International Emission Policy with Lobbying and Technological Change

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Abstract

I examine the implementation of emission policy in a union of countries. Production in any country incurs emissions that pollute all over the union, but efficiency in production can be improved by research and development (R&D). I compare four cases: laissez-faire, Pareto optimal policy, lobbying with centrally-determined emission quotas and lobbying with emission trade. The main findings are as follows. With emission quotas, the growth rate is socially optimal, but welfare sub-optimal. Emission trade speeds up growth from the initial position of laissez-faire, but slows down from the initial position of centrally-determined emission quotas.

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1 Introduction

In this study, I examine the implementation of emission policy in a union of countries. The production of goods in any country incurs emissions that pollute all over the union, but efficiency in production in each country can be improved by research and development which has a random outcome. In every country, there is a local planner that maximizes welfare and has enough instrument to control the allocation of resources in the country. In the union, there are common environmental regulations that compel local planners to spend some of their resources to pollution abatement.

In particular, I examine the following cases of exercising emission policy:

(i) *Laissez-faire.* All countries choose their optimal emissions ignoring the externality through pollution.

(ii) *Pareto optimum.* In the union, there is a benevolent central planner that sets emission quotas for all member and is able to transfer resources between countries.

(iii) *Lobbying without emission trade.* In the union, there is a self-interested central planner that sets emission quotas for all countries. That planner is subject to lobbying and has no financial resources of its own.

(iv) *Lobbying with emission trade.* In the union, there is a self-interested central planner that sets emission quotas for all countries, and a market through which the countries can sell their quotas to each others. The central planner is subject to lobbying and has no financial resources.

In this model, there are two sources of inefficiency. One is negative externality through pollution, for which a single country has too much production with emissions and too little investment in R&D. The second externality is waste due to lobbying. Given that the central planner consists at least partly of different households than the rest of the population, political contributions are waste from the viewpoint of the latter. The relative weight of these sources determine the outcome of the comparison between cases (i)-(iv).

The impact of any environmental policy depends crucially on the existence of uncertainty. The papers Corsetti (1997), Smith (1996), Turnovsky

(1995,1999) consider public policy by a growth model where productivity shocks follows a Wiener process. Soretz (2003) applies that approach to environmental policy. In one of my earlier publications (Palokangas 2008), I examine an economic union where member countries produce emissions in fixed proportion to labor in production and where uncertainty is embodied in technological change in the form of Poisson processes. As a result of this, I obtain Pareto-optimal emission taxes for the member countries. In this paper, I modify Palokangas' (2008) model so that (*i*) the central planner is self-interested and (*ii*) labor and emissions are different inputs in production.

This paper is organized as follows. Sections 2 and 3 present the general structure of the union and a single country. Sections 4, 5, 6 and 7 examine the cases (i)-(iv) above, respectively.

2 The union

I consider a union of fixed number n of similar countries. Each country $j \in \{1, ..., n\}$ has a fixed labor supply L, of which the amount l_j is used in production and the rest

$$z_j = L - l_j \tag{1}$$

in R&D. I assume that all countries $j \in \{1, ..., n\}$ produce the same good, for simplicity.[1] The total supply of the consumption good in the union, y, is the sum of the outputs y_j of all the member countries:

$$y = \sum_{j=1}^{n} y_j. \tag{2}$$

Let m_j be emissions in country j and P be pollution in the union. I assume that pollution is determined by total emissions in the union, $\sum_{j=1}^{n} m_j$:

$$P = \sum_{j=1}^{n} m_j. \tag{3}$$

[1] With some complication, but with no significant effect on the results, it would be possible to assume as well that the final consumption good is composed of the outputs of all countries through CES technology.

The bigger the number of countries, n, the bigger the negative externality through pollution. Fos this reason, I say that the decision making in the union is the more *centralized* (*de-centralized*), the smaller (bigger) n.

All households in the union share the same preferences and take income, prices and the interest rate r as given. Thus, they all behave as if there were a single representative household for the whole union. The household chooses its flow of consumption C to maximize its utility starting at time T,

$$\int_T^\infty (\log C)e^{-\rho(\theta-T)}d\theta,$$

where θ is time and $\rho > 0$ the constant rate of time preference. This utility maximization leads to the Euler equation (cf. Grossman and Helpman 1994b)

$$\frac{\dot{\mathcal{E}}}{\mathcal{E}} = \frac{d\mathcal{E}}{dt}\frac{1}{\mathcal{E}} = r - \rho \quad \text{with} \quad \mathcal{E} \doteq pC, \tag{4}$$

where p the consumption price, $\mathcal{E}$ household spending and r the interest rate.

The goods market is in equilibrium, if the supply y equals the demand C. Because in the model there is no money that would pin down the nominal price level at any time, it is convenient to normalize the households' total consumption expenditure in the common market, $\mathcal{E}$, at unity. From $y = C$, $\mathcal{E} = 1$, (2) and (4) it then follows that the interest rate r is constant:

$$\mathcal{E} = 1, \quad p = \frac{1}{C} = \frac{1}{y} = 1\Big/\sum_{j=1}^{n} y_j, \quad r = \rho > 0. \tag{5}$$

3 The countries

Each country j consists of the *production sector*, which makes the consumption good, and the *abatement sector*, which uses resources to meet the environment regulations in the union. Because pollution P employs resources in the abatement sector, it decreases production y_j. I assume that the marginal rate of substitution between production and pollution is given by

$$\partial y_j/\partial P = -\delta y_j/P, \tag{6}$$

where $\delta > 0$ is a constant. The efficiency of production in country j is a^{γ_j}, where $a > 1$ is a constant and γ_j is the serial number of technology. In the advent of technological change in country j, this efficiency increases from a^{γ_j} to a^{γ_j+1}. Noting this and (6), total output in country j is a function of labor input l_j, emissions m_j and the level of productivity, a^{γ_j}, as follows:

$$\begin{aligned}
&y_j = a^{\gamma_j} f(l_j, m_j) P^{-\delta}, \quad f_l \doteq \partial f/\partial l_j > 0, \;\; f_m \doteq \partial f/\partial m_j > 0, \\
&f_{ll} \doteq \frac{\partial^2 f}{\partial l_j^2} < 0, \quad f_{lm} \doteq \frac{\partial^2 f}{\partial l_j \partial m_j} > 0, \;\; f_{mm} \doteq \frac{\partial^2 f}{\partial m_j^2} < 0, \\
&\frac{f_l f_m}{f_{lm} f} = \sigma \in (0,1) \cup (1,\infty), \quad \frac{m_j f_m(l_j, m_j)}{f(l_j, m_j)} = \frac{m_j}{l_j} \frac{f_m(l_j/m_j, 1)}{f(l_j/m_j, 1)} \doteq \xi\Big(\frac{m_j}{l_j}\Big), \\
&\frac{l_j f_l(l_j, m_j)}{f(l_j, m_j)} = 1 - \frac{m_j f_m(l_j, m_j)}{f(l_j, m_j)}, \quad \xi'\Big(\frac{m_j}{l_j}\Big) \begin{cases} > 0 & \text{for } \sigma > 1, \\ < 0 & \text{for } \sigma < 1, \end{cases}
\end{aligned} \tag{7}$$

where f is a CES production function, σ the constant elasticity of substitution between labor and emissions, δ the constant elasticity of output with respect to pollution and $P^{-\delta}$ the abatement factor.

