Pollution Haven Hypothesis and Trading Partners[1]

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<Abstracts>

2009 Copenhagen Climate Summit reveals the conflicts in environment protection implementation among developed, developing and under developed countries. It seems that each country fears for the loss of its industry because of strong environment regulation. So it is right time to shed the rights on the pollution haven hypothesis, again. The empirical studies of the pollution haven hypothesis are still indecisive. In this article, we argue that the pollution haven hypothesis is a specific example of general location theory and we provide one explanation why the empirical results are so mixed by using newly developed two way spatial sorting theory suggested by the seminal work of Okubo and Rebeyrol(2006). The information about market size, transportation costs and regulation gap must be considered and the choice of host and counter part country in empirical setting can provide a strategy for the identification of the pollution haven.

Key Words : pollution haven hypothesis, two way spatial sorting, Allerano-Bond estimation

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1. Introduction

Even though all countries which participated in 2009 Copenhagen Climate Summit agree to regulate the green house gas emission, there is no formal consent among nations to do that. The background of this dissensus is closely related to an economic motive. One hand, since the developing or under-developed countries worry about the raise of production cost due to the strict environmental regulation and that this would hurt the competitiveness of their products in the world market, they are not willing to bear economic burdens caused by stringent environmental policy. The other hand, the developed countries worry about the job loss in their countries because the companies with heavy burden of pollution abatement would try to change their location sites in the country with loose environmental regulation to save the production costs. The conflict between them makes difficult the consent about the strict environment regulation implementation among nations.

To check the effect of strengthen of environment regulation on an economy, researchers have focused on the arguments of both sides. The one issue which is related to the former argument is, so called, “Porter hypothesis.” And another issue related to the latter argument is “pollution haven hypothesis.” Porter hypothesis argues that the strict environmental regulation inspires the innovation and this innovation will enhance the international competitiveness of the company[3]. Pollution haven hypothesis explains that the change of production sites or the composition change of goods trading is caused by the degree of environment policy implementation and finally the country with loose environmental regulation provides a haven or becomes a main exporter of the pollution intensive industry products[4]. The interest thing is that there are no enough empirical proofs for the both arguments. So it is not easy to support one of both arguments. However, while Porter hypothesis asks for the formal expression of innovation creation path, pollution haven hypothesis can be interpreted with traditional standard economic framework. In this article, we discuss about the pollution haven hypothesis.

There are many researches about the pollution haven hypothesis in view of both theory and empirical study. However, even though there are many studies, the clear proof for the existence of pollution haven has not provided. Since pollution haven is intrinsically the aggregated result of independent heterogeneous each individual location choice decision, it is not easy to identify it. So many researchers consider these heterogeneous characteristics in their empirical and

[3] Porter and van de Linde (1995)

[4] Copeland and Taylor (2003)

theoretical settings. Sometimes it is successful, sometimes is not. Why do we observe these results even though we try to control the heterogeneity?

One possible idea to answer for the above question is that the pollution haven hypothesis can be derived from a standard model of location choice or international trade. That is, the pollution haven phenomenon is a common feature of location choice which is interpreted in view of the environmental policy effect. When we remind that market size, transportation cost and production costs are important factors to explain the location decision, the above idea suggests that we need to consider demand side factors such as market size and transportation costs in a region in the explanation of the pollution haven hypothesis phenomenon. In this article, we discuss the conditions for a country to provide pollution haven when we consider the effect of environment policy stringency on the location decision with the market size and transportation cost.

And then we set up the empirical ground to identify the effect of environmental policy stringency on the net import. To estimate the direct location choice, we need time series of individual firm data. But it is very difficult to collect individual data especially related to the location change. Therefore, we assume that if companies gather together in a specific country, then the products which the companies make in the region be exported to other nations[5]. So we use net import data by industry to identify the effect of regulation stringency on the location choice. Then we can avoid the need for individual level data set. Next, the empirical set-up follows the suggestions of the model to identify the effect. But the estimation equation is not directly derived from the model itself. Since the individual data availability restricts the direct estimation of the effect, we estimate the model with indirect way to identify the effect. So an identification strategy which we hire is empirical setting itself. With this set-up we can find the effective conditions for being pollution haven which are suggested in the theory.

We discuss the literature in section 2 and introduce the model which explains the pollution haven hypothesis in view of location choice in section 3. Empirical findings are shown in Section 4. In section 5, we conclude.

II. Literature

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[5] Levinson and Taylor(2008) estimates the pollution haven hypothesis with the net import. This is based on the suggestion that the country with weak environment regulation has comparative advantage in the production of pollution intensive products. So, while the country with weak environment regulation exports the pollution intensive goods, the country with strong regulation imports those (Ederington et al., 2005).

In this section, we survey the literature in two directions. First one is about the location choice and second is about the pollution haven studies itself. As I mentioned in the introduction, since the pollution haven phenomenon is just a specific case of general location choice decision, we need to survey recently developed location choice theory which is used for the explanation of the pollution haven hypothesis.

New Economic Geography (NEG) model is a theory which explains the result of individual decision making, that is, the concentration of individual company in a region. So the implications from NEG model match well with the usage of aggregated data in empirical work. Initial NEG model is suggested by Krugman(1991), which is called core-periphery model. In this model, the decrease of production cost due to externality motivates individual companies to concentrate in a region. And this concentration of companies also brings production factors, for example, labor and capital into the same region. This again attracts many companies into the same region, too. This circular causality expands one region larger[6]. The main cause of attracting companies and production factors into the region is intrinsically market size. The larger market size is, the greater externalities are. That is, production costs including transportation costs decrease and the overall price level is decreased due to the enlarged number of production varieties in the region. However, the drawback of model is tractability of the effect, because there are complex nonlinear relationships due to functions in the model. Furthermore, it is not easy to identify which companies or industries move first into the region. So the model itself is not appropriate to explain the pollution haven phenomenon.

Martin and Rogers (1995) suggests the model with tractability, which is called Footloose Capital (FC) model. This model has following differences from Krugman's. First, while the owners of production factors can not change their location, only the capital, one of production factors, can be hired regardless of location. But the rewards of capital must be repatriated to the owner. Second, the capital is used for a fixed factor in the production process and 1 unit of capital is required for the production of 1 variety (product). These two assumption help to avoid non-linear type equilibrium but still many characteristics of Krugman's are maintained. This model can not explain the result of heterogeneous company behaviors, so still it is not enough to explain the pollution haven hypothesis.

Baldwin and Okubo (2006) introduce the heterogeneous firms within the NEG framework of

6 This process is well described in Balwin et al.(2003).

FC model. This can explain the quality of industry agglomeration in a region. That is, it shows that the lager market absorbs the firms with relatively high productivity into its region. It is called spatial selection effect. Further, they also show that the firms with relatively low productivity locating in small country do not change their location. And it is called one way spatial sorting. In their conclusion, however, it is difficult to look at the difference between heterogeneous firm model and homogeneous firm model in view of production concentration or so called the degree of the home market effect (HME)[7]. This idea is somewhat possible to be applied for the explanation of pollution haven hypothesis. But since there are no various results in the home market effect and this predicts that the smaller market could always work as a pollution haven. In reality, this is not.

Recently, the seminal work of Okubo and Rebeyrol (2006) suggests some useful concepts for the pollution haven studies. Basically, they develop the model of Baldwin and Okubo (2006). The main contribution of their work is that they consider country specific sunk costs or regulation costs in the choice of location. They argue that the consideration of country specific costs induces so called two way spatial sorting: while the firms with high productivity change its location from small to large country, the firms with low productivity from large to small. Furthermore, they can show that there exist reverse HME or anti HME. Reverse HME means that the location with the larger home market has a less than proportionately smaller manufacturing sector and anti HME means that the larger the size of home market, the less manufacturing sector. Actually, these conclusions match the reality well because even some countries with weak environment regulations does not provide pollution haven and whether a country is pollution haven or not depends on which country has which type of specific regulations or sunk costs. So we will provide the condition of country to be pollution haven with Okubo and Rebeyrol model in the next section.

<Tabe 1> Recent Empirical Researches about Pollution Haven Studies

Authors		Countries	Explanatory variables	Method
	Eskeland and Harrison(2003)	Mexico Morocco Côte d'Ivoire, Venezuela	production cost related variables, productivity related variables, market size, pollution abatement costs, etc…	GLS and Fixed Effect

[7] Home market effect is defined as "…*other things being equal, the location with the larger home market has a more than proportionately larger manufacturing sector and therefore also exports manufactured goods*. (Fujita, Krugman and Venables, 1999, pp.57)"

FDI		U.S. outward FDI		
	Elliot and Shimamoto(2008)	Japanese outward FDI ASEAN countries	production cost related variables, productivity related variables, economic growth rate, pollution abatement costs, etc…	GLS with Fixed Effects
	Zhang and Fu(2008)	Chinese regional in ward FDI	environmental policy stringency index, regional characteristics (including production cost and productivity related variables)	GLS with Fixed Effects
Inward FDI Location	Dean, Lovely and Wang (2005)	Chinese inward FDI location choice	agglomeration related variables, regional characteristics (including skilled labor distribution, road, telephone, number of firms, etc…), other regional economic variables, environmental levies	Conditional and Nested Logit
Net Imports	Ederington, Levinson and Minier(2005)	U.S. net imports OECD Non-OECD	human and physical capital, tariff, environmental cost	Fixed Effects
	Levinson, Taylor(2008)	U.S. net imports Mexico Canada	tariff, regional pollution measure (for instruments), pollution abatement costs	Fixed Effects with Instrument Variable Method.

