Greenhouse-gas Emission Controls and International Carbon Leakage through Trade Liberalisation*

Jota Ishikawa (Hitotsubashi University)[α]
Toshihiro Okubo (University of Manchetser)[β]

December 2007

ABSTRACT. This paper studies greenhouse-gas (GHG) emission controls in the presence of carbon leakage through international firm relocation. The Kyoto Protocol requires developed countries to reduce a certain amount of GHG emissions. Comparing emission quotas with emission taxes, we show that taxes coupled with lower trade costs facilitate more firm relocation than quotas, causing more international carbon leakage. Thus, if a country is concerned about global emissions, emission quotas would be adopted to mitigate the carbon leakage. The firm relocation entails a trade-off between trade liberalisation and emission regulations. Emission regulations may be hampered by trade liberalisation, and vice versa.

JEL: F18, Q54

Keywords: trade liberalisation, global warming, Kyoto Protocol, emission tax, emission quota, carbon leakage

* We thank seminar participants at Nagoya University. We acknowledge financial support from the Ministry of Education, Culture, Sports, Science and Technology of Japan under the 21st Century Center of Excellence Project

α jota@econ.hit-u.ac.jp

β Toshihiro.Okubo@manchester.ac.uk

1. INTRODUCTION

Global environmental problems have lately attracted considerable attention in the world. In particular, global warming caused by greenhouse gas (GHG) emissions has been the central issue among the problems. To cope with global warming, an international environmental treaty, the United Nations Framework Convention on Climate Change (UFNCCC), was made at the Earth Summit held in Rio de Janeiro in 1992. Then the Kyoto Protocol was adopted at the third session of the Conference of Parties to the UFNCCC (COP3) in December 1997.[1] In the protocol, the industrialised countries called Annex I Parties made a commitment to decrease their GHG emissions 5.2% below their 1990 baseline over the 2008 to 2012 period. However, the United States, which is a signatory to the protocol, has not ratified the protocol. Moreover, developing countries including China and India have no obligation to the reduction.

It is no doubt that the Kyoto Protocol is a significant step for the reduction of GHG emissions. Obviously, however, only partial participation of countries to the framework of GHG emission reduction is a vital drawback. In particular, the United States and China are the largest GHG emitters in the world.[2] Moreover, with partial participation, a serious concern is international carbon leakage. That is, the reduction of GHG emissions in some countries increases those in the other countries. As a result, the worldwide emissions may rise.

International carbon leakage occurs though a number of channels. For example, it may occur through fuel price changes (Ishikawa and Kiyono, 2000). When a country adopts some policies to reduce GHG emissions, its demand for fossil fuels is likely to decrease. If their world prices fall as a result, the demand for fossil fuels rises in other countries with weak regulations. Carbon leakage may also arise through the changes in country's industrial structures (Copeland and Taylor 2005; Ishikawa and Kiyono, 2006). With stringent GHG emission regulations, the comparative advantage of the emission-intensive industry may shift abroad. This is the so-called pollution haven hypothesis. In particular, in response to environmental

---

[1] The Kyoto Protocol entered into force in February 2005.

[2] In 2004, the shares of CO_2 emissions in the world are 22.1% for the United States and 18.1% for China, respectively.

policy differences across countries, firms may relocate to countries with lax environmental regulations (Markusen et al, 1993, 1995). Recent improvements in transportation and communications technology as well as trade liberalisation allow firms to relocate their plants more easily.

In this paper, we compare emission taxes with emission quotas (including creation of a competitive emission-permit market) in the presence of the possibility of firm relocation. Specifically, using a new economic geography (NEG) framework, we examine the effects of trade costs on emission taxes and quotas. In our model, there are two countries (North and South), two sectors (agriculture and manufacturing), and two factors (capital and labour). The agricultural product, which perfectly competitive firms produce from labor alone with constant-returns-scale (CRS) technology, is freely traded internationally. The manufactured products are subject to Dixit-Stiglitz (1977) type of monopolistic competition and are costly to ship internationally. Following Martin and Rogers (1995), we assume that only capital is mobile across countries and determines plant location.[3]

To make our point as clearly as possible, in the benchmark, the northern market is larger than the southern market and all firms in the manufacturing sector are located in the North as stable equilibrium due to small or intermediate trade costs. The northern government unilaterally adopts an environmental policy, either an emission tax or an emission quota. Then we consider the effects of these policies when trade costs fall and firms are free to relocate to the South.

One of our main results is as follows. If the North cares only local emissions, then the North prefers emission taxes to emission quotas. On the other hand, if the North is concerned about global emissions, then emission quotas should be adopted. This result has interesting implications for the Kyoto Protocol when regarding Annex I Parties as the North. As mentioned above, the target of GHG emission reductions set by Annex I Parties in the protocol is a local one. In the presence of firm relocation from Annex I Parties to the other countries, therefore, trade liberalisation may induce Annex I Parties to adopt emission taxes rather than emission quotas to achieve the

[3] This model is known as the footloose capital model, which is the simplest model in NEG. See Baldwin et al. (2003).

target. From the viewpoint of the worldwide emission reduction, however, emission quotas are more effective.

Another main result is that when emission taxes are adopted in the North to attain a target of global emission reduction, trade costs and tax rates must satisfy certain conditions. Intuitively, lower trade costs coupled with tougher regulations facilitate firm relocation, which leads to carbon leakage. Thus, free firm relocation entails a trade-off between trade liberalisation and emission regulations. Emission regulations may be hampered by trade liberalisation, and vice versa.

There are many papers that examine the pollution haven hypothesis. In the framework of open economy, the first theoretical analysis on the hypothesis is Pethig (1976).[4] Then Markusen et al. (1993, 1995) investigate the hypothesis in the presence of foreign direct investment (FDI). In Markusen et al. (1993), two polluting firms (one is home and the other is foreign) choose the number of plant and plant locations when only the home country adopts emission taxes. They are primarily concerned with market structures induced by taxes. In Markusen et al. (1995), a single firm decides the plant number and locations when both countries adopt environmental policies non-cooperatively. The governments have an incentive to lower (raise) environmental standards to attract (deter) investment to each other if the benefit from investment is greater (less) than the loss (i.e., the environmental damage).[5]

Firm locations and trade costs are central issues in the NEG literature. A few NEG studies have introduced environmental policies (Pfluger, 2001; Venables, 2001; Elbers and Withagen, 2004).[6] Pfluger (2001) considers Pigouvian emission taxes in a

---

[4] Evidence of the pollution haven hypothesis is mixed. According to Jaffe et al. (1995), differences in environmental policy have little or no effect on trade patterns, investment, or firm location. However, Henderson (1996), Becker and Henderson (2000), Greenstone (2002), and List et al. (2003) find that pollution-intensive plants are responding to environmental regulations. Smarzynska Javorcik and Wei (2004) discuss factors which may make the evidence of the hypothesis weak. Levinson and Taylor (2005) point out that the pollution haven effects have been underestimated.

[5] When a country adopts too-lax environmental policies to keep its competitive advantage, it is sometimes called "environmental (or ecological) dumping." On the other hand, when a country adopts too-stringent environmental policies to reduce local pollution, it is called "Not in my back yard (NIMBY)." There are a number of studies which, following Markusen et al. (1995), analyze environmental dumping and NIMBY. See, for example, Rauscher (1995) and Ulph and Valentiti (2001).

[6] Venables (2001) studies the impact of tax on equilibrium in vertical linkage model. In the case of energy taxes which are unilaterally introduced in one country, he discusses hysteresis in location but does not investigate any environmental policy. Elbers and Withagen (2004) study the impact of emission tax on agglomeration in the presence of labour migration.

NEG model similar to ours. However, his analysis is along the line of Markusen et al. (1995). Thus, environmental damages are local and governments can detect emitters, estimate the damage, and can impose optimal emission taxes. By contrast, emissions in our model are global-wide and hence it is hard to specify polluters and estimate its damage. This makes it impossible to levy tax on each polluter and compensate public through tax imbursement. In our paper, global warming is an impending issue and each country is required to reduce a certain amount of emissions in total.

