a developing country if $\frac{\omega}{v_z} < \frac{\omega^*}{v_z^*}$. Implication of 17 is that firms in industry z will keep reallocating until wages for a unit of effective labor allocated for producing goods z are equalized between two countries.

From 14 and 16,

$$\frac{l_z}{l_z^*} = \left(\frac{A}{A^*}\right)^{\frac{\alpha_z\gamma_z - 1}{1-\alpha_z}} \left(\frac{W}{W^*}\right)^{\frac{\alpha_z\gamma_z}{1-\alpha_z}} \tag{18}$$

For the second equilibrium, the world demand needs to be met by the world supply.

$$\beta_z(I + I^*) = p_z\lambda_z l_z^* v_z^* \left(\frac{l_z}{l_z^*}\frac{v_z}{v_z^*} + 1\right) \tag{19}$$

Combining 17, 18 and 19, values of goods z produced in a developed country is derived.

$$p_z\lambda_z l_z^* v_z^* = W^*\beta_z L\Psi_z^* \tag{20}$$

where Ψ_z^* is,

$$\Psi_z^* \equiv \frac{\frac{W}{W^*} + 1}{\left(\frac{W}{W^*}\right)^{\frac{1-\alpha_z+\alpha_z\gamma_z}{1-\alpha_z}} \left(\frac{A^*}{A}\right)^{\frac{\alpha_z(\gamma_z-1)}{1-\alpha_z}} + 1} \tag{21}$$

The value of goods produced in a developed country depends on Ψ_z^* that is the share of domestic supply to domestic demand. 21 implies $\Psi_z^* > 0$. The value of goods z output in a developed country is $\beta_z LW^*\Psi_z^*$. Since the value of demand for goods z is $\beta_z I^*$, output of goods z in a developed country will be exported if it is larger than the domestic demand. Conversely, goods z will be imported if domestic demand cannot be fulfilled by domestic supply. Ψ_z^* is a domestic supply share for a unit domestic demand. If $\Psi_z^* < 1$, domestic supply is not enough to meet domestic demand so that imports of the goods are needed. On the contrary, $\Psi_z^* > 1$ implies domestic supply exceed domestic demand so that the goods are exported. $\Psi_z^* = 1$ is the case for no trade. For example, $\Psi_z^* > 1$ is equivalent to $\left(\frac{W}{W^*}\right)^{\frac{1-\alpha_z+\alpha_z\gamma_z}{1-\alpha_z}} \left(\frac{A^*}{A}\right)^{\frac{\alpha_z(\gamma_z-1)}{1-\alpha_z}} > \frac{W}{W^*}$ and it can be checked as follows.

(1) $\Psi_z^* < 1$ case: A developed country imports goods z from a developing country.

$$\left[\left(\frac{\omega}{\omega^*}\right)^{\gamma_z}\left(\frac{A}{A^*}\right)\right]^{\frac{\alpha_z}{1-\alpha_z}} < 1 \tag{22}$$

(2) $\Psi_z^* = 1$ case: No trade occur between two countries.

$$\left[\left(\frac{\omega}{\omega^*}\right)^{\gamma_z}\left(\frac{A}{A^*}\right)\right]^{\frac{\alpha_z}{1-\alpha_z}} = 1 \tag{23}$$

(3) $\Psi_z^* > 1$ case: A developed country export goods z to a developing country.

$$\left[\left(\frac{\omega}{\omega^*}\right)^{\gamma_z}\left(\frac{A}{A^*}\right)\right]^{\frac{\alpha_z}{1-\alpha_z}} > 1 \tag{24}$$

Trade will definitely occur at least for some goods because 23 cannot hold for all z. The cases that one country imports/exports all types of goods are also impossible because trade balance is not met. In this model, both countries produce all types of goods and they don't give up producing any types of goods. A condition for trade balance is $\frac{\omega}{\omega^*} > 1$. An unique $\frac{\omega}{\omega^*}$ is determined as in proposition below. From 17, $\frac{\omega}{\omega^*} > 1$ means $\frac{v}{v^*} > 1$ and regulations are tougher in a developed country for all z. As pollution regulations are tougher in a developed country, more effective labor is allocated to abatement activities. This will bring down the effective wage in a developed country. By 19, the world demand and supply match so that the arguments above apply for a developing country in a reciprocal way.