There are several empirical papers about the pollution haven. However, as we mentioned before, the pollution haven hypothesis is indeterminate[8]. The empirical setting and methods in recent empirical papers are summarized in <table 1>. The empirical studies take three directions to check the pollution haven hypothesis. First is related to the foreign direct investment (FDI). Second is related to the location choice of inward FDI and the last is related to the estimation of net import function by industries. These articles suggest some common features for the identification of pollution haven. First, all researches consider the unobserved

[8] However, in the case of location choice of new plant, Jeppessen et al. (2002) show the negative effect of environment regulation on the location choice. They use meta-analysis of past 11 studies and argue that methodological specification is important to identify the effects.

effects of country or industries. Therefore, they use commonly panel approach to estimate the model. Second, except China case, all estimations are based on the bilateral relationships. So they estimate the model with each pair of countries; one country and its counter part. Based on these commons, the last paper (Levinson and Taylor, 2008) suggests two-stage approach or instrument variable method to control the endogeneity between the strength of regulation implementation and unobserved factors.

Even though they follow their scrutinized identification strategy to identify pollution haven hypothesis, it is curious how they select counterpart country in their bilateral settings (Eskeland et al., 2003; Eliott et al., 2008; Levinson et al. 2008). As <table 1> shows, it seems that researchers pick the country which is near to the host country and the countries with relatively less developed. Sometimes, instead of country itself, researchers pick the country group in which each country has similar characteristics in view of economic development stage (Ederington et al. 2005). However, we argue that the country selection in empirical setting itself can provide a clue for the identification of a specific effect. Since each country has different characteristics in view of market potential, distance from host country and institutions etc., those country specific attributes can affect the decision of location choice. Therefore, the country selection in estimation process can show different results in view of the pollution haven hypothesis. We investigate conditions for the country to be pollution haven theoretically in section 3 and, based on this theory, we propose prior information for the identification of pollution haven in empirical setting. And then, with this prior information, we choose the appropriate empirical method based on the suggestions of previous empirical literatures.

III. Conditions for the pollution haven

III.1. Home market effects and industry location

The seminal paper of Okubo and Rebeyrol(2006) deals with the effect of heterogeneous firms and country specific regulation on the industrial concentration of a region. Their model expand footloose capital model and suggest two way spatial sorting. In this section, we moderate their model to explain the pollution haven hypothesis. The theoretical setting of the model is as follows; there are two regions such as north and south. And two regions are identical in every side except market size. We assume that the market size of north is larger than the south's. These two regions engage in the production of agriculture and manufacture industry. While the market for agricultural products is complete competitive market, the market for manufacture products is monopolistic competitive markets. Let's assume that production factors are labor and capital. The total quantities of labor and capital over whole region are normalized to unity, 1. Both countries are endowed with identical relative factor supplies. One specific assumptions of FC model is introduced here. The supply of capital is not restricted to the space but the labor supply depends on the space. This means that labor is immobile factor and capital is mobile one. However, the owner of capital is not mobile. So if the residential place of capital owner and the employed place of capital are different, then the reward for the capital is repatriated to the residential place of capital owner.

On the production technology side, agricultural industry is in constant returns to scale phase and we assume that a unit labor is required to produce a unit agricultural product. Agricultural good is used as numeraire. We assume that the price of numeraire is 1. In manufacture industry, since we assume that it is in monopolistic competitive market, each manufacture produces its own variety. And, as a specific assumption for FC model, we assume that each variety requires 1 unit of capital as fixed factor and labor is used for the variable factor. The type of transportation cost is ice-berg type. If one unit of manufacture products is shipped to the other region, then only $1/\tau$ unit is arrived. So $\tau > 1$ units must be shipped to the other region to get 1 unit of product. And we assume that there is no cost for the transportation of agricultural product.

Utility function is defined as follows;

$$U = \mu \ln C_M + C_A, \qquad C_M = \left(\int_{\in \Theta} c_i^{1-1/\sigma} \right)^{1/(1-1/\sigma)} \tag{1}$$

C_M : consumption of composite differentiated varieties

C_A: consumption of agricultural products

Θ : set of varieties, σ : elasticity of substitution, $\sigma > 1$

The utility function is quasi-linear type with CES composite subutility of manufacture varieties consumption. If the value of σ approaches to the infinity, the varieties are near to perfect substitutability. When σ is near to 1, the substitutability among varieties is rare. The demand function for a variety can be derived from utility maximization as follows[9];

$$c_k = \frac{\mu E}{\int_{\in \Theta} p_i^{1-\sigma}} p_k^{-\sigma} \tag{2}$$

c_k : demand of differentiated variety k, p_i : price of differentiated variety i.

[9] Derivation of demand function is typical practice. So we do not provide for the derivation process.

E : total expenditure

On supply side, the mill price setting of monopolistic competitive companies for profit maximization follows the rule of "MR=MC". Here, we assume that the only variable factor is labor. So the marginal cost depends on the labor. If we define that a_m is the labor requirement for the unit production of a variety and w_L is the wage in manufacture sector, then marginal cost is $w_L a_m$. From (2), we know that the price elasticity of demand is σ. When this firm sets the price of its good in the other region, it must consider transportation cost. Therefore, the prices this company charges to the consumer in domestic and foreign are as follows;

$$p = \frac{w_L a_m}{1 - 1/\sigma}, \quad p^* = \frac{\tau w_L a_m}{1 - 1/\sigma} \tag{3}$$

* represents the other region which is not production site.

If we assume that the companies in north and south are symmetric, the number of varieties in north is n and the number of varieties in south is n*, then we can rewrite the price level (the denominator in (2)) with (3) as follows;

$$\int_{\in\Theta} p_i^{1-\sigma} = np^{1-\sigma} + n^* p^{*1-\sigma} = (n + \phi n^*)\left(\frac{w_L a_m}{1 - 1/\sigma}\right)^{1-\sigma} \tag{4}$$

here, $\phi = \tau^{1-\sigma} > 0$.

Then we can calculate the regional sales benefits of one company which is located in, for example, north as follows;[10]

$$RS_N = pc = \frac{s_E}{s_n + \phi(1 - s_n)} \frac{\mu E^W}{N^W}, \quad RS_S = p^* c^* = \frac{\phi(1 - s_E)}{\phi s_n + (1 - s_n)} \frac{\mu E^W}{N^W} \tag{5}$$

here, RS_i : total sales revenue of northern firm in i region. (i = south, north)

s_E : world share of expenditure of the north region

s_n : world share of varieties which are produced in the north region.

E^W : world total expenditure, N^W : world total number of varieties

c : consumption of the variety.

Since the employment of capital is not restricted to the space, we need to characterize the

[10] Derivation of (5) is shown in Appendix.

spatial equilibrium at which the regional employment of capital is not changed. To do that, we must know the reward of capital in each region. In the long run equilibrium of monopolistic competitive market, the economic profit is zero. This means that the reward of capital is the difference between total revenue and variable costs if there are no regulation costs[11].

$$\pi = \left(p - w_L a_m\right)c = \frac{pc}{\sigma} \tag{6}$$

At this time, let's consider country specific regional environment regulation. We assume that while the region with large expenditure share (north) charges relatively low pollution abatement lax, the region with small expenditure share (south) charges high pollution abatement lax. The reason why we choose this asymmetric regulation assumption is related to the home market effect which we will show later. The baseline of this idea is that the pollution haven phenomenon is a part of the home market effect phenomenon, because pollution haven problem is substantially the results of location choice. When we consider several combination of market size and regulation stringency between regions, we can find that, in the combination of large expenditure share region–low regulation costs and small expenditure share region–high regulation costs, there are conditions which clearly show pollution haven phenomenon. Except that, it is difficult to standardize the conditions for the pollution haven because we can observe, so called, anti or reverse home market effects[12]. We assume that the pollution abatement regulation is levied by lump-sum type to make the model simple. Regulations are simply defined as follows;

$$R_L^N < R_H^S \tag{7}$$

R_L^N : low environment regulation costs in north region (large market size)

R_H^S : high environment regulation costs in south region (small market size)

Then we can finally express the rewards of capital in the long-run equilibrium which are employed in each region with environment regulation costs. When we substitute (6) with (5) and then subtract (7), we can derive rewards of capital in each region such as (8).

