Private Secondary Benefits of Greenhouse Gas Abatement and the Renegotiation of International Environmental Treaties

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Abstract

Countries participating in international negotiations on climate change, which are primarily negotiations on greenhouse gas abatement levels, widely ignore secondary benefits of climate policies. The reasons may lie in the complexity of an integration of secondary benefit considerations, information problems and missing knowledge on the importance of these benefits. But underestimating benefits yields a suboptimal level of commitments in an international agreement on greenhouse gas abatement levels. If in political reasoning the urgency of the consideration of secondary benefits gets a higher weight subsequently, the necessity of an international renegotiation arises. Otherwise, the climate protection measures will persist on a suboptimal level.

In this paper it is investigated if a renegotiation could become unnecessary, if an agreement on climate change does not assess distinct abatement quantities but distinct matching rates. The results demonstrate that the more flexible matching scheme could adjust the international greenhouse gas abatement to a Pareto-optimal level without a costly renegotiation. Thus, actual international negotiations should consider the implementation of flexible instruments which can react to new insights in the future without great efforts.

Keywords: Climate Change, Collective Action, Matching, Secondary Benefits

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1 Introduction

In the preceding years the impacts of several pollutants have been investigated intensely and abatement regulations and treaties on national as well as on international level have been developed. Prominent examples of the latter are the Montreal Protocol from 1987 which has been initiated in order to protect the ozone layer, the UN Framework Convention on Climate Change[1] which has been implemented in 1992 and the US 1990 Clean Air Act Amendments (CAAA) which constitute the first large-scale use of the tradable permit approach to pollution control and have been initiated in order to limit SO_2 emissions and with it, to avoid acid rain and other acidic depositions[2]. Such policies regularly impose positive effects on the environmental system which go far beyond their primary intentions.

Economic investigations of environmental policies aiming at the reduction of one pollutant's emissions have to consider that these policies might be accompanied by the decrease of other pollutants. Because these emissions regularly cause different negative externalities - even the emission of one pollutant may cause several external effects - the positive influence of abatement policies on the ecological system are manifold.

Meyer, Bockermann, Ewerhart, Lutz (1998: 95-109, 1999: 123-133, 177-187) and Lutz (1998: 161-171, 199-202) simulate the effects of CO_2 tax scenarios and of CO_2 permit scenarios in Germany. A result of these simulations is that the tax- or permit-induced CO_2 reduction would be accompanied by a substantial reduction of NO_X and SO_2 emissions.[3] By the latter, benefits arise in addition to the benefits expected from the tax- or permit-induced CO_2 decrease.

Actual emission management widely ignores these facts but compares the benefits of the reduction of one pollutant to the cost of this reduction[4]. Regularly, the benefits reveal to the mitigation of one environmental problem and do not consider side effects. Furthermore, the secondary or ancillary benefits caused by the accompanied reduction of several other pollutants are neglected[5]. With it, the optimal provision quantity of environmental protection measures is underestimated. The underestimation is not negligible since secondary benefits are substantial (Ekins 1996; Glomsrød, Vennemo and Johnsen 1992; Pearce[6] 1992; Wang and Smith 1999).

If an international agreement on GHG abatement levels would be based on the consider-

[1] A shot summary of the history of climate policy can be found in Hackl and Pruckner (1999: 1-2).

[2] For an investigation on the CAAA see Joskow, Schmalensee and Bailey (1998).

[3] Barker (1993: 11-13) investigates the effects of a carbon/energy tax for the UK. He also determines substantial reductions of SO_2 and NO_X accompanying reductions in CO_2.

[4] Söllner(1999: 1) criticizes that in actual emission management the "pollutants are dealt with separately and inconsistently".

[5] Ekins (1996*: 15) criticizes that "neither of the two main cost-benefit analyses of global warming [...] make any attempt to incorporate into their assessment, even tentatively, the various estimates of secondary benefits that have so far been made".

[6] Pearce's (1992: 7-8) analysis "suggests that secondary benefits far outweigh primary benefits from CO_2 control". According to his investigation, the inclusion of the secondary benefits aspect would rise Nordaus' (1991) highest GHG marginal damage estimates by more than 125 percent (from \$66 tC to over \$150 tC).

ation of primary benefits and would underestimate or neglect secondary benefits[7], then this agreement will yield a suboptimal low level of GHG abatement[8]. Becoming more aware of these secondary benefits it would be collectively and possibly also individually rational to the single countries to adjust their climate policies afterwards. Then, a renegotiation of international agreements on GHG abatement levels would be necessary to correct the failure of underestimating secondary benefits in the initial negotiations. The question arises, if a different negotiation scheme could reduce or delete the necessity of a renegotiation. To investigate this question, international negotiations on matching rates are considered.

For it, international negotiations on climate change are presented in a two-stage matching model. The subgame perfect equilibrium will be determined and incentives to renegotiate an international treaty - caused by modified secondary benefit estimates - investigated. The aim is to demonstrate, that even if the countries do not consider the secondary benefits fully in the initially assented international agreement, collective action might still yield a Pareto-optimal outcome without a costly renegotiation of the treaty.

2 Primary and Secondary Benefits of Measures Mitigating Global Warming

GHG abatement measures can be considered as impure public goods since they generate private and public characteristics.

The primary intention of climate policies is, of course, the stabilization of the world climate. The stabilization of the world climate has the properties of a pure public good since no country can be excluded from the climate stabilization and since there is no rivalry among it. Therefore, GHG abatement measures provide a pure public characteristic[9]. The utility countries derive from the amount of the pure public characteristic accruing from the stabilized climate, represents the 'primary benefits' of GHG abatement measures.

But further global impacts might arise from GHG abatement measures which also contribute to the pure public characteristic: Reducing the greenhouse gases CFCs, for example, does not only have a positive influence on earth's climate, but it also protects the ozone layer[10]. The positive effect on the ozone layer is a global secondary effect of climate policies reducing CFCs and also has the properties of a pure public good. Any country enjoys the generated pure public 'global secondary benefits' since non-excludability and non-rivalry among the ozone layer stabilization are prevailing.

Finally, GHG abatement measures also generate some private characteristic with only regional influence. This characteristic can be exclusively enjoyed by the regions or coun-

[7]According to Ekins (1995: 262) there "are relatively few calculations of secondary benefits of CO_2 reduction, and those that exist stress the preliminary and tentative nature of their results."

[8]But, it has to be considered that regarding secondary benefits in international negotiations might rise the conflict potential between the negotiating parties.

[9]For a distinction of characteristics and commodities see Cornes (1992: 139).