Proposition 2 *For goods produced with relatively inefficient abatement technology (smaller γ), a developed country becomes an importer of goods. On the other hand, goods with efficient abatement technology are exported from a developed country.*

Proposition 3 *The traded value of goods z increases when pollution z has relatively less impacts on consumer(α_z is bigger).*

Two propositions are easily derived from 22 and 24. Proposition 2 suggests that the pollution haven hypothesis can be interpreted in a different way from the conventional understanding. Among a variety of pollution, some increase in a developed country and others increase in a developed country. Efficiency of abatement technology determines which pollution to increase in a developed or in a developing country. Production of goods with inefficient abatement technology increase in a developing country and goods are exported to a developed country. Production of other goods increase in a developed country. The pollution haven hypothesis claiming that pollution increase in a developing country doesn't apply for all types of pollution when there are a variety of pollution. But it holds in a way that those industries with relatively inefficient abatement technology increase their production and emission in a developing country, otherwise, pollution increase in a developed country. On the other hand, pollution's impacts on consumer's utility don't contribute to firms' relocation but it determines the size of trade. Trade value of goods are smaller when emitted pollution have more serious impacts on consumers'.

Third equilibrium condition is trade balance for both countries. From 20,

$$\sum_{z=1}^{Z} p_z \lambda_z l_z^* v_z^* = LW^* \sum_{z=1}^{Z} \beta_z \Psi_z^* \tag{25}$$

But the value of all the goods produced in a developed country is equal to total wages for domestic labor LW^*.

$$\sum_{z=1}^{Z} p_z \lambda_z l_z^* v_z^* = LW^* \tag{26}$$

25 and 26 implies,

$$\sum_{z=1}^{Z} \beta_z \Psi_z^* = 1 \tag{27}$$

This is the trade balance condition.

Proposition 4 *An equilibrium wage ratio* $\frac{W}{W^*}$ *is determined to satisfy 27.*

PROOF. According to 21, Ψ_z^* is a monotonically increasing function in $\frac{W}{W^*}$ for all z. Since 27 is constructed by taking weighted average of monotonically increasing functions Ψ_z^* for all z, it is a monotonically increasing function. Therefore equilibrium wage ratio $\frac{W}{W^*}$ is uniquely determined.

Given equilibrium wage $\frac{W}{W^*}$, 17 and 20 yields effective labor used for production of goods z.

$$l_z^* = A^* \beta_z L \Psi_z^* \tag{28}$$

Let y_{za}^* output for a closed economy then,

$$y_z^* = \lambda_z l_z^* v_z^* = \left(\beta_z \Psi_z^{*1+\alpha_z(\gamma_z - 1)}\right)^{\frac{1}{\alpha_z \gamma_z}} y_{za}^* \tag{29}$$

Opening an economy will change the environmental regulations, a composition of various pollution and goods. Given $\frac{W}{W^*}$, 14 and 16 yields production technique for an open economy v_z^* as a function of production technique for a closed economy v_{za}^*.

$$v_z^* = \left(\beta_z \Psi_z^{*1-\alpha_z}\right)^{\frac{1}{\alpha_z \gamma_z}} v_{za}^* \tag{30}$$

where v_{za}^* is for a closed economy case.

$$v_{za}^* = \left(\frac{\beta_z^{1-\alpha_z}}{\gamma_z (AL)^{\alpha_z}}\right)^{\frac{1}{\alpha_z \gamma_z}} \tag{31}$$

Proposition 5 *Environmental regulations under free trade are tougher for exported goods than in a case for a closed country. Especially, regulations for non-traded goods($\Psi_z^* = 1$) become severer for the case with free trade.*

PROOF. *Goods exported from a developed economy which is represented by $\Psi_z^* > 1$, $(\beta_z \Psi_z^{*1-\alpha_z})^{\frac{1}{\alpha_z \gamma_z}} < 1$ follows. Therefore v_z^* is smaller than v_{za}^*. For non-traded goods with $\Psi_z^* = 1$, $v_z^* < v_{za}^*$. QED*

The above proposition applies for a developing country, too. Export industries as well as industries for non-traded goods are regulated to use cleaner production techniques after joining free trade from autarky.

