International Environmental Agreement Formation and Trade

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Abstract

This paper examines how International Environmental Agreements (IEAs) will be affected when countries change from closed economy to open economy. Using an extended model from Barrett (1994)'s seminal paper on self-enforcing IEA, this paper shows that: (i) instead of free trade, tariff trade will arise in equilibrium; (ii) the endogenously determined size and the effectness of the IEA are the tradeoff of four effects, namely entry effect, level effect, leakage effect and tariff effect. The paper also offers an alternative explanation for the minimum participation clause adopted by most IEAs, i.e., signatories of an IEA have incentive to make higher abatement than nonsignatories (determined by domestic envrionmental policy) only if the size of the agreement reaches a minimum level.

Key words: IEA, trade, leakage.

JEL Classification: H41, Q20, F12

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1 Introduction

One of the biggest and most urgent environmental problems is global warming, brought about by human activities with "greenhouse gas" (GHG) emission. Global atmospheric concentration of greenhouse gases (GHGs) like CO_2 increased by 30% during the past 200 years. As the consequence, the Earth has warmed by 0.6°C over the past 100 years. Such changes have not only caused damages to human-built infrastructure because of rising sea level, but also reduced productivity, and life hazard etc. As the atmosphere is a global public goods, its management requires multilateral endeavor across all nations through international environmental agreements (IEAs) such as the Kyoto Protocol that ratified by participating nations in 1997.

Cooperation in international environmental issues differs from most other international problems (Barrett (2005)). For instance, in free trade agreements (FTAs), the formation can be on a bilateral basis since free trade is not a global public goods and non-signatories can be excluded from enjoying the benefits of a FTA. By contrast, in an IEA, the participating members can not exclude non-participants from enjoying the benefits of better global environment.

However, this is not to say, that all IEAs are equally difficult to form and/or implement. At present, there are close to 300 multilateral IEAs in force (Barrett (2003)), and the topics of them are various, including GHG emission control, ozone layer protection, marine pollution, fisheries conservation and acid rain etc. Some of these agreements have been very successful[1]. However, some IEAs are not that successful: they are still not in force, or have too few members, or are not effective in addressing their concerned problems. This is because not all IEAs are the same. In some IEAs, violators face a shrinking market hence externalities can be reduced (MARPOL) or entry deterrence (for violators) is technically feasible. In Montreal Protocol, rich countries gain much higher from Ozone layer protection, and abatement is relatively inexpensive.

Most papers in this area focus on international public goods problems with aggregate supply. This setting is suitable for the case of self-enforcing IEA of GHG emission. The seminal papers on such self-enforcing IEA include

[1]For example, Montreal Protocol, one for alleviating ozone depletion, which was put into force in 1989, now has 175 signatories, and MARPOL dealing with marine pollution (deliberate dumping of oil into sea), has member countries up to 113.

Hoel (1991); Carraro and Siniscalco (1993) and Barrett (1994) and their simulation results are pessimistic: the number of signatories is very small, or full cooperation can realize only when the difference in net benefits between the noncooperative and full cooperative outcome is very small. Such result is confirmed by Diamantoudi and Sartzetakis (2001) who proves that the size of the unique stable IEA is small (either 2, 3 or 4), using an analytical approach[2]. McGinty (2006) studies how the asymmetry between countries will make any difference. He finds that though IEA can achieve substantial emissions reduction with asymmetric players, the tradeoff between the gains to an IEA and the number of signatories still exists. Dutta and Radner (2004) under a dynamic game framework finds that uncooperative equilibrium is not global Pareto optimal, and countries do not make any effort to reduce emission after the first stage.

On the other hand, given that the world economy is becoming increasingly integrated, an IEA problem without consideration of international trade may not suit the reality. In fact, the 1990s saw a heated debate on the effect of foreign trade on global environment and an associated growing literature on trade and the environment. A group of researchers believe that free trade is not the cause of environmental problems, instead, the impetus of environment protection because free trade will promote optimal resource allocation globally (Anderson and Blackhurst (1992), Cole (1999)). Trade will induce more resources devoted to clean production and abatement, and freer trade eliminates the distortionary trade policies which are generally bad for the environment (Torres (1999)). However, there is no consensus that trade will in general promote environment. For instance, Dean (1992), a literature survey on trade and environment, has flavor that trade is bad for environment. Copeland and Taylor (1995) using a general equilibrium model finds that if countries differ significantly in income level, free trade will raise world pollution.

Despite the incongruent conclusions, trade and environmental economists seem to agree on the categorization of effects of foreign trade on environment. In Barrett (1994)'s oligopoly model, optimal environmental policy can be decomposed into marginal environmental damage effect, strategic effect, and

[2]Recently, Ecchia and Mariotti (1997, 1998) show that farsightedness can help a high degree of cooperation in IEA. McGinty (2006) extends the original Barrett (1994) model with asymmetry between countries so that high benefit nations contribute more to total abatement through purchase of permits.

leakage effect[3]. Based on the study of NAFTA, Grossman and Krueger (1991) categorize the impact of trade on environment into three effects, namely, the composite effect, scale effect, and technique effect. This categorization has been also used by a lot of papers including Antweiler, Copeland and Taylor (2001). Such categorization made relevant analyses transparent. For instance, Beghin et al (1995) are able to show that the scale effect dominates the composite effect in Mexico's accession to NAFTA and consequently pollution became worse. However because technique effect is somewhat vague in static models, it makes the total effect ambiguous[4]. Indeed, because of income effect, growth will force lower emission and there is a large body of literature on the environmental Kuznets' curve (EKC).

Obviously the impact of trade on IEA formation deserves serious research because the changes in incentives for individual countries to join an IEA are unclear, even conceptually. However the relevant literature is disproportionally small. One exception is Barrett (1997) in which a framework that incorporates both the environmental damages and abatement costs in an IEA formation problem with free trade is provided, and the paper then illustrates that how trade sanctions can help support IEA cooperation[5]. Using the same framework, Sivers Boyce (2002) shows that higher participation can realize under free trade though total intensity of abatement is less. It is argued that, contrary to the common wisdom, that leakage effect is positive in terms of promoting greater participation when damage cost is high.

These research provides a sound foundation for further research, however, there are important questions still left unanswered such as the relationship between tariff trade and IEA formation. The current paper is meant to address such problems. In this paper, the impact of trade is decomposed

[3]In the open economy environmental policy models, Markusen (1975) claims that domestic environmental policy can be decomposed into three effects, the marginal environmental damage effect, terms-of-trade effect, and leakage effect.

[4]For example, Copeland and Taylor (2005) show that when countries change from autarky to trade, if income effect can more than offset the negative free-riding effect and leakage effect, the relationship between home and foreign emission changes from strategic substitute into strategic complement.

[5]From the compliance point of view, Barrett (1997, 1999) show that leakage can make trade restrictions imposed by signatories can be credible even if unilateral defection is profitable. Thus, minimum parcipation clause of an IEA is necessary in maintaining higher degree of cooperation.

into entry, level, leakage and tariff effects[6], where entry and level effects are similar to scale effects defined in the literature. Given the size of an IEA is fixed, the entry and tariff effects are positive on effectiveness which will increase global abatement level in equilibrium, and level and leakage effects are negative on the effectiveness of an IEA. Therefore the total effect of trade on IEA is contingent on the magnitude of the four effects. When entry and tariff effects dominate leakage and level effects, trade is good for IEA in the sense that greater global abatement level and/or a larger IEA will realize. Furthermore, equilibrium tariff level is shown to be positive, and the introduction of tariff improves the tradeoff between the size and effectiveness of an IEA.

One interesting observation is that in most IEAs, there is a minimum participation clause in which if the number of signatories is below some certain threshold, the IEA becomes void. This is in contrast with other international problems such as FTA where agreements can be formed through a bilateral process. The current paper finds that minimum participation clause is necessary because if there are too few signatories, then optimal abatement levels of signatories will be lower than that of non-signatories, which is in contradiction of the mandate of the IEA and therefore any meaningful IEA fails to meet minimum participation constraint is not self-enforcing.

To summarize, the current paper complements the existing literature in the following aspects. First, to the best of our knowledge, this paper is the first to provide a theoretical analysis on tariff trade and IEA. Second, it articulates the effects of trade on IEA formation in terms of participation and effectiveness, and hence able to interpret when trade is good for the environment. Third, it offers an alternative explanation of minimum participation clause.

The rest of the paper is organized as follows: in Section 2, the model is set up; Section 3 focuses on the analysis of the IEA under autarky; Section 4 analyzes the impact of trade on the IEA; Section 5 is the concluding remarks.

[6] By linear demand assumption (hence no income effect), we are able to eliminate technical effect and concentrate on short run effects of trade.

2 Model Setup

The model in this paper is built on that in Barrett (1994). IEA literature including Barrett (1994) usually models the process of IEA from signature to implementation as a stage game. The three-stage case is that in the first stage, countries make decision whether to sign it or not; then in the second stage, signatories of the IEA cooperatively determine their emission abatement level of the transboundary pollutant; following the signatories, nonsignatories set their abatement level unilaterally in the third stage. Sometimes signatories and nonsignatories are modeled to act simultaneously. The only difference between the sequential move and simultaneous move models is obviously that signatories have first-mover advantage in the former case. Since this advantage is helpful in reducing free riding, the equilibrium of signatory number in the three-stage model is constantly not smaller than that in the two-stage one, *ceteris paribus*. This fact indicates that choosing either one of these two stage games brings no harm to our analysis of an IEA. However, in order to make the result extensively comparable to previous literature and increase the possibility of obtaining optimistic result, sequential move model is adopted in this paper. The complete order of play is:

- stage 1: countries determine whether to join in the IEA or not;
- stage 2: signatories determine their abatement levels collectively (signatories as Stackelberg leaders);
- stage 3: nonsignatories set their abatement levels independently;
- stage 4: under autarky, domestic firms produce goods and sell them; under (tariff) trade, countries set their optimal tariffs;
- stage 5: under trade, firms compete in both domestic and international markets, facing the tariffs of trade partners.

