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

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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 GHG emissions by a certain amount. Comparing emission quotas with emission taxes, we show that taxes coupled with lower trade costs facilitate more firm relocations than quotas do, causing more international carbon leakage. Thus, if a country is concerned about global emissions, emission quotas would be adopted to mitigate the carbon leakage. Firm relocation entails a trade-off between trade liberalization and emission regulations. Emission regulations may be hampered by trade liberalization, and vice versa.

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1. INTRODUCTION

Global environmental problems have recently attracted considerable worldwide attention. 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 (UNFCCC), 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 UNFCCC (COP3) in December 1997.[1] In the protocol, the industrialized countries called Annex I Parties made a commitment to decrease their GHG emissions by 5.2% compared to their 1990 baseline levels 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.

There is no doubt that the Kyoto Protocol is a significant step towards the reduction of GHG emissions. Obviously, however, the partial participation of certain countries in 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 other countries. As a result, worldwide emissions may rise.

International carbon leakage occurs through a number of channels. For example, it may occur through fuel price changes (Ishikawa and Kiyono, 2000; Kiyono and Ishikawa, 2004). When a country adopts 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 a 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

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

[2] In 2005, the shares of world CO_2 emissions were 21.4% for the United States and 18.6% for China, respectively.

response to environmental 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 liberalization 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 labour alone with constant-returns-scale (CRS) technology, is freely traded internationally. The manufactured products are subject to the 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 case North's market is larger than South's market and all firms in the manufacturing sector are located in North in stable equilibrium because of small or intermediate trade costs. The North 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 South.

One of our main results is as follows. If North cares only about local emissions, then North prefers emission taxes to emission quotas. On the other hand, if 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 North. As mentioned above, the target for 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 liberalization 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 worldwide emission reduction, however, emission quotas are more effective.

Another main result is that when emission taxes are adopted in 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 liberalization and emission regulations. Emission regulations may be hampered by trade liberalization, and vice versa.

There are many papers that examine the pollution haven hypothesis. In the framework of an 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 local 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 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 investigate environmental policies (Pfluger, 2001; Venables, 2001; Elbers and Withagen, 2004).[6] Pfluger (2001) considers Pigouvian emission taxes in a

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[4] Evidence on 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 and Wei (2004) discuss factors that may make the evidence of the hypothesis weak. Levinson and Taylor (2008) point out that the pollution haven effects have been underestimated.

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

[6] Venables (2001) studies the impact of tax on equilibrium in a vertical linkage model. In the case of energy taxes that are unilaterally introduced in one country, he discusses hysteresis in location but does not investigate any environmental policies. Elbers and Withagen (2004) study the impact of an 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. In contrast, emissions in our model are global and hence it is hard to identify polluters and estimate emissions damage. This makes it impossible to levy a tax on each polluter and compensate the public through tax reimbursement. In our paper, global warming is an impending issue and each country is required to reduce total emissions by a certain amount.

A key mechanism of environmental policies is agglomeration rent, which is discussed somewhat similarly in the literature of tax competition. 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 spirit and purpose: 1) A reduction of emissions is an obligation in international agreements. Taxation is aimed at reducing emissions to a certain level rather than affecting tax revenue. On the other hand, corporate taxation is intended to absorb agglomeration rent and raise tax revenue; 2) Tax competition is not plausible in our paper. Only 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 environmental agreements leave no room for tax competition to increase government revenue, i.e., a race-to-top or race-to-bottom in the tax rate; and 3) Our discussion involves how to reduce global emissions while refraining from using a pollution haven under trade liberalization. In contrast, tax competition studies show how each government seeks to maximize tax revenue by attracting more firms and widening the tax base.

Turning to the environment and trade literature, Ishikawa and Kiyono (2006) analyse the potential effects of choices over emission controls in an open economy. They specifically compare 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 North's emission level is endogenously determined under emission taxes. However, their model is based on traditional trade models (i.e., both Ricardian and Heckscher–Ohlin models) and does not take firm relocation into account.

In an analysis of global warming, Copeland and Taylor (2005) explore the relationship between international trade in goods and emission permits using a Heckscher–Ohlin framework. They also consider partial participation in the Kyoto protocol. Interestingly, they show that unilateral emission reductions in 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 an 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 organized as follows. In Section 2, we present our basic model. Emission taxes and quotas are investigated in Sections 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 liberalization. Section 7 concludes the paper.

2. BASIC MODEL

2.1. *Two-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). North is bigger than 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 a numéraire. The manufactured goods are subject to the Dixit–

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

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

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 there is no entry and exit. M-sector uses labour, a variable cost, and exclusively employs capital, a fixed cost. Specifically, each firm is required to use one unit of capital, which represents 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., the fixed cost part of total cost, represents capital return. M-sector emits GHGs in the process of production. Specifically, the production of one unit of an M commodity entails one unit of GHG emissions. 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, $\tau = 1$, can be expressed as $\phi = 1$ whereas $\phi = 0$ represents autarchy ($\tau = \infty$).

Turning to the 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 towards 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 monotonic function of GHG emissions, $f(\chi_N + \chi_S)$, where χ_N and χ_S are GHG emissions in North and South, respectively. Each consumer has one unit of capital as well as one unit of labour and gets income from both factors, $w + \pi$. However, the quasi-linear utility function has no income effect and thus each consumer buys a certain number of units of M-goods regardless of his/her income and M-goods prices.

Labour is mobile between sectors but immobile between countries. While capital is mobile between two nations, capital owners are immobile and thus capital

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

rewards are repatriated to the country of origin. Because capital endowment is initially allocated in proportion to labour endowment (market size), North's share of initial capital and labour endowments are given by $s_K = K/K^W = s_L = L/L^W$. However, after the firm has relocated, capital share is generally not equal to population share, whereas population share always corresponds to labour share, s_L, and capital share is always identical to firm share, $n/N^W = s_K$. This is because each footloose firm needs one unit of capital. Because no income effect exists, the quasi-linear utility function ensures $s \equiv s_E = s_L$, where North's expenditure share is defined as $s_E = E/E^W$. For simplicity, total expenditure E^W and total labour and capital endowments, L^W and K^W (thus the total number of firms, N^W), are normalized to one. Thus, *n* is North's share of firms.[10]

2.2. *Initial equilibrium*

Because the A-sector good is the numéraire and is freely traded internationally, wage rates in both countries are normalized to one, $w = w^* = 1$. Utility maximization results in the well-known CES demand function. As a result of maximization, local and export prices of the product variety of the 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 a constant. Consumption per variety is:

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

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

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

[10] Importantly, we use a quasi-linear utility function. The income effect is eliminated. The total number of households (population) is one in the world, because each individual has one unit of labour and capital. The level of demand depends on population size rather than income.

where E (E^*) represents the North's (South's) expenditure, and Δ and Δ^* are defined as $\Delta[n] = na^{1-\sigma} + \phi(1-n)a^{1-\sigma}$ and $\Delta^*[n] = \phi na^{1-\sigma} + (1-n)a^{1-\sigma}$.[11]

Because 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 equalized and then firm shares, n are determined as locational equilibrium.

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

Solving (4), we obtain $n = \frac{1}{2} + \left(\frac{1+\phi}{1-\phi}\right)(s - \frac{1}{2})$.

As trade costs fall (a rise in ϕ), n increases: more South firms go to North, so-called gradual agglomeration. Then, below a certain trade cost, called the sustain point ($\phi = (1-s)/s$), all firms concentrate in North, i.e., full agglomeration. That is, trade costs above the sustain point (small trade costs) create full agglomeration in the big country as a stable equilibrium. For simplicity, we first consider full agglomeration before considering 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*

The quantity produced by each North-based firm (j) for the North market is given by $x_j = \frac{\mu p^{-\sigma}}{np^{1-\sigma} + n^* p^{*1-\sigma}}$, which is identical to c. Turning to the export market, only x/τ units arrive for export because of iceberg trade costs. While North's consumption is equal to the quantity produced in North for each variety, i.e., $x_j = c_j$,

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

the quantities produced for the foreign market need $x_j^* = c_j^* \tau = \dfrac{\mu \tau p^{*-\sigma}}{np^{1-\sigma} + n^* p^{*1-\sigma}}$. It follows that the total quantity produced by a North-based firm, firm *j*, is written as:

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

For simplicity, we assume that producing one unit of goods entails one unit of GHG emissions. Thus, the amount of local emissions in each country corresponds to each country's total quantity produced. Local emission levels in North and South are, respectively, defined as:

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

where $b \equiv \dfrac{\mu}{(1-1/\sigma)}$ is exogenously given and constant. Without loss of generality, by an appropriate choice of units we can normalize $b = 1$. Note that GHG emissions in North and South correspond to quantities produced in each country. In sum, world emissions 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 no-policy equilibrium (full agglomeration in North) can be written as $\chi^{initial} = \chi_N^{initial} = \dfrac{a^{-\sigma}}{a^{1-\sigma}} = \dfrac{1}{a}$ because of $\Delta = a^{1-\sigma}$ and $\Delta^* = \phi \Delta$. Note that GHGs are initially emitted only in North because of North's full agglomeration and the emissions remain constant and are independent of trade costs.[12]

Proposition 1: The total amount of emissions is unaffected by trade costs at full agglomeration (no environmental policy) equilibrium.