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11 $p = \frac{w_L a_m}{1 - 1/\sigma} \Leftrightarrow \frac{p}{\sigma} = p - w_L a_m$

12 It is well explained in Okubo and Rebeyrol (2006). Especially, main cause of these phenomena is regulation cost gaps. We investigate only one combination in this article because it is difficult to observe the regulation cost of not only other country but also home country in empirical points of view.

$$\text{North}: \quad \pi_N = \frac{\mu E^W}{\sigma N^W}\left(\frac{s_E}{\Delta} + \phi\frac{1-s_E}{\Delta^*}\right) - R_L^N$$

$$\text{South}: \quad \pi_S = \frac{\mu E^W}{\sigma N^W}\left(\frac{1-s_E}{\Delta^*} + \phi\frac{s_E}{\Delta}\right) - R_H^S \tag{8}$$

$$\text{here} \quad \Delta \equiv s_n + \phi(1-s_n), \quad \Delta^* \equiv \phi\, s_n + (1-s_n)$$

Let's total number of firms or varieties of world and total expenditure of world is normalized to 1. And we can find the spatial distribution of firm in the long run equilibrium in which there is zero incentive of capital movement. This condition means that there is no difference between the rewards of capital in each region. The condition is $\pi_N - \pi_S = 0$. With (8), we can rewrite this condition as follows;

$$\pi_N - \pi_S = \frac{\mu}{\sigma}(1-\phi)(B - B^*) - R_L^N + R_H^S \tag{9}$$

$$\text{here,} \quad B \equiv \frac{s_E}{\Delta}, B^* \equiv \frac{1-s_E}{\Delta^*}$$

(9) shows that if the reward of capital does not depend on the place where the capital is employed and the level of reward is same at each region, then the company does not have any incentive to change its employed place. Therefore, we can not observe any movement of capital between regions. Since (9) is combined to (8), it shows not only long-run equilibrium but also spatial equilibrium. In (9), we can derive the set of pairs of the regional share of expenditures and the regional share of companies to satisfy long-run and spatial equilibrium[13].

$$\left(s_n - \frac{1}{2}\right) = \frac{1+\phi}{1-\phi}\left(s_E - \frac{1}{2}\right) - \frac{GR}{b}\left(s_n - s_n^2\right) - \frac{GR}{b}\left(\frac{\phi}{(1-\phi)^2}\right) \tag{10}$$

$$\text{here,} \quad GR \equiv R_L^N - R_H^S, b \equiv \frac{\mu}{\sigma}$$

To make (10) simple, let's redefine some variables again;

i) $\hat{m} \equiv s_E - \frac{1}{2}$: since we assume that the share of north expenditure is greater than $\frac{1}{2}$, the range of $\hat{m}$ is $0 \le \hat{m} \le \frac{1}{2}$.

ii) $k \equiv b/_{GR}$: since $GR = R_L^N - R_H^S < 0$, $\mu > 0$ and $\sigma > 1$, $k < 0$.

13 Derivation of (10) is shown in Appendix.

iii) $z \equiv {}^{1+\phi}\!/_{1-\phi}$: since $\phi > 0$, $z > 1$.

With this new variable definition, we rewrite (10) as follows[14];

$$s_n^2 - (1+k)s_n + \frac{1}{2}k + kz\hat{m} - \left(\frac{z^2-1}{4}\right) = 0 \qquad (11)$$

Thus when we solve the root of (11), we finally get the relationship between the world share of expenditure of north and the world share of the number of varieties of north to meet the long run and spatial equilibrium condition[15];.

$$\hat{n} = \frac{k}{2} \pm \frac{1}{2}\sqrt{k^2 - 4\hat{m}kz + z^2}, \quad \hat{n} = s_n - {}^{1}\!/_{2} \qquad (12)$$

Since there is restriction of range of $\hat{m}$, $0 \le \hat{m} \le {}^{1}\!/_{2}$, we can consider the endpoints of the range. When $\hat{m} = 0$, $\hat{n} = {}^{k}\!/_{2} \pm {}^{1}\!/_{2}\sqrt{k^2 + z^2}$. And because $|k| + |z| > |k|$, $\hat{n}$ has two values of opposite sign. When $\hat{m} = 0.5$, $\hat{n} = {}^{k}\!/_{2} \pm {}^{1}\!/_{2}(k - z)$. Here, $\hat{n}$ has two values of opposite sign, too. Especially, the value of $\hat{n}$ with positive sign is greater than 0.5. When we also need to restrict the range of $\hat{n}$, we can draw the graph within meaningful range of $\hat{m}$ and $\hat{n}$ such as <figure 1>. This figure shows the relationship between the world share of expenditure of north and that of the number of varieties or companies in north which satisfy the (11).

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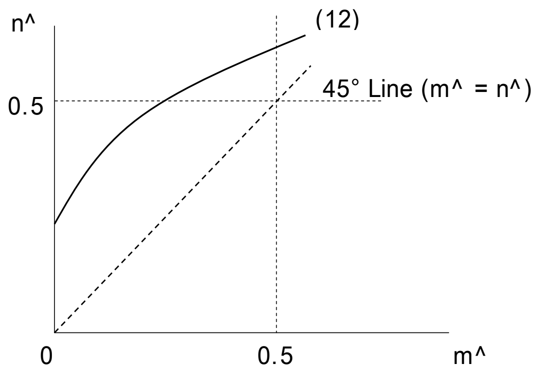
14 Derivation of (11) is shown in Appendix.

15 Derivation of (12) is shown in Appendix. Here, we need to note that k is negative. In this case, the function is typical parabola which is open to the right side of x-axis. But when k is positive, that is large country levies high environment lax than small one, it is possible not to have real roots. Therefore, in that case, the analysis is so complex to decide the direction of effects. But as long as it has real roots, it can be parabola which opens to the left side of x-axis, we can expect reverse or anti HME phenomena depending on the size of capital reward gap.



<Figure 1> long run equilibrium relationship between $\hat{m}$ and $\hat{n}$

This graph shows standard home market effects. This explains that the region with large size economy attains more proportional share of companies or varieties in its region in the long-run or spatial equilibrium. This means that even though the region levies environment lax on the companies, they do not choose to change their location and further the new comer chooses its location at north because the agglomeration in the north is sustainable. When the large size country levies relatively high environment regulation lax on the company in its region, the companies want to leave and the new companies hesitate to place their plants in the north because of production cost increase. But when the large size country levies relatively low lax on the company in its region, it can sustain its attractiveness to previous residences and new comers by keeping its pulling power coming from its economy scale even with regulation costs.

Through this practice, we can show that the home market effect can work as agglomeration force which makes companies concentrated in a region under large economy low regulation situation. But still we show that whole industries are concentrated. This is not what the pollution haven hypothesis predicts. Therefore, we must consider the type of industry or companies which are concentrated in the north. And we must check which type of industry can stay or choose at south as its location. This can be done when the distribution of industry or companies are known. The next section shows this process.

III.2. Two way spatial sorting and the pollution haven hypothesis

In previous section, the existence of home market effects is investigated. In this section, we consider industry or company heterogeneity in view of productivity, that is labor requirements for unit production. First we assume that we can make the distribution of companies with the productivity which includes pollution abatement technique. And we assume again that it is Pareto distributed within the range of 0 to 1 after normalization of the productivity[16]. The density and cumulative distribution function is as follows;

$$f(e)=\kappa\left(\frac{e^{\kappa-1}}{e_0^{\kappa}}\right)=\kappa e^{\kappa-1}, \quad 1\equiv e_0\geq e\geq 0, \quad \kappa>1 \tag{13.1}$$

$$F(e)=\left(\frac{e}{e_0}\right)^{\kappa}=e^{\kappa} \tag{13.2}$$

here κ is parameter which determines shape of distribution.

e represents the labor requirements for unit production.

The larger κ, the more concentrated to 1 the distribution is. When the κ goes infinity, it means that the distribution converges to the mass of homogeneous companies.

With this distribution, we can modify (9) as follows[17];

$$\pi_N-\pi_S=\frac{\mu}{\sigma}(1-\phi)(B-B^*)p^{1-\sigma}-R_L^N+R_H^S \tag{14}$$

In (3), we substitute a_m with e and use normalization as $w_L=1$. And if we assume that e_c is the labor requirements for unit production which satisfies the condition for the long-run equilibrium or spatial equilibrium, then we can get following condition (14.1).

$$\pi_N(e_c)-\pi_S(e_c)=\frac{\mu}{\sigma}\left(\frac{\sigma}{1-\sigma}\right)^{1-1/\sigma}(1-\phi)(B-B^*)e_c^{1-\sigma}-R_L^N+R_H^S=0 \tag{14.1}$$

Then we can evaluate the slope of capital rewards gap in the long run equilibrium at $e=e_c$. The slope is derived as follows;

$$\left.\frac{\partial(\pi_N-\pi_S)}{\partial e}\right|_{e=e_c}=-\mu\left(\frac{\sigma}{\sigma-1}\right)^{-1/\sigma}(1-\phi)(B-B^*)e_c^{-\sigma} \tag{15}$$

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16 This distribution is well used as industry distribution. See Melitz(2003) and Baldwin and Okubo (2005).