Since this paper is aimed to analyze the impact of trade on an IEA, the production and tariff must be taken into account, then the fourth and fifth stages of the game are indispensable. This is the main difference between this model and that in Barrett (1994) which does not consider dirty goods production and consumption. To solve the five-stage game, the standard method is backward induction. Players in this model are *ex ante* symmetric countries (after the signature of the IEA, signatories will be different from nonsignatories due to different abatement level), each country has one firm producing dirty goods. N stands for the total number of all countries, and k is the size or the number of signatories of the IEA ($(N-k)$ is the number of nonsignatories). y is a country's abatement level. $y_{si}(k), y_{nj}(k)$ respectively stand for the abatement levels of signatory i and nonsignatory j (subscript s and n stand for signatory and nonsignatory respectively) when there are k signatories. The benefit function of a country from emission abatement is $B\left(\sum_l y_l\right)$, $l = 1 \dots N$, $B^{'} > 0$.This function captures the nature of transboundary pollution, as a country can not only benefit from its own abatement, but also from all others'. This is where the free riding problem mentioned above lies. It is practical to set $B^{''} < 0$ here, which means diminishing marginal benefit. To simplify the analysis, we assume constant $B^{''}$, namely $B^{'''} = 0$. $C_D(y_i)$ is the direct cost of abatement of country i, when it abates y_i units emission. This function satisfies $C_D^{'} > 0$, $C_D^{''} > 0$. Also for convenience purpose, we set $C_D^{'''} = 0$.

$P(Q_i)$ is the inverse demand function of country i where Q_i is i's consumption level, $P^{'} < 0.C_M(y_i)$ is the marginal cost of production which is related to domestic abatement level, with $C_M^{\prime} > 0.Q_{si}^A$, Q_{si}^T (Q_{nj}^A, Q_{nj}^T) are the total consumption in signatory i (nonsignatory j) under autarky and trade. For firms in signatory i and nonsignatory j, q_{si}^A, q_{nj}^A respectively stand for their production levels under autarky. It is straightforward that $Q_{si}^A = q_{si}^A$, $Q_{nj}^A = q_{nj}^A$. Under trade, q_i^j, q_i^i are the production levels of country i's firm in country j and its home market. T_i stands for the same tariff of country i to all other countries under the most-favored nation treatment (MFN). Other notations will be introduced in their relevant section.

3 IEA under Autarky

In this section, there are two subsections: in Subsection 1, we briefly carry out some discussion on the IEA model in Barrett (1994) which is the basis of this paper's model, because this will bring convenience for the discussion in the rest of the paper and enable us to easily and clearly compare our results with previous literature; in Subsection 2, we discuss the IEA under autarky, providing a benchmark for the analysis of the IEA under trade scenario in Section 4.

3.1 Self-enforcing IEA Regardless of Production

The model in Barrett (1994) is a representative self-enforcing IEA model. One of its characteristics is that it only takes account of the direct benefit and direct cost of abatement, the indirect effect of abatement on a country's welfare generated through dirty goods production and consumption is left unconsidered. Thus, compared with our model in this paper, the representative self-enforcing IEA model can be named as 'IEA regardless of production'. In that model, according to the benefit and direct cost functions defined in Section 2, the net welfare of any country i obtained from transboundary pollutant abatement is

$$W_i^{RP} = B\left(\sum_l y_l\right) - C_D\left(y_i\right) \tag{1}$$

The superscript RP means 'Regardless of Production'. $\sum_l y_l$ is the sum of all countries' abatement, namely global abatement level, $l = 1...N$. Though country i can enjoy the benefit brought by any other country's action in reducing pollutant, itself bears the cost of its own abatement. If j does not sign the IEA, then its objective is just to maximize its net welfare W_{nj}^{RP} unilaterally. For a signatory i,it will cooperatively choose its abatement level to maximize the collective welfare of all the signatories. Under the stage game, signatories are Stackelberg leaders, so when applying backward induction we firstly solve out the FOCs for the nonsignatories who take signatories abatement level as given when making decisions, and then work out the FOCs of signatories based on nonsignatories' best response function. Since countries are *ex ante* symmetric, all nonsignatories will set the same y_n, and all signatories will set the same y_s. Therefore the FOCs are respectively,

$$\frac{\partial W_{nj}^{RP}}{\partial y_{nj}} = B'\left((N-k)y_n + ky_s\right) - C_D'(y_n) = 0 \tag{2}$$

$$\frac{\partial \sum\limits_{m=1}^{k} W_{sm}^{RP}}{\partial y_{si}} = kB'((N-k)y_n + ky_s) \cdot \left[(N-k)\frac{\partial y_n}{\partial y_s} + 1\right] - C_D'(y_s) = 0 \tag{3}$$

In (3), $\frac{\partial y_n}{\partial y_s}$ is the first order derivative of $y_n = y_n\left(y_s\right)$, the best response function of nonsignatories. Since $y_n = y_n\left(y_s\right)$ is derived from (2) we can get the expression of $\frac{\partial y_n}{\partial y_s}$ through differentiating (2) with respect to y_s,

$$\frac{\partial y_n}{\partial y_s} = \frac{B''}{C_D'' - (N-k)B''} \tag{4}$$

According to the assumptions in the third section, $B'' < 0$ and $C_D'' > 0$, so $\frac{\partial y_n}{\partial y_s} < 0$ which means that as any signatory increases its abatement, a nonsignatory will lower its abatement. This result is the very reflection of free riding problem in transboundary pollution. To characterize the magnitude of this response, we should take a further step to multiply it with the number of nonsignatories $(N-k)$, then get $(N-k)\frac{\partial y_n}{\partial y_s} = \frac{(N-k)B''}{C_D''-(N-k)B''} = -1 + \frac{C_D''}{C_D''-(N-k)B''}$, where $\frac{C_D''}{C_D''-(N-k)B''} > 0$. Therefore,

$$-1 < (N-k) \cdot \frac{\partial y_n}{\partial y_s} < \frac{\partial y_n}{\partial y_s} < 0 \tag{5}$$

This series of inequalities shows that though nonsignatories response negatively to a signatory's abatement, the amount of abatement decreased by all nonsignatories will not offset the signatory's effort in creasing environment quality, so signatories' abatement is still socially desirable, and the global abatement level under an IEA is less than the socially optimal level.

Substituting 4 into 3, we can get,

$$\frac{\partial \sum_{m=1}^{k} W_{sm}^{RP}}{\partial y_{si}} = B'((N-k)y_n + ky_s) \cdot \frac{kC_D''}{C_D'' - (N-k)B''} - C_D'(y_s) = 0 \tag{6}$$

To see how y_n and y_s change with k,we could differentiate 2 and 6 w.r.t. k, and solve out

$$\frac{\partial y_n(k)}{\partial k} = \frac{\begin{array}{c} -[y_n(k) - y_s(k)] \cdot B'' \cdot [C_D'' - (N-k)B'']^2 \\ +kB''B' \cdot [C_D'' - (N-2k)B''] \end{array}}{[C_D'' - (N-k)B''] \cdot \{[C_D'' - (N-k)B'']^2 - k^2 B'' C_D''\}} \tag{7}$$

$$\frac{\partial y_s(k)}{\partial k} = \frac{[y_n(k) - y_s(k)] \cdot kB'' C_D'' - B' \cdot [C_D'' - (N-2k)B'']}{k^2 B'' C_D'' - [C_D'' - (N-k)B'']^2} \tag{8}$$

3.2 IEA under Autarky

In the proceeding subsection, I have carried out some discussion on the model regardless of production. Now, I introduce production and consumption into the analysis and get the self-enforcing IEA model of this paper. The focus of this subsection is the IEA under autarky scenario. The results that be obtained here will provide a benchmark for the analysis of the IEA under trade in the next section.

3.2.1 General Discussion

There is one dirty goods firm in each country, every firm's objective is to maximize its own profits. Since the firms are the real polluters, we could assume that they bear all the cost of abating emission and receive no subsidy from the government which makes decision on the abatement level. According to the order of play described in Section 2, the government sets the required amount of abatement first, and then the local firm chooses its optimal production level. So, when firms act, they take the amount of abatement and relevant cost of abating emission as given. The profit function of the firm in any country i under autarky is

$$\pi_i^A = \left(P(q_i^A) - C_M(y_i)\right) q_i^A - C_D(y_i) \tag{9}$$

The FOC of maximizing π_i^A w.r.t. q_i^A is as follows

$$P(q_i^A) - C_M(y_i) + P' q_i^A = 0 \tag{10}$$

To guarantee the existence of an optimal production level, some q_i^{A*}, the single solution or one of the solutions of (10), should satisfies the SOC, that is

$$2P' + P'' q_i^{A*} < 0 \tag{11}$$

In the following discussion, let q_i^{A*} stand for the solution of (10) and satisfies (11) and maximizes (9). Now, we can write down the welfare function of country i,

$$W_i^A = \int_0^{q_i^{A*}} \left[P(x) - P(q_i^{A*})\right] dx + \left[P(q_i^{A*}) - C_M(y_i)\right] q_i^{A*} + B\left(\sum_l y_l\right) - C_D(y_i) \tag{12}$$