[10]But the possible CFC substitutes HCFCs also harm the ozone shield and cause global warming (Clayton 1995: 117-118).

tries providing the climate protection measures. The benefits countries enjoy from the consumption of the private characteristic generated by GHG abatement measures are the 'private secondary benefits'. Examples of private secondary benefits can be observed from CO_2 abatement policies reducing the burning of fossil fuels. "Fossil fuel combustion related emission reductions typically yield 'primary benefits' (avoided greenhouse gas emissions) which are global, and 'secondary benefits' (reduction in other pollutants, particularly SO_2, NO_X, CO, VOC and TSP) which are domestic or regional" (Heintz and Tol 1996: 1). There are immediate risks of SO_2 emissions to human health and negative effects on life expectancy. Furthermore, SO_2 causes acid rain. In contrast to global warming and the ozone layer depletion, the problems of emissions affecting human health directly and of acid rain cause primarily regional disutilities[11]. Thus, CO_2 abatement measures, e.g. in the shape of increasing energy efficiency of engines, would provide - additionally to the pure public characteristic - some private characteristic to the countries abating GHGs. Ayres and Walter (1991: 256) point out that concerning fuel consumption air pollution and health costs depend on the specific fuel in use. Accordingly, policies aiming at a reduction of coal burning yield higher secondary benefits than measures decreasing the utilization of natural gas, because the latter fossil fuel causes lower emissions of pollutants.

Now, consider n countries. A country i (i=1,...,n) consumes a bundle of private goods y^i and the impure public good 'GHG abatement measures' x^i. The arguments of the country's utility function consist of the quantity of a pure public characteristic and the quantity of a private characteristic. The quantity of the pure public characteristic is solely generated by GHG abatement measures, while the quantity of the private characteristic contains the amount of private characteristic provided by the bundle of private goods as well as the amount of the private characteristic generated by GHG abatement measures. The country's utility maximization problem can be expressed as follows[12]:

$$U^i(y, x) \tag{1}$$

subject to the technological constraints

$$y = y^i + \theta x^i, \qquad x = x^i + \tilde{X}^i,$$

and the private budget constraint

$$I^i_{pr} = y^i + x^i, \tag{2}$$

[11] Sandler and Sargent (1995: 157) point out that "unlike ozone and global warming, acid rain is a more localized problem with significant country-specific aspects."

[12] Regularly, regarding impure public good problems, more than two characteristics are considered in the utility function (Andreoni 1990, 1998; Cornes 1996; Cornes and Sandler 1994, 1996; Duncan 1999, Harbaugh 1998). Here, only one private characteristic y is considered since it is assumed that the private joint product simply increases the consumption of this private characteristic.

with $1 > \theta \geq 0$ and $\tilde{X}^i \equiv \sum_{j \neq i} x^j.$

The term $y^i + \theta x^i$ represents actor i's consumption of the private characteristic and $x^i + \tilde{X}^i$ represents the consumption of the pure public characteristic. By the provision of one unit of the impure public good 'GHG abatement measures', country i receives one unit of a pure public characteristic x and θ units of a private characteristic y.[13] We assume θ to be constant. Furthermore, country i can 'buy' the private characteristic directly by the acquisition of y^i and other countries' provision of GHG abatement, $\tilde{X}^i$, contributes to country i's consumption of the pure public characteristic. The benefits induced by the pure public characteristic represent the primary and global secondary benefits. The benefits from the private characteristic provided by the impure public good represent the private secondary benefits.
The price for the direct acquisition of a unit of the bundle of private goods and the price for a unit of the impure public good are normalized to unity. Thus, according to the private budget constraint, the increase in the impure public good provision (and with it in x^i) by one unit will decrease the direct acquisition of y^i by one unit[14]. This can be illustrated under consideration of the partial derivative of private budget constraint for x^i. Then, given the private income I^i_{pr}, by rearranging the terms we get

$$\frac{\partial y^i}{\partial x^i} = -1. \tag{3}$$

3 The Matching Model

The regarded matching game, which is based on a model developed by Guttman (1978, 1987), is divided into two stages[15]. In the first stage each of the countries simultaneously commits itself - within the framework of an international agreement - to the provision of a matching rate b.[16] With it, the countries consider how their matching rates influence the provisions on the second stage of the game. The matching contributions take place in the shape of additional GHG abatement measures and can be considered as compensations by countries for other countries' voluntary actions mitigating climate change[17].
In the second stage unconditional flat contributions a - in the shape of GHG abatement

[13]Since there is a one-to-one relation between a country's provision of the impure public good and the pure public characteristic, x^i denotes country i's provision quantity of the impure public good as well as the amount of the pure public characteristic.

[14]Of course, consumption of the private characteristic only decreases by $1 - \theta$ effectively.

[15]As Barrett (1992: 88-89) points out the relevance of Guttman's approach for the explanation of international collective action with the intention to mitigate climate change.

[16]Positive matching rates would lead to positive conjectures. In contrast, a Nash equilibrium implies a zero conjecture. Positive conjectures have - compared to the zero conjecture case - the advantage that "they can lead to less suboptimality by inducing greater contributions" (Sandler and Posnett 1991: 37).

[17]The matching contributions are direct measures of the matching countries in order to mitigate climate change. Otherwise, e.g. concerning contributions in the shape of monetary transfers, the above depiction does not fit.

measures - are fixed.
For this scenario the subgame perfect equilibrium is determined.
Then, when the matching rates are already fixed, the countries become aware of the fact that they have not considered the private secondary effects completely. The importance of the private secondary benefits makes adaptations in the countries' climate policies urgent. Because of the flexibility of the matching scheme corrections remain possible by modifications of the flat rates. For simplicity it is assumed, that the estimates on global secondary benefits do not change.

Nash and Samuelson Optimality Conditions:
Country i's total contribution of the impure public good consists of its flat and matching provisions:

$$x^i = a_i + b_i \sum_{j \neq i} a_j. \tag{4}$$

The total amount of the (impure) public good provided by the n countries is

$$x = \sum_i x^i = \sum_i a_i (1 + \sum_{j \neq i} b_j). \tag{5}$$

For country i it is optimal to provide climate protection measures up to a quantity where the following condition is satisfied:

$$U_x / U_y = (1 - \theta)/(1 + \sum_{j \neq i} b_j). \tag{6}$$

Thus, the quotient of U_x - the marginal utility of the pure public characteristic - and U_y - the marginal utility of the private characteristic - has to equal the effective price of the pure public characteristic to country i.
The substitution of one private income unit spent on the private good y^i by one unit spent on the impure public good x^i effectively gives the country $(1 + \sum_{j \neq i} b_j)$ additional units of the pure public and does only take away $1 - \theta$ units of the private characteristic. Thus, the effective price of the pure public characteristic is $(1 - \theta)/(1 + \sum_{j \neq i} b_j)$.