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[12] More generally, ignoring a stable equilibrium path, if all firms hypothetically concentrate in one country, either North or South, the amount of emissions can be kept constant. For instance, if all firms are forced to relocate to South by policy, 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 with North's full agglomeration. Hence, the global level of emissions is independent of location in the case of full agglomeration, irrespective of a stable equilibrium path.

3. EMISSION TAX

3.1. *Taxation without relocation*

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

Starting from full agglomeration, North imposes an emission tax so as to reduce emissions and implement the international agreement. At this moment, relocation is prohibited (infinitive relocation costs). Because one unit of GHG emissions corresponds to one unit of quantity produced in our model, an emission tax needs to be levied on each unit of production rather than prices, pure profits or sales. Thus, the emission tax is equivalent to a specific production tax, t. Then the total costs and prices are expressed as:

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

The tax increases total costs and prices.[13] Thus, pure profit of a North-based firm and the North's emissions without relocation are given as:

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

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

where North's full agglomeration leads to $\Delta = a^{1-\sigma}$ and $\Delta^* = \phi a^{1-\sigma}$. Note that taxation without relocation, i.e., without carbon leakage, results in reducing emissions from $1/a$ to $1/(a+t)$.

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

3.2. *Equilibrium with free relocation*

Next, we allow for free firm relocation. Because taxation decreases profits in North, firms may have an incentive to move to the non-taxed country, i.e., South, regardless of a small market size. When tax rates are set at 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 South. Firm share, *n*, is determined so as to equalize pure profits between countries:

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

where $\Delta = na^{1-\sigma} + (1-n)\phi(a+t)^{1-\sigma}$ and $\Delta^* = n\phi a^{1-\sigma} + (1-n)(a+t)^{1-\sigma}$.

Figure 1 plots firm share, *n*, in terms of freeness of trade ϕ, Given a fixed low rate of tax, the firm share locus is hump-shaped. Taxation causes international carbon leakage: firm relocation occurs from North (taxed country) to 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:

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

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

<Figure 1>

In reverse, given a fixed ϕ, a low tax can sustain full agglomeration. The condition for the low tax rate 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 the tax rate is above $\tilde{t}$, North never sustains full agglomeration for any trade cost and instead South is more likely to achieve full agglomeration. Figure 2 illustrates the case of high tax rates without North's full agglomeration.

<Figure 2>

As shown in Figures 1 and 2, all firms relocate to South with a sufficiently small trade cost, i.e., 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 South is more likely to occur. A sufficiently small trade cost coupled with a high tax rate accelerates international carbon leakage, relocating to the country without environmental regulation. 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: An emission tax may lead to international carbon leakage. Full agglomeration in North (taxed country) can be sustained if the tax rate is low and/or trade costs are intermediate. However, when the tax rate is high and/or trade costs are sufficiently small, all North firms move to South (non-taxed country).

Note that the standard FC model (without any taxation) has hump-shaped agglomeration rents, which is a 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 the net benefit from agglomeration. Thus, large or small trade costs lead to a negative net agglomeration benefit, which causes firm relocation to South.

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

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

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

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

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

where $\Delta = na^{1-\sigma} + (1-n)\phi(a+t)^{1-\sigma}$ and $\Delta^* = n\phi a^{1-\sigma} + (1-n)(a+t)^{1-\sigma}$.

<Figure 3>

<Figure 4>

Allowing firm relocation entails more GHG emissions than the target of the international agreements, $1/(a + t)$, because of international carbon leakage when trade costs are either large or small. That is, when trade costs are either large or small, North's emissions fall and South's emissions rise (Figure 3). The carbon leakage decreases North's emissions, which are less than the target, $1/(a + t)$, and South's emissions increase by relocation, and then reach a maximum of $1/a$ with South's full agglomeration: $\chi = \chi_S = n^*\left(\phi\frac{s}{\Delta} + \frac{1-s}{\Delta^*}\right)a^{-\sigma} = \frac{1}{a}$, where $\Delta = \phi\Delta^*$ and $n^* = 1$. Note that South's emissions exceed North's for certain levels of ϕ. As trade costs fall, firm relocation decreases n and then, when $n < \frac{a+t}{2a+t}$ holds, the South's emissions exceed the North's. Lower tax rates lead to a critical n of 0.5, and higher tax rates increase the critical n. This means that lowering tax rates can moderate carbon leakage.

Figure 4 shows global emissions, which are the sum of North's and South's emissions. Because small and large trade costs allow more relocation to the non-taxed country, global emissions increase. In particular, above ϕ_S all firms concentrate in South and no firms pay tax, and thus the emission level becomes $1/a$. Note that this is identical to the initial no-policy level. North's emission policy is nullified and the global amount of emissions returns to the initial equilibrium (no environmental policy). We can say that the only impact of taxation with small trade costs is to transfer GHG emissions from North to South through the relocation of all firms. With small trade costs, unilateral emission taxation results in perfect carbon leakage (full agglomeration in 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, an emission quota. In this case, starting from full agglomeration, North unilaterally introduces an emission quota so as to satisfy international environmental agreements. To make a strict comparison of policy impact on carbon leakage in the tax case, the quota is set so that the emission level under the quota is the same as that under taxation at the initial equilibrium (North's full agglomeration), i.e., $\bar{\chi} = \frac{1}{a+t}$ (constant). Moreover, the quota is assumed to be accompanied by creation of a competitive emission-permit market in North. The quota is implemented by the North government via a fee. Purchasing one unit of the permit allows one unit of production for a North firm. Using (6), the level of the quota is given by:

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

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

The following should be noted. The price of permit, q, is endogenously determined by the number of firms located in North and trade costs so as to satisfy North's emission-permit market clearance, $n\left(\frac{s}{\Delta} + \frac{\phi(1-s)}{\Delta^*} \right)(a+q)^{-\sigma} - \bar{\chi} = 0$, although tax rates are invariant, exogenously given by international agreements. ($\Delta = na^{1-\sigma} + (1-n)\phi(a+q)^{1-\sigma}$ and $\Delta^* = n\phi a^{1-\sigma} + (1-n)(a+q)^{1-\sigma}$).

This results in different impacts on firm location and emission level. Total costs and price are written as $TC_j = \pi + (a+q)x_j$, $p = \frac{a+q}{1-1/\sigma}$ and $p^* = \frac{\tau(a+q)}{1-1/\sigma}$. Firm location is determined by profit equalization and the size of the quota.

4.2. *Equilibrium with free relocation*

At the equilibrium, *n* and *q* are determined by pure profit equalization as well as the emission constraint:[15]

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

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

where $\Delta = na^{1-\sigma} + (1-n)\phi(a+q)^{1-\sigma}$ and $\Delta^* = n\phi a^{1-\sigma} + (1-n)(a+q)^{1-\sigma}$.

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

<Figure 5>

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

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

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

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

However, unlike the effect of an emission tax, a quota does not involve South's full agglomeration with small trade costs. Some firms stay in North at any trade cost. As plotted in Figure 6, q is positive for $0 \le \phi < 1$ and hump-shaped. As long as all firms are in North (full agglomeration) with intermediate trade costs, quota prices equal the values of t (= $\bar{q}$). However, when agglomeration rents fall because of small trade costs, firm relocation to South reduces q, while taxation t remains constant. Firm relocation to South softens the quota constraint in North. The fall of the permit price reduces the disadvantage of locating in North and mitigates relocation.