In this function, $\int_0^{q_i^{A*}} \left[P(x) - P(q_i^{A*})\right] dx$ is consumer surplus, $\left[P(q_i^{A*}) - C_M(y_i)\right] q_i^{A*}$ is local firm's profits from production, $B\left(\sum_l y_l\right) - C_D(y_i)$,like that in Barrett (1994), is the net benefit of the society from abating. It is convenient to let $V_i^A(y_i) = \int_0^{q_i^{A*}} \left[P(x) - P(q_i^{A*})\right] dx + \left[P(q_i^{A*}) - C_M(y_i)\right] q_i^{A*}$, so $V_i^A(y_i)$ represents the welfare generated from dirty goods production and consumption that can be *indirectly* affected by abating pollutant. It is easy to get $\frac{\partial V_i^A}{\partial y_i} = (-3P' - P'' q_i^*) q_i^* \cdot \frac{\partial q_i^*}{\partial y_i}$. Differentiate (10) w.r.t. y_i, we obtain $\frac{\partial q_i^*}{\partial y_i} = \frac{C_M'}{2P' + P'' q_i^*}$. Since $C_M' > 0$ and q_i^{A*} satisfies the SOC (11), we find

$$\frac{\partial V_i^A}{\partial y_i} = (-3P' - P'' q_i^*) q_i^* \cdot \frac{C_M'}{2P' + P'' q_i^*} < 0 \tag{13}$$

This result tells us that under autarky the part of a country's gains from dirty goods production and consumption that can be *indirectly* affected by abating emission is decreasing with abatement level. This is not difficult to comprehend: as the abatement level required by local government increases, the monopolistic firm's marginal cost of production will be increased (through being forced to take some measures in the production process to lower its emission), then the profits from production will be reduced; since the monopoly will try to sustain its profits, it increases its price, then the consumer surplus will be hurt, as a result, both the gains of the firm and consumers shrink. Based on this fact, $-\frac{\partial V_i^A}{\partial y_i}$ could be taken as the indirect marginal cost of abatement (IMC) (the direct marginal cost is C_D'). So, given the same benefit and direct cost function, compare this model under autarky with that regardless of production, the marginal cost of abatement is increased in this model (in Barrett (1994) the marginal cost is C_D', while in this model the marginal cost is $C_D' - \frac{\partial V_i^A}{\partial y_i}$). From this, we can judge that if the number of signatories are the same in these two models, the IEA under autarky model in this paper will have a lower global abatement level. Moreover, such a increased cost may also act as a force to reduce the size of an

IEA. Therefore, during the negotiation period of an IEA, linking production and consumption with environment protection will make the IEA harder to step further.

As in the model regardless of production, nonsignatories and signatories in this model, following the order of play, respectively unilaterally and cooperatively set their optimal abatement levels in order. The FOCs considering symmetry are

$$\frac{\partial W_{nj}^A}{\partial y_{nj}} = \frac{\partial V_n^A}{\partial y_n} + B'((N-k)y_n + ky_s) - C_D'(y_n) = 0, \tag{14}$$

and

$$\frac{\partial \sum_{m=1}^{k} W_{sm}^A}{\partial y_{si}} = \frac{\partial V_s^A}{\partial y_s} + kB'((N-k)y_n + ky_s)\left[(N-k)\frac{\partial y_n}{\partial y_s} + 1\right] - C_D'(y_s) = 0. \tag{15}$$

For the convenience of analysis, we could assume $\frac{\partial^3 V_i^A}{\partial y_i^3} = 0$, thus $\frac{\partial^2 V_i^A}{\partial y_i^2}$ will be constant like B'' and C_D''. Let $\alpha = \frac{\partial^2 V_i^A}{\partial y_i^2}$ so as to simplify the following expressions. Differentiate (14) w.r.t. y_s, it is easy to get

$$\frac{\partial y_n}{\partial y_s} = \frac{B''}{\left(C_D'' - \alpha\right) - (N-k)B''}. \tag{16}$$

The only difference between (4) and (16) is in their denominators. To judge how $\frac{\partial y_n}{\partial y_s}$ has changed after considering production and consumption, we need to judge the sign of α. If $\alpha > 0$,IMC is decreasing, $\left|\frac{\partial y_n}{\partial y_s}\right|$ becomes larger; if $\alpha < 0$,IMC is increasing, $\left|\frac{\partial y_n}{\partial y_s}\right|$ becomes smaller. Substituting (16) into (15), we can get

$$\frac{\partial \sum_{m=1}^{k} W_{sm}^A}{\partial y_{si}} = \frac{\partial V_s^A}{\partial y_s} + B'((N-k)y_n + ky_s)\left[\frac{k\left(C_D'' - \alpha\right)}{\left(C_D'' - \alpha\right) - (N-k)B''}\right] - C_D'(y_s) = 0 \tag{17}$$

Since B'', C''_D and α are all constants, to guarantee the existence of optimal y_n and y_s, the SOCs must satisfy

$$\begin{aligned} \alpha + B'' - C''_D &< 0 \\ \alpha + B'' \cdot \frac{k\left(C''_D - \alpha\right)}{\left(C''_D - \alpha\right) - (N-k)B''} - C''_D &< 0 \end{aligned}$$

From (18), it is easy to prove that $C''_D - \alpha > 0$, or $C''_D > \alpha$. This inequalities serves as the necessary condition of the existence of optimal y_n and y_s. According to this result, it is easy to verify that

$$-1 < (N-k)\frac{\partial y_n}{\partial y_s} < \frac{\partial y_n}{\partial y_s} < 0$$

Again, similar with (5), though nonsignatories response negatively to a signatory's abatement, the amount of abatement decreased by all nonsignatories will not offset the signatory's effort in creasing environment quality, so signatories' abatement is still socially desirable. Now, with the condition $C''_D - \alpha > 0$, we would be able to offer an alternative explanation for the minimum participation clause of an IEA.

Proposition 1 *The minimum participation clause is the necessary condition for a signatory of an IEA to abate more emission than a nonsignatory.*

Proof. (17) – (14), we get

$$\begin{aligned} 0 &= \frac{\partial V_s^A}{\partial y_s} + B'((N-k)y_n + ky_s)\left[\frac{k\left(C''_D - \alpha\right)}{\left(C''_D - \alpha\right) - (N-k)B''}\right] \\ &\quad - C'_D(y_s) - \left[\frac{\partial V_n^A}{\partial y_n} + B'((N-k)y_n + ky_s) - C'_D(y_n)\right] \end{aligned}$$

rearrange this difference,

$$B' \cdot \left[\frac{k\left(C''_D - \alpha\right)}{\left(C''_D - \alpha\right) - (N-k)B''} - 1\right] = \left[C'_D(y_s) - \frac{\partial V_s^A}{\partial y_s}\right] - \left[C'_D(y_n) - \frac{\partial V_n^A}{\partial y_n}\right] \quad (18)$$

Since we have proved that $C''_D - \alpha > 0$, $C'_D(y_i) - \frac{\partial V_i^A}{\partial y_i}$ is decreasing with any country i's abatement level y_i. Therefore, if we require a signatory to abate more than a nonsignatory, say $y_s > y_n$, then the LHS of (18) $\left[C'_D(y_s) - \frac{\partial V_s^A}{\partial y_s}\right] - \left[C'_D(y_n) - \frac{\partial V_n^A}{\partial y_n}\right] > 0$. On the RHS of (18), B' is positive, so if (18) is satisfied, there must be $\frac{k\left(C''_D - \alpha\right)}{\left(C''_D - \alpha\right) - (N-k)B''} - 1 > 0$. B'', C''_D and α are all constants, so we can verify that $\frac{k\left(C''_D - \alpha\right)}{\left(C''_D - \alpha\right) - (N-k)B''} - 1$ is monotonically increasing with k, the number of signatories of the IEA. To solve $\frac{k\left(C''_D - \alpha\right)}{\left(C''_D - \alpha\right) - (N-k)B''} - 1 = 0$,, we find the threshold value $\underline{k} = \frac{\left(C''_D - \alpha\right) - NB''}{\left(C''_D - \alpha\right) - B''}$,the minimum participation level. So, only if the size of the IEA is larger than $\underline{k}$, can there be $y_s > y_n$. ■

In Jane Black, Maurice D. Levi and David de Meza (1993), they points out that the existence of minimum participation rule is due to incomplete information, and the purpose of the rult is try to maximize the expected global surplus. Carlo Carraro, Carmen Marchiori and Sonia Oreffice (2003) provides another explanation for this clause: before countries make decisions whether to sign an IEA or not, they would like to have a minimum participation constraint so as to maximize their expected payoff after the signature of the IEA. In this paper, this proposition is constructive to our understanding of most IEAs' the minimum participation clause. As we all know, the spirit of an IEA is to improve environment quality through combining countries to reduce their pollutant, so if the member countries of the agreement make less efforts than do the nonsignatories, the IEA is practically not acceptable. This is why most IEAs whether in force or not set a minimum participation clause.

3.2.2 Equilibrium and Simulation

Participation problem is one of the most important problems in an IEA: How many countries will finally ratify the agreement? It is time for us to address this problem now. Understandably, for a self-enforcing IEA, the incentive of a country to join in it is determined by the country's potential gain of signing this agreement: if switching from a nonmember of the agreement to a member could increase the total welfare of the country, it will sign the agreement without hesitation; otherwise, it will leave out of the IEA. So, based on this logic, I define the incentive function of participating the IEA under the autarky scenario,

$$
\begin{aligned}
I^A(k) &= V_s + B((N-k)\cdot y_n(k) + k\cdot y_s(k)) - C_D(y_s(k)) - V_n \\
&\quad -B((N-k+1)\cdot y_n(k-1) + (k-1)\cdot y_s(k-1)) \\
&\quad +C_D(y_n(k-1)) \qquad (19)
\end{aligned}
$$

This function represents the gain (or loss) of a country changing from a nonsignatory to a signatory when the size of the IEA is $k-1$. If some k satisfies that $I^A(k-1) > 0$, $I^A(k) < 0$, then the participation equilibrium is k. Given specific functional forms of all those related functions, we would be able to explicitly solve out the participation equilibrium. Especially, when $I(k)$ monotonically decreases with k, the equilibrium number of signatories is $\lfloor k^* \rfloor + 1$, where k^* satisfies $I(k^*) = 0$, and $\lfloor k^* \rfloor$ is the maximum integer less than k^*. (The following model for simulation satisfies the monotonicity when $k \geq 1$.)