The local planner in country j (hereafter local planner j) pays political contributions R_j to the central planner of the union. Real income in country j is therefore given by $y_j - R_j$, where y_j is output and R_j political contributions. Noting (7), I obtain local planner j's utility from an infinite stream of real income beginning at time T as follows:

$$E \int_T^\infty (y_j - R_j) e^{-r(t-T)} dt = E \int_T^\infty \big[a^{\gamma_j} f(l_j, m_j) P^{-\delta} - R_j\big] e^{-r(t-T)} dt, \tag{8}$$

where E is the expectation operator and $r > 0$ the interest rate [cf. (5)].

The improvement of technology in country j depends on labor devoted to R&D, z_j. In a small period of time dt, the probability that R&D leads to development of a new technology is given by $\lambda z_j dt$, while the probability that R&D remains without success is given by $1 - \lambda z_j dt$, where λ is productivity in R&D. Noting (1), this defines a Poisson process χ_j with

$$d\chi_j = \begin{cases} 1 & \text{with probability } \lambda z_j dt = \lambda(L - l_j) dt, \\ 0 & \text{with probability } 1 - \lambda z_j dt = 1 - \lambda(L - l_j) dt, \end{cases} \tag{9}$$

where $d\chi_j$ is the increment of the process χ_j. The expected growth rate of productivity a^{γ_j} in the production sector in the stationary state is given by

$$g_j \doteq E\big[\log a^{\gamma+1} - \log a^{\gamma}\big] = (\log a)\lambda z_j = (\log a)\lambda(L - l_j),$$

where E is the expectation operator (cf. Aghion and Howitt 1998), p. 59, and Wälde (1999). In other words:

Proposition 1 *The expected growth rate g_j of country j's output is in fixed proportion to labor devoted to R&D, $z_j = L - l_j$, in that country.*

Given this result, I can use labor devoted to R&D, z_j, as a proxy for the growth rate in each country j.

4 Laissez-faire

If there is laissez-faire, there is no lobbying and no political contributions either, $R_j = 0$ for all j. Local planner j then maximizes its utility (8) by emissions m_j and labor input l_j subject to Poisson technological change (9), given emissions in the rest of the union,

$$m_{-j} \doteq \sum_{k \neq j} m_k. \tag{10}$$

The value of the optimal program for planner j starting at time T is then

$$\Omega^j(\gamma_j, m_{-j}, n, T) \doteq \max_{(m_j, l_j) \text{ s.t. } (9)} E \int_T^{\infty} a^{\gamma_j} f(l_j, m_j)(m_j + m_{-j})^{-\delta} e^{-r(t-T)} dt. \tag{11}$$

I denote $\Omega^j = \Omega^j(\gamma_j, m_{-j}, n, T)$ and $\widetilde{\Omega}^j = \Omega^j(\gamma_j + 1, m_{-j}, n, T)$. The Bellman equation corresponding to the optimal program (11) is

$$r\Omega^j = \max_{m_j, l_j} \Phi^j(m_j, l_j, \gamma_j, m_{-j}, n, T), \tag{12}$$

where

$$\Phi^j(m_j, l_j, \gamma_j, m_{-j}, n, T) = a^{\gamma_j} f(l_j, m_j)(m_j + m_{-j})^{-\delta} + \lambda(L - l_j)\left[\widetilde{\Omega}^j - \Omega^j\right]. \tag{13}$$

This leads to the first-order conditions

$$\frac{\partial \Phi^j}{\partial m_j} = \frac{a^{\gamma_j} f_m(l_j, m_j)}{(m_j + m_{-j})^{\delta}} - \frac{\delta a^{\gamma_j} f(l_j, m_j)}{(m_j + m_{-j})^{\delta+1}} = 0, \tag{14}$$

$$\frac{\partial \Phi^j}{\partial l_j} = \frac{a^{\gamma_j} f_l(l_j, m_j)}{(m_j + m_{-j})^{\delta}} - \lambda\left[\widetilde{\Omega}^j - \Omega^j\right] = 0. \tag{15}$$

To solve the dynamic program, I try the solution that the value of the program, Ω^j, is in fixed proportion $\varphi_j > 0$ to instantaneous utility:

$$\Omega^j(\gamma_j, m_{-j}, n, T) = \varphi_j a^{\gamma_j} f(l_j, m_j)(m_j + m_{-j})^{-\delta}. \tag{16}$$

This implies

$$(\widetilde{\Omega}^j - \Omega^j)/\Omega^j = a - 1. \tag{17}$$

Inserting (16) and (17) into the Bellman equation (12) and (13) yields

$$1/\varphi_j = r + (1-a)\lambda(L - l_j) > 0. \tag{18}$$

Inserting (16) and (17) into the first-order conditions (14) and (15) yields

$$\begin{aligned} \frac{m_j}{\Omega^j}\frac{\partial \Phi^j}{\partial m_j} &= \frac{1}{\varphi_j}\left[\frac{m_j f_m(l_j, m_j)}{f(l_j, m_j)} - \frac{\delta m_j}{m_j + m_{-j}}\right] = 0, \\ \frac{l_j}{\Omega^j}\frac{\partial \Phi^j}{\partial l_j} &= \frac{1}{\varphi_j}\frac{l_j f_l(l_j, m_j)}{f(l_j, m_j)} - (a-1)\lambda l_j = 0. \end{aligned} \tag{19}$$