<Figure 6>

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

Emission levels are written as:

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

(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. Similarly to the tax case, a quota leads to U-shaped global emissions in terms of trade costs. More generally, in the case of small/large trade costs, some firms relocate and emit GHGs in South, although North's emissions are kept at $1/(a+t)$ because of the emission constraint. However, unlike the effect from taxation, global emissions never return to the no-policy level, $1/a$, for any positive trade costs. Because South never creates full agglomeration and the quota is still binding in North, this diversification of firm location results in less global emissions than the case without any policy and the case of taxation.

<Figure 7>

<Figure 8>

Proposition 5: In the case of an emission quota, North's GHG emissions are always kept at the target level of international environmental agreements, although South increases emissions via international carbon leakage under trade liberalization.

5. EMISSION TAX VERSUS QUOTA

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

The first finding is related to tax rates and the quota price. Because international agreements allocate a certain amount of GHG emissions to North, $\bar{\chi}$, tax rates and the price for the permit in the quota system are all equal ($t = \bar{q}$) as long as all firms concentrate in 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, relocation to South caused by environmental regulations results in q being less than t for a given ϕ (i.e., $t > q$) (see Appendix for an analytical derivation). The tax rate is fixed, but the fee for the emission permit is endogenously determined by the number of North firms. As more firms relocate to South, the emission constraint can be more easily attained and then the permit price decreases. Furthermore, when many firms move to South, the permit price drastically decreases, which hampers firm relocation. To summarize:

Proposition 6: The price of the emission permit under a quota is always lower than the per unit emission tax rate in the presence of relocation.

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

<Figure 9>

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

<Figure 10>

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

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

However, from a global viewpoint such an egoistic attitude by North may not be acceptable. Regarding global emissions, as long as firms are allowed to relocate

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

freely, international carbon leakage could be larger than the reduction in GHGs in North. In particular, tax policy returns to the pre-agreement global emission level. For this reason, with free relocation and small trade costs because of trade liberalization, a quota is a better policy scheme for reducing global emissions. A 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 the quota results in more global emissions than the target as long as some firms locate in South and trade liberalization proceeds.

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

6. GLOBAL EMISSIONS, ENVIRONMENTAL AGREEMENTS AND TRADE LIBERALIZATION

Free relocation with small trade costs mitigates the effect of environmental policy and consequently the global level of emissions is higher than the level determined by international agreements. Now, we study what sorts of policies and agreements can properly control global GHG emissions as expected by international agreements while accommodating international free relocation. One solution may be to choose the combination of environmental tax rates as well as trade costs by international agreement.

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

<Figure 11>

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

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

This result yields an important insight that, when the environmental agreements are ratified only by North, the degree of North's environmental policy may be restricted by trade liberalization and vice versa. Free firm relocation entails a trade-off between trade liberalization and environmental regulation.

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

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 North.[17] When

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

North suffers large damage from global warming, North will have an incentive to set a tax rate higher than t by υ (i.e., $\upsilon + t$). This tax rate is defined by:

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

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, North's (equivalently global) emission level is U-shaped. With positive trade costs, the emission level could be less than $\overline{\chi}$.

<Figure 12>

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

7. CONCLUSION

This paper 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 emissions by a certain amount. We have compared two environmental policy tools, emission tax and quota, under trade liberalization.

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) An emission tax results in more firm relocation than a quota. Thus, an emission tax causes more carbon leakage, increasing global emissions. If North is concerned with only local emissions, a tax is adopted to attain the reduction target. On the other hand, if North is concerned with global emissions, a quota is preferred. Thus, a quota is a better policy tool to cope with global warming. 3) Trade liberalization and environmental policies are a trade-off when environmental agreements are unilateral. Trade liberalization may hamper international environmental agreements. Under certain combinations of tax rates and trade costs, a target reduction in global GHG emissions can be attained.

Our paper is the first step in exploring the relationship between trade liberalization and environmental policies in the presence of firm relocation. This paper has some limitations. For example, the policy target in this paper is to reduce GHG emissions to highlight the different policy effects of a tax and a quota. Of course, it is plausible to think that governments maximize social welfare. Welfare analysis and socially optimal policies are a subject for future research. Because our model assumes one unit of emission per unit of quantity produced, production and emissions are subject to a perfect trade-off: more production (consumption) positively affects welfare but simultaneously has a negative effect through increased emissions. There might exist an optimal level of emissions and production, which hinges on the specification of a social welfare function. To conduct welfare analysis formally, we have to specify disutility in the utility function more rigorously, taking into account trans-boundary/local emissions and accumulation of emissions over time. Furthermore, it might be worthwhile considering the negative impact of emissions on A-sector productivity. A-sector might be subject to decreasing returns to scale by serious emissions. Future research should conduct a more rigorous analysis on the international environmental agreements and negotiation in Section 6 by using game theory.

Moreover, we have assumed a quasi-linear utility function that excludes an income effect. The total demand for manufactured goods remains constant even if firms relocate and prices change through the absence of taxation or a quota in South. The constant total demand implies constant total production and hence the global emission level without any environmental policy is independent of trade costs. This has the advantage of highlighting the different effects of the two policies. We can get analytical solutions allowing us to easily compare the relocation effects of a tax and a quota. Furthermore, even if we take into account tax/quota revenue reimbursement, because we can ignore its impact, we can focus on the effects of each policy scheme just on firm location and carbon leakage.[18]

APPENDIX: QUOTA PRICE AND TAX RATE

Here, we mathematically show the relationship between tax and quota policies using analytical solutions. North's emissions without relocation, which are the target of international agreements, are denoted as:

(A1) $\chi_N^{initial} = \frac{1}{a+t} = \left(\frac{s}{\overline{\Delta}} + \phi\frac{1-s}{\overline{\Delta}^*}\right)(a+t)^{-\sigma}$,

where $\overline{\Delta} = (a+t)^{1-\sigma}$ and $\overline{\Delta}^* = \phi\overline{\Delta}$. As mentioned in the main text, this target level of emissions always corresponds to that of the quota case, regardless of relocation: $\chi_N^Q = \chi_N^{initial} = \frac{1}{a+t} = \frac{1}{a+\overline{q}}$. Note that at an initial equilibrium (full agglomeration without allowing for relocation), q is equal to t ($\overline{q} = t$).

Next, allowing for relocation, North's emissions under tax policy can be written as:

(A2) $\chi_N^T = n\left(\frac{s}{\Delta} + \phi\frac{1-s}{\Delta^*}\right)(a+t)^{-\sigma}$,

where tax rate t is fixed. We compare (A1) and (A2):

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

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

[18] However, it is certainly worthwhile examining the robustness of our results in the presence of an income effect. The presence of an income effect caused by relocation may cause a complete specialization in manufacturing (agriculture) in South (North), though it is an extreme and unrealistic case. Agriculture is not the numéraire any more and factor prices are determined by the trade balance and factor markets. In this case, market size and factor prices may determine emission levels.

Therefore, North's emission level under a quota is higher than under a tax for any trade costs, $\chi_N^Q \geq \chi_N^T$.

Turning to *q*, because North's emissions are always identical to the target in the international agreements, by keeping a constant emission level through adjusting quota prices, North's emissions under free relocation are binding (13).

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

The quota market clearance condition can be rewritten 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 the condition, we need $q \leq t$ because $\dfrac{\phi(1-n)a^{1-\sigma}}{n(a+q)^{-\sigma}} \geq 0$ and

$\dfrac{(1-n)a^{1-\sigma}}{\phi n(a+q)^{-\sigma}} \geq 0$. Therefore, we show that an endogenously determined quota price is always less than the tax rate, given the same emission target in North.