Another mostly concerned problem of IEA is whether such an agreement is effective or not. Here, consistent with Sivers Boyce (2002), we give the definition of absolute effective,

Definition 1 *Absolute Effectiveness: under participation equilibrium, the total amount of abatement of countries in the world, namely* $(N-k)\cdot y_n + k\cdot y_s$.

The higher the absolute effectiveness, the better the environmental quality. So taken the absolute effectiveness under autarky as a benchmark, compare that under trade with this benchmark would enable us to see whether trade can improve the quality of environment or not. In the assumed general functional forms, one can hardly explicitly compute the number of signatories or evaluate the effectiveness of an IEA. Therefore a simulation is needed. In this paper, the specific model used for simulation is linear benefits $B(\sum_l y_l) = \sum_l y_l$, increasing direct marginal cost $C_D(y_i) = \frac{1}{2}y_i^2$, simple linear inverse demand function $P(Q_i) = 1 - Q_i$ and marginal production cost $C_M(y_i) = 0.005 + 0.001y_i$. The interval of N used for simulation is from 10 to 100.

Figure 1 shows that as the total number of countries involved in the environmental problem changes, the participation equilibrium is constantly 3.

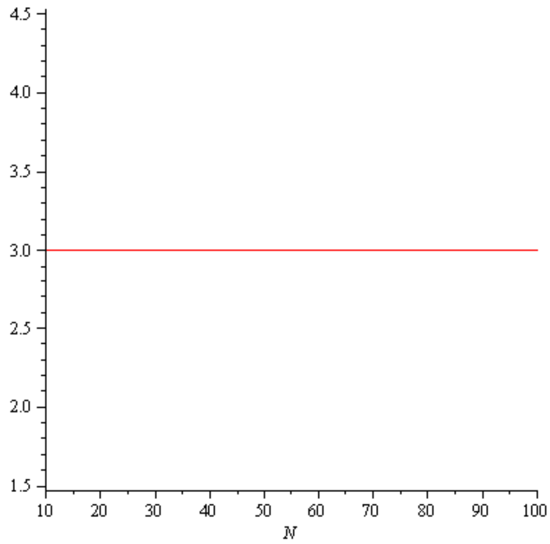

Figure 1: The size of the IEA under Autarky

Undoubtedly, this is still a pessimistic result like that in other IEA literature. We should attribute this to the free riding problem.

Figure 2 indicates that the absolute effectiveness of the IEA is *approximately* monotonically increasing with N. To look at this figure alone is not meaningful. It mainly serves as a benchmark for our analysis of the effectiveness of the IEA under trade.

4 IEA under Trade

In Section 4, we discussed the IEA under autarky scenario, and found that in closed economy when taking gains from dirty goods production and consumption into account, there will be an IMC for emission abatement. However, such an IMC is only related to domestic abatement level of a country. In reality, the basic economic relationship between countries is trade, not autarky. Under trade, a country's gains from consumption and production is not only affected by domestic abatement, but also indirectly affected by for-

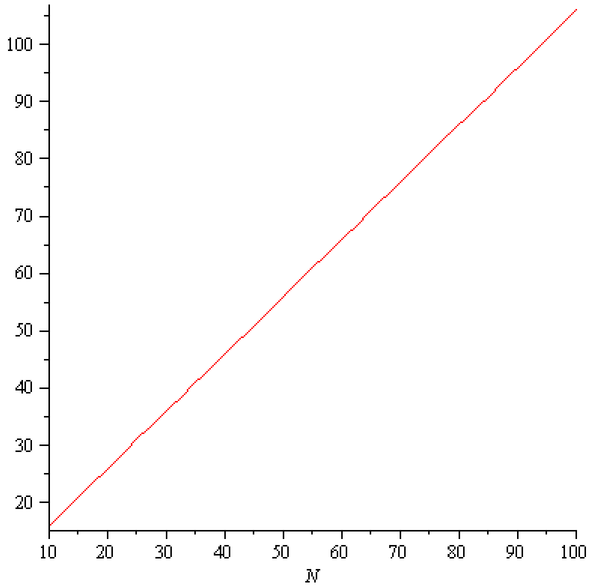

Figure 2: The effectiveness of the IEA under autarky

eign countries'. Then how such a link between a country's welfare with other countries' actions in environment protection affects the country's decision in signing the IEA and abatement level? We will address this problem in this section.

In rest of this section, we first prove that the optimal tariff of a country under MFN treatment is positive rather than zero, so in equilibrium, the economic relationship between countries is tariff trade, not free trade. Then we will analyze the impact of trade on the IEA through dividing it into four effects, say entry effect, level effect, leakage effect and tariff effect, and will demonstrate that the impact of trade on IEA's effectiveness is ambiguous, contingent with the relative magnitude of the four effects. Finally, present the simulation result is presented, and compared with that under autarky.

4.1 The Existence of a Positive Tariff

After a country open its market, firms in all other country will enter this market to compete for profits. Then the monopolistic market will change to a oligopoly market, so the total production level in the market will be increased after trade. In any country i, the FOCs of all the firms competing in this market are respectively

$$\begin{aligned} P(Q_i^T) - C_M(y_i) + P'(Q_i^T)q_i^i &= 0 \\ P(Q_i^T) - C_M(y_j) + P'(Q_i^T)q_j^i - T_i &= 0 \\ &\vdots \\ P(Q_i^T) - C_M(y_N) + P'(Q_i^T)q_N^i - T_i &= 0 \end{aligned} \tag{20}$$

To make sure that every firm has an optimal production level, we assume that,

$$2P'(Q_i^T) + P'(Q_i^T)Q_i^T < 0 \tag{21}$$

(21) can guarantee that all the SOCs for firms' profit maximization are satisfied. The welfare function of any country i is

$$
\begin{aligned}
W_i^T &= \int_0^{Q_i^T} \left[P(x) - P(Q_i^T)\right] dx + \left[P(Q_i^T) - C_M(y_i)\right] q_i^i \\
&+ \sum_{l \neq i}^{N-1} \left[P(Q_l^T) - C_M(y_i) - T_l\right] q_i^l + T_i \left(\sum_{l \neq i} q_l^i\right) + B\left(\sum_l y_l\right) - C_D(y_i)
\end{aligned}
$$

If the country want to choose an optimal tariff to maximize its welfare, the tariff must satisfy

$$
\frac{\partial W_i^T}{\partial T_i} = \left[-P'(Q_i^T)Q_i^T - P''(Q_i^T)\left(q_i^i\right)^2\right] \cdot \frac{\partial Q_i^T}{\partial T_i} - 2P'(Q_i^T)q_i^i \cdot \frac{\partial q_i^i}{\partial T_i} + T_i \left(\sum_{l \neq i} \frac{\partial q_l^i}{\partial T_i}\right) + \sum_{l \neq i} q_l^i = 0 \tag{22}
$$

Solve out the optimal tariff of country i,

$$
T_i = \frac{\left[P'(Q_i^T)Q_i^T + P''(Q_i^T)\left(q_i^i\right)^2\right] \cdot \frac{\partial Q_i^T}{\partial T_i} + 2P'(Q_i^T)q_i^i \cdot \frac{\partial q_i^i}{\partial T_i} - \sum_{l \neq i} q_l^i}{\sum_{l \neq i} \frac{\partial q_l^i}{\partial T_i}} \tag{23}
$$

Proposition 2 *In equilibrium, countries do not have free trade with others. Their optimal tariffs under MFN treatment to all other countries are positive.*

Proof. Considering the market of any country i. To sum all the firms' FOCs in this market, namely to sum the series of equations in 20, we can get

$$
NP(Q_i^T) - \sum_{l=1}^{N} C_M(y_l) + P'(Q_i^T)Q_i^T - (N-1)T_i = 0 \tag{24}
$$

To differentiate (24) w.r.t. T_i, we can get

$$
\left[(N+1)\,P'(Q_i^T) + P''(Q_i^T)Q_i^T\right] \cdot \frac{\partial Q_i^T}{\partial T_i} = N - 1 \tag{25}
$$

According to (21), $(N+1)\,P'(Q_i^T) + P''(Q_i^T)Q_i^T < 0$, so $\frac{\partial Q_i^T}{\partial T_i} < 0$, that is as country i increase its tariff, total production level in its market is decreased. This is because the higher trade barrier reduces the competition in the market, so the total production shrinks at last. Now, differentiate all the FOCs in (20) w.r.t. T_i, we obtain,

$$\begin{aligned}
\left[P'(Q_i^T) + P''(Q_i^T)q_i^i\right] \cdot \frac{\partial Q_i^T}{\partial T_i} + P'(Q_i^T)\frac{\partial q_i^i}{\partial T_i} &= 0 \\
\left[P'(Q_i^T) + P''(Q_i^T)q_j^i\right] \cdot \frac{\partial Q_i^T}{\partial T_i} + P'(Q_i^T)\frac{\partial q_j^i}{\partial T_i} &= 1 \\
&\vdots \\
\left[P'(Q_i^T) + P''(Q_i^T)q_N^i\right] \cdot \frac{\partial Q_i^T}{\partial T_i} + P'(Q_i^T)\frac{\partial q_N^i}{\partial T_i} &= 1
\end{aligned} \tag{26}$$