A key mechanism of environmental policies is agglomeration rent, which is somewhat similar to tax competition literature. The NEG literature has been exploring taxation on agglomeration rent (Kind, et al. 1998; Ludema and Wooton, 2000; Baldwin and Krugman, 2004). However, our environmental policies are substantially different from corporate tax competition and agglomeration rent in its spirit and purpose: 1) A reduction of emissions is an obligation in international agreements. Taxation is aimed at reducing a certain level of emissions rather than tax revenue. On the other hand, corporate taxation is to raise tax revenue in an agglomerated country through imposing taxes on the benefit of agglomeration. 2) Tax competition is not plausible in our paper. Only limited developed countries ratify the international agreements and thus taxation is unilateral in our North-South model. The environmental policies are mandatory across ratified countries so as to reduce emissions to satisfy the agreements. Thus, the international agreements leave no room for tax competition to increase government revenue, i.e. race to top or race to bottom in tax rate. 3) Our discussion involves how to reduce global emissions with refraining pollution haven under trade liberalisation. By contrast, tax competition literature studies how each government seeks to maximise tax revenue by attracting more firms and widening tax base.

Turning to environment and trade literature, Ishikawa and Kiyono (2006) analyse the potential effects of choices over emission controls in an open economy. They specifically compare among emission taxes, quotas and standards in a perfectly competitive general equilibrium trade model. Their analysis is somewhat similar to ours in the sense that one of two countries unilaterally imposes environmental policies, which generates cross-border carbon leakage,[7] and that the northern emission level is endogenously determined under emission taxes. However, their model is on the basis of traditional trade models (i.e., both Ricardian and Heckscher-Ohlin models) and does not take firm relocation into account.

In the analysis of global warming, Copeland and Taylor (2005) explore the relationship between international trade in goods and emission permits by using a Heckscher-Ohlin framework. They are also concerned with partial participation in the Kyoto protocol. Interestingly, they show that unilateral emission reductions in the North can induce the unconstrained South to reduce emissions. This implies that in contrast with our analysis, international carbon leakage may not be a serious issue even without universal participation in the protocol. This contrast basically stems from the presence of income effect as well as the absence of firm relocation in their analysis. Here the income effect means that higher income reduces pollution.[8]

The rest of the paper is organised as follows. In section 2, we present our basic model. Emission taxes and quotas are investigated in section 3 and 4, respectively. Then, in section 5, we compare emission taxes with emission quotas. In section 6, we explore the relationship between emission regulations and trade liberalisation. Section 7 concludes the paper.

2. BASIC MODEL

2.1. *2-country, 2-sector, 2-factor Model without Environmental Policies*

We basically introduce GHG emissions into the footloose capital (FC) model developed by Martin and Rogers (1995).. There are two countries (North and South), two production factors (labour, L, and physical capital, K) and two sectors (agriculture, 'A' sector, and manufacturing, 'M' sector). The North is bigger than the South in population size. The agricultural product is produced from labour alone by perfectly competitive firms under CRS technology and is traded without any trade cost. This product serves as numéraire. The manufactured goods are subject to Dixit-

---

[7] Kiyono and Ishikawa (2004) focus on international interdependence of environmental management policies in the presence of international carbon leakage.

[8] Evidence of income effect is also mixed. See Barbier (1997), for example.

Stiglitz type of monopolistic competition and are traded with trade costs. Firms in M-sector in Martin and Rogers (1995) can move between countries, but has no entry and exit. M-sector uses labour in variable costs part and exclusively employs capital in fixed costs part. Specifically, each firm is required to use one unit of capital for fixed costs and '*a*' units of labour. The cost function for firm *j* is given by $TC_j = \pi + awx_j$, where π, i.e. fixed costs part, stands for capital return. M-sector emits GHGs in the process of production. Specifically, production of one unit of M commodity entails *k* units of pollution. Trade costs, $\tau(>1)$, are iceberg type. The freeness of trade, ϕ, can be defined as $\phi \equiv \tau^{1-\sigma}$. This implies that free trade, τ=1, can be expressed as ϕ =1 whereas ϕ =0 represents autarchy (τ=∞).

Turning to demand side, a representative consumer has the following quasi-linear utility function:

(1)

$$U = \mu \ln M + A - f(\chi_N + \chi_S),\ M \equiv \left(nc^{1-1/\sigma} + n^* c^{*1-1/\sigma}\right)^{1/(1-1/\sigma)}, \qquad 1 > \mu > 0, \quad \sigma > 1$$

where M and A stand for consumption of M-sector varieties and that of A sector, respectively and μ is the intensity of preference toward M-sector goods. *n* and *n** are the number of differentiated varieties, and *c* and *c** are the quantities of consumption for each variety. σ in the CES function for differentiated varieties denotes the constant elasticity of substitution between two varieties.[9] The disutility is expressed as an increasingly monotone function of the total GHG emissions, $f(\chi_N + \chi_S)$, where χ_N and χ_S are GHG emissions in the North and the South, respectively. Each consumer has one unit of capital as well as one unit of labour and get income from both factors, $w+\pi$.

Labour is mobile between sectors but immobile between countries. While capital is mobile between two nations, capital owners are immobile and thus capital rewards are repatriated to the origin of country. Since that capital endowment is initially allocated in proportional to labour endowment (market size), the northern share of initial capital and labour endowments are given by $s_K = K/K^W = s_L = L/L^W$.

---

[9] Equilibrium path in the FC model with quasi-linear utility function is identical to that of the Cobb-Douglas utility function. The quasi-linear function eliminates income effect (See Baldwin, et al. 2003).

However, after firm is allowed for relocation, capital share is generally not equal to population share, whereas capital share is always identical to firm share, $s_n = n / N^W = s_K$. Due to no income effect, the quasi-linear utility function ensures $s \equiv s_E = s_L$, where northern expenditure share is defined as $s_E = E / E^W$. For simplicity, the total expenditure E^W and the total labour and capital endowments, L^W and K^W (thus the total number of firms, N^W) are normalised to be unity. [10]

2.2. *Initial Equilibrium*

Since A-sector good is numeraire and is freely traded internationally, wage rates in both countries are normalised to be one, $w = w^* = 1$. Utility maximisation results in the well-known CES demand function. As a result of maximisation, local and export prices of a variety in north-based M-sector firm are given by

(2) $$p = \frac{a}{1 - 1/\sigma}; \quad p^* = \frac{\tau a}{1 - 1/\sigma}$$

where 'a' is unit labour requirement, equal to marginal cost, which is exogenously given as constant. Consumptions per variety are

(3) $$c = \frac{\mu p^{-\sigma} E}{n p^{1-\sigma} + n^* p^{*1-\sigma}} \text{ and } c^* = \frac{\mu p^{*-\sigma} E^*}{n p^{1-\sigma} + n^* p^{*1-\sigma}}$$

Using (2) and (3), pure profit for a representative firm in the North is given by

$$\pi[n, n^*] = \left(\frac{a^{1-\sigma}}{\Delta[n, n^*]} E \quad + \quad \frac{\phi a^{1-\sigma}}{\Delta^*[n, n^*]} E^* \right) \frac{1}{\sigma}$$

where E (E^*) represent northern (southern) expenditure, and Δ and Δ^* are defined as $\Delta[n, n^*] = n a^{1-\sigma} + \phi n^* a^{1-\sigma}$ and $\Delta^*[n, n^*] = \phi n a^{1-\sigma} + n^* a^{1-\sigma}$, where $n + n^* = 1$. [11]

---

[10] Importantly, we use quasi-linear utility function. The income effect is eliminated. The total number of household (population) is 1, because each individual has one unit of labour and capital.

[11] Likewise, pure profits for south-based firm are $\pi^*[n, n^*] = \left(\phi \frac{a^{1-\sigma}}{\Delta} E + \frac{a^{1-\sigma}}{\Delta^*} E^* \right) \frac{1}{\sigma}$. Note that each firm's profit is $1/\sigma$ times of firm revenue. $(1 - 1/\sigma)$ terms are cancelled out in price of a variety and in CES composition.