Because there is symmetry throughout all countries $j = 1, ..., n$ in the model, it is true that all countries have equal emissions $m_j = m$ in equilibrium. Inserting this into (18) and (19) and noting (1), (7) and (10) yield

$$\xi\Big(\frac{m_j}{l_j}\Big) \doteq \frac{m_j f_m(l_j, m_j)}{f(l_j, m_j)} = \frac{\delta m_j}{m_j + m_{-j}} = \frac{\delta}{n} \in (0, 1), \tag{20}$$

$$\begin{aligned} (a-1)\lambda l_j &= \big[r + (1-a)\lambda(L - l_j)\big]\frac{l_j f_l}{f} = \big[r + (1-a)\lambda(L - l_j)\big]\Big[1 - \frac{m_j f_m}{f}\Big] \\ &= \big[r + (1-a)\lambda(L - l_j)\big](1 - \delta/n). \end{aligned} \tag{21}$$

Solving for m_j/l_j from (20) and l_j from (21) yields

$$\begin{aligned} &\frac{m_j}{l_j} = \xi^{-1}\Big(\frac{\delta}{n}\Big) \doteq \varphi(n), \quad \frac{d\varphi}{dn} = -\frac{\delta}{n^2 \xi'} = \begin{cases} < 0 & \text{for } \sigma > 1, \\ > 0 & \text{for } 0 < \sigma < 1, \end{cases} \\ &l_j = l(n) \doteq \underbrace{\frac{r + (1-a)\lambda L}{(a-1)\lambda}}_{+}\underbrace{\Big(\frac{n}{\delta} - 1\Big)}_{+} > 0, \quad r + (1-a)\lambda L > 0, \quad l' > 0, \\ &z(n) = L - l(n), \quad z' < 0, \quad m_j = m(n) \doteq \varphi(n) l(n), \\ &m' = l\varphi' + \varphi l' > 0 \text{ for } 0 < \sigma < 1. \end{aligned} \tag{22}$$

These results can be rephrased as follows:

Proposition 2 *A higher level of centralization (i.e. a decrease in n)*

(a) decreases the level of output, l_j (i.e. $l' > 0$), but increases the growth rate, z_j (i.e. $z' < 0$),

(b) decreases emissions m_j unambiguously (i.e. $m' > 0$), when labor and emissions are gross complements, $0 < \sigma < 1$,

(c) increases emissions per labor input, m_j/l_j (i.e. $\varphi' < 0$), when labor and emissions are gross substitutes, $\sigma > 1$.

A higher level of centralization helps to internalize the effect of pollution. In that case, the local planners alleviate pollution by transferring resources from production into R&D. This decreases output, but speeds up economic growth. When labor and emissions are gross complements, the decrease of labor in production decreases emissions as well. When labor and emissions are gross substitutes, labor transferred from production into R&D is partly replaced by emissions. This increases the emissions-labor ratio in production.

5 Pareto optimum

Assume a benevolent central planner which has enough instruments to transfer income between countries.[2] Because the countries do not pay political contributions to a benevolent planner, $R_j = 0$ for all j, and because such a planner can internalize the externality of pollution entirely, the outcome is the Pareto optimum where the union behaves as if there were one jurisdiction only, $n = 1$. Noting (22), labor input in production at the Pareto optimum is given by

$$l(1) \doteq \frac{r + (1-a)\lambda L}{(a-1)\lambda}\Big(\frac{1}{\delta} - 1\Big). \tag{23}$$

Furthermore, proposition 2 has the following corollary:

Proposition 3 *The growth rate z is the highest at the Pareto optimum.*

[2]In the model, it would be sufficient if the central planner could tax consumption in al countries at any rate and then use the revenue for subsidizing R&D.

For the remainder of this paper, I assume that the central planner is self-interested, not benevolent. In section 6, I assume that the central planner taylors a specific emission quota m_j for each country, but the countries cannot trade with these quotas. In section 7, I introduce emission trade.

6 Lobbying with emission quotas

Following Grossman and Helpman (1994), I assume that the central planner of the union has its own interests and collects political contributions. Local planner j in each country $j \in \{1, ..., n\}$ pays political contributions R_j to the central planner which decides on a specific emission quota m_j for each country $j \in \{1, ..., n\}$. The order of this common agency game is the following. First, the local planners set their political contributions $(R_1, ..., R_n)$ conditional on the central planner's prospective policy $(m_1, ..., m_n)$. Second, the central planners sets the quotas $(m_1, ..., m_n)$ and collect the contributions for its personal consumption. Third, the local planners maximize their utilities given the level of political contributions $(R_1, ..., R_n)$. This game is solved in reversed order as follows. Subsection 6.1 considers a local planner, subsection 6.2 the central planner and subsection 6.3 the political equilibrium.

6.1 The local planners

Local planner j maximizes its utility (8) by labor input l_j subject to Poisson technological change (9) on the assumption that the interest rate r, the quotas $m_1, ..., m_n$, pollution $P = \sum_j m_j$ [cf. (3)] and and its political contributions R_j are kept constant. It is equivalent to maximize

$$E \int_T^\infty a^{\gamma_j} f(l_j, m_j) P^{-\delta} e^{-r(t-T)} dt$$

by l_j subject to (9), given r, m_j, P and R_j. The value of the optimal program for local planner j starting at time T can then be defined as follows:

$$\Gamma^j(\gamma_j, m_j, P, T) = \max_{l_j \text{ s.t. } (9)} E \int_T^\infty a^{\gamma_j} f(l_j, m_j) P^{-\delta} e^{-r(t-T)} dt. \tag{24}$$

I denote $\Gamma^j = \Gamma^j(\gamma_j, m_j, P, T)$ and $\widetilde{\Gamma}^j = \Gamma^j(\gamma_j + 1, , m_j, P, T)$. The Bellman equation corresponding to the optimal program (24) is

$$r\Gamma^j = \max_{l_j} \Psi^j(l_j, \gamma_j, m_j, P, T), \tag{25}$$

where

$$\Psi^j(l_j, \gamma_j, m_j, P, T) = a^{\gamma_j} f(l_j, m_j) P^{-\delta} + \lambda(L - l_j)\big[\widetilde{\Gamma}^j - \Gamma^j\big]. \tag{26}$$

This leads to the first-order condition

$$\frac{\partial \Psi^j}{\partial l_j} = a^{\gamma_j} f_l(l_j, m_j) P^{-\delta} - \lambda\big[\widetilde{\Gamma}^j - \Gamma^j\big] = 0. \tag{27}$$