Since (21) is given, $P'(Q_i^T) + P''(Q_i^T)q_i^i < 0$. We have proved $\frac{\partial Q_i^T}{\partial T_i} < 0$, so $\frac{\partial q_i^i}{\partial T_i} > 0$. Also, from (21), we can prove $P'(Q_i^T)Q_i^T + P''(Q_i^T)\left(q_i^i\right)^2 < 0$. Then the sign of the nominator of (23), $\left[P'(Q_i^T)Q_i^T + P''(Q_i^T)\left(q_i^i\right)^2\right] \cdot \frac{\partial Q_i^T}{\partial T_i} + 2P'(Q_i^T)q_i^i \cdot \frac{\partial q_i^i}{\partial T_i} - \sum_{l \neq i} q_l^i$, is negative. According to the fact that $Q_i^T = \sum_l q_l^i$, we can get

$$\sum_{l \neq i} \frac{\partial q_l^i}{\partial T_i} = \frac{\partial Q_i^T}{\partial T_i} - \frac{\partial q_i^i}{\partial T_i} < 0 \tag{27}$$

Therefore, the optimal tariff of any country i is positive, say it will not have free trade with others. ■

The discussion of the impact of trade on IEA in Barrett (1997) and in Sivers Boyce (2002) are both based on free trade. Admittedly, if free trade is equilibrium, say all the countries' optimal tariffs are 0, their analysis will be unexceptionable. However, now we have proved that countries in equilibrium choose trade with positive, so negligence of the tariff which makes their model and relevant analysis less complex may make them omit the necessary analysis of tariff's effect on the size and effectiveness of an IEA. In the following discussion, we start our analysis of trade's impact on IEA by dividing the impact into entry effect, level effect, leakage effect and tariff effect.

4.2 The Impact of Trade on IEA

Consider, when the countries in the world change from closed economy to open economy, what will happen? Firstly, the goods of a country enter the markets of other countries. Secondly, due to competition, in all markets, every firm will increase their production level. In the third place, since countries have different abatement levels which affect their marginal costs of production, some countries which abate less emission will have comparative advantage and competitive advantage. Such countries' firms produce more than the ones in other countries which have high abatement level. Finally, in order to guarantee the local firm's profits, the local government will raise tariff to prevent other countries to produce too many in its market and to reduce its disadvantage in cost due to higher abatement level (if it increases its abatement). Admittedly, the four facts which are separately discussed above happen at the same time when countries shift from autarky to trade. However, enlightened by Sivers Boyce (2002), I find that we can logically and mathematically separate them so as to analyze one at a time. The formal definition and mathematical expression are listed below,

• Entry Effect: The product of any country i's firm enters other markets, $q_i^j > 0$, $j = 1 \dots i-1, i+1 \dots N$;

• Level Effect: Any firm from country i increases its production level in any other country j's market, $\delta q_i^j, \delta > 1$;

• Leakage Effect: In all the markets, any country i's increase in its abatement leads the firm from any other country j to increase its product, $\frac{\partial q_j^l}{\partial y_i} > 0$;

• Tariff Effect: Any country i's tariff is increasing with its abatement level, and the increase of tariff will lead other firms reduce their production in country i' market,$\frac{\partial T_i}{\partial y_i} > 0$, $\frac{\partial q_j^i}{\partial T_i} < 0$.

4.2.1 Entry Effect

Since entry effect is the basis of other three effects, we discussed entry effect first. Based on our classification above, what happens when we eliminate the other three effects to focus on entry effect?

• No level effect: firms will not increase their production level in every market (keep q_i^{A*}) ;

• No leakage effect: the production of a firm will not be affected by other countries' abatement level (produce the same amount no matter the competitors have comparative advantages);

• No tariff effect: a country's tariff will not be affected by its own abatement level, and will not affect other countries production in its market (equivalent with zero tariff).

Thus, under entry effect, the firm from any country i will sale equal amount of its production in every market including its own, that is $\frac{q_i^{A*}}{N}$. Consequently, total production in every market is $\frac{\sum_l q_l^{A*}}{N}$. To see how entry effect will affect an IEA, we need to compare the signatories and nonsignatories FOCs of objective functions under autarky and under entry effect.

Under autarky,

$$\frac{\partial W_{nj}^A}{\partial y_{nj}} = \underbrace{\left[P\left(q_n^{A*}\right) - C_M\left(y_n\right)\right]\frac{\partial q_n^{A*}}{\partial y_n}}_{AN:nonsignatory\ under\ autarky} - C_M'\left(y_n\right)q_n^{A*} + B' - C_D'(y_n) = 0 \tag{28}$$

$$\frac{\partial \sum_{m=1}^{k} W_{sm}^A}{\partial y_{si}} = \underbrace{\left[P\left(q_s^{A*}\right) - C_M\left(y_s\right)\right]\frac{\partial q_s^{A*}}{\partial y_s}}_{AS:signatory\ under\ autarky} - C_M'\left(y_s\right)q_s^{A*} + kB' \cdot \left[(N-k)\frac{\partial y_n}{\partial y_s} + 1\right] - C_D'(y_s) = 0 \tag{29}$$

Under entry effect, $(TE : Entry\ Effect\ of\ Trade)$

$$\frac{\partial W_{nj}^{TE}}{\partial y_{nj}} = \underbrace{\left[\left(\frac{q_n^{A*}}{N} - \frac{\sum_l q_l^{A*}}{N^2}\right)P'\left(\frac{\sum_l q_l^{A*}}{N}\right) + \frac{T_n - \sum_l T_l}{N}\right]\frac{\partial q_n^{A*}}{\partial y_n} + \left[P\left(\frac{\sum_l q_l^{A*}}{N}\right) - C_M\left(y_n\right)\right]\frac{\partial q_n^{A*}}{\partial y_n}}_{TEN:\ nonsignatory\ under\ entry\ effect\ of\ trade} - C_M'\left(y_n\right)q_n^{A*} + B' - C_D'(y_n) = 0 \tag{30}$$

$$\frac{\partial \sum_{m=1}^{k} W_{sm}^{TE}}{\partial y_{si}} = \underbrace{k\left\{\left[\left(\frac{q_s^{A*}}{N} - \frac{\sum_l q_l^{A*}}{N^2}\right)\cdot P'\left(\frac{\sum_l q_l^{A*}}{N}\right) + \frac{T_s}{N}\right]\cdot\left[(N-k)\frac{\partial q_n^{A*}}{\partial y_n}\frac{\partial y_n}{\partial y_s} + \frac{\partial q_s^{A*}}{\partial y_s}\right]\right\} - \frac{\sum_l T_l}{N}\cdot\frac{\partial q_s^{A*}}{\partial y_s} + \left[P\left(\frac{\sum_l q_l^{A*}}{N}\right) - C_M\left(y_s\right)\right]\frac{\partial q_s^{A*}}{\partial y_s}}_{TES:signatory\ under\ entry\ effect\ of\ trade} - C_M'\left(y_s\right)q_s^{A*} + kB' \cdot \left[(N-k)\frac{\partial y_n}{\partial y_s} + 1\right] - C_D'(y_s) = 0 \tag{31}$$

Proposition 3 *Given the size of the IEA unchanged, entry effect is beneficial for global abatement level, say the absolute effectiveness of the IEA.*

Proof.

$$
\begin{aligned}
TEN &= \left[\left(\frac{q_n^{A*}}{N} - \frac{\sum_l q_l^{A*}}{N^2}\right) \cdot P'\left(\frac{\sum_l q_l^{A*}}{N}\right) + \frac{T_n}{N} - \frac{\sum_l T_l}{N}\right] \frac{\partial q_n^{A*}}{\partial y_n} \\
&\quad + \left[P\left(\frac{\sum_l q_l^{A*}}{N}\right) - C_M(y_n)\right] \frac{\partial q_n^{A*}}{\partial y_n} \\
&\approx \left[\left(\frac{q_n^{A*}}{N} - \frac{\sum_l q_l^{A*}}{N^2}\right) \cdot P'\left(\frac{\sum_l q_l^{A*}}{N}\right) + \frac{T_n}{N} - \frac{\sum_l T_l}{N}\right] \frac{\partial q_n^{A*}}{\partial y_n} \\
&\quad + \left[P\left(q_n^{A*}\right) + P'\left(q_n^{A*}\right)\left(\frac{\sum_l q_l^{A*}}{N} - q_n^{A*}\right) - C_M(y_n)\right] \frac{\partial q_n^{A*}}{\partial y_n} \quad (\textit{Taylor formula}) \\
&= \left[\left(\frac{\sum_l q_l^{A*}}{N} - q_n^{A*}\right) \cdot P'\left(\frac{\sum_l q_l^{A*}}{N}\right) \cdot \frac{(N-1)}{N} + \frac{T_n}{N} - \frac{\sum_l T_l}{N}\right] \frac{\partial q_n^{A*}}{\partial y_n} + AN \\
&\approx \left(\frac{T_n}{N} - \frac{\sum_l T_l}{N}\right) \frac{\partial q_n^{A*}}{\partial y_n} + AN \quad (\textit{free riding leads to } q_n^{A*} \approx q_s^{A*}) \\
&> AN
\end{aligned}
$$

$$
\begin{aligned}
TES &= k\left\{\left[\left(\frac{q_s^{A*}}{N} - \frac{\sum_l q_l^{A*}}{N^2}\right) \cdot P'\left(\frac{\sum_l q_l^{A*}}{N}\right) + \frac{T_s}{N}\right] \cdot \left[(N-k)\frac{\partial q_n^{A*}}{\partial y_n}\frac{\partial y_n}{\partial y_s} + \frac{\partial q_s^{A*}}{\partial y_s}\right]\right\} \\
&\quad - \frac{\sum_l T_l}{N} \cdot \frac{\partial q_s^{A*}}{\partial y_s} + \left[P\left(\frac{\sum_l q_l^{A*}}{N}\right) - C_M(y_s)\right] \frac{\partial q_s^{A*}}{\partial y_s} \\
&\approx k\left\{\frac{T_s}{N} \cdot \left[(N-k)\frac{\partial q_n^{A*}}{\partial y_n}\frac{\partial y_n}{\partial y_s} + \frac{\partial q_s^{A*}}{\partial y_s}\right]\right\} - \frac{\sum_l T_l}{N} \cdot \frac{\partial q_s^{A*}}{\partial y_s} + AS \quad (q_n^{A*} \approx q_s^{A*}) \\
&= k\frac{T_s}{N} \cdot (N-k)\frac{\partial q_n^{A*}}{\partial y_n}\frac{\partial y_n}{\partial y_s} - \frac{(N-k)T_s}{N} \cdot \frac{\partial q_s^{A*}}{\partial y_s} + AS \\
&> AS \quad \left(\frac{\partial q_n^{A*}}{\partial y_n} < 0, \frac{\partial y_n}{\partial y_s} < 0, \frac{\partial q_s^{A*}}{\partial y_s} < 0\right)
\end{aligned}
$$