Since our model has asymmetric market size, $E(=s)>E^*(=1-s)$, i.e. $s>0.5$, pure profit of a north-based firm is higher than that of a south-based firm with positive trade costs. Therefore, allowing for free relocation, the pure profits are equalised and then firm shares, n and n^*, are determined as locational equilibrium.

$$(4) \quad \pi[n,n^*]-\pi^*[n,n^*]=a^{1-\sigma}\frac{1-\phi}{\sigma}\left(\frac{s}{\Delta[n,n^*]}-\frac{1-s}{\Delta^*[n,n^*]}\right)=0$$

Solving (4), we obtain $s_n=\frac{1}{2}+\left(\frac{1+\phi}{1-\phi}\right)(s-\frac{1}{2}), \quad s\equiv\frac{E}{E+E^*}>\frac{1}{2}$.

As trade costs reduce, n increases: more southern firms go to the North, so called gradual agglomeration. Then, below a certain trade costs, called as the sustain point ($\phi=(1-s)/s$), all firms concentrate in the North, i.e. full agglomeration. That is, trade costs above the sustain point (small trade costs) creates full agglomeration in the big country as stable equilibrium. For simplicity, we first consider full agglomeration before taking any environmental policy. Accordingly, trade costs discussed in our paper are assumed to be from the sustain point through free trade: $(1-s)/s<\phi<1$.

2.3. *Production and GHG Emissions*

Produced quantity of each north-based firm for the North is given by $x=\frac{\mu p^{-\sigma}}{np^{1-\sigma}+n^*p^{*1-\sigma}}$, which is identical to c. Turning to export market, only x/τ units arrive for exports due to iceberg trade costs. While the northern consumption is equal to quantity produced in the North for each variety, i.e. $x=c$, the quantities produced for the foreign market need $x^*=c^*\tau=\frac{\mu\tau p^{*-\sigma}}{np^{1-\sigma}+n^*p^{*1-\sigma}}$. It follows that the total amount of produced quantity for a north-based firm is written as

$$x_j+x_j^*=\frac{\mu p^{-\sigma}}{np^{1-\sigma}+n^*p^{*1-\sigma}}+\frac{\mu\tau p^{*-\sigma}}{np^{1-\sigma}+n^*p^{*1-\sigma}}$$
$$=\mu\left(\frac{s}{np^{1-\sigma}+n^*p^{*1-\sigma}}+\phi\frac{1-s}{np^{1-\sigma}+n^*p^{*1-\sigma}}\right)p^{-\sigma}$$

Producing one unit of goods entails k units of GHG emissions. Thus, the amount of emissions in each country is proportional to each country's total quantity produced. Emission levels in the North and the South are, respectively, defined as

$$\chi_N \equiv kn(x_j + x_j^*) = n\left(\frac{s}{\Delta} + \phi\frac{1-s}{\Delta^*}\right)a^{-\sigma} \text{ and } \chi_S \equiv kn^*(x_j + x_j^*) = n^*\left(\phi\frac{s}{\Delta} + \frac{1-s}{\Delta^*}\right)a^{-\sigma}$$

where by an appropriate choice of units, we set $k \equiv 1/(1-1/\sigma)\mu$ which is exogenously given and constant. In sum, emissions in the world are $\chi \equiv \chi_N + \chi_S = n\left(\frac{s}{\Delta} + \phi\frac{1-s}{\Delta^*}\right)a^{-\sigma} + n^*\left(\phi\frac{s}{\Delta} + \frac{1-s}{\Delta^*}\right)a^{-\sigma}$. Utilising these specifications, emissions at the initial non-policy equilibrium (full agglomeration in the North) can be written as $\chi^{initial} = \chi_N^{initial} = \frac{a^{-\sigma}}{a^{1-\sigma}} = \frac{1}{a}$ due to $\Delta = a^{1-\sigma}$ and $\Delta^* = \phi\Delta$. Note that GHGs are initially emitted only in the North due to northern full agglomeration and the emissions remain constant and are independent of trade costs.[12]

Proposition 1: The total amount of emissions is not affected by trade costs at full agglomeration (non-environmental policy) equilibrium.

3. Emission Tax

3.1. *Taxation without Relocation*

Now we introduce environmental policies. Due to international environmental agreements such as the Kyoto Protocol, an industrialised country, which has manufacturing agglomeration, namely, the North, has to limit emissions to a certain fixed level. To satisfy the upper bound of emissions, we assume that the North introduces either emission tax or quota. In this section, we examine emission tax.

Starting from full agglomeration, the North imposes an emission tax so as to reduce emissions and implement the international agreement. At this moment, relocation is prohibited (infinitive relocation costs). Since GHGs are proportional to produced quantity, emission tax is levied on production quantity rather than prices,

[12] More generally, ignoring a stable equilibrium path, all firms hypothetically concentrate in one country, either North or South, the amount of emissions can be kept as constant. For instance, if all firms are forced to relocate to the South by policy, the global emissions can be derived as $\chi \equiv \chi_N + \chi_S = \chi_S = \left(\phi\frac{s}{\Delta} + \frac{1-s}{\Delta^*}\right)a^{-\sigma} = \left(\frac{1}{\Delta^*}\right)a^{-\sigma} = \frac{1}{a}$, which is the same level as in northern full agglomeration. Hence, the global level of emissions is independent of location in case of full agglomeration, irrespective of a stable equilibrium path.

pure profits and sales. Thus, the emission tax is equivalent to a specific production tax, t. Then the total costs and prices are expressed as:

$$TC_j = \pi + (a+t)x_j \text{ and } p = \frac{a+t}{1-1/\sigma}; \quad p^* = \frac{\tau(a+t)}{1-1/\sigma}$$

Tax increases total costs and prices.[13] Thus, pure profit of a north-based firm and northern emissions are given as:

$$(5) \quad \pi = \left(\frac{s}{\Delta} + \frac{\phi(1-s)}{\Delta^*} \right) \frac{\mu(a+t)^{1-\sigma}}{\sigma} = \frac{\mu}{\sigma}$$

$$(6) \quad \chi = \chi_N = k\left(\frac{s}{\Delta} + \frac{\phi(1-s)}{\Delta^*} \right) \frac{\mu(a+t)^{-\sigma}(1-1/\sigma)}{\sigma} = \frac{1}{a+t}$$

Note that taxation without relocation results in reducing emissions from $1/a$ to $1/(a+t)$.

3.2. *Equilibrium with Free Relocation*

Next, we allow for free firm relocation. Since taxation decreases profits in the North, firms may have an incentive to move to the non-taxed country, i.e. the South, regardless of a small market size. When tax rates take a substantial level such that $\pi < \pi^*$, i.e. $(\frac{a+t}{a})^{1-\sigma} < \phi s + \frac{1-s}{\phi}$, full agglomeration is not stable any more and some firms relocate to the South. Equilibrium is determined so as to equalise pure profits between countries:

$$(7) \quad \pi - \pi^* = \frac{\mu}{\sigma}\left(\frac{s}{\Delta} + \frac{\phi(1-s)}{\Delta^*} \right)(a+t)^{1-\sigma} - \frac{\mu}{\sigma}\left(\phi\frac{s}{\Delta} + \frac{1-s}{\Delta^*} \right) a^{1-\sigma} = 0$$

Figure 1 plots firm share, n in terms of freeness of trade, ϕ. Given a fixed small rate of tax, firm share locus takes hump-shape. Taxation causes international carbon leakage: firm relocation from the North (taxed country) to the South (non-taxed country). Stated differently, it is necessary to have intermediate levels of trade costs to keep full agglomeration, $\phi_{NL} < \phi < \phi_{NU}$, which can be written as

[13] Note that we assume $a+t<1$.

$$(8)\,\phi_{NU} = \frac{(a+t)^{1-\sigma} + \sqrt{(a+t)^{2(1-\sigma)} - 4s(1-s)a^{2(1-\sigma)}}}{2a^{1-\sigma}s}$$

$$(9)\,\phi_{NL} = \frac{(a+t)^{1-\sigma} - \sqrt{(a+t)^{2(1-\sigma)} - 4s(1-s)a^{2(1-\sigma)}}}{2a^{1-\sigma}s}$$

<Figure 1>

In reverse, given a fixed ϕ, a small tax can sustain full agglomeration. The condition is given as $(a+\tilde{t})^{2(1-\sigma)} - 4s(1-s)a^{2(1-\sigma)} > 0 \Leftrightarrow \tilde{t} < a(4s(1-s))^{1/(2(1-\sigma))} - a$. When tax rates are above $\tilde{t}$, the North never sustains full agglomeration for any trade cost and instead the South is more likely to create full agglomeration. Figure 2 illustrates the case of high tax rates without northern full agglomeration.