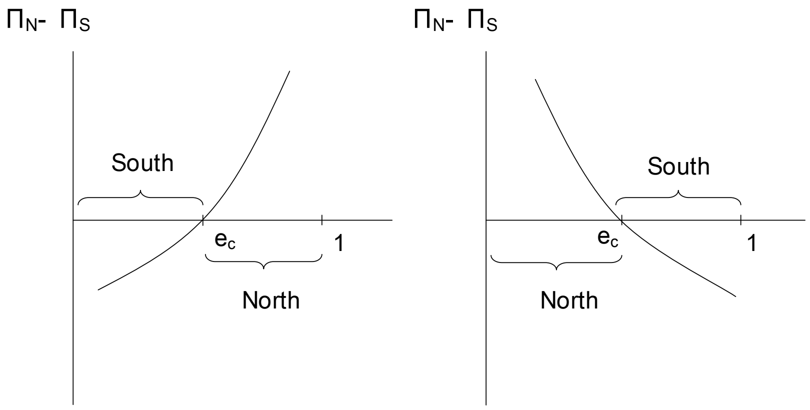
17 Derivation of (14) is shown in Appendix.

The sign of (15) is indeterminate. First, the signs of $\mu, 1-\phi$ and $e_c^{-\sigma}$ are positive. And since $\sigma > 1$, the sign of $\left(\frac{\sigma}{\sigma-1}\right)^{-1/\sigma}$ is negative. Therefore, the whole sign of (15) depends on sign of $B - B^*$. We can summarize the sign of (15) as follows;

$$if \;\; B - B^* < 0 \Rightarrow \left.\frac{\partial(\pi_N - \pi_S)}{\partial e}\right|_{e=e_C} > 0 \qquad (16.1)$$

$$if \;\; B - B^* > 0 \Rightarrow \left.\frac{\partial(\pi_N - \pi_S)}{\partial e}\right|_{e=e_C} < 0 \qquad (16.2)$$

Based on (16.1) and (16.2), we can draw the capital reward gap as <figure 2>.



(16.1) (16.2)

<figure 2> Cost reward gap and location choice

In the case of (16.1), the companies with high productivity (low value of e) will choose south as their location because the reward for the capital is higher than that of north. But the companies with low productivity (high value of e) will choose its location at north. This is the phenomenon of two-way spatial sorting which is named by Okubo and Rebeyrol (2006). But when we remind that the environment regulation cost of north is lower than that of south, this phenomenon also shows the pollution haven. One hand, since, in the north, production costs are much cheaper than south because of low level of environment regulation, the company with low pollution abatement productivity moves into the northern region. The other hand, since the company with high productivity can earn high profits with which it can cover not only the transportation costs but also the regulation costs, it can pay the high reward for the employed capital in the south. So this benefit drives those companies into the southern region. This phenomenon is reflected on the sign of $B-B*$, too. B or $B*$ is called regional sales bias measured with regional price level and expenditure share (Baldwin et al., 2003). So (16.1) condition means that the market potential and existence of transportation costs work favorably as dispersion force from the core or the north for the companies with high productivity. Even though the transportation costs for southern companies are high because of large market size in the north, the congestion costs or competitiveness can be low in south. And the labor productivity of companies is high enough not to move into north. Therefore the only companies whose labor productivity is not high enough choose the north to save both the transportation costs and the regulation compliance costs. This explains the pollution haven hypothesis.

However (16.2) in <figure 2> explains the other way around. The companies with high productivity try to exploit the benefits coming from the large market size and low regulation costs. But the low productivity companies can not survive in the north region because of fierce price competition or congestion costs. They think it is more beneficial in locating at south even though the regulation costs are high. In this situation, we can not observe the pollution haven phenomenon.

Then let's focus on the condition which guarantees $B-B*<0$. It is rewritten as follows with modified definition of B and $B*$;

$$B=\frac{s_E}{\int_{\in\Theta_1} p_i^{1-\sigma}+\phi\int_{\in\Theta_2} p_j^{1-\sigma}}<\frac{1-s_E}{\phi\int_{\in\Theta_1} p_i^{1-\sigma}+\int_{\in\Theta_2} p_j^{1-\sigma}}=B*$$

From the above condition, we can get[18];

$$\phi<\frac{\int_{\in\Theta_1} p_i^{1-\sigma}-s_E\left(\int_{\in\Theta_1} p_i^{1-\sigma}+\int_{\in\Theta 2} p_j^{1-\sigma}\right)}{s_E\left(\int_{\in\Theta_1} p_i^{1-\sigma}+\int_{\in\Theta 2} p_j^{1-\sigma}\right)-\int_{\in\Theta 2} p_j^{1-\sigma}} \tag{17}$$

And for the value of ϕ to be positive, the following condition must be satisfied with.

$$\int_{\in\Theta_2} p_j^{1-\sigma}<s_E\left(\int_{\in\Theta_1} p_i^{1-\sigma}+\int_{\in\Theta_2} p_j^{1-\sigma}\right)<\int_{\in\Theta_1} p_i^{1-\sigma} \tag{18}$$

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[18] Derivation of (17) is in Appendix.

As long as (18) is satisfied, if the transportation cost is less than some critical value defined in (17), then the condition of $B - B^* < 0$ is met and we can observe a region with large market size and weak environment regulation as a pollution haven[19]. So it explains that the existence of the pollution haven phenomenon is so restrictive and it is not easy to observe or find an empirical support of the pollution haven hypothesis. Let's investigate (17) further.

First, let's define the critical value of transportation cost, ϕ_c, which is the upper bound of ϕ for the existence of a pollution haven. And let's define $\int_{\in \Theta_1} p_i^{1-\sigma}$ as K and $\int_{\in \Theta_2} p_j^{1-\sigma}$ south as J. They are functions of s_n, the world share of varieties in north. When the share of the varieties in north is increased, then the set of varieties in north, Θ_1, is expanded so K is increased while the set of varieties in south, Θ_2 is shrunk so J is decreased. We summarize as follows;

$$\int_{\in \Theta_1} p_i^{1-\sigma} = K, \quad \frac{\partial K}{\partial s_n} > 0 \ ; \ \int_{\in \Theta_2} p_j^{1-\sigma} = J, \quad \frac{\partial J}{\partial s_n} < 0 \tag{19}$$

$$\phi_c = \frac{K - s_E(K+J)}{s_E(K+J) - J} \tag{20}$$

Then let's totally differentiate (20) with regard to s_n, s_E and ϕ_c. The result is shown in (21)[20].

$$d\phi_c = \frac{1}{[s_E(K+J) - J]^2} \left\{ \left[-2(s_E - 1/2)\left(K\frac{\partial J}{\partial s_n} - J\frac{\partial K}{\partial s_n} \right) \right] ds_n + [(J-K)(J+K)] ds_E \right\} \tag{21}$$

In (21), while the sign of first term in the $\{\ \}$ is positive, that of second term is negative. That is, the effect of the world share of varieties in north on the critical value is opposite the effect of the world share of north expenditure. So we can summarize the effect of the shares such as <figure 3>.

	Less Varieties ←------ s_n ------→ More Varieties

[19] When ϕ goes to 1, it means that the region is close to free trade. When ϕ goes to 0, it shows that a region is close to the closed economy.

[20] Derivation of (21) refers to Appendix.

↑	Small Gap	ϕ_n^c ⇓ ; ϕ_E^c ⇑	ϕ_n^c ⇑ ; ϕ_E^c ⇑
s_E ↓	Large Gap	ϕ_n^c ⇓ ; ϕ_E^c ⇓	ϕ_n^c ⇑ ; ϕ_E^c ⇓

Note : ϕ_n^c means the effect of world share of varieties in north on the critical value.
ϕ_E^c means the effect of north expenditure share on the critical value

<figure 3> The effect of s_n and s_E on the critical value of transportation cost

When the number of varieties in the north is larger but the gap of the market size between the north and the south is small, it would be possible to identify the north as a pollution haven at a certain degree even though trade liberalization is going. In another way, in this case, even though the distance between two regions are close so the transportation costs are not big, we can expect that the large nation works as a pollution haven as long as the environment regulation is relatively weak at a certain degree.

But when the number of varieties in the north is smaller but the market size of north is big, it is not easy to observe a pollution haven, especially with trade liberalization. Or only the transportation costs are big between two regions, we can possibly expect a north as a pollution haven under the condition of weak environment regulation in the north.

Lastly, let's consider another case; the large market size economy levies higher environment lax on the companies in its region than the small market size economy does. Then the condition to have real roots in (12) is so complex because the sign of k is positive. Even the roots in (12) are real number, we can observe anti-home market effects or reverse home market effects as explained in footnote (12)[21]. And the shape of function and the location of parabola depend on transportation costs and the regulation gap. So the sign of the degree of sales bias gap, $B-B*$, depends on those factors and the share of north expenditure. Thus, it is not easy to generalize the condition. This means that the pollution haven phenomenon would be observed case by case under this setting.