Therefore, if k, the size of the IEA, is fixed, compared to autarky scenario, both nonsignatories' and signatories' marginal cost of abatement $(-AN +$

$C'_M(y_n)\,q_n^{A*} + C'_D(y_n)$ and $-AS + C'_M(y_s)\,q_s^{A*} + C'_D(y_s))$ have been decreased after trade, leaving marginal benefit hardly change, so the global abatement level will be increased. ■

This proposition implies that the entry effect on IEA's absolute effectiveness is positive.

4.2.2 Level Effect

If there is no entry effect, there will not be the other three effects, as all the other three ones are based on competition which happens after firms enter each others' markets. So when we consider how level effect affect the IEA, we should take market entry as prerequisite.

• With level effect: firms will increase their production level in every market

• No leakage effect: the production of a firm will not be affected by other countries' abatement level (produce the same amount no matter the competitors have comparative advantages);

• No tariff effect: a country's tariff will not be affected by its own abatement level, and will not affect other countries production in its market (equivalent with zero tariff).

Thus, compared with only entry effect case, adding level effect to trade will increase the sales of the firm from any country i in every market including its own, that is to increase $\frac{q_i^{A*}}{N}$ to $\delta\frac{q_i^{A*}}{N}, \delta > 1$

Under entry and level effect, the FOCs of countries' objective functions are, $(TV : Level\ Effect\ of\ Trade)$

$$
\begin{aligned}
0 \;=\; & \frac{\partial W_{nj}^{TV}}{\partial y_{nj}} = -C'_M(y_n)\cdot\delta q_n^{A*} + B' - C'_D(y_n) \\
& \underbrace{+\left[\left(\delta\frac{q_n^{A*}}{N} - \delta\frac{\sum_l q_l^{A*}}{N^2}\right)P'(\cdot) + \frac{T_n - \sum_l T_l}{N}\right]\frac{\partial q_n^{A*}}{\partial y_n}\delta + \delta\left[P(\cdot) - C_M(y_n)\right]\frac{\partial q_n^{A*}}{\partial y_n}}_{TVN:\,nonsignatory\ under\ level\ effect\ of\ trade}
\end{aligned} \tag{32}
$$

$$\frac{\partial \sum_{m=1}^{k} W_{sm}^{TV}}{\partial y_{si}} = \underbrace{\begin{array}{l} k\left\{\left[\left(\delta\frac{q_s^{A*}}{N} - \delta\frac{\sum_l q_l^{A*}}{N^2}\right)\cdot P'\left(\delta\frac{\sum_l q_l^{A*}}{N}\right) + \frac{T_s}{N}\right]\cdot\left[(N-k)\frac{\partial q_n^{A*}}{\partial y_n}\frac{\partial y_n}{\partial y_s} + \frac{\partial q_s^{A*}}{\partial y_s}\right]\cdot\delta\right\} \\ -\frac{\sum_l T_l}{N}\cdot\frac{\partial q_s^{A*}}{\partial y_s}\cdot\delta + \left[P\left(\delta\frac{\sum_l q_l^{A*}}{N}\right) - C_M(y_s)\right]\frac{\partial q_s^{A*}}{\partial y_s}\cdot\delta \end{array}}_{TVS:signatory\ under\ level\ effect\ of\ trade} \tag{33}$$

$$-C_M'(y_s)\cdot\delta q_s^{A*} + kB'\cdot\left[(N-k)\frac{\partial y_n}{\partial y_s} + 1\right] - C_D'(y_s) = 0$$

Proposition 4 *Given the size of the IEA unchanged, level effect is detrimental for global abatement level, say the absolute effectiveness of the IEA.*

Proof.

$$\begin{aligned}
& TVN - C_M'(y_n)\cdot\delta q_n^{A*} \\
= & \left[\left(\delta\frac{q_n^{A*}}{N} - \delta\frac{\sum_l q_l^{A*}}{N^2}\right)\cdot P'\left(\delta\frac{\sum_l q_l^{A*}}{N}\right) + \frac{T_n}{N} - \frac{\sum_l T_l}{N}\right]\frac{\partial q_n^{A*}}{\partial y_n}\cdot\delta \\
& + \left[P\left(\delta\frac{\sum_l q_l^{A*}}{N}\right) - C_M(y_n)\right]\frac{\partial q_n^{A*}}{\partial y_n}\cdot\delta - C_M'(y_n)\cdot\delta q_n^{A*} \\
\approx & \left(\frac{T_n}{N} - \frac{\sum_l T_l}{N}\right)\frac{\partial q_n^{A*}}{\partial y_n}\cdot\delta + \left[P\left(\delta\frac{\sum_l q_l^{A*}}{N}\right) - C_M(y_n)\right]\frac{\partial q_n^{A*}}{\partial y_n}\cdot\delta \\
& -C_M'(y_n)\cdot\delta q_n^{A*} \qquad \left(q_n^{A*}\approx q_s^{A*}\right) \\
\approx & \left(\frac{T_n}{N} - \frac{\sum_l T_l}{N}\right)\frac{\partial q_n^{A*}}{\partial y_n}\cdot\delta + \left[P\left(\frac{\sum_l q_l^{A*}}{N}\right) - C_M(y_n)\right]\frac{\partial q_n^{A*}}{\partial y_n}\cdot\delta - C_M'(y_n)\cdot\delta q_n^{A*} \\
& \left(Taylor\ formula\ P\left(\delta\frac{\sum_l q_l^{A*}}{N}\right) = P\left(\frac{\sum_l q_l^{A*}}{N}\right) + P'\left(\frac{\sum_l q_l^{A*}}{N}\right)(\delta-1)\frac{\sum_l q_l^{A*}}{N}\right) \\
\approx & \delta\cdot\left[TEN - C_M'(y_n)\cdot q_n^{A*}\right] \qquad \left(q_n^{A*}\approx q_s^{A*}\right) \\
< & TEN - C_M'(y_n)\cdot q_n^{A*} \\
& \left(P\left(\frac{\sum_l q_l^{A*}}{N}\right) - C_M(y_n) - \left(\frac{\sum_l T_l}{N} - \frac{T_n}{N}\right) > 0, \frac{\partial q_n^{A*}}{\partial y_n} < 0 \Longrightarrow TEN - C_M'(y_n)\cdot q_n^{A*}\right)
\end{aligned}$$

$$\begin{aligned}
& TVS - C_M'(y_s)\cdot\delta q_s^{A*} \\
= \;& k\left\{\left[\left(\delta\frac{q_s^{A*}}{N}-\delta\frac{\sum_l q_l^{A*}}{N^2}\right)\cdot P'\left(\delta\frac{\sum_l q_l^{A*}}{N}\right)+\frac{T_s}{N}\right]\cdot\left[(N-k)\frac{\partial q_n^{A*}}{\partial y_n}\frac{\partial y_n}{\partial y_s}+\frac{\partial q_s^{A*}}{\partial y_s}\right]\cdot\delta\right\} \\
& -\frac{\sum_l T_l}{N}\cdot\frac{\partial q_s^{A*}}{\partial y_s}\cdot\delta+\left[P\left(\delta\frac{\sum_l q_l^{A*}}{N}\right)-C_M(y_s)\right]\frac{\partial q_s^{A*}}{\partial y_s}\cdot\delta - C_M'(y_s)\cdot\delta q_s^{A*} \\
\approx \;& k\left\{\frac{T_s}{N}\cdot\left[(N-k)\frac{\partial q_n^{A*}}{\partial y_n}\frac{\partial y_n}{\partial y_s}+\frac{\partial q_s^{A*}}{\partial y_s}\right]\cdot\delta\right\}-\frac{\sum_l T_l}{N}\cdot\frac{\partial q_s^{A*}}{\partial y_s}\cdot\delta \\
& +\left[P\left(\delta\frac{\sum_l q_l^{A*}}{N}\right)-C_M(y_s)\right]\frac{\partial q_s^{A*}}{\partial y_s}\cdot\delta - C_M'(y_s)\cdot\delta q_s^{A*} \quad \left(q_n^{A*}\approx q_s^{A*}\right) \\
\approx \;& k\left\{\frac{T_s}{N}\cdot\left[(N-k)\frac{\partial q_n^{A*}}{\partial y_n}\frac{\partial y_n}{\partial y_s}+\frac{\partial q_s^{A*}}{\partial y_s}\right]\cdot\delta\right\}-\frac{\sum_l T_l}{N}\cdot\frac{\partial q_s^{A*}}{\partial y_s}\cdot\delta \\
& +\left[P\left(\frac{\sum_l q_l^{A*}}{N}\right)-C_M(y_s)\right]\frac{\partial q_s^{A*}}{\partial y_s}\cdot\delta - C_M'(y_s)\cdot\delta q_s^{A*} \quad (Taylor\ formula) \\
\approx \;& \delta\cdot\left[TES - C_M'(y_s)\,q_s^{A*}\right] \\
< \;& TES - C_M'(y_s)\,q_s^{A*} \quad \left(TES<\left[P\left(\frac{\sum_l q_l^{A*}}{N}\right)-C_M(y_s)-T_s\right]\frac{\partial q_s^{A*}}{\partial y_s}<0\right)
\end{aligned}$$

So, if k, the size of the IEA, is fixed, compared with the analysis which consider entry effect only, the marginal cost of abatements for signatories and nonsignatories are all increased, while the marginal benefit is hardly unchanged, level effect will decrease the effectiveness of the IEA ■

This proposition is consistent to intuition. Under level effect, in each market, any firm's production is larger than that under only entry effect. When a country increases amount of abatement, the marginal cost of production will be increased, since production is larger under level effect, the loss of the firm's profit will be greater, so the country has less incentive abate the same amount as that under only entry effect.