<Figure 2>

As shown in Figures 1 and 2, all firms relocate to the South with a sufficiently small trade cost, i.e. a perfect carbon leakage. The critical value of trade costs, ϕ_S, is analytically given by

$$(10)\,\phi_S = \frac{a^{1-\sigma} + \sqrt{a^{2(1-\sigma)} - 4s(1-s)(a+t)^{2(1-\sigma)}}}{2a^{1-\sigma}(1-s)}$$

As the tax rate, *t,* rises, the critical value, ϕ_S, decreases and full agglomeration in the South is more likely to occur. A sufficiently small trade cost coupled with a high tax rate accelerates international carbon leakage, relocating to non-environmental regulation country. Note that $\phi_S > \phi_{NU} > \phi_{NL}$ is always ensured. ϕ_S is a real number, because $a^{2(1-\sigma)} - 4s(1-s)(a+t)^{2(1-\sigma)} > 0$. We can also verify that ϕ_S is always larger than ϕ_{NU}.[14]

Proposition 2: Emission tax may lead to international carbon leakage. Full agglomeration in the North (taxed country) can be sustained if tax rates are small and/or trade costs are intermediate. However, when tax rates are high and/or trade costs are sufficiently small, all northern firms move to the South (non-taxed country).

Note that the standard FC model (without any taxation) has hump-shaped agglomeration rents, which is net-benefit from agglomeration (See Baldwin and Krugman, 2004): when trade costs decrease, the rents first rise and then fall. Free trade has no agglomeration rents. Taxation on the rents reduces net-benefit from agglomeration. Thus, large or small trade costs lead to negative net-agglomeration benefit, which causes firm relocation to the South.

Turning to emission levels, Figures 3 and 4 plot them for the North, the South and the world, which are given by

$$\chi_N = nk\left(\frac{s}{\Delta} + \frac{\phi(1-s)}{\Delta^*}\right)\frac{\mu(a+t)^{-\sigma}(1-1/\sigma)}{\sigma} = n\left(\frac{s}{\Delta} + \phi\frac{1-s}{\Delta^*}\right)(a+t)^{-\sigma}$$

$$\chi_S = n^* k\left(\phi\frac{s}{\Delta} + \frac{1-s}{\Delta^*}\right)\frac{\mu a^{-\sigma}(1-1/\sigma)}{\sigma} = n^*\left(\phi\frac{s}{\Delta} + \frac{1-s}{\Delta^*}\right)a^{-\sigma}$$

$$\chi = \chi_N + \chi_S = n\left(\frac{s}{\Delta} + \frac{\phi(1-s)}{\Delta^*}\right)(a+t)^{-\sigma} + n^*\left(\phi\frac{s}{\Delta} + \frac{1-s}{\Delta^*}\right)a^{-\sigma}$$

<Figure 3>

<Figure 4>

---

[14] This is due to 4(1-*s*)*s*<1 for *s*>0.5 and $a^{2(1-\sigma)} > (a+t)^{2(1-\sigma)}$.

Allowing firm relocation entails more GHG emissions than the target of international agreements due to international carbon leakage when trade costs are either large or small. That is, when trade costs are large or small, northern emission reduces and southern emission rises (Figure 3). The carbon leakage decreases northern emissions, which are less than the target: $1/(a+t)$, and southern emissions increase by relocation, and then reach $1/a$ at maximum with southern full agglomeration: $\chi = \chi_S = n^* k\left(\phi\frac{s}{\Delta} + \frac{1-s}{\Delta^*}\right)\frac{\mu a^{-\sigma}}{(1-1/\sigma)} = \frac{1}{a}$, where $\Delta = \phi\Delta^*$ and $n^*=1$. Note that southern emissions exceed northern ones for certain levels of ϕ. As trade costs reduce, firm relocation decreases n and then when $\frac{a}{a+t}\frac{n}{1-n} < 1$ holds, southern emissions exceed northern ones.

As seen in Figure 4, global emissions, which are the sum of northern and southern emissions, initially decrease and then increase. Since small and large trade costs allow more relocation to non-taxed country, global emissions increase. In particular, above ϕ_S all firms concentrate in the South and no firms pay tax, and thus emission level becomes $1/a$. Note that it is identical to the initial non-policy level. Northern emission policy is nullified and the global amount of emissions returns to the initial equilibrium (non-environmental policy). We can say that only the impact of taxation with small trade costs is to transfer GHG emissions from the North to the South by involving relocation of all firms. With small trade costs, unilateral emission taxation results in a perfect carbon leakage (full agglomeration in the South) and taxation cannot control pollution any more.

Proposition 3: With emission taxation, the global emission level is generally U-shaped in terms of freeness of trade. Emission taxation has no impact on the global emission level when trade costs are sufficiently small.

4. EMISSION QUOTA

4.1. *Quota without Relocation*

Now we discuss the other policy, emission quota. Likewise, starting from full agglomeration, the North unilaterally introduces an emission quota so as to satisfy international environmental agreements. To make a strict comparison in policy impact with taxation, the quota is set so that the emission level under the quota is the same with that under taxation at the initial equilibrium (northern full agglomeration), i.e., $\overline{\chi} = \dfrac{1}{a+t}$. Moreover, the quota is assumed to be accompanied by creation of a competitive emission-permit market in the North. The quota is implemented by the northern government via fee. Purchasing one unit of the permit allows one unit of production for a northern firm. Using (6), the level of quota is given by

$$(11)\ \overline{\chi} = \left(\frac{s}{(a+\overline{q})^{1-\sigma}} + \frac{1-s}{(a+\overline{q})^{1-\sigma}} \right)(a+\overline{q})^{-\sigma} = \frac{1}{a+\overline{q}} = \frac{1}{a+t}$$

Thus, the price of emission-permit q is equal to t at full agglomeration (initial equilibrium), i.e., $\overline{q}=t$.

The following should be noted. The price of permit, q, is endogenously determined by the number of located firms in the North and trade costs so as to satisfy the total amount of northern emissions, $n\left(\frac{s}{\Delta} + \frac{\phi(1-s)}{\Delta^*} \right)(a+q)^{-\sigma} - \overline{\chi} = 0$, while tax rates are invariant, exogenously given by international agreements. This results in different impacts on firm location and emission level. Total costs and price are written as $TC_j = \pi + (a+q)x_j$, $p = \dfrac{a+q}{1-1/\sigma}$ and $p^* = \dfrac{\tau(a+q)}{1-1/\sigma}$. Firm location is determined as profit equalisation and quota.

4.2. *Equilibrium with Free Relocation*

Equilibrium is determined by pure profit equalisation as well as emission constraint:[15]

$$(12)\ \pi - \pi^* = \frac{\mu}{\sigma}\left(\frac{s}{\Delta} + \frac{\phi(1-s)}{\Delta^*} \right)(a+q)^{1-\sigma} - \frac{\mu}{\sigma}\left(\phi\frac{s}{\Delta} + \frac{1-s}{\Delta^*} \right)a^{1-\sigma} = 0$$

$$(13)\ \pi = n\left(\frac{s}{\Delta} + \frac{\phi(1-s)}{\Delta^*} \right)(a+q)^{-\sigma} = \overline{\chi}$$

[15] In our model quota is always binding and has positive permit price. If q is negative or zero, then no firms have an incentive to relocate and full agglomeration is kept. In addition, total emission level is reduced by international regulation and thus the number of permit supplied by the government is less than produced quantities in full agglomeration. It follows that q should be positive.