These are interesting results. As we see in the empirical literature, many researches focus on the bilateral relationships or group relationship to identify the pollution haven. For example, to find out the pollution haven, Levinson and Taylor (2008) investigate relationship between US and Mexico, US and Canada, Elliot and Shimamoto (2008) focus on the Japan and each

[21] Some cases are drawn in Appendix.

individual ASEAN countries. Other researchers analyze the relationship between host country of FDI alone, like China, Venezuela, etc or focus on OECD-non OECD groups. However, our practice shows that to know why they select the some countries or group as counter-parts is important in the pollution haven empirical studies because the market size, transportation costs and the regulation gap play their role in the decision of being the pollution haven. Therefore, it is somehow natural that the empirical studies show that there is no consistency in their estimation results in view of the theory which we suggest here. But what we can suggest with some certainty is that if the country with large market, weak environment policy and many varieties trades with a country of which the market size gap between them is small and has strong environment policy, then it is highly possible that the large country can provide the pollution haven even with trade liberalization.

In next section, we choose some countries and try to find out the pollution haven empirically. In this study, we choose the empirical set-up based on the theory which we provide. But, unfortunately we can not use the empirical estimation equation directly derived from the theory which we suggest because of the lack of data availability. As we mentioned, to estimate the model which is consistent with the above theory, we need to collect the each individual location choice data of companies. So, we use the trade data by industry and by nations to identify the pollution haven but we will adopt the identification strategy which the above model suggests.

IV. Empirical Results

To identify the pollution haven, the information of market size, regulation gap and transportation costs are required according to the theory which we suggest. However, exact data of those variables are not easy to be collected. Especially, there is no way to measure the stringency of even domestic environment policy. This constraint of data availability means that it is difficult to identify the pollution haven hypothesis in the case of the large size market and strong environment policy situation. Rather, the situation of large size market and weak environment policy is suitable to identify the pollution haven.

In this point of view, we investigate the trade relationship between Korea and other countries from 1995 to 2002. The candidate countries for a pollution haven in the case of the trade with Korea are chosen such countries as China, Indonesia, Philippine, Thailand and Vietnam. The GDP size and the distances from Seoul to the capital city of each nation are shown in <Table 2>.

<Table 2> GDP of each nations and the distance among countries

	GDP (current price, billion dollar)		Distance from Seoul to its capital city (Km)
	1995	2002	
Korea	539.0	575.9	-
China	727.9	1,453.8	962
Indonesia	223.4	195.6	2,849
Philippine	75.5	76.8	2,614
Thailand	168.0	126.9	3,719
Vietnam	20.8	31.5	2,745

Sources : https:// www.imf.org ;   https://www.indo.com/cgi-bin/dist .

While China has larger market size than Korea, the market sizes of the other four countries are relatively small to that of Korea as shown in <Table 2>. In view of distance China is the closest to Korea but the other four countries are far distant. And during 1995 to 2002, China experiences the quick move to the trade liberalization than before.

One hand, during those periods, the environment policy in Korea is more stringent than before. Especially, after 90's, the environment laws break down in detail and the environment management of central government is more strengthened. For example, the volume-rate garbage disposal system starts nationally from 1995. Furthermore, the air regulation is stronger, since Korea are planned to hold World Cup games at 2002. So the environment policy stringency in Korea is high. The other hand, the environment stringency of China is not that strong, since the economy of China is booming during those periods. Particularly, the inward FDI growth rate into heavy polluted industry in China is relatively higher than that of the domestic investments to the same industry in China during 1996 to 2002[22]. Furthermore, the high growth of inward FDI in China means that the share of number of varieties in China could be increased. Based on these situations, we can expect that there is high possibility of China working as a pollution haven to Korea. For the other countries, as the theory expects, we can have case by case situation because the market size of Korea is larger than the other countries. So by estimating the net import function of Korea with each country, we hope to identify the pollution haven hypothesis.

In this empirical study, we estimate net import function of Korea from 1995 to 2002. Net

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[22] Refer to "The Role of China in Global Dirty Industry Migration" (2008, Haitian Lu)

import function estimation is used often to show pollution haven hypothesis because industry export and import data is available[23]. Terms of trade of Korea, labor productivity gap and pollution abatement costs per unit value added are chosen as explanatory variables. Terms of trade is defined as imports unit value of index divided by exports unit value of index. Both unit value of indexes are released from the Bank of Korea and it is normalized at year 2005=100. Since the unit value of index is based on US$, the variations of terms of trade itself contain exchange rate variations. With these indexes, we calculate imports and exports which are evaluated at constant prices 2005=100. Then we get net imports by subtracting constant price exports from constant price imports by industry.

To capture production cost advantage, we calculate the labor productivity data from each country. Labor productivity is defined as real production value (dollar) per worker. And we get the gap between Korea and other countries by subtracting labor productivity of other countries from that of Korea. Chinese data is collected from the National Bureau of Statistics of China, other country data is collected from UNCTAD INDSTAT Rev.4[24].

To measure the stringency of environment policy, we use Pollution Abatement and Control Expenditure (PAC) data of business sector in Korea from 1995 to 2002. These data is released from the Bank of Korea. But the name of series is changed from PAC to EPEA (Environmental Protection Expenditure Accounts) and the collecting item is changed from 2003. Therefore, the periods of time series which has consistency is only from 1995 to 2002[25]. And this PAC data does not release about the depreciation cost and capital stock information. So we estimate the depreciation costs and add this estimation to the current expenditure of PAC[26]. Finally, by dividing this expenditure with value added of industry, we can get the data to proxy the stringency of environment policy in Korea. The industry is classified 10 sections such as food and beverage products, textile, clothes and leather products, lumber and wooden products, pulp, paper and printing products, chemical, petroleum and rubber products, non-metal products, metal products, fabricated metal and machinery products, transportation products and other products. As Levinson and Taylor (2008) indicate, it is not easy to get PAC data from other countries. So we can not use the PAC per unit value added of other countries into the estimation process. The summary of data is provided in <Table 3>.

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[23] Ederington et al. (2005), Levinson and Taylor (2008).

[24] The calculation of labor productivity is explained in Appendix.

[25] Actually, the time series of PAC starts from 1992. But the major environmental policy change in Korea starts from 1995, for example, volume rate garbage disposal system. Furthermore, we can not get labor data from China before 1995. This explains why we choose the estimation periods from 1995 to 2002.

[26] The estimation steps and data results are explained in Appendix.

<Table 3> Descriptive Statistics, 1995-2002 (Pooled)

	Mean	S. D.	Min	Max
Common Data				
Terms of Trade	0.923	0.325	0.231	1.754
PAC per Unit Value Added	0.011	0.010	0.002	0.045
Trade with China				
Imports (constant price, Million $)	1123.4	1125.0	8.8	4968.1
Exports (constant price, Million $)	1527.0	2222.6	22.4	9054.2
Labor Productivity Differential (Thousand $)	167.4	77.8	56.5	364.9
Trade with Indonesia				
Imports (constant price, Million $)	548.6	964.2	0.2	4484.1
Exports (constant price, Million $)	314.9	356.0	0.5	1386.1
Labor Productivity Differential (Thousand $)	131.4	96.6	-192.4	370.9
Trade with Philippine1)				
Imports (constant price, Million $)	106.3	230.2	0.0	1241.2
Exports (constant price, Million $)	211.6	289.9	0.1	1488.4
Labor Productivity Differential (Thousand $)	171.5	84.5	31.0	378.7
Trade with Thailand2)				
Imports (constant price, Million $)	121.6	150.2	0.3	642.1
Exports (constant price, Million $)	186.3	223.3	0.0	933.7
Labor Productivity Differential (Thousand $)	106.3	39.7	32.8	181.6
Trade with Vietnam3)				
Imports (constant price, Million $)	29.1	39.0	0.0	184.8
Exports (constant price, Million $)	163.9	186.2	0.2	793.9

Note: 1) In the case of labor productivity data by industry, only 1995-1999 data are available.

2) In the case of labor productivity data by industry, only 1996, 1998, 2000 data are available

3) Labor productivity data are not available.

4) The number of observation is 80 for every country except Indonesia which is 70.