4.2.3 Leakage Effect

Leakage effect is an old topic in IEA problems. It is such an phenomenon: as some countries increase their abatement levels, the comparative advantage in producing dirty goods may shift from these countries to others, then the other countries will increase their production of dirty goods and emission. At last, the increased emission may partially or completely offset those countries' efforts in abatement. So, traditionally, economists hold a negative view on leakage effect. However, Sivers Boyce (2002) demonstrates that sometimes when full cooperation cannot be realized under autarky, it can be realized under free trade, only if leakage effect is present. This view points out a potential positive role that the leakage effect may play in an IEA formation. Now, we start to study how the leakage effect affects an IEA in our model.

• No level effect: firms will not increase their production level in every market (keep q_i^{A*}) ;

• With leakage effect: the production of a firm will be affected by other countries' abatement level $\frac{\partial q_j^l}{\partial y_i} > 0$;

• No tariff effect: a country's tariff will not be affected by its own abatement level, and will not affect other countries production in its market (equivalent with zero tariff).

Thus, under entry and leakage effect, the firm from any country i will still sale equal amount of its production, $\frac{q_i^{A*}}{N}$, in every market including its own, as that under only entry effect. However, when leakage is taken into consideration, $\frac{\partial q_i^{A*}}{\partial y_j} > 0$, while under only entry effect $\frac{\partial q_i^{A*}}{\partial y_j} = 0$. One thing we need to point out is that under autarky $q_i^{A*} = q_i^{A*}(y_i)$, but under trade $q_i^{A*} = q_i^{A*}(y_1, \ldots y_n)$. We use q_i^{A*} here is to indicate that quantity is the same as that under autarky.

The FOCs of countries' objective functions are ($TL : Leakage\ Effect\ of\ Trade$)

$$\frac{\partial W_{nj}^{TL}}{\partial y_{nj}} = \frac{\partial W_{nj}^{TE}}{\partial y_{nj}} + \underbrace{\left[\left(\frac{q_n^{A*}}{N} - \frac{\sum_l q_l^{A*}}{N^2}\right) P'\left(\frac{\sum_l q_l^{A*}}{N}\right) + \frac{T_n}{N}\right] \cdot \sum_{l \neq i} \frac{\partial q_l^{A*}}{\partial y_i}}_{TLN: nonsignatory\ under\ leakage\ effect\ of\ trade} = 0 \tag{34}$$

$$0 = \frac{\partial \sum_{m=1}^{k} W_{sm}^{TL}}{\partial y_{si}} = \frac{\partial \sum_{m=1}^{k} W_{sm}^{TE}}{\partial y_{si}} \tag{35}$$

$$+k\underbrace{\left\{\left[\left(\frac{q_s^{A*}}{N} - \frac{\sum_l q_l^{A*}}{N^2}\right) P'(\cdot) + \frac{T_s}{N}\right] D_{si} + \left[P(\cdot) - C_M(y_s) - \frac{\sum_l T_l}{N}\right] \sum_{j=1}^{N-k} \frac{\partial q_{si}^{A*}}{\partial y_{nj}} \frac{\partial y_{nj}}{\partial y_{si}}\right\}}_{TLS:\ signatory\ under\ leakage\ effect\ of\ trade}$$

where

$$D_{si}=\sum_{m\neq i}\left[\left(\sum_j \frac{\partial q_{sm}^{A*}}{\partial y_{nj}}\frac{\partial y_{nj}}{\partial y_{si}}\right)+\frac{\partial q_{sm}^{A*}}{\partial y_{si}}\right]+\sum_j \frac{\partial q_{si}^{A*}}{\partial y_{nj}}\frac{\partial y_{nj}}{\partial y_{si}}+\sum_j\left[\left(\sum_{r\neq j} \frac{\partial q_{nj}^{A*}}{\partial y_{nr}}\frac{\partial y_{nr}}{\partial y_{si}}\right)+\frac{\partial q_{nj}^{A*}}{\partial y_{si}}\right] \tag{36}$$

Proposition 5 *Given the size of the IEA unchanged, leakage effect is detrimental for global abatement level, say the absolute effectiveness of the IEA.*

Proof.

$$\begin{aligned} TLN &= \left[\left(\frac{q_n^{A*}}{N}-\frac{\sum_l q_l^{A*}}{N^2}\right)P'\left(\frac{\sum_l q_l^{A*}}{N}\right)+\frac{T_n}{N}\right]\cdot\sum_{l\neq i}\frac{\partial q_l^{A*}}{\partial y_i} \\ &\approx \frac{T_n}{N}\cdot\sum_{l\neq i}\frac{\partial q_l^{A*}}{\partial y_i} \qquad \left(q_n^{A*}\approx q_s^{A*}\right) \\ &> 0 \qquad \left(\sum_{l\neq i}\frac{\partial q_l^{A*}}{\partial y_i}>0\right) \end{aligned}$$

$$\begin{aligned} TLS &= k\left[\left(\frac{q_s^{A*}}{N}-\frac{\sum_l q_l^{A*}}{N^2}\right)P'\left(\frac{\sum_l q_l^{A*}}{N}\right)+\frac{T_s}{N}\right]\cdot D_{si} \\ &\quad +k\left[P\left(\frac{\sum_l q_l^{A*}}{N}\right)-C_M\left(y_s\right)-\frac{\sum_l T_l}{N}\right]\cdot\sum_{j=1}\frac{\partial q_{si}^{A*}}{\partial y_{nj}}\frac{\partial y_{nj}}{\partial y_{si}} \\ &\approx k\left\{\frac{T_s}{N}\cdot D_{si}+\left[P\left(\frac{\sum_l q_l^{A*}}{N}\right)-C_M\left(y_s\right)-\frac{\sum_l T_l}{N}\right]\cdot\sum_{j=1}\frac{\partial q_{si}^{A*}}{\partial y_{nj}}\frac{\partial y_{nj}}{\partial y_{si}}\right\} \quad \left(q_n^{A*}\approx q_s^{A*}\right) \\ &\approx k\left\{\frac{T_s}{N}\cdot\sum_{j=1}\frac{\partial q_{si}^{A*}}{\partial y_{nj}}\frac{\partial y_{nj}}{\partial y_{si}}+\left[P\left(\frac{\sum_l q_l^{A*}}{N}\right)-C_M\left(y_s\right)-\frac{\sum_l T_l}{N}\right]\cdot\sum_{j=1}\frac{\partial q_{si}^{A*}}{\partial y_{nj}}\frac{\partial y_{nj}}{\partial y_{si}}\right\} \end{aligned}$$

$$\left(\sum_j \frac{\partial q_{sm}^{A*}}{\partial y_{nj}}\frac{\partial y_{nj}}{\partial y_{si}}\right)+\frac{\partial q_{sm}^{A*}}{\partial y_{si}}\approx-\frac{\partial q_s^{A*}}{\partial y_n}+\frac{\partial q_s^{A*}}{\partial y_s}\approx 0;$$

where the last step, $\left(\sum_{r\neq j}\frac{\partial q_{nj}^{A*}}{\partial y_{nr}}\frac{\partial y_{nr}}{\partial y_{si}}\right)+\frac{\partial q_{nj}^{A*}}{\partial y_{si}}\approx-\frac{\partial q_{nj}^{A*}}{\partial y_{nr}}+\frac{\partial q_n^{A*}}{\partial y_s}\approx 0$. Hence,

$$\begin{aligned} TLS &= k\left[P\left(\frac{\sum_l q_l^{A*}}{N}\right)-C_M\left(y_s\right)-\frac{\sum_l T_l}{N}+\frac{T_s}{N}\right]\cdot\sum_{j=1}\frac{\partial q_{si}^{A*}}{\partial y_{nj}}\frac{\partial y_{nj}}{\partial y_{si}} \\ &< 0 \end{aligned}$$

and the last inequality comes from the fact that $\sum_{j=1} \frac{\partial q_{si}^{A*}}{\partial y_{nj}} \frac{\partial y_{nj}}{\partial y_{si}} < 0$.

