Emission Permit Management with Simultaneous Localized and Global Externality Problems

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Contents

Motivation

- ***The research question***:

  Does emission permit trading cause inefficiency, when production causes simultaneous localized and global externality problems (e.g. smog and global warming)?

- I examine this question in a simple framework where a benevolent international common agency determines emission permits.
- In Palokangas (2015), I derive the same results in an extended case where the common agency is self-interested, elected by the countries, and subject to lobbying by the countries (cf. Dixit et al. 1997).

Literature 1

- Caplan and Silva (2005) examine joint tradable permits when pollutants cause regional and global externalities. They find that joint domestic and commonly international permit markets are Pareto efficient.
- 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 find that emission permit trading increases emissions and decreases efficiency.
- In contrast to these articles, however, I assume that there is a benevolent international common agency that issues emission permits.

Literature 2

- Montgomery (1972), Shiell (2003) and MacKenzie et al. (2008) consider the redistributive effects of the initial allocation of emission permits. I use the representative household framework to ignore all such redistributive effects.
- I ignore the effects of market imperfections (cf. Hintermann 2011 and Meunier 2011), and assume that there is a competitive market for emission permits.

The economy

- The economy consists of 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.
- The international common agency grants emission permits.

Energy and pollution

- The use of energy causes both global (called ***global warming***) and localized externality (called ***smog***).
- Global externality is represented by a single index M, which is called ***global pollution***, for convenience.
- I define the energy inputs m_j and emission permits M_j for countries $j \in [0,1]$ in terms of global pollution. Then, total emissions $\int_0^1 m_k dk$ are equal total emission permits:

$$\int_0^1 m_k dk = M = \int_0^1 M_j dj.$$

- Because the use of energy m_j causes locally smog n_j, the former can be used as a proxy of the latter as follows:

$$n_j = m_j.$$

Production

- The representative firm in country j produces the quantity f_j of the final good from energy m_j and fixed factors:

$$f_j(m_j), \quad f_j' > 0, \quad f_j'' < 0, \quad f_j(0) = 0.$$

- At the same time, in country j, smog n_j causes abatement costs g_j according to an increasing and convex function

$$g_j(n_j), \quad g_j' > 0, \quad g_j'' > 0, \quad g_j(0) = 0.$$

- Total consumption c is equal to aggregate output $\sum_j f_j$ minus abatement costs $\sum_j g_j$ throughout all countries:

$$c \doteq \int_0^1 f_j(m_j)dj - \int_0^1 g_j(n_j)dj = \int_0^1 [f_j(m_j) - g_j(n_j)]dj.$$

Households

- To avoid distributional considerations, I consider the representative household of the whole economy.
- Consumption c increases and global pollution M decreases household utility u according to the function

$$u(c, M), \quad u_c \doteq \frac{\partial u}{\partial c} > 0, \quad u_M \doteq \frac{\partial u}{\partial M} < 0, \quad u \text{ strictly concave.}$$

Welfare maximization

- Nontraded emission permits determine energy inputs $m_j = M_j$.
- The international common agency maximizes household welfare $u(c, M)$ by emission permits $m_j = M_j$ subject to
  - global emissions $M = \int_0^1 M_j dj$
  - smog $n_j = m_j$ for $j \in [0, 1]$
  - total consumption $c = \int_0^1 [f_j(m_j) - g_j(n_j)] dj$.

Pareto optimum

- The welfare maximization leads to the the Pareto optimum M^p, c^p and m_j^p for $j \in [0,1]$:

$$M^p = \int_0^1 m_j^p dj, \quad c^p = \int_0^1 [f_j(m_j^p) - g_j(m_j^p)] dj,$$

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

where

f_j'	the marginal product of energy
g'	the marginal costs of smog
$-u_m/u_c$	the marginal disutility of global warming, in terms of consumption.

Emission permit trading

- With emission permit trading, the representative firm in country $j \in [0, 1]$ can sell its excess supply of permits, $M_j - m_j$, or buy its excess demand for permits, $m_j - M_j$, in the competitive market at the price p.
- The profit of that firm is

$$\Pi_j \doteq f_j(m_j) + (M_j - m_j)p,$$

where

$f_j(m_j)$	income from production
$M_j - m_j$	the net supply of emission permits
p	the international price for emission permits
$(M_j - m_j)p$	net revenue from emission permits.

Total consumption

- Noting abatement costs $g(n_j)$, the revenue of country j is

$$\pi_j = \Pi_j - g(n_j) = f_j(m_j) - g(n_j) + (M_j - m_j)p.$$

- Given this, total consumption is equal to total revenue:

$$c = \int_0^1 [f_k(m_k) - g_k(n_k)]dk = \int_0^1 \pi_k dk.$$

The extensive form game

- There is an extensive form game with the following stages:

  (i) The common agency sets emission permits M_j for countries $j \in [0, 1]$ to maximize the household welfare $u(c, M)$ by emission permits $m_j = M_j$ subject to
    - global emissions $M = \int_0^1 M_j dj$
    - smog $n_j = m_j$ for $j \in [0, 1]$
    - total consumption $c = \int_0^1 \pi_k(M_k, M)dk$.