Figure 5 plots firm share, n, in terms of freeness of trade, ϕ. Similar to taxation, small or large trade costs lead to firm relocation and international carbon leakage, while intermediate trade costs can sustain full agglomeration in the North.

<Figure 5>

Since we assume that the emission level under quota is the same with that under taxation with full agglomeration, $\overline{q}=t$ and trade costs which result in full agglomeration are fully equivalent to those under taxation:

$$(14)\ \phi_{NU}=\frac{(a+\overline{q})^{1-\sigma}+\sqrt{(a+\overline{q})^{2(1-\sigma)}-4s(1-s)a^{2(1-\sigma)}}}{2a^{1-\sigma}s}$$

$$(15)\ \phi_{NL}=\frac{(a+\overline{q})^{1-\sigma}-\sqrt{(a+\overline{q})^{2(1-\sigma)}-4s(1-s)a^{2(1-\sigma)}}}{2a^{1-\sigma}s}.$$

However, different from emission tax, quota does not involve southern full agglomeration with small trade costs. Some firms stay at the North for any trade cost. As plotted in Figure 6, q is always positive and hump-shaped. As long as all firms are in the North (full agglomeration) with intermediate trade costs, quota prices are the same as t and $\overline{q}$ When agglomeration rents reduce with small trade costs, a fall of "q" in trade liberalisation mitigates firm relocation to the South, while taxation has constant "t". Firm relocation to the South softens quota constraint. The fall of permit price reduces the disadvantage of northern location.

<Figure 6>

Proposition 4: With emission quota, full agglomeration in the North can be sustained with intermediate trade costs. However, full agglomeration never occurs in the South for any positive level of quota.

Emission levels are written as

$$(16)\ \chi_N = n\left(\frac{s}{\Delta} + \phi\frac{1-s}{\Delta^*}\right)(a+q)^{-\sigma} = \overline{\chi} = \frac{1}{a+t}\ \text{(constant)}$$

$$(17)\ \chi_S = n^*\left(\phi\frac{s}{\Delta} + \frac{1-s}{\Delta^*}\right)a^{-\sigma}$$

$$(18)\ \chi = \chi_N + \chi_S = \frac{1}{a+t} + n^*\left(\phi\frac{s}{\Delta} + \frac{1-s}{\Delta^*}\right)a^{-\sigma}.$$

Figures 7 and 8 plot emissions in terms of trade costs. Similar to tax case, quota leads to U-shaped global emissions in terms of trade costs. Likewise, a small restriction of emissions sustains full agglomeration and leads to $1/(a+t)$ which is the target of global emissions in international agreements. More generally, in case of small/high trade costs, some firms relocate and emit GHGs in the South, although northern emissions are kept as $1/(a+t)$ due to emission constraint. However, global emissions never returns to the non-policy level, $1/a$, for any positive trade costs. Since the South never creates full agglomeration and quota is still binding in the North, this diversification of firm location results in less global emissions than the case without any policy.

<Figure 7>

<Figure 8>

Proposition 5: In the case of emission quota, northern GHG emissions are always kept as the target level of international environmental agreements, though the South increases emissions via international carbon leakage under trade liberalisation.

5. EMISSION TAX VERSUS QUOTA

Here, we make a comparison of two-policy impacts on emissions. The only target of the northern government is to implement international environmental agreement and reduce northern local GHG emissions.

The first finding is related to tax rates and quota price. Since international agreements allocate a certain amount of GHG emissions to the North, $\overline{\chi}$, tax rates and price for the permit in quota system are the same level ($t=\overline{q}$) as long as all firms concentrate in the North. For this reason, both policies have the same full agglomeration range: the same levels of ϕ_{NL} and ϕ_{NU}. This implies that firm relocation begins at the same critical trade costs. However, diversification force by environmental regulations results in *q* less than *t* for a given ϕ (i.e., $t>q$) (see Appendix 1 for an analytical derivation). The tax rate is fixed, but the fee for emission permit is endogenously determined by the number of northern firms. As more firms relocate to the South, the emission constraint can be more easily attained and then the permit price decreases. Furthermore, when many firms move to the South, the permit price drastically decreases, which hampers firm relocation. To summarise,

Proposition 6: The price of emission permit under quota is always lower than per unit emission tax rate.

In other words, we can say that quota has weaker diversification force than tax. As is clear in Figure 9, carbon leakage is moderate in quota. Since tax has stronger diversification force, it always leads to more carbon leakage and full agglomeration in the South.

<Figure 9>

Turning to global emissions, this implies that the emission in the North is larger in quota than in taxation for any ϕ (see Appendix 1 for derivation).

<Figure 10>

Proposition 7: The GHG emission level in the North is higher with quota than with tax policy. Compared with taxation, quota can mitigate international carbon leakage.

This suggests that if the North seeks to reduce only the local emissions to satisfy the international environmental agreements, the North prefers taxation to quota with small trade costs. While quota keeps some firms in the North, taxation with trade liberalisation can push out all firms to the South and thus the North has no firms to emit GHGs, perfectly satisfying international agreements. Then, the North will import manufactured goods from fully agglomerated South with small trade costs.[16] Accordingly, the North will take taxation with pro-trade liberalisation.

However, from global viewpoints such a northern egoistic attitude may not be allowed. Concerning global emissions, as long as firms are allowed to relocate freely, international carbon leakage could be larger than the reduction of GHGs in the North. In particular, tax policy returns to the pre-agreement emission level. For this reason, with free relocation and small trade costs due to trade liberalisation, quota is better policy scheme for the cut of global emissions. Quota has a weaker impact on firm relocation. The quota system could be more effective and make the emission level closer to the global target, although not only tax but also quota result in more global emissions than the target as long as some firms locate in the South and trade liberalisation proceeds.

Proposition 8: Emission quota is a better policy scheme than emission tax in the sense of more stringent constraint on global emissions under free relocation with small trade costs.

6. Global Emissions, International Environmental Agreements and Trade Liberalisation

Free relocation with small trade costs mitigates the effect of environmental policy and consequently a global level of emissions is higher than the level determined by international agreements. This section studies what sort of policies and agreements can properly control global GHG emissions as expected by international agreements with accommodating international free relocation.

---

[16] Note that the South still has agriculture. Since our model adopts the quasi-linear utility function to exclude income effect and we assume that each consumer holds capital and labour, the expenditure to M-goods is not too high to induce complete specialisation to M-sector in the South.

One solution may be to choose the combination of environmental tax rates and trade costs by international agreements (section 6.1). The other is that the South joins agreements and tax is globally imposed in both countries so as to lessen international carbon leakage (section 6.2). The possible policy variables in this section are trade costs and environmental tax.[17] The policy bodies are northern and southern governments and international organisation to promote trade liberalisation and reduction of global emissions (or international trade liberalisation agreements and environmental agreements). The only target of policies is to reduce global level of emission as it is internationally agreed for simplification.

6.1. *Trade Liberalisation and Environmental Agreements*

Here, we keep the situation where only the North ratifies international environmental agreements. The policy stems from the outcomes so far. Given the international environmental agreement on the total emissions $\bar{\chi}=1/(a+t)$, it is required to prevent firm relocation and keep full agglomeration in the North. To do so, tax rates and trade costs should be in the shaded area in Figure 11: intermediate trade costs and small tax rate.

<Figure 11>

When any combination of both tax rate and trade costs in the shaded area is set up by international agreements and international organisation, the target global emissions in international environmental agreements can be achieved. To summarise,

Proposition 9: When only the North ratifies environmental agreements, it needs to keep intermediate trade costs and levy a small environmental tax to prevent international carbon leakage and achieve target global emissions in international agreements.

This result yields an important insight that when the environmental agreements are ratified only by the North, the degree of northern environmental policy may be

---

[17] Even if we replace tax with quota, the discussion below is the same. This is because the heart of this section is to keep full agglomeration in the North. As shown in section 5, quota has the same full agglomeration range as tax does.

restricted by trade liberalisation and vice versa. Free firm relocation entails a trade-off between trade liberalisation and environmental regulation.