To solve the dynamic program, I try the solution that the value of the program, Γ^j, is in fixed proportion $\vartheta_j > 0$ to instantaneous utility:

$$\Gamma^j(\gamma_j, m_j, P, T) = \vartheta_j a^{\gamma_j} f(l_j, m_j) P^{-\delta}, \quad \frac{\partial \Gamma^j}{\partial m_j} = \frac{f_m(l_j, m_j)}{f(l_j, m_j)}\Gamma_j, \;\; \frac{\partial \Gamma^j}{\partial P} = -\delta\frac{\Gamma^j}{P}. \tag{28}$$

This implies

$$(\widetilde{\Gamma}^j - \Gamma^j)/\Gamma^j = a - 1. \tag{29}$$

Inserting (28) and (29) into the Bellman equation (25) and (26) yields

$$1/\vartheta_j = r + (1 - a)\lambda(L - l_j) > 0. \tag{30}$$

Inserting (28), (29) and (30) into the first-order conditions (27) and noting (7), one obtains

$$\begin{aligned} \frac{l_j}{\Gamma^j}\frac{\partial \Psi^j}{\partial l_j} &= \frac{1}{\vartheta_j}\frac{l_j f_l(l_j, m_j)}{f(l_j, m_j)} - (a-1)\lambda l_j = \frac{1}{\vartheta_j}\left[1 - \xi\Big(\frac{m_j}{l_j}\Big)\right] - (a-1)\lambda l_j \\ &= \big[r + (1-a)\lambda(L - l_j)\big]\left[1 - \xi\Big(\frac{m_j}{l_j}\Big)\right] - (a-1)\lambda l_j = 0. \end{aligned} \tag{31}$$

Noting (3), (7), (24) and (28), local planner j's utility (8) becomes

$$\begin{aligned} \Upsilon^j(R_j, m_1, ..., m_n) &= \Gamma^j(\gamma_j, m_j, P, T) - \int_T^\infty R_j e^{-r(t-T)} dt \\ &= \Gamma^j(\gamma_j, m_j, P, T) - R_j/r, \end{aligned}$$

$$\frac{\partial \Upsilon^j}{\partial m_j} = \frac{\partial \Gamma^j}{\partial m_j} + \frac{\partial \Gamma^j}{\partial P}\frac{\partial P}{\partial m_j} = \Gamma^j\left[\frac{f_m(l_j, m_j)}{f(l_j, m_j)} - \frac{\delta}{P}\frac{\partial P}{\partial m_j}\right] = \frac{\Gamma^j}{m_j}\left[\xi\Big(\frac{m_j}{l_j}\Big) - \frac{\delta m_j}{P}\right],$$

$$\frac{\partial \Upsilon^j}{\partial m_k} = \frac{\partial \Gamma^j}{\partial P}\frac{\partial P}{\partial m_k} = -\frac{\delta \Gamma^j}{P}\frac{\partial P}{\partial m_k} = -\frac{\delta \Gamma^j}{P} \text{ for } k \neq j, \quad \frac{\partial \Upsilon^j}{\partial R_j} = -\frac{1}{r}. \tag{32}$$

6.2 The self-interested central planner

The present value the expected flow of the real political contributions R_j from all countries j at time T is given by

$$E\int_T^\infty \sum_{j=1}^n R_j e^{-r(\theta-T)}d\theta. \tag{33}$$

Given this, (3) and (32), I specify the central planner's utility function as:

$$\begin{aligned} G(m_1,...,m_n,R_1,...,R_n) &\doteq E\int_T^\infty \sum_{j=1}^n R_j e^{-r(\theta-T)}d\theta + \sum_{j=1}^n \zeta_j \Upsilon^j(R_j,m_1,...,m_n) \\ &= \frac{1}{r}\sum_{j=1}^n R_j + \sum_{j=1}^n \zeta_j \Upsilon^j(R_j,m_1,...,m_n), \end{aligned} \tag{34}$$

where constants $\zeta_j \geq 0$ are the weight of planner j's welfare in the central planner's preferences. Grossman and Helpman's (1994a) objective function (34) is widely used in models of common agency and it has been justified as follows. The politicians are mainly interested in their own income which consists of the contributions from the public, $\sum_j R_j$, but because they must defend their position in general elections, they must sometimes take the utilities of the interest groups Υ^j into account directly. The linearity of (34) in $\sum_j R_j$ is assumed, for simplicity.

6.3 The political equilibrium

Each local planner j tries to affect the central planner by its contributions R_j. The contribution schedules are therefore functions of the central planner's policy variables (= the emission quotas m_j):

$$R_j(m_1,...,m_n), \ \ j=1,...,n. \tag{35}$$

Following proposition 1 of Dixit, Grossman and Helpman (1997), a subgame perfect Nash equilibrium for this game is a set of contribution schedules $R_j(m_1,...,m_n)$ and a policy $(m_1,...,m_n)$ such that the following conditions $(i)-(iv)$ hold:

(i) Contributions R_j are non-negative but no more than the contributor's income, $\Upsilon_j \geq 0$.

(ii) The policy $(m_1, ..., m_n)$ maximizes the central planner's welfare (34) taking the contribution schedules R_j as given,

$$(m_1, ..., m_n) \in \arg\max_{m_1,...,m_n} G\big(m_1, ..., m_n, R_1(m_1, ..., m_n), ..., R_n(m_1, ..., m_n)\big); \quad (36)$$

(iii) Local planner j cannot have a feasible strategy $R_j(m_1, ..., m_n)$ that yields it a higher level of utility than in equilibrium, given the central planner's anticipated decision rule,

$$(m_1, ..., m_n) = \arg\max_{m_1,...,m_n} \Upsilon^j\big(R_j(m_1, ..., m_n), m_1, ..., m_n\big). \quad (37)$$

(iv) Local planner j provides the central planner at least with the level of utility than in the case it offers nothing ($R_j = 0$), and the central planner responds optimally given the other local planners contribution functions,

$$G\big(m_1, ..., m_n, R_1(m_1, ..., m_n), ..., R_n(m_1, ..., m_n)\big) \geq \max_{m_1,...,m_n} G\big(m_1, ..., m_n, R_1(m_1, ..., m_n), ..., R_{j-1}(m_1, ..., m_n), 0, R_{j+1}(m_1, ..., m_n), ..., R_n(m_1, ..., m_n)\big).$$