An increase in the matching rates of the other countries reduces the effective price country i has to pay for the pure public characteristic. With it, the effective price of the impure public good decreases. Furthermore, the effective price of the pure public characteristic decreases with rising secondary benefits[18].

The sum of the matching rates of all countries $j \neq i$ is defined to be r_i. It is further assumed that the utility functions and the incomes of all countries are identical. Besides of some exceptions only symmetrical equilibria are considered and the equilibrium r_i will

[18] The individual optimal quantity of climate measures also depends on other countries' flat rates. An increase of the latter shifts the country's demand function for climate measures to the right since its full income has been raised.

equal the common value r. Instead of the special optimality condition for country i given by equation (6), we can apply a common optimality condition for each single country. Therefore, the *Nash optimality condition* is:

$$U_x/U_y = (1-\theta)/(1+r). \tag{7}$$

Accordingly, the *Samuelson optimality condition* can be expressed. The marginal costs of the pure public characteristic have to be equal to the sum of marginal rates of substitution between pure public characteristic and private characteristic of all n countries:

$$n(U_x/U_y) = 1-\theta. \tag{8}$$

4 Impact of One Country's Matching Rate Modification on the Other Countries' Reaction Functions

4.1 The Reaction Functions

Since a country chooses its optimal matching rate with the knowledge on how its matching rate b influences the equilibrium of the flat rates in the game's second stage, we first have to investigate this influence. For it, the countries' reaction functions in stage two of the game are formulated, and subsequently, the impact of one country's matching rate modification on the other countries' reaction functions investigated. It is assumed that in the equilibrium all countries have equal matching rates, and furthermore, choose the same 'isolation demand' x^* as well as the same 'isolation flat rate' a^*. Isolation flat rate a^* and isolation demand x^* are defined to represent a country's individual optimal flat rate and demand respectively for a situation where this country is the only contributor of a flat rate. Isolation demand and isolation flat rate are both functions of the matching rates.

The reaction functions in stage 2 can be expressed:

$$\begin{aligned} a_i &= a_i^* - \gamma_{ij}(n-1)a_j \qquad && for\ i \\ a_j &= a_j^* - \gamma_{jj}(n-2)a_j - \gamma_{ji}a_i \qquad && for\ j \neq i \end{aligned} \tag{9}$$

where γ_{ij},γ_{ji} and γ_{jj} are reaction coefficients.

As we will see in the subsequent investigation, the reaction coefficients will never exceed unity. Therefore, if country i would provide the isolation flat rate and the other countries would start to contribute positive flat rates, the sum of all flat contributions will exceed the isolation flat contribution though the flat contribution of country i will decline[19]. This is a consequence of the positive income effect generated by the additional contribution of pure public characteristics raising the countries' demand for GHG abatement measures. Furthermore, the 'stickiness' of country i to provide flat contributions

[19]This holds as long as $b \neq 1$; if b equals unity, the reaction coefficient also becomes unity. Then, country i's flat contribution is crowded out by the other countries' flat contributions.

raises with increasing θ, i.e. the sum of the flat contributions will exceed the isolation flat rate the more, the larger the amount of the private characteristic, provided by a unit of the impure public good, becomes.

4.2 Impact of a Country's Matching Rate Modification on the Isolation Flat Rate

In order to explore the impact of country i's matching rate modification on other countries' reaction functions, the impacts on the single terms on the right hand side of (9) are derived. For it, we start with the first term on the right hand side, i.e. explore the impact of a modification in one country's matching rate on other countries' isolation flat rates. Regarding equation (4) country j's isolation flat rate can be expressed:

$$a_j^* = x_j^*/(1 + r_j). \tag{10}$$

The derivation of the expression for da_j^*/db_i is divided into three steps. In order to determine the impact of a country i's change (with $i \neq j$) in its matching rate b_i on other countries' isolation flat rates, the impact of b_i on the isolation demands x_j^* of all other (n-1) countries has to be derived first; this happens in the steps one and two. The expression for dx_j^*/db_i derived in the first two steps is employed in step three in order to determine the impact of a rise in country i's matching rate on country j's isolation flat rate.

Step 1: The effect of b_i on the effective price of the pure public characteristic will be calculated.

Since the country setting its matching rate takes the matching rates of the other (n-1) countries as given, i.e. $db_k/db_i = 0$ for all $k \neq i$, the effect of an increase in country i's matching rate on r_j is

$$dr_j/db_i = 1 + \sum_{\substack{k \neq j \\ k \neq i}} (db_k/db_i) = 1. \tag{11}$$

Hence, the influence of a change in b_i on the effective price is:

$$d[(1-\theta)/(1+r_j)]/db_i = -\frac{1-\theta}{(1+r_j)^2}. \tag{12}$$

Rearranging yields:

$$d[(1-\theta)/(1+r_j)] = -\frac{1-\theta}{(1+r_j)^2} db_i. \tag{13}$$

Step 2: The expression for uncompensated price elasticity of demand for the pure public characteristic, ϵ, has to be reformulated and introduced into the expression calculated in the first step.

Reformulation of the expression for the uncompensated price elasticity of demand, ϵ, for the pure public characteristic yields:

$$d[(1-\theta)/(1+r_j)] = \frac{-dx_j^*}{\epsilon} \frac{1-\theta}{1+r_j} \frac{1}{x_j^*}. \tag{14}$$

By combining (13) and (14) we obtain

$$dx_j^*/db_i = \frac{\epsilon x_j^*}{1+r_j}. \tag{15}$$

This equation specifies how the modification of country i's matching rate b_i influences every single country j's isolation demands for the impure public good, assuming the demands of the single countries j, with $j \neq i$, to be all the same[20].