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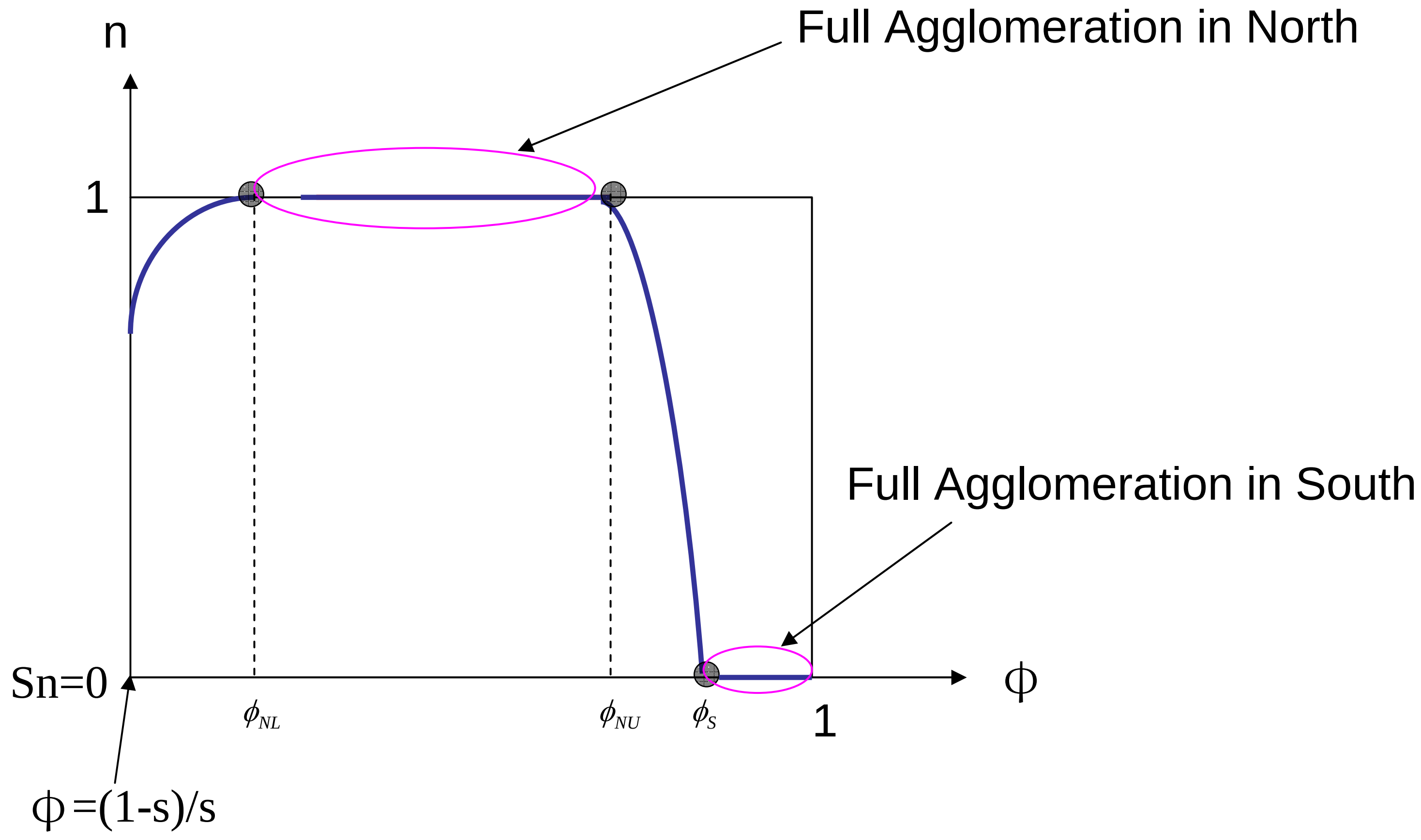

Figure 1: Tax and Firm Share

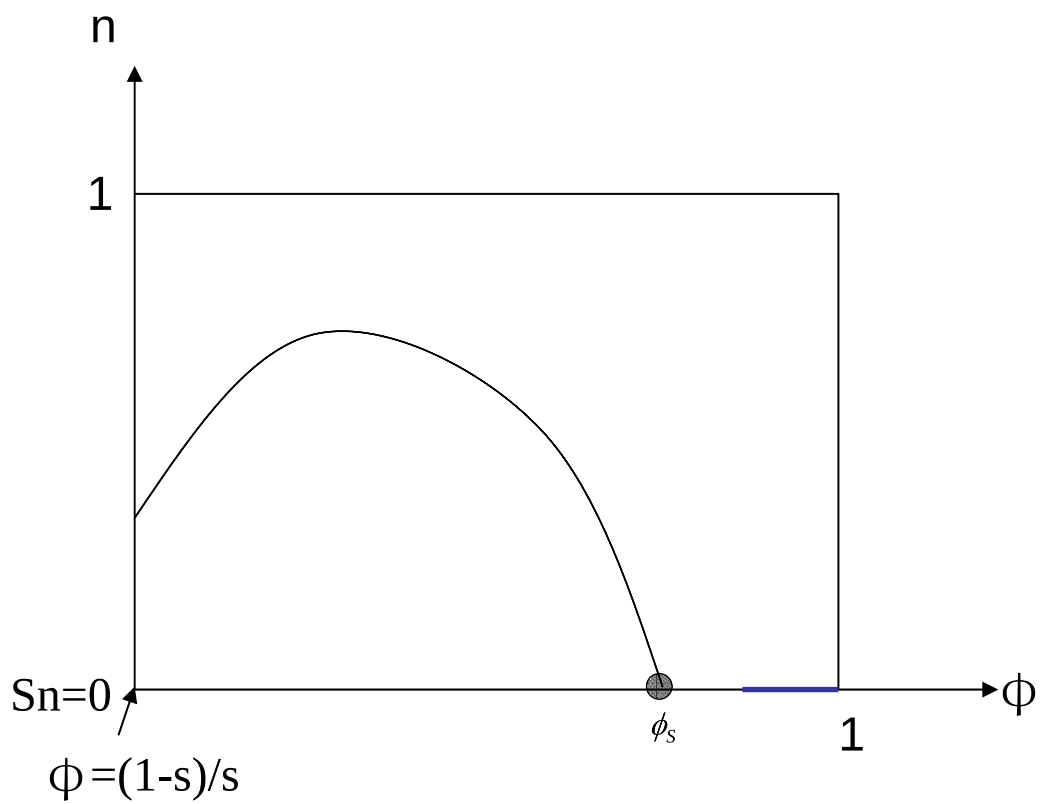

Figure 2: Tax and Firm Share (high tax rates)

