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Abstract

Heterogeneous countries produce goods from fixed resources and emitting inputs that cause simultaneous localized and global externality problems (e.g. smog and global warming). Since there is no benevolent international government, the issue of emission permits is delegated to an international self-interested regulator whom the countries try to influence. A single country can exceed its emission permits with a fixed penalty. In this setup, this article shows that emission trading is welfare diminishing, because it grants less (more) permits to countries with relatively clean (dirty) localized technology.

JEL Classification: H23, F15, Q53

Keywords: smog, GHG emissions, emission quotas, emission trading, lobbying

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1 Introduction

This article considers the case where a single source of emissions (e.g. energy) causes simultaneous localized and global externality problems (e.g. smog and global warming), the issue of emission permits is delegated to an international self-interested regulator whom the countries try to influence. A country faces a penalty when it exceeds its permits. In this setting, it is instructive to see how emission trading affects welfare and total emissions.

This article is motivated as follows. Under the European Union Emission Trading System, the governments of the EU Member States agree on national emission caps which have to be approved by the EU commission, and then allocate allowances to their industrial operators. Because countries bargain over emission caps, but smog is external for the firms but not for the countries, emission permit trading between firms makes a difference.

In a world of two goods and two primary inputs, emission trading may increase emissions and make both trading partners worse off through the terms-of-trade effect (Copeland and Taylor 2005). In this article, however, I ignore the terms-of-trade effect with the assumption that there is one internationally-traded good, for simplicity.

Caplan and Silva (2005) examine emission permit management in the case where an independent and benevolent agent enacts international income transfers, after the countries have chosen their respective endowments of the local pollutant. They show that the introduction of domestic and international permit markets commonly leads to Pareto efficiency. According to Caplan et al. (2003), an international policy scheme with permit trading and redistributive transfers yields an efficient allocation for a global economy. Gersbach and Winkler (2011) propose that a fraction of emission permits is freely allocated, but the remainder is auctioned with revenues being reimbursed to member countries in fixed proportions. They show that if the share of freely allocated permits is sufficiently small, this leads to socially optimal emission reductions. In contrast to all of these articles, I assume that the emission cap for a country is not given but endogenously determined by bargaining between the local governments and the self-interested regulator.

MacGinty (2006) examines the stability of an international environmental agreement between asymmetric countries, showing that with international transfer payments the countries can establish stable coalitions with the ability of reducing emission. Holtsmark and Sommervoll (2012) consider emission trading when the governments set their national emission targets individually and grant emission permits for the domestic firms. They show that the introduction of emission permit trading increase emissions and decrease efficiency. Godal and Holtsmark (2011) and MacKenzie (2011) obtain similar results. Using a calibrated general equilibrium model, Carbone et al. (2009) show that emission trade agreements can be effective. In contrast to all of these articles, I assume that an international regulator issues emission permits.

Because a common agency game has no solution outside the steady state, this article focuses on steady state analysis and ignores intertemporal trading (cf. Liski and Montero 2005). Smith and Yates (2003) show that a fixed cap for global pollution is inefficient, because the regulator, having imperfect information about the benefits and damages of pollution, is unable to select the efficient permit endowment. Malueg and Yates (2006) consider the case where two interest groups – firms that generate pollution and households that are harmed by the pollution – lobby the regulator that issues emission permits. They show whether and on what conditions the households' trade in emission permits change the outcome. In this article, I examine the effect of emission permit trading in the case where countries are the interest groups that influence the self-interested international regulator.

Montgomery (1972), Shiell (2003) and MacKenzie et al. (2008) consider the redistributive effects of the initial allocation of emission permits. To focus entirely on bargaining over emission permits, I use the representative household framework to ignore all such redistributive effects. While cf. Hintermann (2011) and Meunier (2011) consider the effects of market power or asymmetric information efficiency, I assume a competitive emission permit market where all agents share the same information.