6.2. *Southern Agreement*

If the South ratifies an international environmental agreement, things would be much easier. When the global warming becomes serious, the South may have an incentive to ratify agreements so as to prevent firm relocation from the North. When the emission tax rates are the same across countries, firms prefer to stay in the bigger market, the North and no firms locate in the South. Therefore, in this case the target of global emissions can be achieved for any trade cost: $\overline{\chi}=1/(a+t)$. It is necessary that international agreements specify the target emissions as well as internationally levied tax rate. The common tax rate is the key to the implementation. In this case, trade liberalisation is not hampered by environmental policy, because of no international carbon leakage.

6.3. *More Effective Agreement—Voluntary Additional Emission Tax*

If both countries ratify the agreement, global GHG emissions could be reduced below the target, $\chi<\overline{\chi}=1/(a+t)$. In addition to the given global target, $\overline{\chi}=1/(a+t)$, international agreements state that tax rate, *t*, is a lower bound and allows for a higher tax rate on the condition that full agglomeration can be kept in the North.[18] When the North suffers huge damage from global warming, the North will have an incentive to set a tax rate higher than *t* by υ (i.e. $\upsilon+t$) which is defined by

$$(19)\ (a+t+\upsilon)^{1-\sigma}=\frac{(\phi^2 s+1-s)(a+t)^{1-\sigma}}{\phi}\Leftrightarrow\upsilon=\left(\left(\frac{\phi^2 s+1-s}{\phi}\right)^{1/(1-\sigma)}-1\right)(a+t)$$

When freeness of trade is (1-*s*)/*s* or 1, the additional tax rate υ is zero. Otherwise, υ is strictly positive. υ is hump-shaped with respect to freeness of trade. As shown in Figure 12, (northern, equivalently global) emission level is U-shaped. With positive trade costs, emission level could be less than $\overline{\chi}$.

---

[18] If North imposes sufficiently high tax rates, firms relocate to the South (lax environment country) and emission increases due to emission haven as is discussed in previous sections. Here, we assume that a marginal tax rate is allowed so as to promote the reduction of local emission but to prevent from emission haven.

<Figure 12>

Proposition 10: If international agreements accommodate to voluntarily impose more stringent (local) emission tax and if environmental damage in the North is huge, the North has an incentive to set higher tax rates, which could make GHG emissions lower than a target in international agreements.

7. CONCLUSION

This paper has studied the impact of environmental policies on firm location and carbon leakage when international agreements such as the Kyoto Protocol require the ratified countries to reduce a certain amount of emissions. We have compared two environmental policy tools, emission tax and quota, under trade liberalisation.

We have found the following. 1) When trade costs are small, either environmental policy leads firms to relocate to a country without any environmental regulation, which causes international carbon leakage. Thus, either environmental policy causes carbon leakage with free trade and free relocations. 2) Emission tax results in more firm relocation than quota. Thus, emission tax causes more carbon leakage, increasing global emissions. If the North is concerned with only local emissions, tax policy is adopted to attain the reduction target. On the other hand, if North is concerned with global emissions, quota is preferred. Thus, quota is a better policy tool to cope with global warming. 3) Trade liberalisation and environmental policies are a trade-off when environmental agreements are unilateral. Trade liberalisation may hamper international environmental agreements. Under certain combinations of tax rates and trade costs, a target of the reduction of global GHG emissions can be attained.

Our paper is the first step to explore the relationship between trade liberalisation and environmental policies in the presence of firm relocation. We have some limitations. For example, the policy target in this paper is to reduce GHG emissions to highlight different policy impacts of tax and quota. Of course, it is plausible to think that governments maximise social welfare. Welfare analysis and socially optimal policies remain in the future research space. To do so, we have to specify disutility in the utility function more rigorously, taking into account transboundary emissions and accumulation of emissions over time. Another research space may be more rigorous analyses on international environmental agreements and negotiation in section 6 by using some game structure.

Moreover, we have assumed quasi-linear utility function which excludes income effect. This has many advantages to highlight different impacts of two policies. Without income effect, we can get analytical solutions allowing us to easily compare the relocation effects of tax and quota. Also the total demand for manufacturing goods remains constant. The constant total demand implies the constant total production and hence the global emission level without any environmental policy is independent of trade costs. Furthermore, since we can ignore the impact of tax/quota revenue reimbursement, we can focus on the effects of each policy scheme on firm location. However, it is certainly worthwhile to examine the robustness of our verdicts in the presence of income effect. Furthermore, the presence of income effect caused by relocation may cause a complete specialisation in manufacturing (agriculture) in the South (North), though it is an extreme and unrealistic case. The agriculture is not numeraire any more and factor prices are determined by trade balance and factor market. In this case, market size and factor prices may determine emission levels.

APPENDIX 1:

Northern emissions without relocation, which is the target of international agreements, are denoted as

$$\overline{\chi}_N = \frac{1}{a+t} = \left(\frac{s}{\overline{\Delta}} + \phi\frac{1-s}{\overline{\Delta}^*}\right)(a+t)^{-\sigma}$$

which is correspondent to northern emission under quota: $\chi_N^Q = \overline{\chi}_N = \frac{1}{a+t} = \frac{1}{a+\overline{q}}$.

Note that at an initial equilibrium (full agglomeration without allowing for relocation), q is equal to t ($\overline{q} = t$).

Allowing for relocation, emissions in tax policy can be written as

$$\chi_N^T = n\left(\frac{s}{\Delta} + \phi\frac{1-s}{\Delta^*}\right)(a+t)^{-\sigma}$$

Note that t is fixed.

$$\frac{\Delta}{n} = (a+t)^{1-\sigma} + \frac{1-n}{n}\phi a^{1-\sigma} > \overline{\Delta} = (a+t)^{1-\sigma}$$

$$\frac{\Delta^*}{n} = \phi(a+t)^{1-\sigma} + \frac{1-n}{n}a^{1-\sigma} > \overline{\Delta}^* = \phi(a+t)^{1-\sigma}$$

Therefore, northern emission level under quota is higher than in tax, $\chi_N^Q > \chi_N^T$.

Turning to q, northern emissions under free relocation are

$$\overline{\chi}_N = \frac{1}{a+t} = n\left(\frac{s}{\Delta} + \phi\frac{1-s}{\Delta^*}\right)(a+q)^{-\sigma}$$

We can rewrite as

$$\frac{1}{a+t} - \left(\frac{s}{(a+q) + \dfrac{\phi(1-n)a^{1-\sigma}}{n(a+q)^{-\sigma}}} + \frac{1-s}{(a+q) + \dfrac{(1-n)a^{1-\sigma}}{n\phi(a+q)^{-\sigma}}}\right) = 0$$

To satisfy this equation, q<t is necessary due to $\frac{\phi(1-n)a^{1-\sigma}}{n(a+q)^{-\sigma}} > 0$ and $\frac{(1-n)a^{1-\sigma}}{\phi n(a+q)^{-\sigma}} > 0$.

REFERENCE

Baldwin, R. and R. Forslid, P. Martin, G. Ottaviano and F. Robert-Nicoud (2003) *Economic Geography and Public Policy*, Princeton University Press, Princeton.

Baldwin, R E and P.Krugman (2004). "Agglomeration, Integration and Tax Harmonisation", *European Economic Review* 48 (1): pp1-23.

Barbier, E.B. (1997) "An Introduction to the Environmental Kuznets Curve Special Issue," *Environment and Economic Development* 2, 369-381.

Copeland, B. and M. S. Taylor (2005) "Free Trade and Global Warming: a Trade Theory View of the Kyoto Protocol", *Journal of Environmental Economics and Management* 49, 205-234.

Dixit, A.K. and J.E. Stiglitz (1977) “Monopolistic competition and optimum product diversity,” *American Economic Review* 67, 297-308.