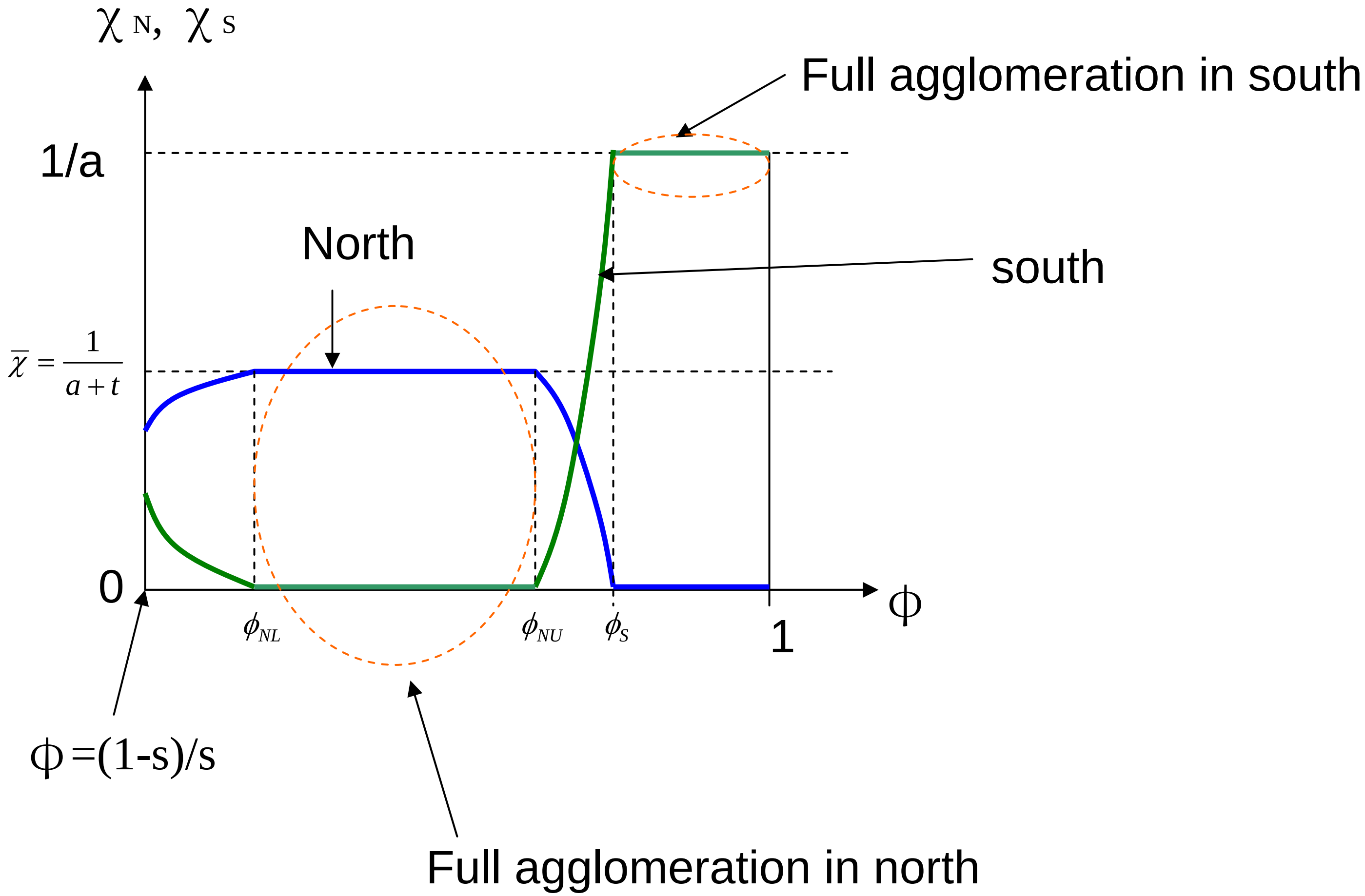

Figure 3: Local Emission levels

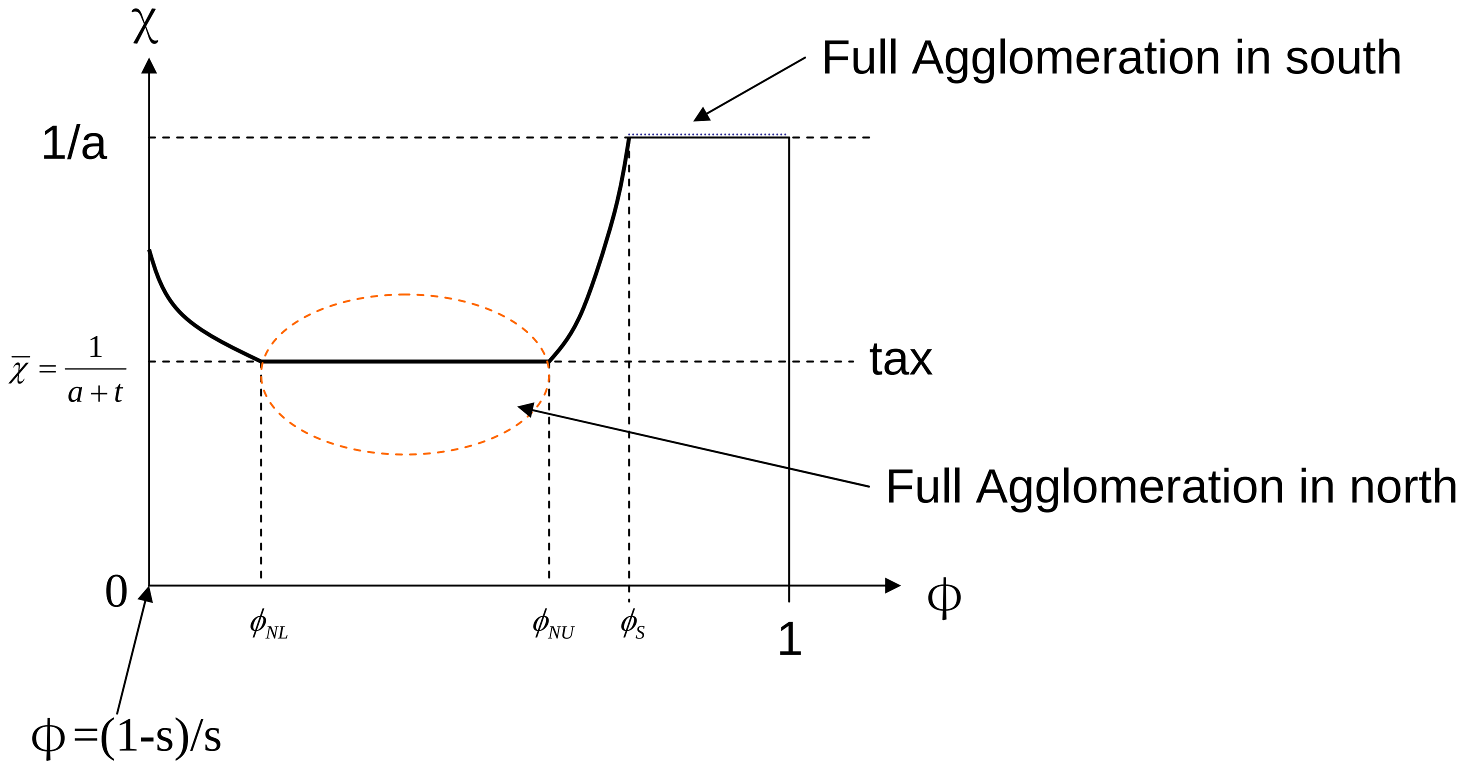

Figure 4: Global Emissions (Tax)