Noting (32), the conditions (37) are equivalent to

$$0 = \frac{\partial \Upsilon^j}{\partial R_j}\frac{\partial R_j}{\partial m_k} + \frac{\partial \Upsilon^j}{\partial m_j} = -\frac{1}{r}\frac{\partial R_j}{\partial m_k} + \frac{\partial \Upsilon^j}{\partial m_k} \text{ for all } k,$$

and

$$\frac{\partial R_j}{\partial m_j} = r\frac{\partial \Upsilon^j}{\partial m_j} = r\frac{\Gamma^j}{m_j}\left[\xi\left(\frac{m_j}{l_j}\right) - \frac{\delta m_j}{P}\right], \quad \frac{\partial R_j}{\partial m_k} = -\frac{r\delta\Gamma^j}{P} \text{ for } k \neq j.$$

Given these equations, one obtains

$$\frac{\partial}{\partial m_k}\sum_{j=1}^{n} R_j = \sum_{j=1}^{n}\frac{\partial R_j}{\partial m_k} = \frac{\partial R_k}{\partial m_k} + \sum_{j\neq k}\frac{\partial R_j}{\partial m_k} = r\frac{\Gamma^k}{m_k}\left[\xi\left(\frac{m_k}{l_k}\right) - \frac{\delta m_k}{P}\right] - \sum_{j\neq k}\frac{r\delta\Gamma^j}{P} = r\frac{\Gamma^k}{m_k}\left[\xi\left(\frac{m_k}{l_k}\right) - \frac{\delta m_k}{P}\frac{1}{\Gamma^k}\sum_{j=1}^{n}\Gamma^j\right]. \quad (38)$$

Noting (35) and (37), the central planner's utility function (34) becomes

$$\mathcal{G}(m_1, ..., m_n) \doteq G\big(m_1, ..., m_n, R_1(m_1, ..., m_n), ..., R_n(m_1, ..., m_n)\big)$$
$$= \frac{1}{r}\sum_{j=1}^{n} R_j(m_1, ..., m_n) + \sum_{j=1}^{n} \zeta_j \max_{m_1,...,m_n} \Upsilon^j\big(R_j(m_1, ..., m_n), m_1, ..., m_n\big). \tag{39}$$

Noting (38) and (63), the equilibrium conditions (36) are equivalent to the first-order conditions

$$\frac{\partial \mathcal{G}}{\partial m_k} = \frac{1}{r}\frac{\partial}{\partial m_k}\sum_{j=1}^{n} R_j = \frac{\Gamma^k}{m_k}\left[\xi\Big(\frac{m_k}{l_k}\Big) - \frac{\delta m_k}{P}\frac{1}{\Gamma^k}\sum_{j=1}^{n}\Gamma^j\right] = 0 \text{ for all } k. \tag{40}$$

The political equilibrium is now specified by the equilibrium conditions (31) for all local planners $j = 1, ..., n$ plus those (40) for the central planner. In this system, there are $2n$ unknowns, (l_j, m_j) for $j = 1, ..., n$. I assume, for simplicity, uniform initial productivity in the union, $\gamma_k = \gamma_1$ for all $k \neq 1$. In the system, noting (28), this yields perfect symmetry $l_j = l$, $m_k = m$ and $\Gamma_j = \Gamma$ for the countries $j = 1, ..., n$ in equilibrium. Given this and (3), the equilibrium conditions (31) and (40) change into

$$\xi\Big(\frac{m_j}{l_j}\Big) = \frac{\delta m_k}{P}\frac{1}{\Gamma^k}\sum_{j=1}^{n}\Gamma^j = \delta\frac{m_k}{P}n = \delta,$$
$$\frac{(a-1)\lambda l_j}{r + (1-a)\lambda(L - l_j)} = 1 - \frac{m f_m}{f} = 1 - \xi = 1 - \delta. \tag{41}$$

The results (41) are the same as the result (20) and (21) with $n = 1$. This shows that m, l and $z = L - l$ are the same as at the Pareto optimum (23):

Proposition 4 *In the case of lobbying with given emission quotas, emissions m and the growth rate z are socially optimal.*

The introduction of the central planner as a decision maker for emissions eliminates the externality through pollution. This effect is the same for both a benevolent and a self-interested central planner.

In the case of lobbying, the countries pay political contributions, $R_j > 0$ for all j, while in the case of Pareto-optimal policy, there are no such contributions, $R_j = 0$ for all j. If the central planner consists of different households than the rest of the population (even partly), one can define political contributions are a waste from the viewpoint of the latter. Thus, there is the following corollary for proposition 4:

Proposition 5 *In the case of lobbying with given emission quotas, welfare is sub-optimal.*

7 Lobbying with emission trade

In this section, I assume that the central planner defines a quota for each country's emissions, but the countries can trade emissions among themselves. To enable a stationary state equilibrium in the model, I assume that the quotas are in fixed proportion to the level of productivity a^{γ_j} so that more advances countries get tighter restrictions. Therefore, the quota for country j's productivity-adjusted emissions $m_j a^{\gamma_j}$ is given by q_j. When country j has excess quotas, $q_j > m_j a^{\gamma_j}$, it can sell the difference $q_j - m_j a^{\gamma_j}$ to the other members of the union at the price p. Correspondingly, when country j has excess emissions, $m_j a^{\gamma_j} - q_j$, it must buy the difference $m_j a^{\gamma_j} - q_j$ from other countries at the price p. At the level of the whole union, productivity-adjusted emissions $\sum_{j=1}^{n} m_j a^{\gamma_j}$ are equal to total quotas $\sum_{j=1}^{n} q_j$,

$$\sum_{j=1}^{n} m_j a^{\gamma_j} = \sum_{j=1}^{n} q_j. \tag{42}$$

Local planner j in each country $j \in \{1, ..., n\}$ pays political contributions R_j to the central planner. The order of this common agency game is the following. First, the local planners set their political contributions $(R_1, ..., R_n)$ conditional on the central planner's prospective policy $(q_1, ..., q_n)$. Second, the central planners sets the quotas $(q_1, ..., q_n)$ and collect the contributions for its personal consumption. Third, the local planners maximize their utilities given the level of political contributions $(R_1, ..., R_n)$. This game is solved in reversed order as follows. Subsection 7.1 considers a local planner, subsection 7.2 the central planner and subsection 7.3 the political equilibrium.