  (ii) The international price p for emission permits adjusts to clear the market for these.

  (iii) Firm j uses energy m_j to maximize its profit $\Pi_j \doteq f_j(m_j) + (M_j - m_j)p$.

- This game is solved in reverse order.

Stage (iii): the behavior of firms

- The firm in country j maximizes its profit

$$\Pi_j \doteq f_j(m_j) + (M_j - m_j)p$$

by energy input m_j, given the emission permits M_j and the price p for those.

- This yields the equilibrium profit and the inverse demand function for energy as follows:

$$\Pi_j = \max_{m_j}[f_j(m_j) + (M_j - m_j)p],$$

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

Stage (ii): the market for emission permits

- Differentiating the inverse demand function, and noting the smog $n_j = m_j$, one obtains pollution n_j and energy input m_j as a function of the price:

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

- Total emissions then become

$$M = \int_0^1 n_k dk = \int_0^1 N_k(p) dk.$$

- Differentiating this equation totally yields the price as a function of total emissions:

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

Stage (ii): the market for emission permits; 1

- Plugging this price function into the demands for energy $n_j = m_j = N_j(p)$ yields smog n_j as a function of total emissions M in all countries $j \in [0, 1]$:

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

Stage (ii): the market for emission permits; 2

- Given the price and energy-demand functions, the revenue of country j is a function of total emissions M and the emission permits for that country, M_j:

$$\pi_j(M_j, M) \doteq \max_{m_j}\left[f_j(m_j) - g_j\big(n_j(M)\big) + (M_j - m_j)p(M)\right]$$

$$\text{with } \frac{\partial \pi_j}{\partial M_j} = p \text{ and } \frac{\partial \pi_j}{\partial M} = -g_j' n_j' + (M_j - m_j)p'.$$

Stage (i): the behavior of the common agency

- The common agency maximizes household utility $u(c, M)$ subject to
  - global emissions $M = \int_0^1 M_j dj$
  - smog $n_j(M)$ for $j \in [0, 1]$
  - total consumption $c = \int_0^1 \pi_k(M_k, M) dk$.
- This leads to the first-order conditions:

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

- This implies that terms $f_j'(m_j)$ are equal for all $j \in [0, 1]$, which violates the first of the Pareto optimality conditions.

The first result

Proposition

Emission permit trading decreases welfare by equalizing the marginal product of energy, $f_j'(m_j)$, throughout all countries $j \in [0, 1]$.

The case of identical countries

- If the countries are fully identical,

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

then it follows that $N_j(p) = N(p)$ and $n_j' = 1$ for $j \in [0,1]$.

- This leads to the Pareto optimum:

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

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

The effect of emission permit trading

- Next, to consider the effect of emission permit trading on total emissions, I introduce a parameter β so that $\beta = 0$ holds true without $m_j = M_j$ and $\beta = 1$ with emission permit trading $m_j \neq M_j$.
- By this variable, I can combine the equilibrium conditions without and with trading as follows:

$$0 = -\beta \int_0^1 g_k' n_k' dk + f_j' - (1 - \beta) g_j' + \frac{u_m}{u_c} \text{ for } j \in [0, 1].$$

- 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 is extended for the discrete choice $\beta \in \{0, 1\}$.

Some definitions

- The ***damage of smog*** in country j – i.e. the decrease of income in that country due to smog n_j – is g_j'.
- The localized technology in country j is called ***relatively clean***, if the damage in country j, g_j', is smaller than the the weighed average of the damages of all countries,

$$g_j' < \int_0^1 g_k' n_k' dk,$$

and ***relatively dirty***, if the damage g_j' is greater than that average,

$$g_j' > \int_0^1 g_k' n_k' dk.$$

The second result

- Assuming the equilibrium unique and differentiating the combined equilibrium condition totally yields the result

$$\frac{dM_j}{d\beta} < 0 \;\Leftrightarrow\; g_j' < \int_0^1 g_k' n_k' dk.$$

This can be rephrased as follows:

Proposition

With the introduction of emission permit trading, the common agency provides less permits to countries with relatively clean localized technology (i.e. $g_j' < \int_0^1 g_k' n_k' dk$ holds), and more permits to countries with relatively dirty localized technology (i.e. $g_j' > \int_0^1 g_k' n_k' dk$ holds).

Interpretation

- The use of non-traded emission permits lead to Pareto optimum: the marginal product of energy is equal to the marginal cost of smog plus the disutility of global warming in terms of consumption.
- Emission permit trading restricts the common agency's policy set by equalizing the marginal product of energy for all countries.
- Welfare decreases in that case, because the common agency provides less permits to countries with relatively clean and more permits to those with relatively dirty localized technology.