With this data set, we estimate net import equation with Arellano-Bond estimation method

(Arellano and Bond, 1991). Since the estimation equation has several unobserved factors, we need to control endogeneity. For example, we can not include the stringency measure of environmental policy of counter-part country. In the case of Levinson and Taylor (2008), they use instrument variable methods (2 stage least square estimation) with instruments such as ambient regional air and water pollutant level. But as they indicates it is difficult to find aggregated variable which represents overall ambient environment quality. So we choose to use characteristics of time series itself. Since we have data availability problem, past data itself is appropriate to use as instruments to control the endogeneity. Arellano and Bond estimator is used because this method controls the covariance problem between error terms and dependent variable with time lag by using their past data as instruments in first differenced panel estimation setting[27]. The estimation equation is set up as follows;

$$\Delta y_{it} = \gamma_1 \Delta y_{i,t-1} + \mathbf{\Delta X}'_{it}\boldsymbol{\beta} + \Delta \varepsilon_{it} \tag{22}$$

where Δ means first difference between time.

y_{it} : net import of industry i at year t.

$$\mathbf{X}_{it} = \begin{bmatrix} \text{Terms of Trade} \\ \text{PAC per Unit Value Added} \\ \text{Labor Productivity Differential} \end{bmatrix}_{it}$$: explanatory variables of industry i at year t

ε_{it} : error terms of industry i at year t.

We check the appropriateness of instrumental variables with Sargan test and for the model specification we check the Wald statistics and the Arellano-Bond test statistics for time lag appropriateness. First, we estimate the model with only both terms of trade and PAC per unit value added. This estimation model is called (1). Second we put the whole explanatory variable into the equation and estimate it. This model is called (2). The estimation results are shown in <Table 4>

<Table 4> Estimation Results of Net Imports Function

	China		Indonesia		Philippine		Thailand		Vietnam
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)
Tot	-1.712	-1.663	-0.550	-0.548	0.052	-0.422	-0.122	-0.044	-0.080
	(2.17)**	(2.10)**	(1.50)	(1.49)	(0.50)	(1.98)**	(1.14)	(0.19)	(0.94)
PAC	4.701	5.073	-1.572	-1.595	0.904	0.418	-0.403	-0.035	-0.892

[27] Refer to Cameron and Trivedi (2005).

	(1.74)*	(1.82)*	(1.05)	(1.05)	(1.99)**	(0.76)	(1.06)	(0.08)	(3.49)**
Lpdiff	-	-0.005	-	-0.002	-	-0.001	-	-0.002	-
	-	(0.55)	-	(0.40)	-	(0.70)	-	(0.51)	-
Lags(1)	0.630	0.633	0.277	0.272	0.317	-0.172	0.488	-	0.885
	(4.79)**	(4.78)**	(1.87)*	(1.81)*	(2.23)**	(0.74)	(4.23)**	-	(5.87)**
Lags(2)	-	-	-	-	-0.500	-	-0.081	-	-
	-	-	-	-	(3.50)**	-	(0.66)	-	-
Const	-396.1	-428.3	252.0	269.0	-125.3	-191.6	-5.611	462.0	-14.0
.	(1.11)	(1.20)	(1.49)	(1.57)	(1.88)*	(1.89)*	(0.10)	(0.26)	(0.38)
Wald	24.9**	24.8**	7.5	7.5	20.0**	6.8	22.0**	-	55.6**
Sargan	45.1**	44.8**	39.3**	38.5**	37.6**	1.7	25.0**	-	41.2**
A-B (1)	-2.45**	-2.43**	-4.27**	-4.24**	-3.40**	2.37**	-1.78*	-	-1.49
A-B (2)	0.42	0.54	-0.95	-1.03	-0.00	-0.14	0.11	-	-1.31

Note : 1) To adjust the estimated coefficient scale, we change the scale of terms of trade and PAC per unit value added.

2) In the case of Philippine and Thailand, we include lags(2) in the estimation model based on the results of with Arellano-Bond statistics from the lag(1) included model.

3) Because of data availability, the total observation number of Indonesia estimation is 72. (9 industries 8 years). And the estimation periods of Philippine (2) model is 1995-1999.

4) In the case of Thailand, labor productivity data is obtained only three years, 1996, 1998 and 2000. Therefore, we use fixed effect AR(1) model instead of Arellano-Bond estimation method. The model specification statistics is F(3, 7) = 0.09.

5) ( ) represents z-value. * means significant at 10% significance level and ** at 5%.

In the case of China, the model itself is acceptable. In the case of Sargan test statistics which is used to know the possibility of over-identifying restriction rejects the over-identification. Also, Arellano-Bond test shows the time lag selection is acceptable[28]. The estimation results show that, at 10% significance level, the increase of the pollution abatement and control expenditure per unit value added raises the imports of Korea from China. So we can weakly argue that China works as a pollution haven for Korea. The reason why the effect is not much strong is the gap of market size between two countries are expanded at the end of 2002 as <table 2> shows. When we look at <figure 3>, if the gap is larger the critical value is dropped.

[28] It tests whether average autocovariance in residuals of order 1 or 2 is zero. Null hypothesis is no autocorrelation. Since we use difference format, the first order autocorrelation must be found. But second order autocorrelation is not acceptable if the specification is right. (Cameron and Trivedi, 2009)

Furthermore, trade liberalization is accelerated in China around 2000. So we can expect that the role of pollution haven is relatively strong around the end of 90's but its role fades out when time goes by. This is one possible explanation and we can observe that the condition for the pollution haven which we suggest explains well the situation.

In the case of Indonesia, the model specification itself does not explain the net imports of Korea with Indonesia well. Therefore, we can not confirm that Indonesia provide the pollution haven for Korea. Even the estimated coefficient is not significant the sign is negative. So, as the suggested theory expects, we can not confirm the case. In the case of Philippine, it looks this country provides the pollution haven for the Korea. But when we add some other explanatory variable then the significance of the variable is weaker. And since we use lags(2) in the model, the significance test is not reliable. Therefore, the role of pollution haven in the case of Philippine is indecisive. The case of Thailand also shows that it does not provide the pollution haven for the Korea. And sign is negative even though it is not significant. In the case of Vietnam, the sign of PAC per unit value added is significant and negative. Therefore, the overall results show that the role of ASEAN countries as a pollution haven for Korea is indecisive. This results are similar to the result of Elliott and Shimamoto(2008) in Japanese case, too. And this phenomenon is also well explained by the suggested theory.

V. Conclusion

The pollution haven hypothesis is thought as a specific phenomenon which can be observed if the countries have weak environmental regulation. So many researchers have tried to the empirical evidence of the pollution haven hypothesis and still the empirical results are mixed. In this article, we argue that the pollution haven hypothesis is a specific example of general location theories with newly suggested two way spatial sorting theory of Okubo and Rebeyrol(2006). So, in conclusion, we suggest that to identify the pollution haven hypothesis it needs to scrutinize the pair relationship of host country and counter part country settings. Even though the counter part country has weak environment regulation, it may not provide the pollution haven because the relative market size, transportation costs (it means the degree of trade liberalization) and the gap of the stringency of environment policies between two nations determine the possibility of the pollution haven. That is one explanation why the several empirical studies have different empirical results. Furthermore, we can also suggest the pollution haven phenomenon can be transient phenomenon because when the full trade liberalization is achieved, as we suggest in <figure 3>, it is highly possible that the condition to be pollution haven can not be met. Therefore, these whole stuffs indicate that it is not easy to find a pollution haven and we need to think carefully about the realization of the race to the bottom situation in the case of environmental policy in reality.

However, the model which we suggest in this article is not perfect. First of all, the FC model itself is not widely acceptable in other economics area except new economic geography and some international trade section. So the model itself has substantially its limitation. Second, in our model, we do not endogenize the possibility of the birth of new varieties in the region. If we consider this, then we can explain the relationship between the economic growth and the pollution haven hypothesis more plentifully. Even though the model has some deficiencies, it provides an answer to why empirical results of the pollution haven hypothesis are indecisive. And we suggest the empirical setting itself, that is which countries are chosen as the host and counterpart country to study pollution haven phenomenon, can provide an identification strategy to the pollution haven hypothesis.

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<Appendix>

1. Derivation of (5)

$$RS_N = p \times \frac{\mu E}{(n+\phi n^*)\left(\frac{w_L a_m}{1-1/\sigma}\right)^{1-\sigma}} \times p^{-\sigma} = \frac{\mu E}{(n+\phi n^*)\left(\frac{w_L a_m}{1-1/\sigma}\right)^{1-\sigma}} \times \left(\frac{w_L a_m}{1-1/\sigma}\right)^{1-\sigma}$$

$$= \frac{s_E}{s_n + \phi(1-s_n)} \frac{\mu E^W}{N^W}$$

$$RS_S = p^* \times \frac{\mu E^*}{(\phi n+n^*)\left(\frac{w_L a_m}{1-1/\sigma}\right)^{1-\sigma}} \times p^{*-\sigma} = \frac{\mu E^*}{(\phi n+n^*)\left(\frac{w_L a_m}{1-1/\sigma}\right)^{1-\sigma}} \times \left(\frac{\tau w_L a_m}{1-1/\sigma}\right)^{1-\sigma}$$

$$= \frac{\phi(1-s_E)}{\phi s_n + (1-s_n)} \frac{\mu E^W}{N^W}$$

2. Derivation of (10)

First, we calculate some part of the equation.

$$\Delta + \Delta^* = 1+\phi \quad \text{(A.1)}$$

$$\frac{1}{2}(\Delta - \Delta^*) = (1-\phi)\left(s_n - \frac{1}{2}\right) \quad \text{(A.2)}$$

$$\Delta\Delta^* = (1-\phi)^2\left(s_n - s_n^2\right) + \phi \quad \text{(A.3)}$$

We define that $R_L^N - R_H^S \equiv GR$ and $\frac{\mu}{\sigma} \equiv b$. We rewrite (9) such as $b(1-\phi)(B-B^*) = GR$.