7.1 The local planners

Planner j's utility starting at time T, (8), can be extended into

$$\Upsilon^j \doteq E\int_T^\infty \Big[a^{\gamma_j} f(l_j, m_j)(m_j + m_{-j})^{-\delta} + p\big(q_j - m_j a^{\gamma_j}\big) - R_j\Big] e^{-r(t-T)}dt, \tag{43}$$

where $p(q_j - m_j a^{\gamma_j})$ is country j's net income from emission trade. Local planner j maximizes its utility (43) by labor input l_j and emissions m_j subject to Poisson technological change (9) on the assumption that the interest rate r, the quotas $q_1, ..., q_n$, the emission price p, emissions in the rest of the union, m_{-j}, and its political contributions R_j are kept constant. It is equivalent to maximize

$$\int_T^\infty a^{\gamma_j}\left[f(l_j, m_j)(m_j + m_{-j})^{-\delta} - pm_j\right] e^{-r(t-T)}dt$$

by (l_j, m_j) subject to (9), given r, $q_1, ..., q_n$, p, m_{-j} and R_j. The value of the optimal program for local planner j can then be defined as follows:

$$\Gamma^j(\gamma_j, p, m_{-j}, T) = \max_{(m_j, l_j) \text{ s.t. } (9)} E\int_T^\infty a^{\gamma_j}\big[f(l_j, m_j)(m_j + m_{-j})^{-\delta} - pm_j\big] e^{-r(t-T)}dt. \tag{44}$$

I denote $\Gamma^j = \Gamma^j(\gamma_j, p, m_{-j}, T)$ and $\widetilde{\Gamma}^j = \Gamma^j(\gamma_j + 1, p, m_{-j}, T)$. The Bellman equation corresponding to the optimal program (44) is

$$r\Gamma^j = \max_{l_j, m_j} \Psi^j(l_j, \gamma_j, p, m_{-j}, T), \tag{45}$$

where

$$\Psi^j(l_j, \gamma_j, p, m_{-j}, T) = a^{\gamma_j}\big[f(l_j, m_j)(m_j + m_{-j})^{-\delta} - pm_j\big] + \lambda(L - l_j)\big[\widetilde{\Gamma}^j - \Gamma^j\big]. \tag{46}$$

This leads to the first-order conditions

$$\frac{\partial \Psi^j}{\partial m_j} = a^{\gamma_j}\left[\frac{f_m(l_j, m_j)}{(m_j + m_{-j})^\delta} - \frac{\delta f(l_j, m_j)}{(m_j + m_{-j})^{\delta+1}} - p\right] = 0, \tag{47}$$

$$\frac{\partial \Psi^j}{\partial l_j} = \frac{a^{\gamma_j} f_l(l_j, m_j)}{(m_j + m_{-j})^\delta} - \lambda\big[\widetilde{\Gamma}^j - \Gamma^j\big] = 0. \tag{48}$$

I try the solution that the value of the program, Γ^j, is given by

$$\Gamma^j(\gamma_j, p, m_{-j}, T) = \vartheta_j a^{\gamma_j}\left[\frac{f(l_j, m_j)}{(m_j + m_{-j})^\delta} - pm_j\right], \quad \frac{\partial \Gamma^j}{\partial p} = -\vartheta_j a^{\gamma_j} m_j, \quad (49)$$

where $\vartheta_j > 0$ is independent of the control variables. This implies

$$(\widetilde{\Gamma}^j - \Gamma^j)/\Gamma^j = a - 1. \quad (50)$$

Inserting (49) and (50) into the Bellman equation (45) and (46) yields

$$1/\vartheta_j = r + (1 - a)\lambda(L - l_j) > 0. \quad (51)$$

Given (49), (50) and (51) the first-order conditions (47) and (48) change into

$$p = \frac{f_m(l_j, m_j)}{(m_j + m_{-j})^\delta} - \frac{\delta f(l_j, m_j)}{(m_j + m_{-j})^{\delta+1}}, \quad (52)$$

$$\frac{1}{\Gamma^j}\frac{\partial \Psi^j}{\partial l_j} = \frac{r + (1 - a)\lambda(L - l_j)}{f(l_j, m_j)(m_j + m_{-j})^{-\delta} - pm_j}\frac{f_l(l_j, m_j)}{(m_j + m_{-j})^\delta} - (a - 1)\lambda = 0. \quad (53)$$

7.2 The self-interested central planner

In the system (10), (52) and (53) for $j = 1, .., n$, there are $3n$ equations, $3n$ unknown variables, l_j, m_j and m_{-j} for $j = 1, .., n$, and the known variable p. This and the symmetry throughout $j = 1, ..., n$ imply

$$m_j = m(p) \text{ and } l_j = l(p) \text{ for } j = 1, ..., n. \quad (54)$$

Inserting this into (42) yields

$$m(p)\sum_{\ell=1}^{n} a^{\gamma_\ell} = \sum_{j=1} q_j$$

and

$$p = m^{-1}\left(\sum_{j=1}^{n} q_j \Big/ \sum_{\ell=1}^{n} a^{\gamma_\ell}\right), \quad \frac{\partial p}{\partial q_j} = \frac{1}{m' \sum_{\ell=1}^{n} a^{\gamma_\ell}}, \quad (55)$$

where m^{-1} is the inverse function of m.

Noting (44), (49) and (55), Local planner j's utility (43) changes into

$$\Delta^j(R_j, q_1, ..., q_n) = \Upsilon^j = \Gamma^j(\gamma_j, p, m_{-j}, T) + \int_T^\infty (pq_j - R_j)e^{-r(t-T)}dt$$
$$= \Gamma^j(\gamma_j, p, m_{-j}, T) + \frac{1}{r}(pq_j - R_j), \quad \frac{\partial\Delta^j}{\partial R_j} = -\frac{1}{r},$$
$$\frac{\partial\Delta^j}{\partial q_j} = \frac{p}{r} + \left(\frac{q_j}{r} + \frac{\partial\Gamma^j}{\partial p}\right)\frac{\partial p}{\partial q_j} = \frac{p}{r} + \left(\frac{q_j}{r} - \vartheta_j a^{\gamma_j} m_j\right)\frac{\partial p}{\partial q_j}$$
$$= \frac{p}{r} + \frac{q_j/r - m_j a^{\gamma_j}\vartheta_j}{m' \sum_{\ell=1}^n a^{\gamma_\ell}},$$
$$\frac{\partial\Delta^j}{\partial q_k} = \left(\frac{q_j}{r} + \frac{\partial\Gamma^j}{\partial p}\right)\frac{\partial p}{\partial q_k} = \frac{q_j/r - m_j a^{\gamma_j}\vartheta_j}{m' \sum_{\ell=1}^n a^{\gamma_\ell}} \text{ for } k \neq j. \tag{56}$$

From the conditions (51), (52) and (53) it follows that labor input l_j and emissions m_j in production are constant over time for all countries j.