Therefore, if k, the size of the IEA, is fixed, compared with entry effect case, the nonsignatories' marginal costs of abatement are decreased, while the signatories' marginal costs of abatement are increased. Since the marginal benefit of them are hardly unchanged, nonsignatories will abate more and signatories will abate less after leakage effect is present. When the socially optimal abatement level is reached, there must be $-1 = (N-k)\frac{\partial y_n}{\partial y_s}$, because when $-1 < (N-k)\frac{\partial y_n}{\partial y_s}$, it is still socially desirable for the signatories to abate more (nonsignatories' response will not offset the signatories' increase in abatement); when $-1 > (N-k)\frac{\partial y_n}{\partial y_s}$, it is socially desirable for the signatories to abate less (nonsignatories' response will more than offset the signatories' decrease in abatement). Since an self-enforcing IEA under which the global amount of abatement is less than desired is not socially optimal, it must satisfy $-1 < (N-k)\frac{\partial y_n}{\partial y_s}$. From this condition, we can conclude that when leakage effect is present, the amount of abatement that signatories decrease is larger than that of the nonsignatories decrease. Therefore, absolute effectiveness of the IEA is hurt by leakage effect. ■

4.2.4 Tariff Effect

As we discussed at the beginning of 5.2, the effect of tariff on an IEA is from two aspects: (i) the tariff of a country will reduce foreign firms' competitiveness in its market, thus make the market less competitive and have a lower production level; (ii) the tariff is the very force that can help a country to deal with comparative disadvantage induced by the country's increased abatement level (See Barrett (2005)). Therefore, we can find that tariff effect goes in the opposition directions of level effect and leakage effect, both of which are detrimental to the absolute effectiveness of an IEA. Thus, without strict mathematical proof, we can clearly judge that the tariff effect is a positive force for an IEA's effectiveness.

4.3 Equilibrium and Simulation

To determine the participation equilibrium, we still use the incentive function like that defined in Section 4. But the specific form of the function under trade is different from that under autarky. Under trade, it is

$$I^T(k) = W_s^T(k+1) - W_n^T(k) \tag{37}$$

If some k satisfies $I^T(k-1) > 0$, $I^T(k) < 0$, then the k is the very equilibrium. when $I(k)$ monotonically decreases with k, the equilibrium number of signatories is $\lfloor k^* \rfloor + 1$, where k^* satisfies $I(k^*) = 0$, and $\lfloor k^* \rfloor$ is the maximum integer less than k^*. The absolute effectiveness of an IEA is still the sum of all signatories' and nonsignatories' abate level, say $(N-k) \cdot y_n + k \cdot y_s$.

We still use the simulation model introduced in Section 4. The functions of the model are linear benefits $B(\sum_l y_l) = \sum_l y_l$, increasing direct marginal cost $C_D(y_i) = \frac{1}{2}y_i^2$, simple linear inverse demand function $P(Q_i) = 1 - Q_i$ and marginal production cost $C_M(y_i) = 0.005 + 0.001 y_i$. The interval of N used for simulation is from 10 to 100.

Figure 3 describes the relationship between k^*, which satisfies $I(k^*) = 0$, and N. From the figure it is clear to see that k^* is monotonically increasing with N. However, since the participation equilibrium is $\lfloor k^* \rfloor + 1$, when N is between 10 and 100, the equilibrium IEA size is still 3 which is the same as that under autarky. This is a pessimistic result, it makes us realize that sometimes trade may not be helpful in increasing countries' incentive to participate an IEA.

Figure 4 characterizes the relationship between absolute effectiveness and N under trade. We can see that the effectiveness is increasing with the total number of countries. Now, one of our concern is whether the IEA under trade has larger effectiveness than under autarky. However, since this figure is extremely similar with Figure 2, we could not explicitly compare these two to find an answer to this question. Figure 5 is provided for this purpose.

The absolute effectiveness under autarky is always larger than that under trade, and the difference between them is increasing with the total number of countries, even though the difference between them is small. This result indicates that in our simulation model, the level effect and leakage effect which have negative effects on the global abatement level dominate the entry and tariff effects. Yet, this is definitely not always the truth. For some specific simulation models where entry and tariff effects are stronger than level and leakage effects, we could get a result showing that trade can be beneficial for the effectiveness of an IEA.

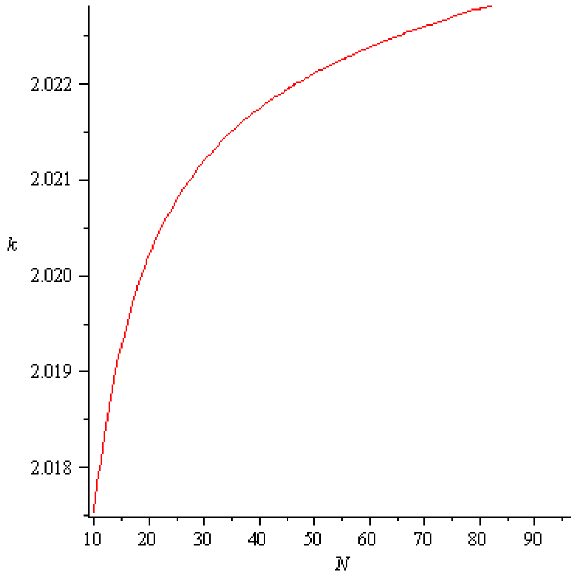

Figure 3: The size of the IEA under trade

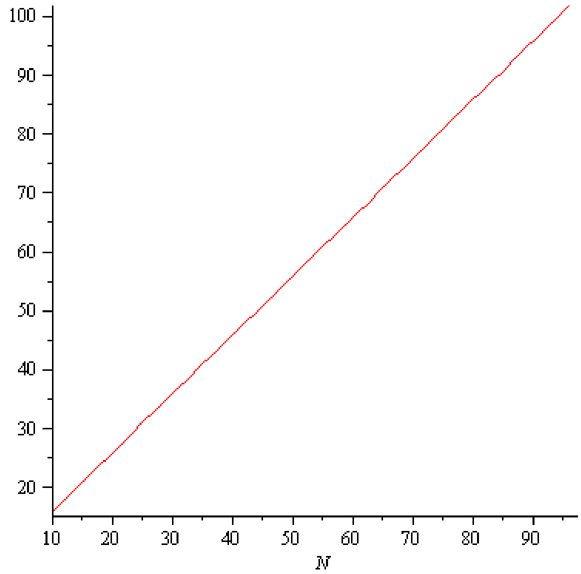

Figure 4: The effectiveness of the IEA under trade

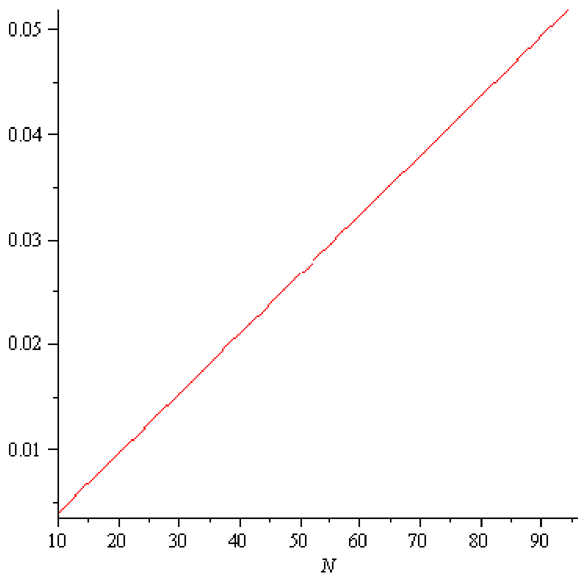

Figure 5: The difference between effectiveness (A-T)

5 Concluding Remarks

This paper evaluates the impact of trade on the formation (participation equilibrium) and effectiveness (global abatement level) of an IEA. The model employed for analysis is an extended form of the self-enforcing IEA model in Barrett (1994). The Barrett model, when considering the welfare of a country from abatement, only takes account of the direct benefit and direct cost of abating emission. However, in this model, a country's welfare from dirty goods production and consumption which is indirectly affected by the decision of abatement level is also considered, otherwise the impact of trade cannot be studied.

In order to set a benchmark, this paper first analyzes the IEA under autarky. The general model result has shown that the social welfare from producing and consuming the dirty goods generates an indirect marginal cost of abatement which has a downward pressure on a country's abatement level. The simulation result of participation equilibrium is pessimistic: no matter what the total number of countries involved in the environmental problem is (between 10 and 100), in equilibrium, the number of signatories of the IEA will constantly be 3. Besides, the simulation shows the IEA's absolute effectiveness will increase with the total number of countries.

When changing the economic relationships between countries from autarky to trade, the current paper demonstrates that the optimal tariff under most-favored nation treatment (MFN) is not zero, but a positive one, which indicates that countries will not have free trade with each others. This finding implies that the assumption of free trade in Barrett (1997) and Sivers Boyce (2002) is a strong one, and their analysis of IEAs based on this assumption is incomplete, because of their omission of the potential effect of the tariff on an IEA. Due to the complexity in computation, this paper logically decompose the impact of trade on an IEA into four aspects which are entry effect, level effect, leakage effect and tariff effect. Such a decomposition enables us to find that trade's impact on an IEA's effectiveness is ambiguous, because, given that the number of signatories is unchanged, entry and tariff effects tend to increase the global abatement level, while level and leakage effects have negative effect on the global abatement level, the direction of trade's impact on an IEA depends on the relative magnitude of the four effects. In the simulation model, participation equilibrium is the same as that under autarky, so also pessimistic; the entry and tariff effects are dominated by the other two, namely the absolute effectiveness under trade is smaller than that under autarky, and the gap in the absolute effectiveness will be enlarged when the total number of countries increases. However, the possibility of finding a model which can demonstrate that trade can improve an IEA's size and effectiveness could not be eliminated .

Additionally, this paper gives an new explanation of the minimum participation clause adopted by most IEAs: if the number of signatories is lower than some threshold value, signatories which have first mover advantage will strategically abate less than the nonsignatories, then the IEA will go against the spirit of itself and become meaningless.

The defect of the model is that it does not have analytical solution which could make us directly analyze the equilibrium of participation and of global abatement level without applying simulations. Maybe a more suitable model could be found to realize this.

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