Palokangas (2009) examines the case where a self-interested regulator manages of emissions for a large number of identical countries with R&D-based growth, showing that emission trading speeds up growth relative to laissez-faire, but may slow down growth relative to centrally-determined emission quotas. Palokangas (2014) considers the possibility of one-parameter emission policy for countries with R&D-based growth, showing that if emission caps are allocated in fixed proportion to past emissions (i.e. grandfathering practise), the Pareto optimum can be attained. In contrast to Palokangas (2009, 2014), I ignore the dynamics with R&D as an additional complication in the model and examine a number of heterogeneous countries for which the self-interested regulator runs emissions policy in this article.

This article is organized as follows. Section 2 presents the structure of the economy. Section 3 constructs Pareto optimum by assuming a benevolent regulator, as a point of reference. Section 4 models the behavior of a self-interested regulator, by which section 5 examines the use of country-specific emission quotas and section 6 that of traded emission permits. Section 7 considers the effects of emission trading. Finally, section 8 generalizes the results for the case where pollution is a stock, not a flow of emissions.

2 The economy

There is a large number ("continuum") of countries $j \in [0, 1]$ that produce the same good from a single source of emissions (called hereafter energy, for convenience) and fixed local resources (e.g. land and labor). The extraction costs of energy are ignored, for simplicity. There is an international self-interested regulator that grants emission permits. I assume for a while that pollution is proportional to the flow of emissions, for tractability. In section 8, the results are generalized for the case where pollution is a stock.

In the model, the use of energy cause both global (called global warming) and localized externality (called smog).[1] I assume that global externality can be represented by a single index M called *green house gases (GHGs)*. Defining the energy inputs m_j for countries $j \in [0, 1]$ in terms of GHGs yields

$$M \doteq \int_0^1 m_j dj. \tag{1}$$

Because smog n_j is caused by the use of energy m_j in the same country, the latter can be used as a proxy of the former in the model. Then, without

[1]Smog plays two roles in the model. First, there is a laissez-faire equilibrium without emission policy. If output were a function of energy input m_j only, then country j would use an infinite amount of energy in the laissez-faire case. With smog, there is a finite upper limit m_j^L for the demand for energy in that case [cf. equation (5)]. Second, with smog, emission permit trading distorts the allocation of resources [cf. section 6].

losing any generality, one can assume

$$n_j = m_j. \tag{2}$$

Country j produces the quantity f_j of the final good from energy m_j and fixed factors. At the same time, smog n_j causes welfare losses g_j in terms of the final good according to an increasing and convex function g^j. Thus, the net output of country j, y_j, is determined by

$$y_j = f_j(m_j) - g_j(n_j),\ \ f_j' > 0,\ \ f_j'' < 0,\ \ g_j' > 0,\ \ g_j'' > 0,\ \ f_j(0) = g_j(0) = 0. \tag{3}$$

Total consumption c is equal to the sum of the outputs y_j of all countries:

$$c \doteq \int_0^1 y_j dj = \int_0^1 [f_j(m_j) - g_j(n_j)]dj. \tag{4}$$

Because isolation from international cooperation involves direct and indirect costs, I assume that country $j \in [0, 1]$ faces fixed cost ξ_j, if it exceeds its emission permits.[2] With that cost, (2) and (3), the revenue of region j for not participating in international emission policy is a constant

$$\overline{y}_j \doteq \max_{m_j}[f_j(m_j) - g_j(m_j)] - \xi_j = f_j(m_j^L) - g_j(m_j^L) - \xi_j. \tag{5}$$

where $m_j^L \doteq \arg\max_{m_j}[f_j(m_j) - g_j(m_j)] \geq 0$ is the laissez-faire energy input.

To avoid distributional considerations, I consider the representative household of the whole economy. This derives utility u from consumption c and GHGs M according to the function

$$u(c, M),\ \ u_c > 0,\ \ u_M < 0,\ \ u_{cc} < 0,\ \ u_{MM} < 0,\ \ u_{cM} \equiv 0, \tag{6}$$

where the subscripts c and M denote the partial derivative of the function u with respect to c and M, correspondingly.

[2]To obtain an equilibrium with lobbying, there must be some penalty for refusing to participate in the lobbying game. Because this cost is an outside option which is never paid in equilibrium, it is all the same whether ξ_j is a real loss of resources in the economy or a payment to the other countries $k \neq j$.