The local planners $j = 1, ..., n$ lobby the central planner which decides on the emission quotas $(q_1, ..., q_n)$. Following Grossman and Helpman (1994), I assume that the central planner has its own interests and collects contributions $(R_1, ..., R_n)$ from the local planners. Given this, I specify Grossman and Helpman's (1994) utility function for the central planner as follows:

$$G(q_1, ..., q_n, R_1, ..., R_n) \doteq E\int_T^\infty \sum_{j=1}^n R_j e^{-r(\theta-T)}d\theta + \sum_{j=1}^n \zeta_j\Delta^j(R_j, q_1, ..., q_n)$$
$$= \frac{1}{r}\sum_{j=1}^n R_j + \sum_{j=1}^n \zeta_j\Delta^j(R_j, q_1, ..., q_n), \tag{57}$$

where constants $\zeta_j \geq 0$ is the weight of planner j's welfare.

7.3 The political equilibrium

Each local planner j tries to affect the central planner by its contributions R_j. The contribution schedules are therefore functions of the central planner's policy variables, the emission quotas m_j:

$$R_j(q_1, ..., q_n), \quad j = 1, ..., n. \tag{58}$$

The central planner maximizes its utility function (57) by $(q_1, ..., q_n)$, given the contribution schedules (58). A subgame perfect Nash equilibrium for this game is a set of contribution schedules $R_j(q_1, ..., q_n)$ and policy $(q_1, ..., q_n)$ such that the conditions $(i) - (iv)$ in subsection 6.3 hold, with $(m_1, ..., m_n)$ being replaced by $(q_1, ..., q_n)$. Thus, it must be true that $\Delta_j \geq 0$ and

$$(q_1, ..., q_n) \in \arg\max_{q_1,\cdots,q_n} G\big(q_1, ..., q_n, R_1(q_1, ..., q_n), ..., R_n(q_1, ..., q_n)\big); \tag{59}$$

$$(q_1, ..., q_n) = \arg\max_{q_1,\cdots,q_n} \Delta^j\big(R_j(q_1, ..., q_n), q_1, ..., q_n\big). \tag{60}$$

$$\begin{aligned} &G\big(q_1, ..., q_n, R_1(q_1, ..., q_n), ..., R_n(q_1, ..., q_n)\big) \\ &\geq \max_{q_1,\cdots,q_n} G\big(q_1, ..., q_n, R_1(q_1, ..., q_n), ..., R_{j-1}(q_1, ..., q_n), 0, \\ &\qquad\qquad R_{j+1}(q_1, ..., q_n), ..., R_n(q_1, ..., q_n)\big). \end{aligned}$$

Noting (56), the conditions (60) are equivalent to

$$0 = \frac{\partial \Delta^j}{\partial R_j}\frac{\partial R_j}{\partial q_k} + \frac{\partial \Delta^j}{\partial q_k} = -\frac{1}{r}\frac{\partial R_j}{\partial q_k} + \frac{\partial \Delta^j}{\partial q_k} \text{ for all } j \text{ and } k,$$

and

$$\frac{\partial R_j}{\partial q_j} = r\frac{\partial \Delta^j}{\partial q_j} = p + \frac{q_j - rma^{\gamma_j}\vartheta_j}{m'\sum_{\ell=1}^n a^{\gamma_\ell}},\ \frac{\partial R_j}{\partial q_k} = r\frac{\partial \Delta^j}{\partial q_k} = \frac{q_j - rma^{\gamma_j}\vartheta_j}{m'\sum_{\ell=1}^n a^{\gamma_\ell}} \text{ for } k \neq j, \tag{61}$$

which suggests that in equilibrium the change in the lobby's contribution (R^j) due to a change in quota m_j is equal to the change in the lobby's rent Δ^j due to this same fact, holding the contribution R^j constant.

Given (1), (3), (51) and (54), it is true that $m_j = m$, $m_{-j} = (n-1)m$, $l_j = l$, $z_j = z = L - l$, $\vartheta_j = \vartheta$ and $P = nm$. In the stationary state, all these variables must be kept constant over time. Given (54) and (55), the ratio

$$\sum_{j=1}^n q_j \Big/ \sum_{\ell=1}^n a^{\gamma_\ell} = m$$

is then kept constant over time. This is true, if $q_j = ma^{\gamma_j}$ for all j. Thus, in the vicinity of the stationary state, from (51), (54) and (61) it follows that

$$\begin{aligned} \frac{\partial}{\partial q_k}\sum_{j=1}^n R_j &= \frac{\partial R_k}{\partial q_k} + \sum_{j\neq k}\frac{\partial R_j}{\partial q_k} = p + \frac{q_k - rma^{\gamma_k}\vartheta_k}{m'\sum_{\ell=1}^n a^{\gamma_\ell}} + \sum_{j\neq k}\frac{q_k - rma^{\gamma_k}\vartheta_k}{m'\sum_{\ell=1}^n a^{\gamma_\ell}} \\ &= p + \sum_{j=1}^n \frac{q_k - r\vartheta_k ma^{\gamma_k}}{m'\sum_{\ell=1}^n a^{\gamma_\ell}} = p + \sum_{j=1}^n \frac{(1-r\vartheta)ma^{\gamma_k}}{m'\sum_{\ell=1}^n a^{\gamma_\ell}} = p + (1-r\vartheta)\frac{m}{m'} \end{aligned}$$

$$= p + \left[1 - \frac{r}{1 + (1-a)\lambda(L-l)}\right]\frac{m}{m'} = p + \frac{(1-a)\lambda(L-l)}{1+(1-a)\lambda(L-l)}\frac{m(p)}{m'(p)}. \quad (62)$$

Noting (58) and (60), the central planner's utility function (57) becomes

$$\mathcal{G}(q_1, ..., q_n) \doteq G\big(q_1, ..., q_n, R_1(q_1, ..., q_n), ..., R_n(q_1, ..., q_n)\big)$$
$$= \frac{1}{r}\sum_{j=1}^{n} R_j(q_1, ..., q_n) + \sum_{j=1}^{n}\zeta_j \max_{q_1,...,q_n} \Delta^j\big(R_j(q_1, ..., q_n), q_1, ..., q_n\big). \quad (63)$$