Step 3: Finally, by employing equation (15) and the derivation of equation (10) with regard to b_i, we receive the effect of a rise in b_i on a_j^*:[21]

$$\begin{aligned}\frac{\partial a_j^*}{\partial b_i} &= \frac{\frac{\epsilon x_j^*}{1+r}(1+r) - x_j^*}{(1+r)^2} \\ &= \frac{(\epsilon - 1)a_j^*}{(1+r)}. \end{aligned} \tag{16}$$

4.3 Impact of a Country's Matching Rate Modification on the Reaction Coefficients

In order to be able to determine the full impact of a rise in one country's matching rate above the common rate on the equilibrium in the second stage of the game, the impacts on the reaction coefficients have also to be explored. First, the reaction coefficients themselves have to be determined. The reaction coefficients can be derived with the help of the 'full income' conception[22]. In contrast to the private income the full income additionally considers income enjoyed from the other countries' provision of the public good. The total income of country j can be expressed as

$$I^j = x + y = x^j + y^j + \theta x^j + \tilde{X}^j = \sum_i a_i(1 + \sum_{i \neq k} b_k) + y^j + \theta(a_j + b_j \sum_{i \neq j} a_i). \tag{17}$$

In order to determine the reaction coefficients the effect of the change in a country i's flat contribution on another country j's flat contribution is derived. By k=(1,2, ..., i-1, i+1, ..., j-1, j+1, ..., n) the remaining (n-2) countries are denoted.
Then, the change in country j's full income is

$$dx + dy = (1 + r_j)(da_j)^* + b_j da_i + dy^j + da_i(1 + \sum_{\substack{k \neq i \\ k \neq j}} b_k) + \theta[(da_j)^* + b_j da_i]. \tag{18}$$

Here, $(da_j)^*$ stands for the optimal change in actor j's flat contribution in response to da_i. Because private income constraint (2) of country j is assumed to be constant, and

[20] Remember the one-to-one assumption, which constitutes that by the provision of one unit of the impure public good one unit of the pure public characteristic is provided.
[21] Consider the assumption made in equation (11).
[22] 'Full income' is just another expression for Becker's (1974) conception of 'social income'.

hence, has not altered at all, the change in total income of country j is only induced by changes of other countries' contributions of the impure public good and the change in the quantity of country j's jointly - with the pure public characteristic - generated private characteristic induced by substitutions between y^j and x^j. More accurately, country j's full income changes by

- the change in country i's flat contribution plus the effect of the other (n-2) countries' response - in the shape of a modification in their matching contributions - to this modification: $da_i(1 + \sum_{\substack{k\neq j \\ k\neq i}} b_k)$;
- the reaction of the other (n-1) countries - in the shape of a modification in their matching contributions - to the induced change in actor j's flat contribution: $r_j(da_j)^*$;
- the change in the quantity of the jointly generated private characteristic, caused by the substitutions between y^j and x^j: $\theta[(da_j)^* + b_j da_i]$.

Equating these changes to the right-hand side of equation (18) we have:

$$\theta[(da_j)^* + b_j da_i] + da_i(1 + \sum_{\substack{k\neq j \\ k\neq i}} b_k) + r_j(da_j)^*$$
$$= \theta[(da_j)^* + b_j da_i] + da_i(1 + \sum_{\substack{k\neq i \\ k\neq j}} b_k) + (da_j)^*(1 + r_j) + b_j da_i + dy^j. \tag{19}$$

This can be rearranged in order to get:

$$1 - \frac{dy^j}{dx + dy} = 1 + \frac{b_j da_i + (da_j)^*}{da_i(1 + \sum_{\substack{k\neq j \\ k\neq i}} b_k + \theta b_j) + (da_j)^*(\theta + r_j)}. \tag{20}$$

The left-hand side represents the income elasticity (η) of demand for the good 'GHG abatement measures' multiplied by the share (s_{xy}) of this good in the country's full income. Thus, we can write

$$\frac{(da_j)^*}{da_i} = \frac{(s_{xy}\eta - 1)[1 + (n-2)b_k + \theta b_j] - b_j}{1 + (\theta + r_j)(1 - s_{xy}\eta)}. \tag{21}$$

Multiplied by minus one, we have the expression for the the reaction coefficient γ_{ji}:

$$\gamma_{ji} = \frac{(1 - s_{xy}\eta)[1 + (n-2)b_j + \theta b_j] + b_j}{1 + (\theta + r_j)(1 - s_{xy}\eta)}.$$

And for γ_{ij} and γ_{jj}, where $\gamma_{jj} = -da_j/da_k, k \neq j \neq i$:

$$\begin{aligned} \gamma_{ij} &= \frac{(1 - s_{xy}\eta)[1 + (n-2)b_j + \theta b_i] + b_i}{1 + (\theta + r_i)(1 - s_{xy}\eta)}; \\ \gamma_{jj} &= \frac{(1 - s_{xy}\eta)[1 + (n-3)b_j + \theta b_j + b_i] + b_j}{1 + (\theta + r_j)(1 - s_{xy}\eta)}. \end{aligned}$$

Deriving the reaction coefficients with regard to b_i yields

$$\partial\gamma_{ij}/\partial b_i = \frac{(1-s_{xy}\eta)\theta+1}{1+(\theta+r_i)(1-s_{xy}\eta)};$$

$$\partial\gamma_{ji}/\partial b_i = -\frac{\gamma_{ji}(1-s_{xy}\eta)}{1+(\theta+r_j)(1-s_{xy}\eta)}; \tag{22}$$

$$\partial\gamma_{jj}/\partial b_i = \frac{(1-s_{xy}\eta)(1-\gamma_{jj})}{1+(\theta+r_j)(1-s_{xy}\eta)}.$$

4.4 Impacts of Matching and Flat Rate Changes on the Reaction Functions

As already pointed out, country can influence the other countries' reaction functions, and therefore, the equilibrium on stage 2 by changes in its matching rate. The knowledge on this influence is employed by the single countries when they decide on the values of their matching rates. Now, that the impacts of a rise in one country's matching rate on other countries' single components of their reaction functions are derived, the whole effect of this matching rate rise on the equilibrium in the second stage can be summarized. A rise of one country's matching rate above the common matching rate of the others has the following effects on the equilibrium in stage 2:

- The rise induces a shift in the other countries' reaction curves. The shift of the reaction curves of the countries j - keeping their matching rate constant on a common level - can be observed from equation (16). The shift is outwards if the derivative is non-negative. This is the case if we assume that $\epsilon > 1$ and that $r_j \geq -1$.