3 Pareto optimum

As a point of reference, I consider a benevolent regulator that maximizes the welfare of the representative household, (6), by the emissions m_j of all countries $j \in [0,1]$, subject to global emissions (1), smog (2) and total consumption (4). This maximization leads to the first-order conditions:

$$0 = u_c \frac{\partial c}{\partial m_j} + u_m \frac{\partial M}{\partial m_j} = u_c(c,M)[f_j'(m_j) - g_j'(m_j)] + u_m(c,M) \;\; j \in [0,1]. \tag{7}$$

for $j \in [0,1]$. The equations (2), (4) and (7) define the Pareto optimum – M^p, c^p and m_j^p for $j \in [0,1]$ – as follows:

$$M^p = \int_0^1 m_j^p dj, \quad c^p = \int_0^1 [f_j(m_j^p) - g_j(m_j^p)]dj,$$
$$f_j'(m_j^p) - g_j'(m_j^p) = -\frac{u_c(c^p, M^p)}{u_m(c^p, M^p)} \text{ for } j \in [0,1]. \tag{8}$$

4 The self-interested regulator

With a self-interested regulator, the revenue of country j is equal to its income y_j minus its political contributions R_j to the regulator [cf. (3)]:

$$\pi_j \doteq y_j - R_j = f_j(m_j) - g_j(n_j) - R_j. \tag{9}$$

Consumption c is then equal to the revenues π_k from countries $k \in [0,1]$ plus the regulator's total revenue $\int_0^1 R_k dk$:

$$c = \int_0^1 \pi_k dk + \int_0^1 R_k dk. \tag{10}$$

To avoid distributional considerations that result from the payment of contributions R_j, $j \in [0,1]$, I assume that all countries $j \in [0,1]$ and the regulator belong to the representative household. This means that the regulator maximizes the utility of the representative household.[3]

[3]The assumption of the common representative household implies that the marginal utility of income is the same for the regulator and the countries. The alternative is the model of Dixit et al. (1997), in which the regulator's utility $W(u,R)$ is an increasing function of both the household's utility u and total political contributions R. With that extension, distributional considerations would complicate the analysis, without any qualitative impact on the results that concern the subsidies and regulatory stardards.

The political economy of the management of emissions can be expressed as an extensive form game with the following stages: (I) The countries influence the regulator by their prospective political contributions that depend on the latter's decisions. (II) The regulator decides its policy and collects political contributions. (III) If emission permits are traded, then the international market for them clears. (IV) The local firms produce from energy and fixed local resources. Next, I present two versions of this game: one with nontraded (section 5), and the other with traded emission permits (section 6).

5 Emission quotas

Assume that the regulator determines nontraded emission permits (i.e. quotas) m_j for countries $j \in [0,1]$, but that countries themselves allocate their quotas to the firms in efficient manner. The order of the game is then the following. First, each country $j \in [0,1]$ sets its political contributions R_j conditional on the regulator's prospective policy m_j. Second, the regulator sets its policy $\{m_j\} \doteq \{m_j | \, j \in [0,1]\}$, and collects the contributions $R \doteq \int_0^1 R_j dj$. This extensive form game is solved in reverse order.

Country j observes smog (2). Because it influences the regulator by its contributions R_j, its contribution schedule depends on the regulator's prospective policy m_j. Given this and (2), its revenue (9) becomes

$$\pi_j = f_j(m_j) - g_j(m_j) - R_j(m_j). \tag{11}$$

Given this and the contribution functions $R_j(m_j)$, consumption (10) becomes

$$c = \int_0^1 \pi_k dk + \int_0^1 R_k(m_k) dk. \tag{12}$$

The regulator maximizes its utility (6) subject to total emissions (1) and consumption (12), while each country j maximizes its revenue (11). According to Dixit at al. (1997), a subgame perfect Nash equilibrium for this game is a set of contribution schedules $R_j(m_j)$ and a policy m_j for all countries $j \in [0,1]$ such that the following conditions $(i)-(iv)$ hold true:

(i) Contributions R_j are non-negative but no more than the contributor's income.