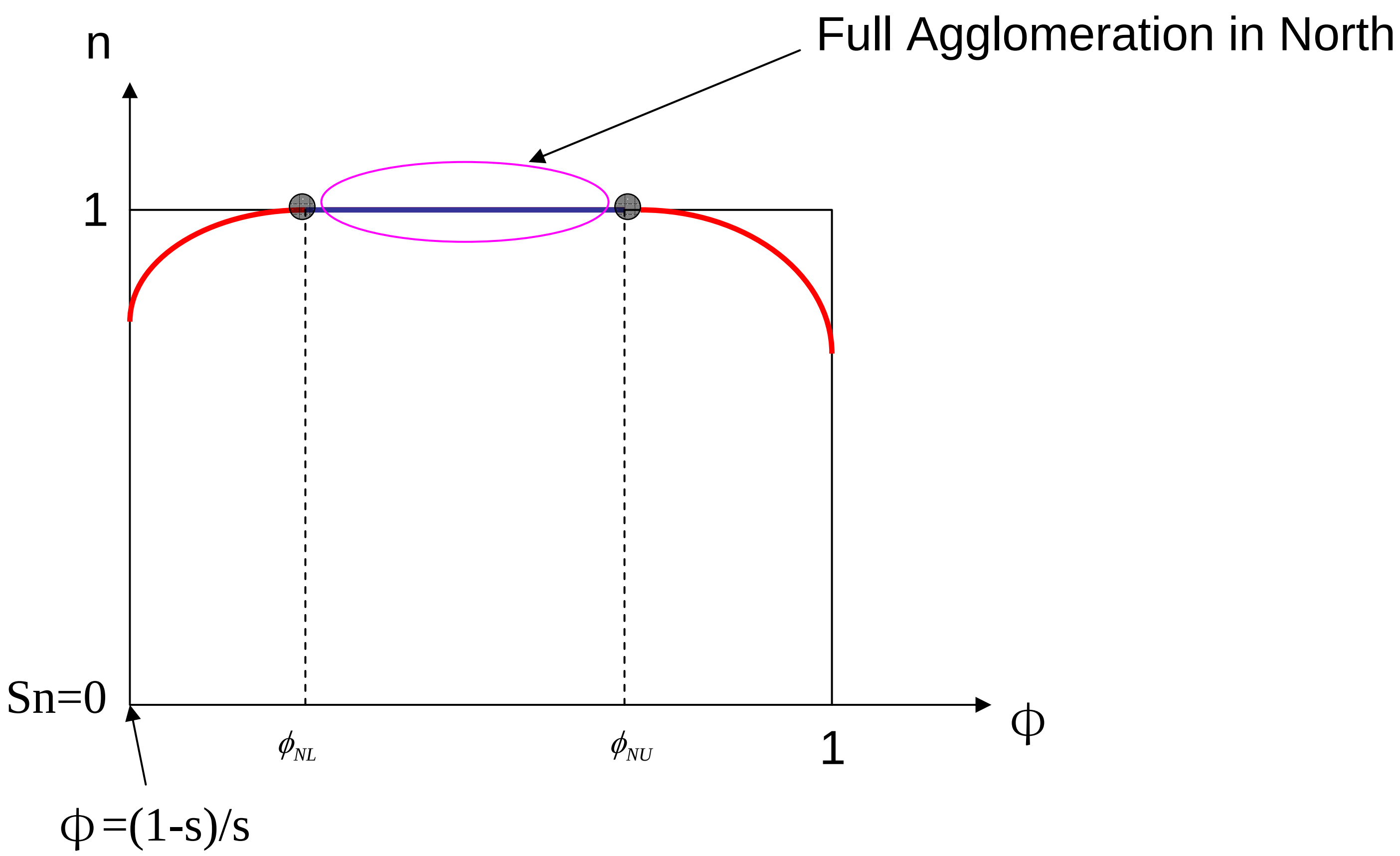

Figure 5: Quota and Firm Share

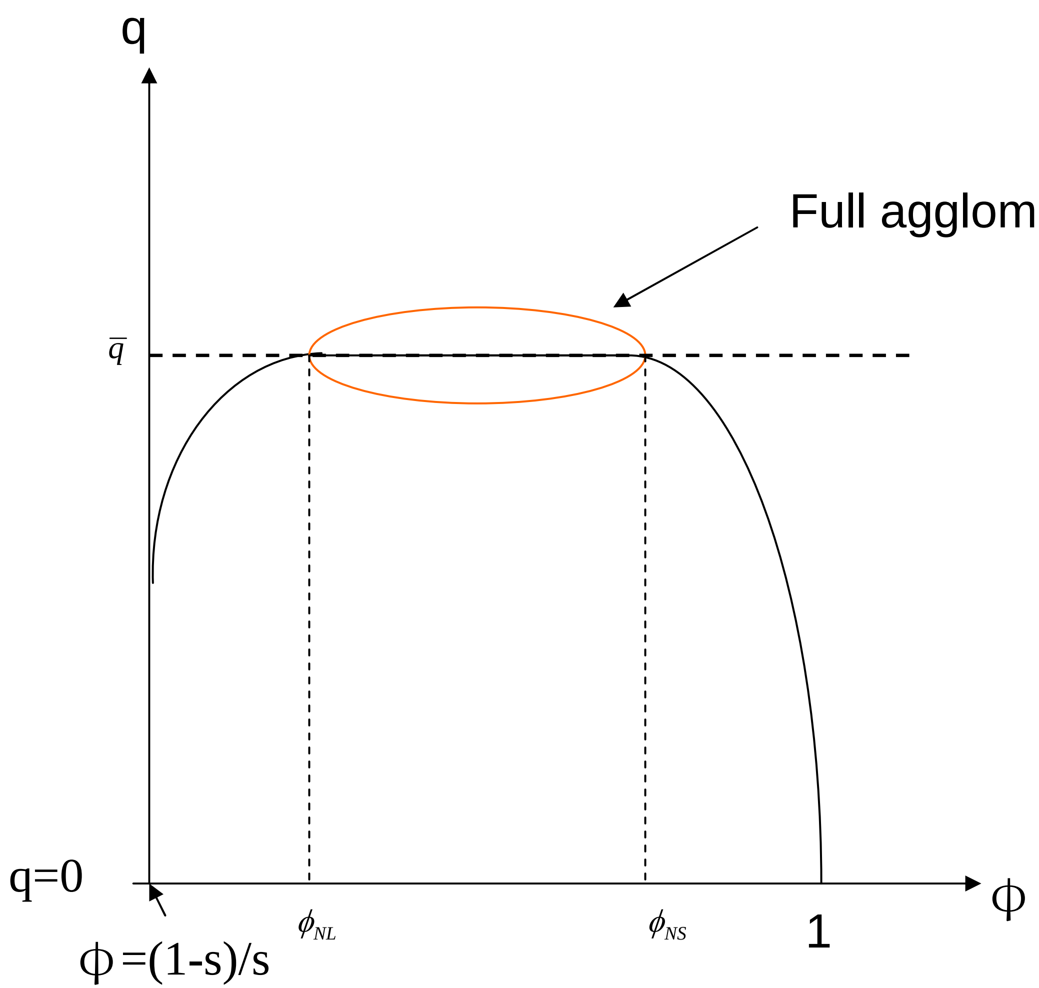

Figure 6: Quota prices

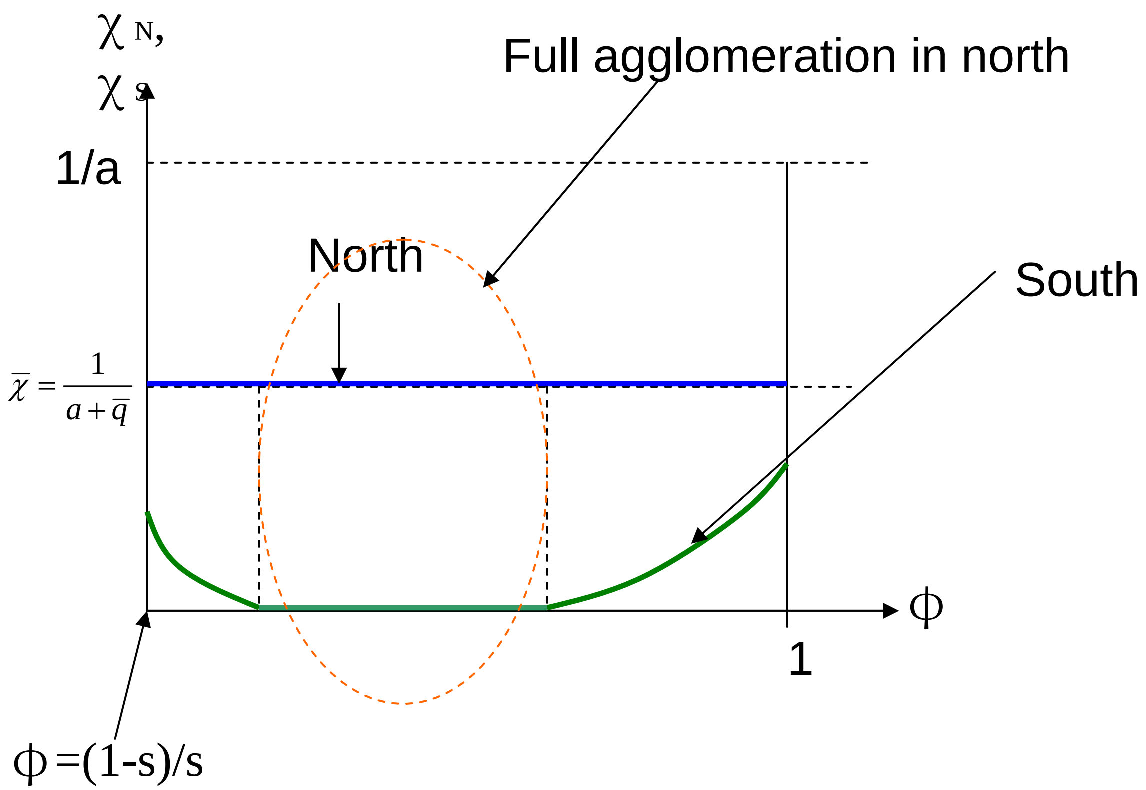

Figure 7: Local Emission Levels (quota)