- Furthermore, the reaction curves rotate because the slopes of the reaction curves are themselves functions of the increased matching rate; the reaction function of the country increasing its matching rate rotates inwards (in the point determining its isolation flat contribution) and the reaction functions of the other countries rotate outwards in the point determining their 'new' isolation flat contributions. The effect of the matching rates on the reaction coefficients - and with it, on the slopes of the reaction functions - can be observed from the derivations of the reaction coefficients

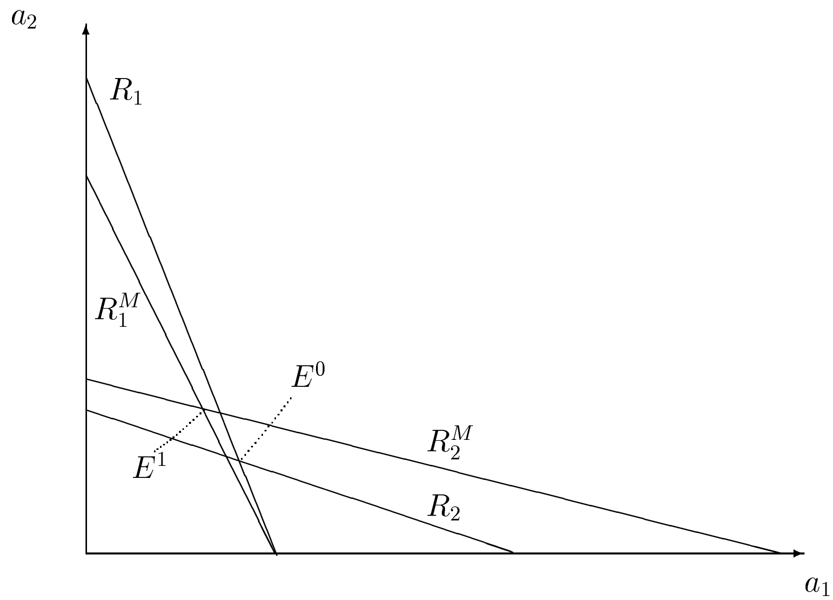

Figure 1: Effects of Country 1's Matching Rate Increase.

The modifications (R_1^M and R_2^M) of the reaction functions (R_1 and R_2), caused by country 1 raising its matching rate, are illustrated in Figure 1.[23] As can be observed from Figure 1, country 1's flat rate decreases while the other country's flat rate rises.
The total effect $(n-1)\frac{\partial a_j}{\partial bi}$ of the rise of a country i's matching rate on the other (n-1) countries flat contributions can be derived analytically and is presented in Appendix A.4. A rise in country i's matching rate lowers the effective price of the impure public good to the other countries. Therefore, the other countries' demand for the impure public good rises and with it, the flat contributions of the other countries increase as long as the uncompensated price elasticity of demand for the pure public characteristic is not too small. The elasticity needs not to exceed unity because there is the 'rotation effect' mentioned above, which also has a positive influence on the other (n-1) countries' flat contributions. With rising flat rates of these countries, the matching component in country i's income will increase. The impact of a rise in the other (n-1) countries' flat rates on the reaction function of the regarded country i can be easily observed from (9). The reaction functions show that a country reduces its flat contribution if another country raises its flat rate.

5 Increasing Awareness and the Leakage Effect

Now, if we assume that on stage 2 (when stage 1 has already passed) the countries become more aware of regional secondary effects and with it, of private secondary benefits, then the countries would increase their estimates of θ in their reasoning. By the integration

[23] A similar figure can be found in Guttman (1987: 9) for the pure public good case.

of additional private secondary effects the effective price for the impure public good decreases. Thus, the reaction functions move outwards.
Additionally, the reaction functions rotate (see Figure 2). A rise in one country's contribution will induce the other countries to reduce their contribution by less than the amount they would reduce it in the pure public good case or in any other case where θ is lower, i.e. the easy rider incentives decrease[24]. If the countries would respond with a reduction of the same quantity as in the latter cases they would be worse off, because they give up the same quantity of the pure public characteristic as in these cases but additionally loose (more of the) private secondary benefits. Thus, the so-called leakage effect, i.e. the decrease of environmental standards as a response to the voluntary increase by another country, will be mitigated. The proof for this is presented in Appendix B.

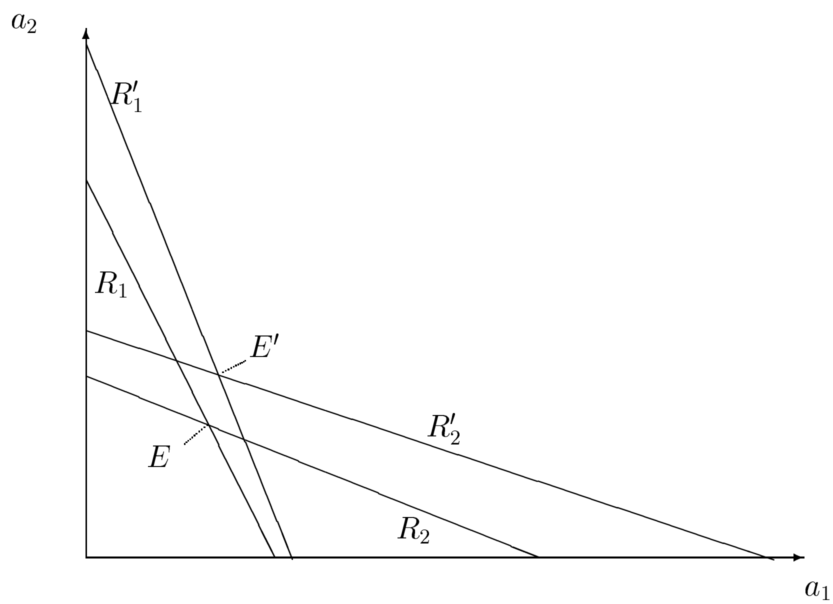

Figure 2: Reaction Functions Completely Considering (R') and Partially Considering (R) Secondary Benefits.

Accordingly, the equilibrium flat provision of the impure public good 'GHG abatement' which is determined by the intersection of the reaction pairs, is higher in the case where private secondary effects are completely considered. The equilibrium regarding higher private secondary benefits is indicated by E' and the one regarding less is E. The equilibrium provision has increased because the privateness of the impure public good has risen and its effective price has lowered by the full integration of private secondary effects in the investigation.

[24]This holds for all values for b in the economically relevant range, except for the upper limit $b = 1$, where the slope of the reaction functions is obviously not influenced by the private secondary benefits. For the determination of the relevant range of b, see section 6.

6 Investigation of the Matching Rate

The country's choice of an optimal matching rate is done with the knowledge of how its matching rate b influences the equilibrium of the flat contributions in the game's second stage. This influence has been investigated in chapter 4.
But the determination of the optimal matching rate is complex and it isn't even guaranteed if a utility maximum will be determined. To handle these associated problems first the economically sensible range of matching rates is determined. The computation of the equilibrium matching rate b is delegated to Appendix A.