(ii) The policy $\{m_j\} \doteq \{m_j | \, j \in [0,1]\}$ maximizes the regulator's welfare,

$$\{m_j\} = \arg \max_{\{m_j\} \text{ s.t. (1) and (12)}} u(c, M). \tag{13}$$

(iii) Region j cannot have a feasible strategy $R_j(m_j)$ that yields it higher revenue (11) than in equilibrium, given the regulator's anticipated decision rule,

$$m_j = \arg\max_{m_j} \pi_j = \arg\max_{m_j} [f_j(m_j) - g_j(m_j) - R_j(m_j)]. \tag{14}$$

(iv) Region j provides the regulator at least with the level of utility than in the case it offers nothing ($R_j = 0$), and the regulator responds optimally given the other countries contribution functions,

$$u(c, M) \geq \max_{\{m_j\} \text{ s.t. (1) and (12)}} u(c, M)\big|_{R_j=0}.$$

The conditions (14) for all j are equivalent to the first-order conditions

$$\frac{\partial \pi_j}{\partial m_j} = f_j'(m_j) - g_j'(m_j) - R_j'(m_j) = 0 \text{ for } j \in [0,1]. \tag{15}$$

Thus, in equilibrium, the change in the contributions of country j, R_j, due to a change in the instrument m_j equals the effect of that instrument on the net output of that country, $f_j(m_j) - g_j(m_j)$. These contribution schedules are locally truthful. This concept can be extended to a globally truthful contribution schedule that represents the preferences of country j at all policy points (cf. Dixit et al. 1997) as follows:

$$R_j = \max[f_j(m_j) - g_j(m_j) - \overline{y}_j, 0], \tag{16}$$

where the integration constant $\overline{y}_j$ is the output of country j in the case it does not pay contributions, $R_j = 0$, and exceeds its emission quota [cf. (5)], but the regulator chooses its best response, given the contribution schedules of the other countries $k \neq j$.

From (12), (14) and (15) it follows that

$$c = \int \arg\max_{m_k} \pi_k(m_k) dk + \int_0^1 R_k(m_k) dk, \;\; \frac{\partial c}{\partial m_j} = R_j' = f_j'(m_j) - g_j'(m_j).$$

Given this and (1), the conditions (13) are equivalent to

$$0 = \frac{1}{u_c(c,M)}\frac{du(c,M)}{dm_j} = \frac{1}{u_c(c,M)}\left[u_c(c,M)\frac{\partial c}{\partial m_j} + u_m(c,M)\frac{\partial M}{\partial m_j}\right]$$
$$= f_j'(m_j) - g_j'(m_j) + \frac{u_m(c,M)}{u_c(c,M)} \text{ for } j \in [0,1]. \tag{17}$$

Given this, (1) and (16), the *equilibrium with emission quotas* – $\{m_j^q\}$, M^q and c^q – is given by

$$f_j'(m_j^q) - g_j'(m_j^q) + \frac{u_m(c^q,M^q)}{u_c(c^q,M^q)} = 0, \quad R_j^q = \max[f_j(m_j^q) - g_j(m_j^q) - \overline{y}_j, 0] \text{ and}$$
$$m_j^q \doteq \arg\max_{m_j}[f_j(m_j^q) - g_j(m_j^q) - R_j(m_j^q)]dj \text{ for } j \in [0,1],$$
$$c^q = \int_0^1 \max_{m_j}[f_j(m_j^q) - g_j(m_j^q) - R_j(m_j^q)]dj, \quad M^q \doteq \int_0^1 m_j^q dj. \tag{18}$$

This leads to the following result:

Proposition 1 *The use of emission quotas leads to the Pareto optimum,* $\{m_j^q\} = \{m_j^p\}$*,* $M^q = M^p$ *and* $c^q = c^p$*.*

6 Traded emission permits

In this section, the regulator determines traded emission permits M_j for countries $j \in [0,1]$. Total GHGs (1) are then equal to total emission permits:

$$\int_0^1 m_k dk = M = \int_0^1 M_j dj. \tag{19}$$

The common agency game is then the following. First, the countries $j \in [0,1]$ set their contributions R_j conditional on the regulator's prospective policy M_j. Second, the regulator sets its policy $\{M_j\} \doteq \{M_j | \, j \in [0,1]\}$ and collects the contributions R_j, $k \in [0,1]$. Third, the price for emission permits, p, adjust to clear the market (19) for emission permits. Fourth, the representative firm in each country $j \in [0,1]$ chooses its energy input m_j. This game is solved in reverse order.