Since $B \equiv \frac{s_E}{\Delta}, B^* \equiv \frac{1-s_E}{\Delta^*}$, we put this definition into (9) and substitute (A.1)-(A.3) again. Then we get;

$$\left(\frac{s_E}{\Delta} - \frac{1-s_E}{\Delta^*}\right) = \frac{GR}{b(1-\phi)} \Leftrightarrow \Delta^* s_E - \Delta(1-s_E) = \frac{GR}{b(1-\phi)}\Delta\Delta^*$$

$$\Leftrightarrow (\Delta^*+\Delta)s_E - \Delta = \frac{GR}{b(1-\phi)}\Delta\Delta^* \Leftrightarrow \Delta = (\Delta^*+\Delta)s_E - \frac{GR}{b(1-\phi)}\Delta\Delta^*$$

$$\Leftrightarrow \Delta = (\Delta^* + \Delta)s_E - (\Delta^* + \Delta)\frac{1}{2} + (\Delta^* + \Delta)\frac{1}{2} - \frac{GR}{b(1-\phi)}\Delta\Delta^*$$

$$\Leftrightarrow \Delta - \frac{1}{2}\Delta - \frac{1}{2}\Delta^* = (\Delta^* + \Delta)\left(s_E - \frac{1}{2}\right) - \frac{GR}{b(1-\phi)}\Delta\Delta^*$$

$$\Leftrightarrow \frac{1}{2}(\Delta - \Delta^*) = (1+\phi)\left(s_E - \frac{1}{2}\right) - \frac{GR}{b(1-\phi)}\Delta\Delta^*$$

$$\Leftrightarrow \left(s_N - \frac{1}{2}\right) = \frac{(1+\phi)}{(1-\phi)}(s_E - \frac{1}{2}) - \frac{GR}{b(1-\phi)^2}\Delta\Delta^*$$

$$\Leftrightarrow \left(s_n - \frac{1}{2}\right) = \frac{1+\phi}{1-\phi}\left(s_E - \frac{1}{2}\right) - \frac{GR}{b}\left(s_n - s_n^2\right) - \frac{GR}{b}\left(\frac{\phi}{(1-\phi)^2}\right)$$

3. Derivation of (11)

$$\left(s_n - \frac{1}{2}\right) = \frac{(1+\phi)}{(1-\phi)}m - \left(\frac{1}{k}\right)\left(s_n - s_n^2\right) - \left(\frac{1}{k}\right)\left(\frac{\phi}{(1-\phi)^2}\right)$$

$$\Leftrightarrow s_n^2 - (1+k)s_n + \frac{1}{2}k + kzm - \left(\frac{z^2-1}{4}\right) = 0$$

4. Derivation of (12)

By using square root formula, we can derive the root as follows;

$$s_n = \frac{1}{2}\left[(1+k) \pm \sqrt{(1+k)^2 - 4\left\{\frac{1}{2}k + \hat{m}kz - \left(\frac{z^2-1}{4}\right)\right\}}\right]$$

$$\Leftrightarrow s_n - \frac{1}{2} = \frac{k}{2} \pm \frac{1}{2}\sqrt{k^2 - 4\hat{m}kz + z^2}$$

5. Derivation of (14)

Since companies are no more symmetric, (4), the overall price level of north, is modified as follows;

$$\int_{\in\Theta} p_i^{1-\sigma} = \int_{\in\Theta_1} p_i^{1-\sigma} + \tau^{1-\sigma}\int_{\in\Theta_2} p_j^{1-\sigma} = \int_{\in\Theta_1} p_i^{1-\sigma} + \phi\int_{\in\Theta_2} p_j^{1-\sigma}$$

where Θ_1 : the number of varieties which is produced in north

Θ_2 : the number of varieties which is produced in south

Then the regional sales revenue of companies in north is derived;

$$RS_N = p \times \frac{\mu E}{\int_{\in\Theta_1} p_i^{1-\sigma} + \phi \int_{\in\Theta_2} p_j^{1-\sigma}} \times p^{-\sigma} = \frac{\mu E}{\int_{\in\Theta_1} p_i^{1-\sigma} + \phi \int_{\in\Theta_2} p_j^{1-\sigma}} \times p^{1-\sigma}$$

$$RS_S = p^* \times \frac{\mu E^*}{\phi \int_{\in\Theta_1} p_i^{1-\sigma} + \int_{\in\Theta_2} p_j^{1-\sigma}} \times p^{*-\sigma} = \frac{\mu E^*}{\phi \int_{\in\Theta_1} p_i^{1-\sigma} + \int_{\in\Theta_2} p_j^{1-\sigma}} \times \tau^{1-\sigma} \times p^{1-\sigma}$$

Then the profit is defined as follows;

$$\pi_N = \frac{\mu}{\sigma}\left(\frac{s_E}{\Delta} + \phi \frac{1-s_E}{\Delta^*}\right) p^{1-\sigma} - R_L^N, \quad \pi_S = \frac{\phi\mu}{\sigma}\left(\frac{1-s_E}{\Delta^*} + \phi \frac{s_E}{\Delta}\right) p^{1-\sigma} - R_H^S$$

where $\Delta \equiv \int_{\in\Theta_1} p_i^{1-\sigma} + \phi \int_{\in\Theta_2} p_j^{1-\sigma}$, $\quad \Delta^* \equiv \phi \int_{\in\Theta_1} p_i^{1-\sigma} + \int_{\in\Theta_2} p_j^{1-\sigma}$

Therefore, finally, we can get (14).

6. Derivation of (17)

$$B = \frac{s_E}{\int_{\in\Theta_1} p_i^{1-\sigma} + \phi \int_{\in\Theta_2} p_j^{1-\sigma}} < \frac{1-s_E}{\phi \int_{\in\Theta_1} p_i^{1-\sigma} + \int_{\in\Theta_2} p_j^{1-\sigma}} = B^*$$

$$\Leftrightarrow s_E\left(\phi \int_{\in\Theta_1} p_i^{1-\sigma} + \int_{\in\Theta_2} p_j^{1-\sigma}\right) < (1-s_E)\left(\int_{\in\Theta_1} p_i^{1-\sigma} + \phi \int_{\in\Theta_2} p_j^{1-\sigma}\right)$$

$$\Leftrightarrow \phi\left[s_E\left(\int_{\in\Theta_1} p_i^{1-\sigma} + \int_{\in\Theta_2} p_j^{1-\sigma}\right) - \int_{\in\Theta_2} p_j^{1-\sigma}\right] < \left[\int_{\in\Theta_1} p_i^{1-\sigma} - s_E\left(\int_{\in\Theta_1} p_i^{1-\sigma} + \int_{\in\Theta_2} p_j^{1-\sigma}\right)\right]$$

$$\Leftrightarrow \phi < \frac{\int_{\in\Theta_1} p_i^{1-\sigma} - s_E\left(\int_{\in\Theta_1} p_i^{1-\sigma} + \int_{\in\Theta_2} p_j^{1-\sigma}\right)}{s_E\left(\int_{\in\Theta_1} p_i^{1-\sigma} + \int_{\in\Theta_2} p_j^{1-\sigma}\right) - \int_{\in\Theta_2} p_j^{1-\sigma}}$$

7. Derivation of (21)

To make simple, let's define the variables, first; $K_n = \frac{\partial K}{\partial s_n}$, $\mathrm{J_n} = \frac{\partial J}{\partial s_n}$

Then, take the partial differentiation of ϕ_c with regard to s_n.

$$\frac{\partial \phi_c}{\partial s_n} = \frac{\{\ [K_n - s_E(K_n + J_n)]\ [s_E(K+J) - J] - [s_E(K_n + J_n) - J_n]\ [K - s_E(K+J)]\ \}}{[\mathrm{s_E}(K+J) - J]^2}$$

Here, the numerator is calculated as follows;

$$
\begin{aligned}
&\left[K_n - s_E\left(K_n + J_n\right)\right]\left[s_E\left(K + J\right) - J\right] - \left[s_E\left(K_n + J_n\right) - J_n\right]\left[K - s_E\left(K + J\right)\right] \\
&= \left(1 - s_E\right)s_E K_n K - \left(1 - s_E\right)s_E K_n K - \left(1 - s_E\right)^2 K_n J + \left(1 - s_E\right)^2 J_n K - s_E^2 J_n K + s_E^2 K_n J + \left(1 - s_E\right)s_E J_n J - \left(1 - s_E\right)s_E J_n J \\
&= \left[\left(1 - s_E\right)^2 - s_E^2\right]\left(J_n K - K_n J\right) = -2\left(s_E - \tfrac{1}{2}\right)\left(J_n K - K_n J\right)
\end{aligned}
$$