Noting (62) and (63), the equilibrium conditions (59) are equivalent to

$$\frac{\partial\mathcal{G}}{\partial q_k} = \frac{1}{r}\frac{\partial}{\partial q_k}\sum_{j=1}^{n} R_j = p + \frac{(1-a)\lambda(L-l)}{1+(1-a)\lambda(L-l)}\frac{m(p)}{m'(p)} = 0.$$

Thus, the equilibrium price p is determined by

$$\frac{pm'(p)}{m(p)} = \frac{(a-1)\lambda(L-l)}{1+(1-a)\lambda(L-l)}.$$

Given (7), local planner j's first-order conditions (52) and (53) become

$$\xi\Big(\frac{m}{l}\Big) = \frac{mf_m(l,m)}{f(l,m)} = \delta\frac{m}{P} + \frac{pmP^\delta}{f} = \frac{\delta}{n} + \frac{pmP^\delta}{f(l,m)} > \frac{\delta}{n}, \quad (64)$$

$$1 - \xi\Big(\frac{m}{l}\Big) = \frac{lf_l(l,m)}{f(l,m)} = \frac{(a-1)\lambda l}{r+(1-a)\lambda(L-l)}\left[1 - \frac{pmP^\delta}{f(l,m)}\right]$$
$$= \frac{(a-1)\lambda l}{r+(1-a)\lambda(L-l)}\left[1 - \xi\Big(\frac{m}{l}\Big) + \frac{\delta}{n}\right],$$

$$l = \frac{r+(1-a)\lambda L}{(a-1)\lambda}\frac{1-\xi(m/l)}{\delta/n} < \frac{r+(1-a)\lambda L}{(a-1)\lambda}\Big(\frac{n}{\delta} - 1\Big). \quad (65)$$

The comparison of the equilibrium in the case of laissez-faire, (20) and (21), to that in the case of emission trade, (64) and (65), shows the following. First, l is equal to

$$\frac{r+(1-a)\lambda L}{(a-1)\lambda}\Big(\frac{n}{\delta} - 1\Big) \quad (66)$$

in the case of laissez-faire, but smaller than (66) in the case of emission trade. Second, in the case of no emission policy, the function $\xi(m/l)$ is equal to $\frac{\delta}{n}$, but in the case of emission trade, it higher than $\frac{\delta}{n}$. Because $\xi' > 0$ (< 0) for $\sigma > 1$ ($0 < \sigma < 1$) by (7), it follows that m/l is bigger (smaller) with emission trade than in with laissez-faire for $\sigma > 1$ ($0 < \sigma < 1$). These results can be rephrased as follows:

Proposition 6 *In the lobbying equilibrium with emission trade,*

(a) the level of employment in production, l, is lower, but the growth rate $z = L - l$ higher,

(b) the level of emissions, m, is lower when labor and emissions are gross complements (i.e. $0 < \sigma < 1$),

(c) the emissions-labor ratio m/l is higher when labor and emissions are gross substitutes (i.e. $\sigma > 1$),

than with laissez-faire.

With emission trade, one more unit of R&D costs less in terms of lost output. Thus, emission trade boosts R&D and decreases labor in production. When labor and emissions are gross complements, a smaller labor input in production leads to smaller emissions as well. When labor and emissions are gross substitutes, labor transferred from production into R&D is partly replaced by emissions and the emissions-labor ratio increases.

Finally, given (23), l is bigger and the growth rate $z = N - l$ smaller in the case of lobbying with emission trade than in at Pareto optimum if and only if

$$\frac{r + (1-a)\lambda L}{(a-1)\lambda} \frac{1-\xi}{\delta/n} > \frac{r + (1-a)\lambda L}{(a-1)\lambda} \Big(\frac{1}{\delta} - 1 \Big).$$

This is equivalent to $n > (1-\delta)/(1-\xi)$. The proportion of emissions in technology, $\xi \doteq m f_m / f$, is very likely less than $\frac{1}{2}$, and the elasticity of output with respect to pollution through abatement, δ, cannot be greater than one. Thus, with a large enough number of countries, n, it is true that $n > 2(1-\delta) \geq (1-\delta)/(1-\xi)$ and I conclude:

Proposition 7 *In the lobbying equilibrium with emission trade, the growth rate z is sub-optimal.*

Because with emission trade the levels of emissions are decided at the level of countries rather than at the level of the union, the externality through pollution cannot be internalized. Consequently, the growth rate is then smaller than at the Pareto optimum.

8 Conclusions

A higher level of centralization decreases the level of output, but increases the growth rate, increases emissions per labor input, when labor and emissions are gross substitutes, and decreases the level of emissions unambiguously, when labor and emissions are gross complements. A higher level of centralization helps to internalize the effect of pollution. In that case, a local planner alleviates pollution by transferring resources from production into R&D. This will speed up economic growth. When labor and emissions are gross substitutes, the transfer of resources from production into R&D is partly outweighed by higher emissions so that the emissions-labor ratio in production rises. When labor and emissions are gross complements, the decrease of labor in production decreases emissions as well.

In Pareto optimum, the union of countries behaves as if there were only one jurisdiction. Given the result above, the level of output is then at the lowest, but the growth rate at the highest level in Pareto optimum. Furthermore, increases emissions per labor input are at the highest level, when labor and emissions are gross substitutes, but the level of emissions at the lowest level, when labor and emissions are gross complements in Pareto optimum.

In the case of lobbying with given emission quotas, the emissions-labor ratio, the growth rate, total consumption and pollution are the same as in the case of Pareto-optimal policy. The introduction of the central planner as a decision maker for emissions eliminates the externality through pollution. This effect is the same for both a benevolent and a self-interested central planner. On the other hand, the welfare is lower in the case of lobbying with given emission quotas than in the case of Pareto-optimal policy. In the case of lobbying, the countries pay political contributions, while in the case of Pareto-optimal policy, there are no such contributions. If the central planner consists of different households than the rest of the population (even partly), political contributions are a waste from the viewpoint of the latter.

With emission trade, one more unit of R&D costs less in terms of lost output. Thus, emission trade boosts R&D and decreases labor in production. When labor and emissions are gross complements, a smaller labor input in production leads to smaller emissions as well. When labor and emissions are gross substitutes, labor transferred from production into R&D is partly replaced by emissions and the emissions-labor ratio increases. Because with emission trade the levels of emissions are decided at the level of countries rather than at the level of the union, the externality through pollution cannot be internalized. Consequently, the growth rate is then smaller than at the Pareto optimum.

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