The profit of the representative firm in country j is [cf. (3)]

$$\Pi_j \doteq y_j + (M_j - m_j)p = f_j(m_j) - g_j(n_j) + (M_j - m_j)p, \tag{20}$$

where y_j is income from production, $M_j - m_j$ the net supply of emission permits and $(M_j - m_j)p$ net revenue from emission permits. The firm maximizes its profit (20) by energy input m_j, given smog n_j, the emission permits M_j and the price p for emissions. This yields the first-order condition

$$p = f_j'(m_j) \quad \text{with} \quad \frac{dp}{dm_j} \doteq f_j'' < 0. \tag{21}$$

Country j observes smog (2). From (2) and (21) it follows that pollution n_j and energy input m_j depend on the price for emission permits:

$$n_j = m_j = N_j(p) \quad \text{with} \quad N_j' \doteq 1/f_j'' < 0. \tag{22}$$

The equilibrium condition for the emission permit market, (19), then becomes $M = \int_0^1 N_k(p)dk$. Differentiating this equation totally yields the price as a function of total pollution:

$$p(M), \quad p' = \left(\int_0^1 N_k' dk\right)^{-1} < 0. \tag{23}$$

Finally, plugging (23) into (22), yields smog n_j as a function of GHGs M:

$$n_j(M) \doteq N_j(p(M)) \quad \text{with} \quad n_j' \doteq N_j' p' = \left(\int_0^1 N_k' dk\right)^{-1} N_j' \in [0,1]. \tag{24}$$

Because country j influences the regulator by its contributions R_j, its contribution schedule depends on the regulator's prospective policy M_j. The revenue of country j is equal to the profit (20) minus contributions $R_j(M_j)$, and it is a function of the emission permits M_j of that country and GHGs M [cf. (3) and (24)] as follows:

$$\begin{aligned} \pi_j(M_j, M) &\doteq \Pi_j - R_j = y_j + (M_j - m_j)p - R_j(M_j) \\ &= \max_{m_j}\big[f_j(m_j) - g_j\big(n_j(M)\big) + (M_j - m_j)p(M)\big] - R_j(M_j), \end{aligned}$$

$$\frac{\partial \pi_j}{\partial M_j} = p - R_j', \quad \frac{\partial \pi_j}{\partial M} = -g_j' n_j' + (M_j - m_j)p'. \tag{25}$$

Given this and the contribution functions $R_j(M_j)$, consumption (10) becomes

$$c = \int_0^1 \pi_k(M_k, M)dk + \int_0^1 R_k(M_k)dk. \tag{26}$$

The regulator maximizes utility $u(c, M)$ subject to emissions (19) and consumption (26), while each country j maximizes its revenue (25). A subgame perfect Nash equilibrium for this game is a set of contribution schedules $R_j(M_j)$ and a policy M_j for all countries $j \in [0, 1]$ such that

$$\{M_j\} = \arg \max_{\{M_j\} \text{ s.t. (19) and (26)}} u(c, M), \tag{27}$$

$$M_j = \arg \max_{M_j \text{ s.t. (19)}} \pi_j(M_j, M), \tag{28}$$

$$u(c, M) \geq \max_{\{M_j\} \text{ s.t. (19) and (26)}} u(c, M)\big|_{R_j=0}.$$

The conditions (28) are equivalent to

$$0 = \frac{\partial \pi_j}{\partial M_j} + \frac{\partial \pi_j}{\partial M} \underbrace{\frac{\partial M}{\partial M_j}}_{=1} = p - R'_j(M_j) - g'_j n'_j + (M_j - m_j)p'$$

and

$$R'_j(M_j) = p - g'_j n'_j + (M_j - m_j)p' \text{ for } j \in [0, 1]. \tag{29}$$

Conditions (29) say that in equilibrium the change in the contributions of country j, R_j, due to a change in the instrument M_j equals the effect of that instrument on the revenue of that country, π_j. These contribution schedules are locally truthful. This concept can be extended to a globally truthful contribution schedule that represents the preferences of country j at all policy points (cf. Dixit et al. 1997) as follows:

$$R_j = \max[\pi_j - \overline{y}_j, 0], \tag{30}$$

where the integration constant $\overline{y}_j$ is the revenue of country j in case it does not pay contributions, $R_j = 0$, but the regulator chooses its best response, given the contribution schedules of the other countries $k \neq j$. If country j refuses to pay contributions, $R_j = 0$, then it must content itself with its opportunity revenue $\overline{y}_j$ [cf. (5)].