Therefore, $\dfrac{\partial \phi_c}{\partial s_n} = \dfrac{-2\left(s_E - \frac{1}{2}\right)\left(J_n K - K_n J\right)}{\left[\mathrm{s_E}\left(K + J\right) - J\right]^2} > 0$

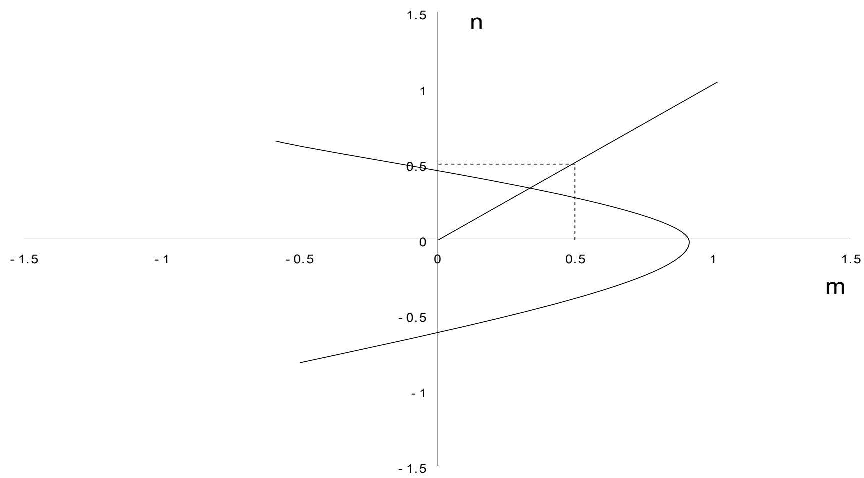
Next, take the partial differentiation of ϕ_c with regard to s_E.

$$
\begin{aligned}
\frac{\partial \phi_c}{\partial s_E} &= \frac{-\left(\mathrm{K} + \mathrm{J}\right)\left[s_E\left(K + J\right) - J\right] - \left(K + J\right)\left[K - s_E\left(K + J\right)\right]}{\left[\mathrm{s_E}\left(K + J\right) - J\right]^2} \\
&= \frac{-\left(\mathrm{K} + \mathrm{J}\right)\left\{\left[s_E\left(K + J\right) - J\right] + \left[K - s_E\left(K + J\right)\right]\right\}}{\left[\mathrm{s_E}\left(K + J\right) - J\right]^2} = \frac{-\left(\mathrm{K} + \mathrm{J}\right)\left(K - J\right)}{\left[\mathrm{s_E}\left(K + J\right) - J\right]^2}
\end{aligned}
$$

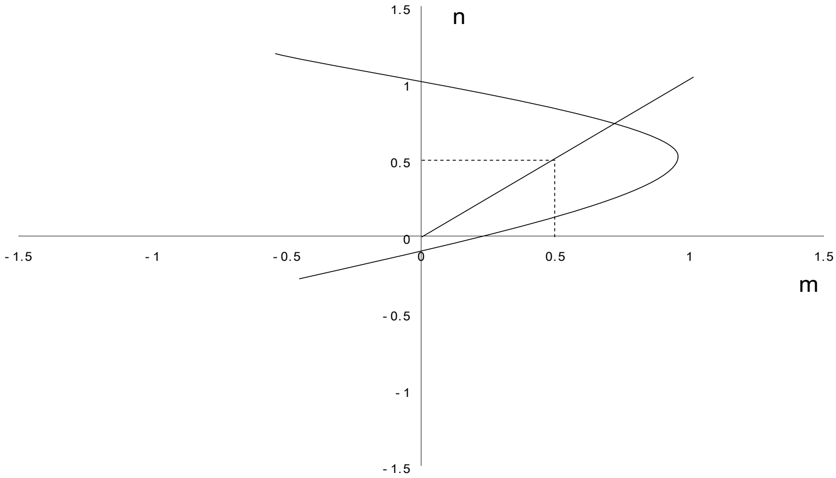
Therefore, $\dfrac{\partial \phi_c}{\partial s_E} = \dfrac{-\left(\mathrm{K} + \mathrm{J}\right)\left(K - J\right)}{\left[\mathrm{s_E}\left(K + J\right) - J\right]^2} < 0$.

8. Some cases when $k > 0$

<anti-HME>



<reverse-HME>



9. Labor productivity Calculation

In the case of China, the data are extracted from the web site such as http://www.stat.gov.cn/english/statisticaldata/yearlydata/. We collect the number of industrial staff and workers by industrial branch, gross output value of industry. And from IMF, http://www.imf.org/external/pubs/ft/weo/2009/02/weodata/index.aspx, we derive data about Chinese current and constant domestic price GDP and dollar base current GDP data. From this, we calculate the GDP deflator and exchange rate. By using calculated GDP and exchange rate, first, we calculate the constant dollar price of gross output value of industry and by dividing this constant dollar value by the number of industrial staff and workers we can get the labor productivity data. We apply this method to collect the labor productivity data from each country. As we mentioned the the related data of other country are collected from INDSTAT rev4. from UNCTAD.

10. Estimation of depreciation costs in PAC(in business sector)

PAC data in Korea does not release asset for pollution abatement activity information but release only current expenditure and investments. Therefore, we need to estimate the capital cost by using depreciation rate. Since we do not know the asset information but we know the current investment information, we estimate the depreciation rate for the asset by dividing depreciation expenditure with investments in industry survey data which do not include any information about environment expenditure. Finally, by adding the current expenditure for PAC and the estimated depreciation costs, we can collect the pollution abatement expenditure. The following table shows the results by industry

<Table A.1> Pollution Abatement and Control Expenditure (PAC) and Total Production Costs by Industry

(Bil. Won, %)

	1992	1995	2000	2002
Food and Beverage				
Pollution Abatements and Control (A)	98.3	131.5	199.9	220.9
Total Production Costs (B)	13,063.2	18,762.3	25,546.0	30,421.2
Share of PAC ($A/B \times 100$)	0.753	0.701	0.782	0.726
Textile, Clothes and Leather				
Pollution Abatements and Control (A)	98.4	121.5	161.4	177.1
Total Production Costs (B)	21,128.7	26,573.4	30,376.8	32,934.0
Share of PAC ($A/B \times 100$)	0.466	0.457	0.531	0.538
Lumber and Wooden Products				
Pollution Abatements and Control (A)	3.9	3.6	4.5	7.0
Total Production Costs (B)	1,678.7	2,360.0	2,387.4	2,901.9
Share of PAC ($A/B \times 100$)	0.229	0.151	0.189	0.242
Pulp, Paper and Printing				
Pollution Abatements and Control (A)	56.5	99.1	157.7	170.3
Total Production Costs (B)	6,808.3	11,516.2	16,181.5	18,506.3
Share of PAC ($A/B \times 100$)	0.829	0.860	0.974	0.920
Chemical, Petroleum and Rubber				
Pollution Abatements and Control (A)	236.5	382.2	664.6	770.9
Total Production Costs (B)	30,313.0	45,768.0	93,579.8	96,268.9
Share of PAC ($A/B \times 100$)	0.780	0.835	0.710	0.801
Non-metal				
Pollution Abatements and Control (A)	71.3	78.6	70.3	95.0
Total Production Costs (B)	7,695.1	10,285.1	11,121.7	13,950.7
Share of PAC ($A/B \times 100$)	0.927	0.764	0.632	0.683
Metal				
Pollution Abatements and Control (A)	244.3	329.9	488.1	714.7
Total Production Costs (B)	15,291.6	24,191.3	35,448.0	39650.7
Share of PAC ($A/B \times 100$)	1.598	1.364	1.377	0.683

Fabricated Metal and Machinery				
Pollution Abatements and Control (A)	134.2	216.4	230.9	275.6
Total Production Costs (B)	45,010.6	80,176.9	141,276.6	161591.0
Share of PAC ($A/B \times 100$)	0.298	0.270	0.163	0.171
Transportation				
Pollution Abatements and Control (A)	84.2	114.8	161.0	210.5
Total Production Costs (B)	21,218.7	35,820.6	54,546.7	70,416.4
Share of PAC ($A/B \times 100$)	0.397	0.321	0.295	0.299
Others				
Pollution Abatements and Control (A)	14.4	16.7	16.3	22.5
Total Production Costs (B)	3,849.7	5,274.8	6,809.1	8,123.3
Share of PAC ($A/B \times 100$)	0.374	0.317	0.240	0.277

Note : Total Production Costs = Compensation Employee + Major Production Costs + Fixed Asset Depreciation Costs.

Source : Bank of Korea, Korean Statistical Information Service.