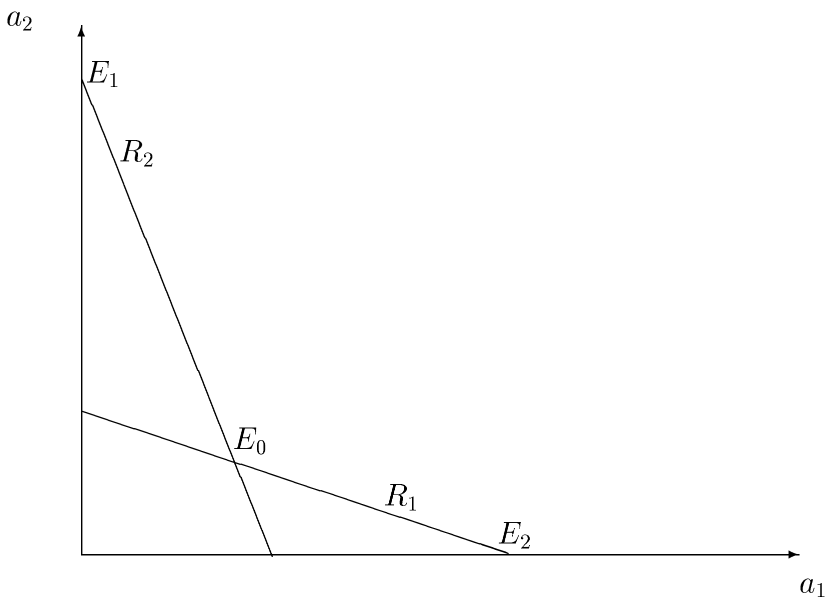

Figure 3: Corner Solutions.

Upper Limit:
The slope of the reaction functions in the stage where the flat rates are determined equals -1 if there is a critical value of $b = 1$ prevailing[25]. Since only symmetrical equilibria are considered, the reaction functions of the single countries have to coincide[26]. If b exceeds unity, the value of the slope is lower than -1 and the symmetric equilibrium E_0 becomes unstable while the corner solutions E_1 and E_2 are stable (see Figure 3)[27]. If $b < 1$, there prevails the possibility of an unique symmetrical equilibrium.
Now, it has to be investigated more concisely, which incentives might exist for country i starting from a matching rate $b = 1$ to increase this rate. With an elasticity $\epsilon \geq 1$ the outcome would be that $a_i = 0$ since the reaction functions of the j countries (with $j \neq i$)

[25]This can be checked by simply setting each b in the reaction coefficients equal to unity. Then, the coefficients become equal to unity, and therefore, the reaction functions have the slope of -1.

[26]The symmetrical equilibrium prevails where every country i chooses its flat rate a_j to equal $\sum_{i=1}^{n} a_i/n$.

[27]Local stability of the equilibrium E_0 requires that $\frac{da_1}{da_2}\frac{da_2}{da_1} < 1$. For an analysis of local stability see Cornes (1980).

move outwards[28]. Now we consider, which effect on country i's utility results in this case. The sum of flat contributions by the other countries after the rise in b_i is

$$\frac{x_0 + dx}{1 + r_j} = \frac{x_0 + dx}{n + db_i}. \tag{23}$$

Therefore, country i's provision of the impure public good increases - from $\frac{x_0}{n}$ to $\frac{x_0+dx}{n+db_i}(1+db_i)$ - though country i's flat contribution becomes zero. Here, dx is the change in the impure public good provision induced by country i increasing its matching rate. Furthermore, let db_i be the change in b_i and x_0 the quantity of the total provision of the impure public good 'GHG abatement measures' when all matching rates are equal to 1. The change in country i's private good consumption is

$$dy^i = \{-\frac{x_0 + dx}{n + db_i}[1 + db_i] + \frac{x_0}{n}\}(1 - \theta) < 0, \tag{24}$$

i.e. country i's private good consumption decreases. The total change in country i's utility divided by U_y is represented by

$$\frac{U_x}{U_y}dx + dy^i. \tag{25}$$

Because before the change we had $\frac{U_x}{U_y} = \frac{1-\theta}{n}$, and this value decreases as x rises, it characterizes an upper limit for $\frac{U_x}{U_y}dx + dy^i$,

$$\frac{dx(1 - \theta)}{n} - \{\frac{x_0 + dx}{n + db_i}[1 + db_i] - \frac{x_0}{n}\}(1 - \theta). \tag{26}$$

This term is unambiguously negative for $n \geq 2$ and $db_i > 0$. Thus, in this case no incentives exist to increase b and relevant matching rates do not exceed 1.

For the case of $\epsilon < 1$, it can be demonstrated that country i's provision of the impure public good 'GHG abatement measures' and its utility remain unchanged if it raises its matching rate above unity. By the rise in b_i the other countries' reaction curves move inwards and country i is left as the only provider of a flat contribution. Then, country i solely substitutes its matching contributions by flat contributions and keeps its total contribution constant. Before the change in b_i country i provided a total contribution of $\frac{a^*}{n} + \frac{(n-1)a^*}{n} = a^*$, which equals its isolation flat rate. Therefore, global contribution of the impure public good 'GHG abatement measures' was equal to na^*. After the rise in b_i country i contributes a flat contribution of a^* which is matched by the other countries with a rate $b = 1$. Hence, country i's as well as the global provision of 'GHG abatement measures' remain unchanged.
We can conclude that no incentives prevail for any country to increase its matching rate above unity.

<u>Lower Limit:</u> The lower limit is determined by $-\frac{1}{n-1}$, which yields an infinite effective

[28] This can be observed from equation (16).

price for the public characteristic. With it, the demanded quantity of the impure public good becomes zero. Therefore, a higher price couldn't reduce the demand anymore.