Elbers, C and C.Withagen (2004) “Environmental Policy, Population Dynamics and Agglomeration” *Contributions to Economic Analysis & Policy*, Volume 3, Issue 2 Article 3

Gokturk, S.S. (1979) “A theory of pollution control, location choice, and abatement decisions,” *Journal of Regional Science* 19, 461-467.

Hoel, M (1997) “Environmental Policy with Endogenous Plant Locations,” *Scandinavian Journal of Economics* 99 (2), pp241-259

Ishikawa, J and K. Kiyono (2000) “International Trade and Global Warming,” CIRJE Discussion Paper Series, CIRJE-F-78, Faculty of Economics, University of Tokyo.

Ishikawa, J. and K.Kiyono (2006) “Greenhouse-gas Emission Controls in an Open Economy,” *International Economic Review* 47, 431-450.

Jaffe, A.B., S. R. Peterson, P.R. Portney, and R.N. Stavins (1995) “Environmental Regulations and the Competitiveness of U.S. Manufacturing: What does the Evidence Tell Us?” *Journal of Economic Literature* 33(1):132-63.

Kind, H., Midelfart-Knarvik, K., Schjelderup, G., (1998). Industrial agglomeration and capital taxation. Norwegian School of Economics, Department of Economics, Discussion Paper 7/98.

Kiyono, K.and J. Ishikawa (2004) “Strategic Emission Tax-quota Non-equivalence under International Carbon Leakage”, in H. Ursprung and S. Katayama (ed.) *International Economic Policies in a Globalized World*, (Springer Verlag), 133-150.

Lahiri, S and Y. Ono (2006) “Emission Standard versus Tax under Oligopoly: The Role of Free Entry,” mimeo.

Levinson, A (1995) “Environmental Regulations and Industry Location: International and Domestic Evidence,” mimeo, Department of Economics, University of Wisconsin.

Levinson, A. and M. S. Taylor (2005) "Unmasking the Pollution Haven Effect," forthcoming *International Economic Review*.

Ludema, R and I. Wooton (1994) “Cross-border Externalities and Trade Liberalization: The Strategic Control of Pollution,” *Canadian Journal of Economics* 27, 950-966.

Ludema, R and I.Wooton (2000). “Economic geography and the fiscal effects of regional integration”, *Journal of International Economics* 52 (2): pp331-357.

Markusen, J.R. (1975) “Cooperative control of international pollution and common property resources,” *Quarterly Journal of Economics* 89, 618-632.

Markusen, J.R (1998), “Multinational Firms, Location and Trade”, *the World Economy*, vol 21 (6), pp.733-756.

Markusen, J.R., E.R. Morey, and N.D. Olewiler (1993) “Environmental policy when market structure and plant locations are endogenous,” *Journal of Environmental Economics and Management* 24, 69-86.

Markusen, J, E. Morey, N. Olewiler (1995) “Competition in regional environmental policies when plant locations are endogenous”, *Journal of Public Economics* 56, 55-77.

Martin,P and C.A Rogers (1995) “Industrial location and public infrastructure,” *Journal of International Economics* 39, 335-351.

Pfluger, M(2001) “Ecological dumping under monopolistic competition,” *Scandinavian Journal of Economics* 103, 689-706.

Pethig, R (1976) “Pollution, welfare, and environmental policy in the theory of Comparative Advantage,” *Journal of Environmental Economics and Management* 2, 160-169.

Rauscher, M. (1995) “Environmental regulation and the location of polluting industries,” *International Tax and Public Finance* 2, 229-244.

Smarzynska J, B and S. Wei (2004) "Pollution Havens and Foreign Direct Investment: Dirty Secret or Popular Myth?," *Contributions to Economic Analysis & Policy*: Vol. 3 : Iss. 2, Article 8.

Ulph, A (1992) “The choice of environmental policy instruments and strategic international trade,” in: R. Pething (ed.), *Conflicts and cooperation in managing environmental resources,*(Springer-Verlag, Berlin).

Ulph, A (1996) “Environmental policy instruments and imperfectly competitive international trade,” *Environmental and Resource Economics* 7, 333-355.

Ulph, A and L. Valentini (2001) “Is environmental dumping greater when plants are footloose?” *Scandinavian Journal of Economics* 103, 673-688.

Venables, A J. (2001) “Economic Policy and the Manufacturing base: hysteresis in location”. in A. Ulph (ed), *Environmental Policy, International Agreements, and International Trade*, OUP.

Wilson, J. D. (1985) “Optimal property taxation in the presence of interregional capital mobility,” *Journal of Urban Economics* 17, 73-89.

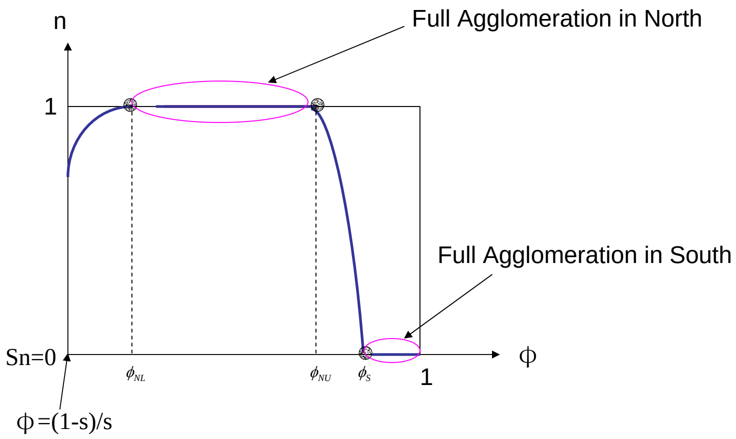

Figure 1: Tax and Firm Share

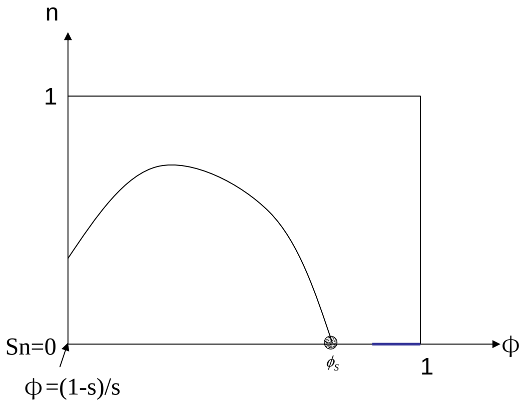

Figure 2: Tax and Firm Share (high tax rates)

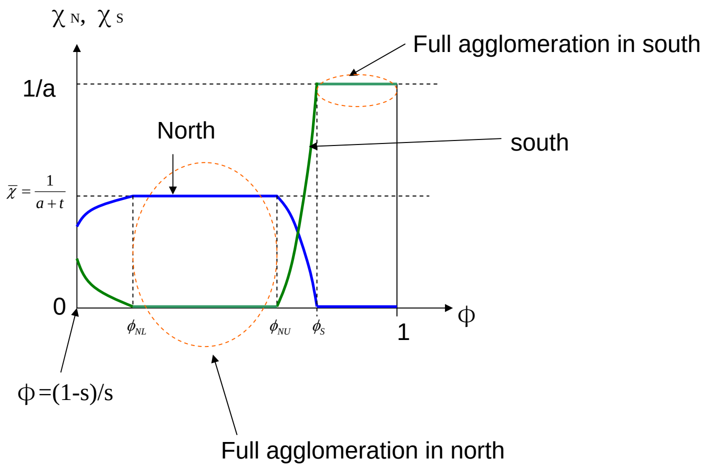

Figure 3: Local Emission levels

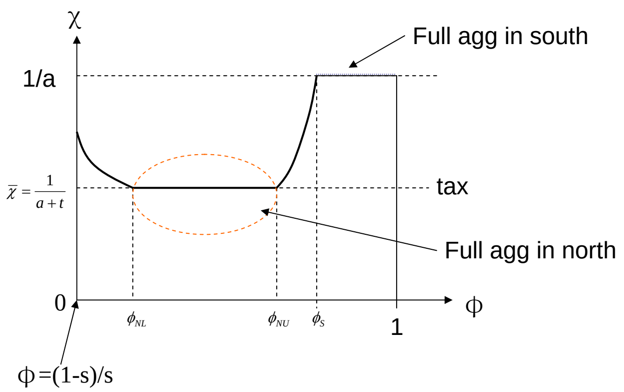

Figure 4: Global Emissions (Tax)