From (26) and (28) it follows that

$$c = \int \arg \max_{M_k} \pi_k(M_k, M) dk + \int_0^1 R_k(M_k) dk.$$

Noting this, (19), (21), (25) and (29), one obtains the partial derivatives

$$\begin{aligned}\frac{\partial c}{\partial M_j} &= \int_{k\neq j} \frac{\partial \pi_k}{\partial M} \underbrace{\frac{\partial M}{\partial M_k}}_{=1} dk + R_j' = \int_{k\neq j} [-g_k' n_k' + (M_k - m_k)p']dk + R_j' \\ &= -\int_{k\neq j} g_k' n_k' dk + p' \underbrace{\int_{k\neq j} (M_k - m_k)dk}_{=m_j - M_j} + R_j' \\ &= -\int_{k\neq j} g_k' n_k' dk + \underbrace{(m_j - M_j)p' + R_j'}_{=p - g_j' n_j'} = -\int_0^1 g_k' n_k' dk + p \\ &= -\int_0^1 g_k' n_k' dk + f_j' \text{ for } j \in [0,1].\end{aligned}$$

Given this, the conditions (27) are equivalent to

$$0 = \frac{1}{u_c(c,M)} \frac{du(c,M)}{dM_j} = \frac{\partial c}{\partial M_j} + \frac{u_m}{u_c} \underbrace{\frac{\partial M}{\partial M_j}}_{=1} = -\int_0^1 g_k' n_k' dk + f_j' + \frac{u_m}{u_c} \text{ for } j \in [0,1]. \tag{31}$$

Because terms $\int_0^1 g_k' n_k' dk$ and u_m/u_c are equal for all $j \in [0,1]$, from (31) it follows that f_m^j are equal for all $j \in [0,1]$ as well. The equations (31) violate the first of the Pareto optimality conditions (18). Comparing this with proposition 1, the following result is obtained:

Proposition 2 *Emission trading decreases welfare by equalizing the marginal product of energy, f_m^j, throughout all countries $j \in [0,1]$.*

7 Effects of emission trading

As a point of reference, I consider first the case where technology and resources are identical in all countries,

$$m_j = n_j = m,\ f_j(m) = f(m) \text{ and } g_j(n) = g(n) \text{ for } j \in [0,1]. \tag{32}$$

From (22) and (24), it then follows that $N_j(p) = N(p)$ and $n_j' = 1$ for $j \in [0,1]$. Noting this and (32), the equilibrium condition (31) becomes the first of the Pareto optimality conditions (18):

$$0 = -\int_0^1 g'(m) n_k' dk + f_m + \frac{u_m}{u_c} = -g'(m) + f'(m) + \frac{u_m}{u_c}.$$

Thus, the inefficiency of emission permit trading is due to the heterogeneity of the countries.

Finally, I examine the effect of emission trading on GHGs. For this purpose, I introduce a parameter β so that there is no emission trading $m_j = M_j$ for $\beta = 0$ and emission trading $m_j \neq M_j$ for $\beta = 1$, and combine the equilibrium conditions without and with trading, (17) and (31), as follows:

$$0 = \frac{1}{u_c(c, M)} \frac{du(c, M)}{dM_j} = -\beta \int_0^1 g'_k n'_k dk + f'_j - (1-\beta) g'_j + \frac{u_m}{u_c} \text{ for } j \in [0, 1]. \tag{33}$$

The effect of β on emission permits M_j is first derived on the assumption that β is continuous in the limit $[0, 1]$. Then, by the mean value theorem, the result can be extended for the discrete choice $\beta \in \{0, 1\}$.