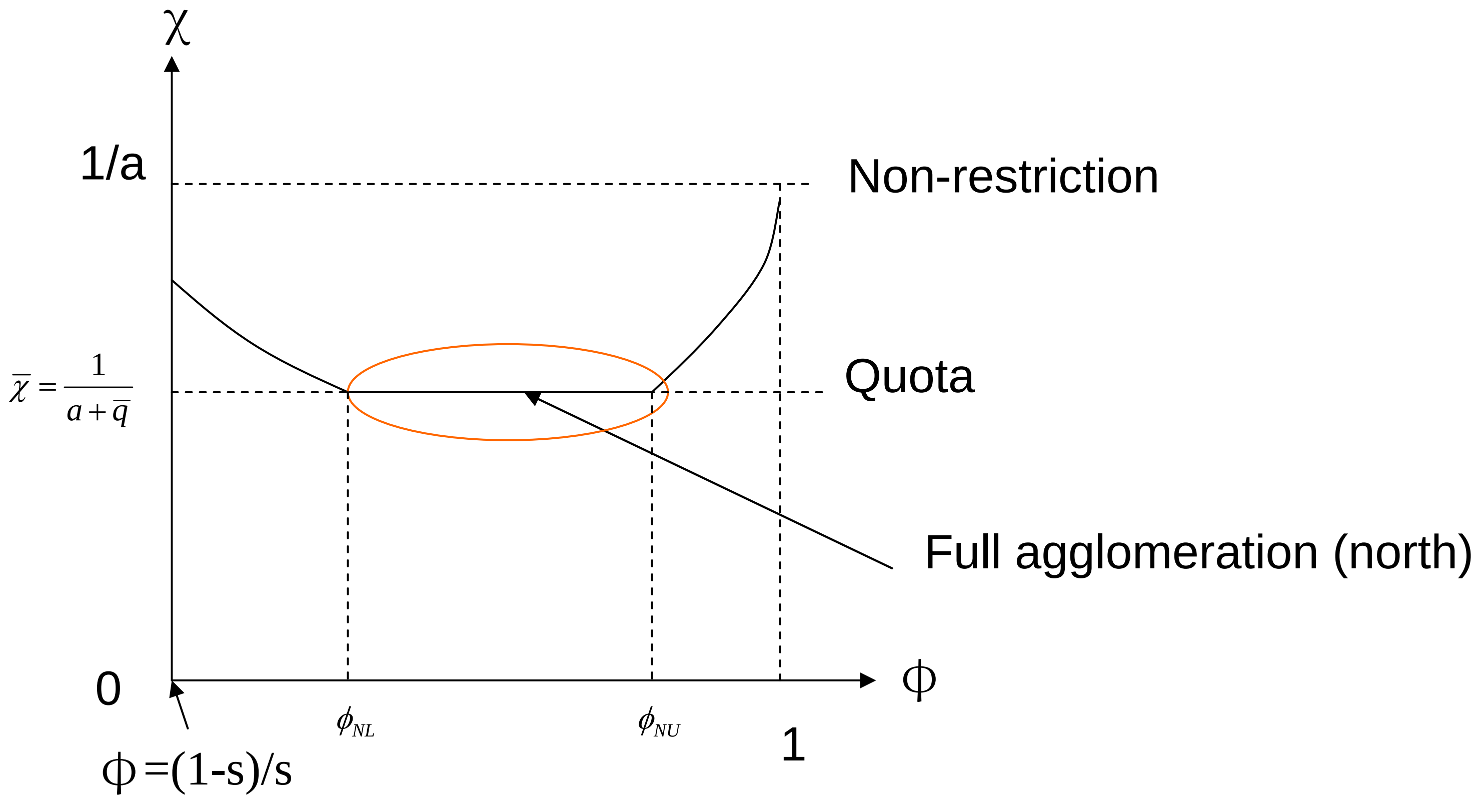

Figure 8: Global Emissions (quota)

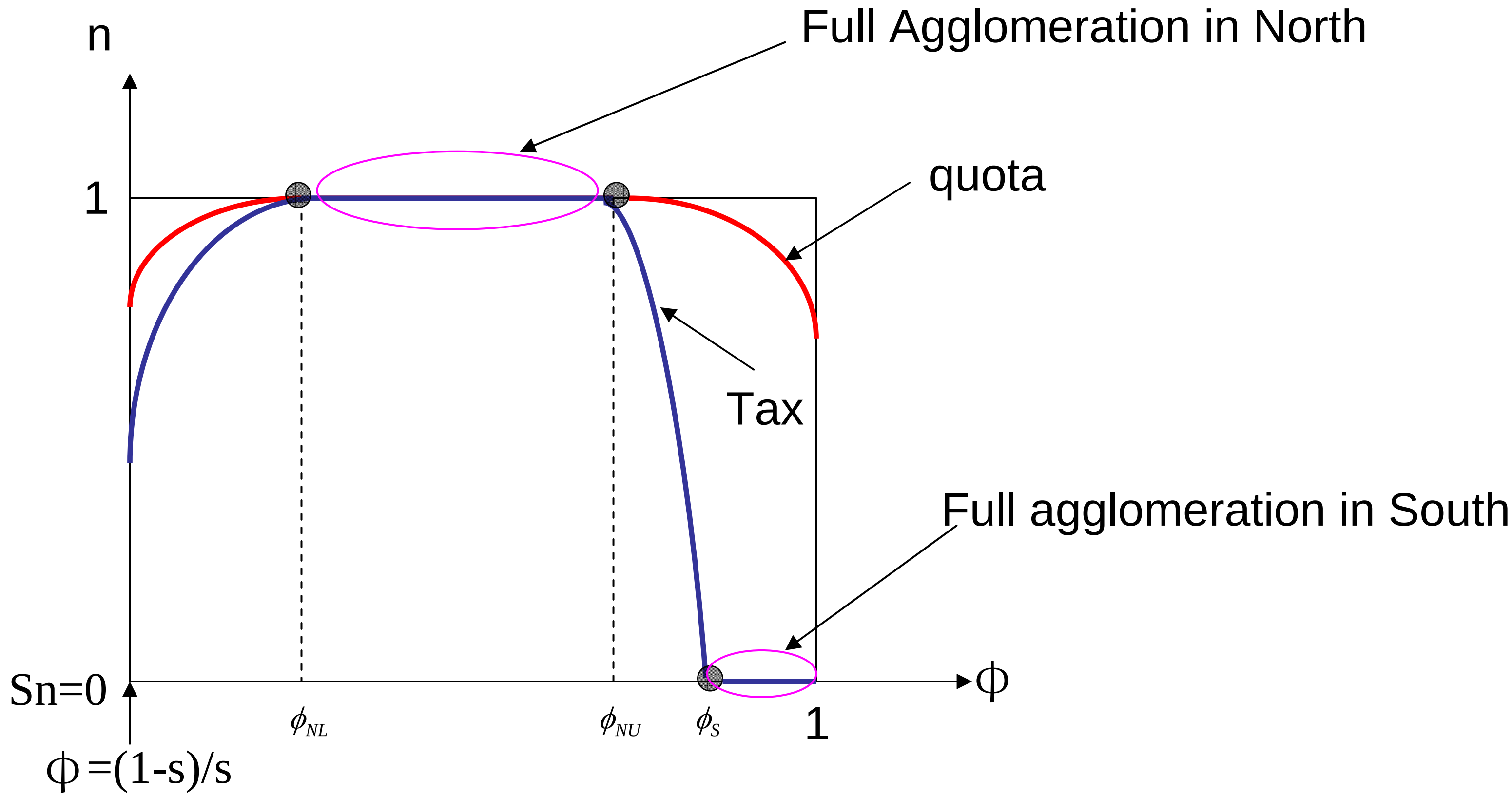

Figure 9: Firm Share (Tax and Quota)