Thus, the relevant range of matching rates lie on the interval $]-\frac{1}{n-1},1]$. The unique matching rate satisfying the first-order condition for maximum utility has to be located in this range. As we calculated in Appendix A, this matching rate has to correspond to the value of γ^*:

$$\begin{aligned}\gamma^* &= \frac{\frac{\theta}{s(n-1)}\{n-(1-s)[(\epsilon-1)\theta+1]-(n-2)[\epsilon s+s]-n\epsilon\}}{1+\frac{\theta}{s}-\theta} \\ &+ \frac{\frac{1-\epsilon}{(n-1)(1-s)}-\epsilon+\frac{n-2}{n-1}}{1+\frac{\theta}{s}-\theta}. \end{aligned} \tag{27}$$

Of course, this first-order condition does not guarantee an utility maximum. And even if an utility maximum is prevailing for a matching rate in the relevant range, this Nash equilibrium is unstable. In the relevant range, values of b initially exceeding the equilibrium rate will increase up to the upper level of this range. Values of b lower than the equilibrium matching rate will decrease until they reach the lower limit $-\frac{1}{n-1}$. This results from the facts (see Appendix A.4) that

$$\frac{\partial U}{\partial b} = \begin{cases} <0 & for \quad \gamma<\gamma^* \\ \;\;0 & for \quad \gamma=\gamma^* \\ >0 & for \quad \gamma>\gamma^* \end{cases}$$

and that

$$\frac{\partial b}{\partial \gamma} > 0$$

for $b \in [-\frac{1}{n-1},1]$.
If γ^* lies below $-\frac{1}{n-1}$ then γ will always be above γ^* and the matching rate will rise up to unity. Then, the matching rate inducing a Pareto-optimal solution coincides with the upper provision level, since the Samuelson optimality condition $n(U_x/U_y)=1-\theta$ is satisfied[29].

[29]In the case where every country provides a matching rate of unity, the effective price becomes equal to $\frac{1-\theta}{n}$. The Nash optimality condition postulates an equality of effective price and marginal substitution rate. By transformation of this condition we get the Samuelson optimality condition. Thus, individually and collectively optimal matching rate coincide.

7 Private Secondary Benefits and Renegotiation

As mentioned before, the commitment to provide a distinct matching rate will be realized on stage one of the game. On stage two the flat rates are set and with it, the all-over matching provisions are determined.
On stage two, after the international agreement has already fixed the matching rates, the countries' awareness on the regional secondary effects and with it, the estimates on the private secondary benefits are assumed to rise. Therefore, the parameter θ increases. Now, it has to be checked, if a renegotiation becomes necessary to achieve a Pareto-optimal level of GHG abatement. Furthermore, the cases will be distinguished where a renegotiation might induce Pareto-improvements and where not.
In the last section it has been demonstrated that there might be solutions for the subgame perfect equilibrium which yield a matching rate $b = 1$ for all countries and this matching rate implies that Nash- and Pareto-optimal provision level of the impure public good coincide. The correspondence of Nash and Samuelson optimality condition holds in this case regardless of the amount of the private characteristic provided by a unit of the impure public good. As it is observable from the Nash and Samuelson optimality conditions in (7) and (8) respectively, a rise in θ is accompanied by a decrease in the marginal rate of substitution U_x/U_y in the case where all matching rates are fixed to equal unity. A decrease in the marginal rate of substitution arises if the provision of the impure public good increases relatively to the consumption of the private good. Since the matching rates are fixed, the flat rates have to rise and this will induce an increase in the matching contributions (but the matching rates remain unchanged). The countries will rise their contributions until the marginal rate of substitution equals the effective price of the pure public characteristic, i.e. until the Nash optimality condition is satisfied; with it, the Samuelson condition is met. Thus, the Pareto-optimum remains without the necessity of a costly international renegotiation.

But for matching rates lower than unity, an international renegotiation might cause a Pareto-improvement. It is assumed that the starting bid in the renegotiation is the former negotiated matching rate. The former negotiated matching rate serves as a focal point. Here, the focal point does not represent the outcome of the renegotiation but serves as a sign of where to look for the outcome of the renegotiation[30]. Two cases are distinguished since the impact of θ on the equilibrium matching rate is ambiguous[31].

1) The new equilibrium matching rate b^{**}, i.e. the rate that considers the modified value of θ, is lower than the former equilibrium matching rate b^*: When the former stipulated matching rate neither corresponds to the lowest nor the highest value of the economically relevant range a renegotiation will induce a Pareto-improvement. This is a consequence from starting the renegotiation with a proposal that exceeds the utility maximizing matching rate, which considers the new estimates on private secondary benefits. Because of the instability of the equilibrium the renegotiated matching rate will become unity and therefore, Pareto-optimal. If the former negotiated matching rate equals to

[30] On the issue of focal points see Schelling (1980: 111-113).
[31] The case where former and new equilibrium matching rate coincide is neglected.

Former Negotiated Matching Rate	Relations Between Former Matching Rate and New Equilibrium Matching Rate b^{**}	A Renegotiation Leads to a Pareto-Improvement
1	of no importance	**no**
b^*	$b^* > b^{**}$	**yes**
$-1/(n-1)$	$-1/(n-1) > b^{**}$	**yes**
	$-1/(n-1) = b^{**}$	**no**
	$-1/(n-1) < b^{**}$	**no**

Table 1: Scenarios for the Renegotiation of Matching Rates (Case 1).

Former Negotiated Matching Rate	Relations Between Former Matching Rate and New Equilibrium Matching Rate b^{**}	A Renegotiation Leads to a Pareto-Improvement
1	of no importance	**no**
b^*	$b^* < b^{**}$	**no**
$-1/(n-1)$	$-1/(n-1) > b^{**}$	**yes**
	$-1/(n-1) = b^{**}$	**no**
	$-1/(n-1) < b^{**}$	**no**

Table 2: Scenarios for the Renegotiation of Matching Rates (Case 2).

-1/(n-1) the result is ambiguous.

For the given case Table 1 illustrates when a Pareto-improvement is possible and when not.

2) The new equilibrium matching rate b^{**}, i.e. the rate that considers the modified value of θ, is larger than the former equilibrium matching rate b^*: When the former matching rate equals the equilibrium matching rate b^*, a renegotiation cannot improve the outcome. If a renegotiation is initiated and the starting bids are among the former matching rate, the new matching rate will coincide with the lower limit $-1/(n-1)$. In a situation where the former matching rate is equal to the lower limit $-1/(n-1)$ the result is ambiguous. Interestingly, when a higher 'new' equilibrium matching rate arises, the possibility of inducing a Pareto-improvement with the help of new negotiations becomes more unlikely (compared to case 1). In the case of a higher propensity to match other countries' flat contributions a renegotiation might even worsen the outcome.

For the second case Table 2 illustrates when a Pareto-improvement is possible and when not.

8 Concluding Remarks

As the preceding chapters demonstrated, an intensified consideration of private secondary benefits of climate policies raises the incentives to provide the impure public good "GHG abatement measures" because the effective price of climate measures decreases. But if GHG abatement levels are already negotiated internationally, a consideration of additional benefits would be costly: It will be necessary to renegotiate the international agreements. In contrast, the flexibility of the investigated matching scheme - which determines fixed matching rates but no fixed abatement quantities - allows at least partially corrections of former false estimates of GHG abatement benefits. This might reduce the urgency for an international renegotiation of abatement commitments or even make them unnecessary. This result suggests to make international negotiation schemes more flexible. Politics and even science still do not seize all benefits of climate policies. Countries working on international agreements should consider this and integrate mechanisms which allow for adaptations without large expense if new insights are gained.