From (24) it follows that $n'_j > 0$ and $\int_0^1 n'_j dj = 1$. The *damage of smog* in country j – i.e. the decrease of income in that country due to smog n_j – is given by g'_j [cf. (3)]. If that damage is smaller in country j than the n'_j-weighed average of the damages of all countries,

$$g'_j < \int_0^1 g'_k n'_k dk, \tag{34}$$

then one can call the localized technology in country j is *relatively clean*. If

$$g'_j > \int_0^1 g'_k n'_k dk, \tag{35}$$

then the localized technology in country j is called *relatively dirty*.

If the equilibrium defined by the first-order condition (33) is unique, then the second-order condition $(1/u_c) \frac{d^2 u}{dM_j^2} < 0$ must hold true. Given this, differentiating (33) totally yields

$$\frac{dM_j}{d\beta} = -\frac{1}{u_c} \frac{du^2}{dM_j d\beta} \left[\frac{1}{u_c} \frac{d^2 u}{d^2 M_j} \right]^{-1} = \left[\int_0^1 g'_k n'_k dk - g'_j \right] \underbrace{\frac{1}{u_c}}_{+} \underbrace{\left[\frac{1}{u_c} \frac{du^2}{d^2 M_j} \right]^{-1}}_{-} < 0$$

$$\Leftrightarrow \quad g'_j < \int_0^1 g'_k n'_k dk.$$

This result shows that the source of welfare loss for emission trading (cf. proposition 2) is the following:

Proposition 3 *With the introduction of emission trading, the self-interested regulator provides less permits to countries with relatively clean localized technology [for which* (34) *holds], and more permits to countries with relatively dirty localized technology [for which* (35) *holds].*

8 Pollution as a stock

In global warming problems, it is the stock of GHGs that causes damages and not the flow. For this reason, I assume now that aggregate pollution M and smog n_j are stocks that are accumulated by emissions. The equations (1) and (2) must then be replaced by the differential equations

$$\frac{dM}{dt} = \int_0^1 m_j dj - \delta M, \quad \frac{dn_j}{dt} = m_j - \delta_j n_j \text{ for } j \in [0,1], \tag{36}$$

where t is time and the constants $\delta > 0$ and $\delta_j > 0$ characterize the absorbtion of GHGs and the absorbtion of smog in country j, correspondingly.

If the system (36) is stable, it converges to the equilibrium

$$M = \frac{1}{\delta}\int_0^1 m_j dj, \quad n_j = \frac{m_j}{\delta_j} \text{ for } j \in [0,1]. \tag{37}$$

Because the common agency game between the regulator and the countries $j \in [0,1]$ can be solved only in the stationary state (37), where GHGs M are in fixed proportion $1/\delta$ to global energy input $\int_0^1 m_j dj$ and smog n_j in fixed proportion $1/\delta_j$ to local energy input m_j, $j \in [0,1]$, then its solution leads to the same results as in static case with the equations (1) and (2). This means that proportions 1, 2 and 3 hold as they stand also when pollution is a stock.

9 Conclusions

This article examines the design of international emission policy when the use of an emitting input (called energy) cause both global and localized externality problems. The countries can authorize a self-interested regulator to allocate emission permits and decide whether these permits can be traded. Countries lobby the regulator, and they can exceed their permits only with a penalty. The results are the following.

With non-traded emission permits, the outcome is Pareto optimal: because the countries bargain over their quotas with the regulator, the marginal product of energy in production is equal to the disutility of energy through both global warming and smog. In the presence of emission trading, the countries bargain over emission permits, but the trading of the firms sets the marginal product of energy in production equal to the disutility of energy through global warming only. Welfare then decreases, because the regulator provides less permits to countries with relatively clean localized technology, and more permits to countries with relatively dirty localized technology.

The analysis in this document is however based on the assumption that the regulator belongs to the representative household. This clarifies the results, for changes of income distribution due to political contributions do not affect efficiency in the model. Alternatively, one could use the model of Dixit et al. (2007), in which the regulator's utility is an increasing function of both the household's utility and the political contributions. This extension would complicate the analysis, without nullifying the results concerning the policies with emission quotas and the emission cap.

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