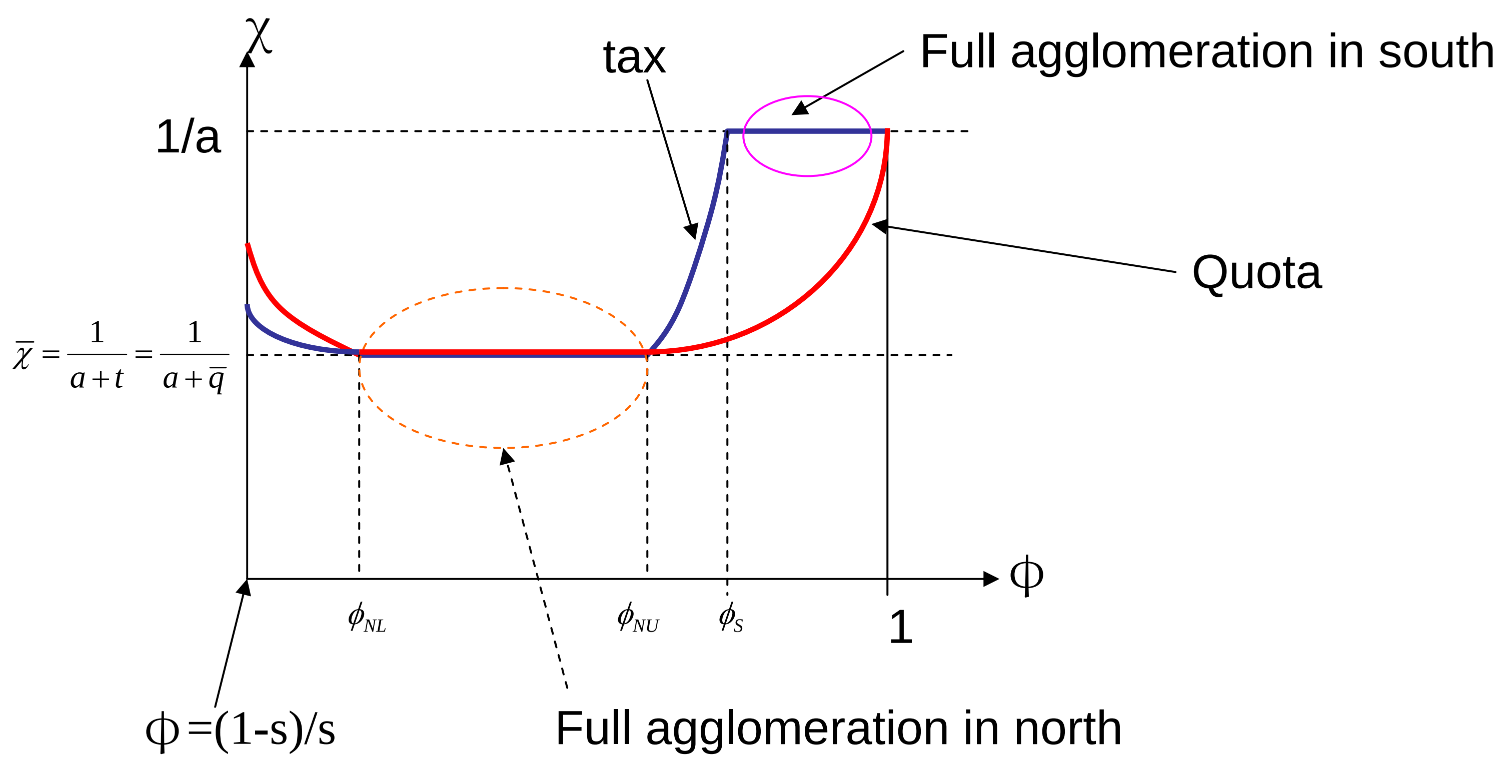

Figure 10: Global Emissions with tax and quota

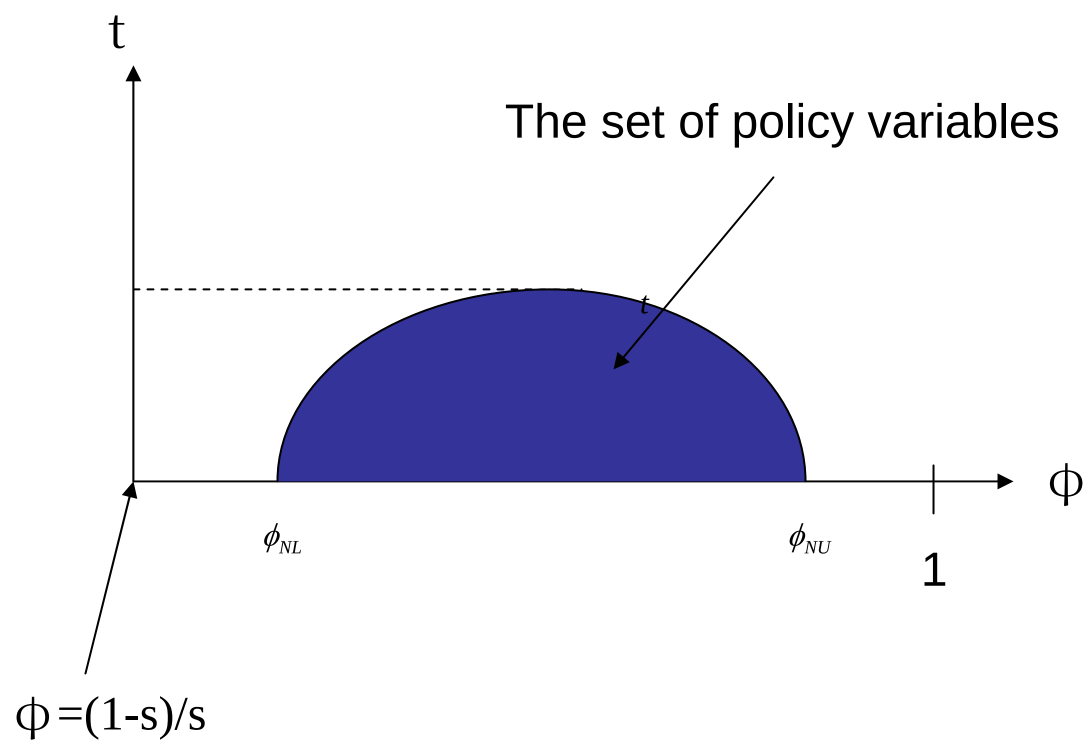

Figure 11: Trade Liberalisation and Tax

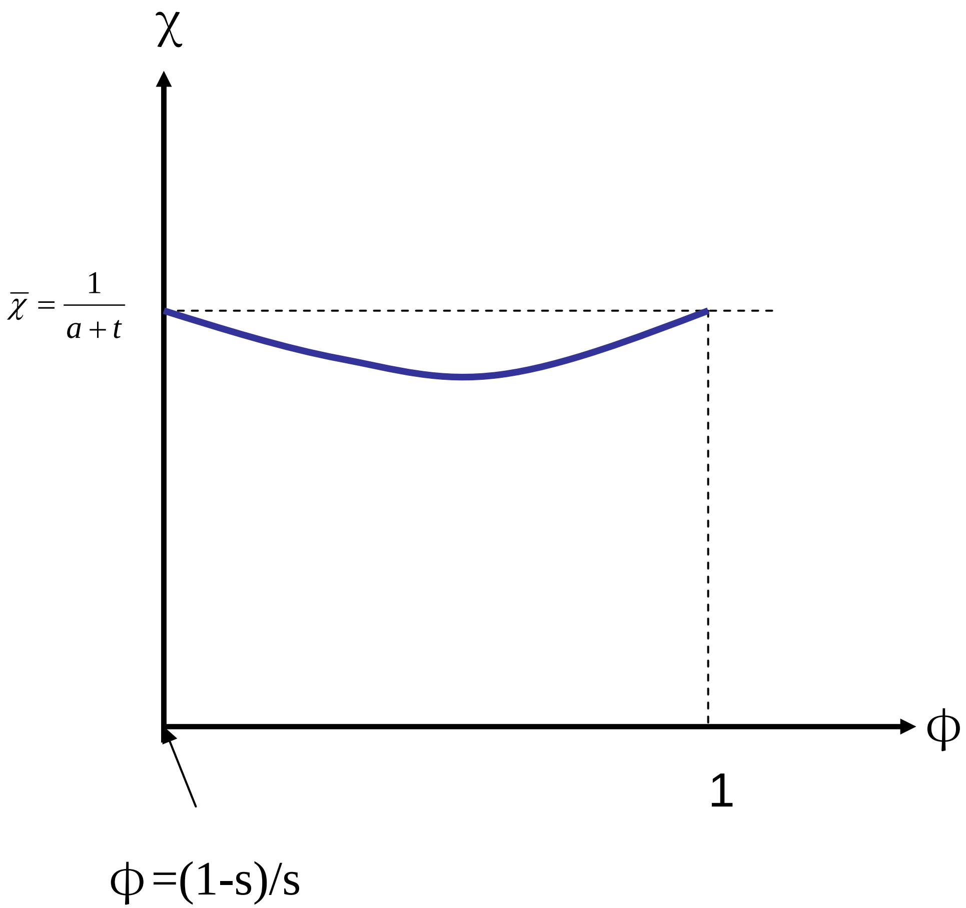

Figure 12: Emissions and Voluntary Tax