Demand for goods z is derived by using 30. It depends on an optimal production technique for free trade v_z^* and potential production $\hat{y}_{za}^*$ for a closed economy.

$$x_z^* = \frac{\beta_z I^*}{p_z} = \frac{v_z^*}{v_{za}^*} x_{za}^* = v_z^* \hat{y}_{za}^* \tag{32}$$

where demands for goods z in a closed economy is x^*_{za}.

$$x^*_{za} = \hat{y}^*_{za} v^*_{za} \tag{33}$$

32 suggests that domestic demand for goods with tougher regulations is lower. Low demand reflects higher goods' prices that have an inverse relationship with v as mentioned before. Therefore, types of goods that are exported or that are not traded will have lower domestic demands for an open economy compared to a closed economy. It is not determined if domestic demand for imported goods becomes larger for an open economy.

On the other hand, levels of pollution are

$$d^*_z = (\beta_z \Psi^*_z)^{\frac{1}{\alpha_z}} d^*_{za} \tag{34}$$

where d^*_{za} is an equilibrium pollution level for a closed economy.

Proposition 6 *For an open economy, pollution levels for all the goods will decrease.*

PROOF. *From 25 and 27,* $\beta_z \Psi^*_z < 1$. $d^*_z < d^*_{za}$ *holds for all* z.

This is an interesting conclusion. Gains from trade are not distributed to increase consumption but to lower the optimal levels of all types of environmental pollution.

Once effectiveness of labor change in an imbalanced way between two countries such that the share of $\frac{A}{A^*}$ change, it will change trade and production of goods through changing Ψ^*_z.

As shown in 25 and 27, $d_z < 1$ for all z, a larger α_z implies lower pollution emission. For a closed economy, optimal levels of pollution are equal to both countries irrelevant to the size of economy. By free trade, pollution in a country exporting goods z is relatively high and pollution in an importing country is lower even though the levels of emission for all types of pollution are lower than in a closed economy.

Potential output in a developed country for industry z, $\hat{y}_z^*$ is,

$$\hat{y}_z^* = \lambda_z \beta_z A^* L \Psi_z^* = \hat{y}_{za}^* \Psi_z^* \tag{35}$$

Therefore, Ψ_z^* determines the level of potential output for each industry. And the larger the demand from abroad $\Psi_z^* > 1$, the more the potential output for an open economy exceed that for a closed economy. The effective labor input for z follows.

$$l_z^* = A^* \beta_z L \Psi_z^* = l_{za}^* \Psi_z^* \tag{36}$$

4 Conclusion

This paper has presented a simple closed economy model to examine how a government regulates various types of pollution at each development stage by setting environmental policy. The model suggests that not only pollution regulations that have already introduced get tougher but also more types of pollution start to be regulated as income rises. Results show that environmental regulations are not introduced equally for all the types of pollution at equilibrium but by a step-by-step manner which is determined based on consumer's taste for goods and pollution as well as abatement technology.

The environmental policy changes the composition of pollution as well as the location of firms as income rises.

Then the model has incorporated international trade between a developed country and a developing country to show how trade between two countries affect composition of pollution and goods. Most important result with a setting of various pollution emitted from various goods is that the conventional pollution haven hypothesis doesn't hold because not all the types of pollution increase in a developing country. Instead, it has been shown that those types of pollution with relatively inefficient abatement technology increase in a developing country but those pollution with efficient abatement technology increase in a developed country. This is derived in order to meet the trade balance condition where each country needs to export some goods as well as imports other goods to balance their trade. The model contributes to propose a new interpretation about the pollution haven hypothesis. For those goods emitting pollution with more serious impacts on consumers, the direction of trade are not affected but trade values shrinks.

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