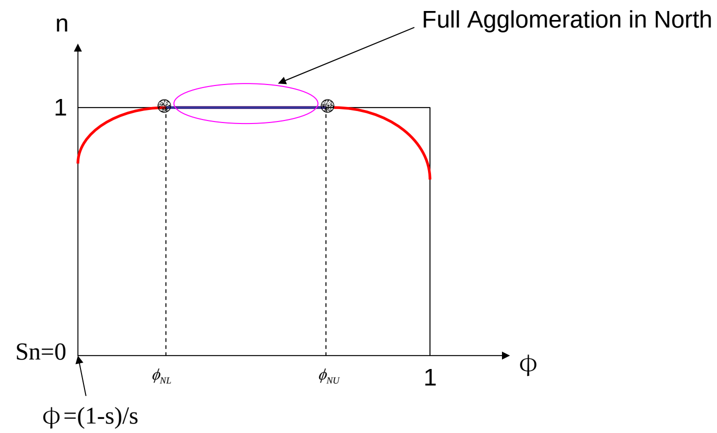

Figure 5: Quota and Firm Share

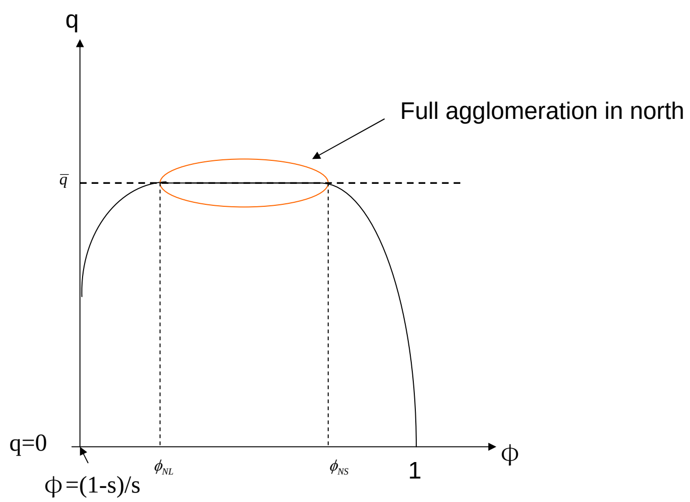

Figure 6: Quota prices

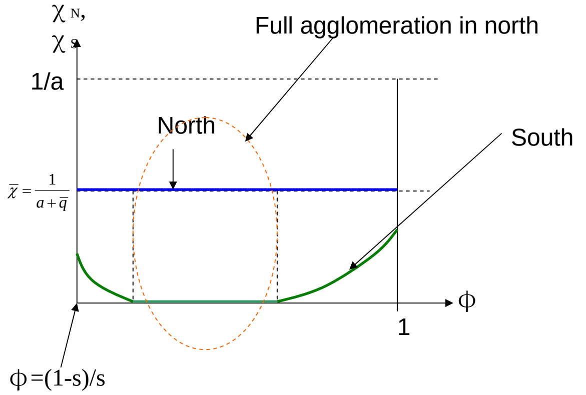

Figure 7: Local Emission Levels (quota)

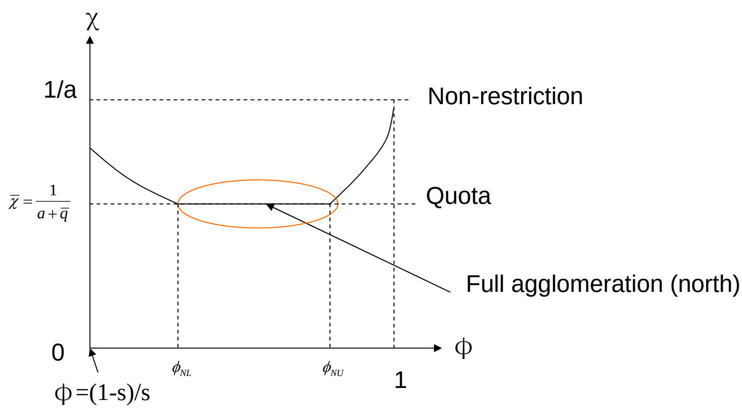

Figure 8: Global Emissions (quota)

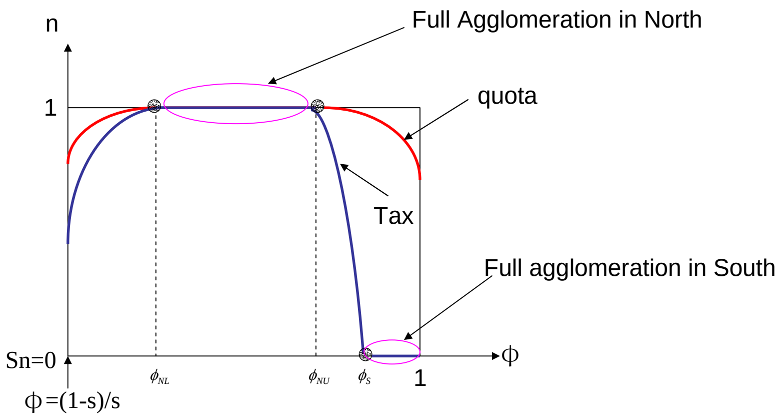

Figure 9: Firm Share (Tax and Quota)

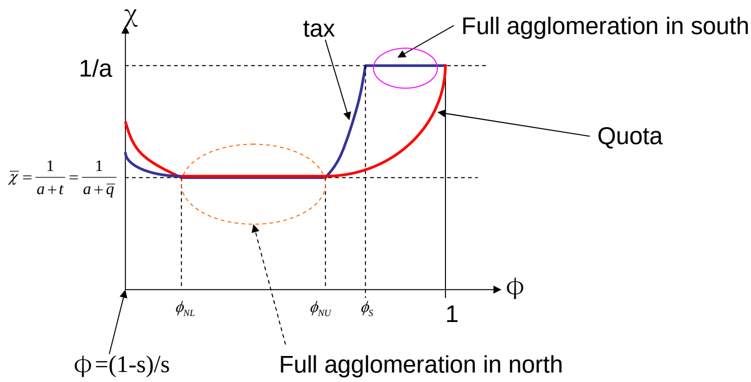

Figure 10: Global Emissions with tax and quota

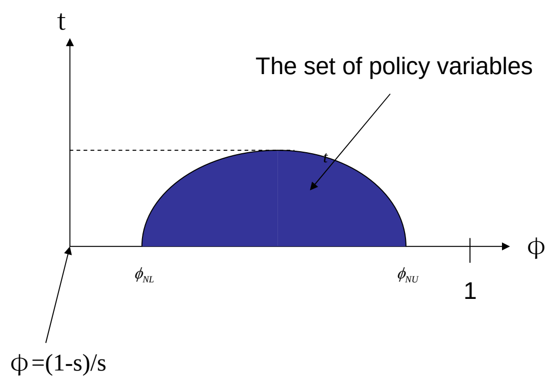

Figure 11: Trade Liberalisation and Tax

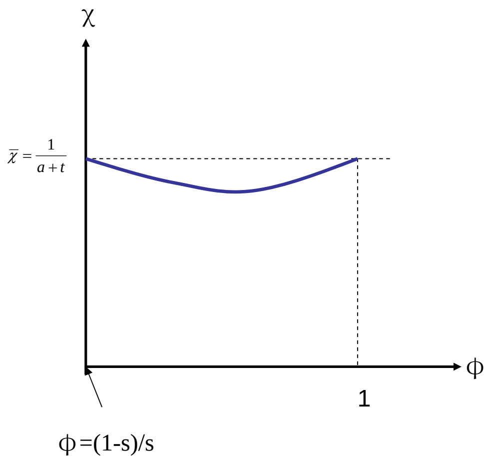

Figure 12: Emissions and Voluntary Tax