Finally, in order to put the results in perspective the two main simplifications of the considered model are pointed out: the assumptions of identical countries and of countries' commitment fulfillment.

By the assumption of identical countries[32], asymmetries between countries concerning, e.g. abatement benefits and costs are neglected[33]. Furthermore, in many developing countries the perception of the climate problem is much smaller than the perception of other problems like poverty or regional environmental problems (low air quality inducing high mortality rates of children, for example). Thus, the importance of secondary benefits might be much larger in developing than in industrialized countries. Further research has to be done in order to investigate how these asymmetries between countries might even improve the outcome of international cooperation. By stressing the link between primary and secondary aspects of climate policies, GHG abatement policies might become more attractive for developing countries.

Furthermore, why should countries fulfill their commitments to provide distinct matching rates? One possible justification for the assumption that commitments will be fulfilled is that the international agreement is subject to international law and countries might be disinclined to break this law. Another justification is that countries are interacting in different fields. Thus, missing cooperation in the environmental field could have negative effects on other fields like trade. The agreement on stage one could also be linked explicit with other issues in order to achieve a self-enforcing agreement[34].

[32]This assumption was necessary in order to cope with the many information in this model.

[33]Hackl and Pruckner (1998) investigate abatement scenarios by considering data comprising annual emissions of CO_2, methane, and CFCs for 135 countries. They point out that there are divergencies - especially between developed and less developed world - concerning abatement cost. For the evaluation of abatement benefits in developed and developing countries see Fankhauser, Tol and Pearce (1998).

[34]Issue linkage with club goods is intensely investigated by Carraro and Siniscalco (1998: 565-566) as well as by Carraro (1999: 14-16).

The simplifications considered here may provide opportunities for further research. Especially an investigation of collective action between asymmetric countries under consideration of primary and secondary benefits as well as transfers seems to be promising[35].

Appendix

A Investigation of the Optimal Matching Rate

A.1 Utility Maximization

To find the optimal matching rate we should start by maximizing country i's utility with respect to b_i:

$$\frac{\partial U}{\partial b_i} = U_x(\partial x/\partial b_i) + U_y(\partial y^i/\partial b_i) + U_y(\partial y/\partial x^i)(\partial x^i/\partial b_i) = 0. \tag{A1}$$

Since all countries are assumed to be identical, all will be at an interior solution such that

$$\frac{U_x}{U_y} = \frac{1-\theta}{1+r}. \tag{A2}$$

We employ this equation to simplify (A1) to:

$$\{\frac{\partial x}{\partial b_i} + \frac{1+r}{1-\theta}[\frac{\partial y^i}{\partial b_i} + \theta\frac{\partial x^i}{\partial b_i}]\}U_x = 0. \tag{A3}$$

A.2 Consideration of the First Term on the Left-hand Side of Equation (A2)

We assume that $\partial r_i/\partial b_i = 0$ and, that subjectively to i, $\partial r_j/\partial b_i = 1$ for all $j \neq i$. The total provision can be expressed by

$$x = \sum a_j(1+r_j) + a_i(1+r_i).$$

Thus, we have

$$\frac{\partial x}{\partial b_i} = \sum_{j\neq i}(1+r_j)\frac{\partial a_j}{\partial b_i} + \sum_{j\neq i} a_j + (1+r_i)\frac{\partial a_i}{\partial b_i}. \tag{A4}$$

[35] As Cesar and de Zeeuw (1996: 158-159) point out, transfers in the shape of "side-payments are rare in the practice of international agreements." Transfers by issue linkage seem "to be preferred in the arena of international negotiations." Thus, especially issue linkage seems to be the kind of transfer that is highly relevant for further investigations.

To express this equation more precisely we specify the partial derivatives of this equation. Differentiating the first equation of (9) with respect to b_i we get

$$\frac{\partial a_i}{\partial b_i} = -\gamma_{ij}(\partial \sum_{j \neq i} a_j / \partial b_i) - (\sum_{j \neq i} a_j)\partial \gamma_{ij}/\partial b_i. \tag{A5}$$

This equation can be written more precisely by introducing the expression for the last partial derivative which we already determined in (22). Substituting the expression for $\frac{\gamma_{ij}}{b_i}$ into (A3), we obtain:

$$\frac{\partial a_i}{\partial b_i} = -\gamma_{ij}(n-1)\frac{\partial a_j}{\partial b_i} - \frac{(n-1)a_j[(1-s_{xy}\eta)\theta + 1]}{1 + (\theta + r_i)(1 - s_{xy}\eta)}. \tag{A6}$$

By substituting (A3) into (A2) and considering that in equilibrium we have $r_i = r_j = r$:

$$\frac{\partial x}{\partial b_i} = (1+r)(n-1)(1-\gamma_{ij})\frac{\partial a_j}{\partial b_i} + (n-1)a_j[1 - \frac{[(1-s_{xy}\eta)\theta + 1](1+r)}{1 + (\theta + r)(1 - s_{xy}\eta)}]. \tag{A7}$$

A.3 Consideration of the Second and Third Term on the Left-hand Side of Equation (A2)

First, we consider country i's private budget constraint given by equation (2) and describe it more precisely:

$$I^i_{pr} = x^i + y^i = a_i + b_i \sum_{j \neq i} a_j + y^i = constant. \tag{A8}$$

Accordingly, we obtain

$$\frac{\partial y^i}{\partial b_i} = -\frac{\partial x^i}{\partial b_i} = -[\frac{\partial a_i}{\partial b_i} + (n-1)a_j + b_i(n-1)\frac{\partial a_j}{\partial b_i}]. \tag{A9}$$

Substituting (A3) into the above equation and simplifying, we get

$$\frac{\partial y^i}{\partial b_i} = -(b_i - \gamma_{ij})(n-1)\frac{\partial a_j}{\partial b_i} - (n-1)a_j\frac{r(1-s_{xy}\eta)}{1 + (\theta + r)(1 - s_{xy}\eta)}. \tag{A10}$$

Thus, for $\theta \partial x^i / \partial b_i$ we have

$$\theta\frac{\partial x^i}{\partial b_i} = \theta(b_i - \gamma_{ij})(n-1)\frac{\partial a_j}{\partial b_i} + \theta(n-1)a_j\frac{r(1-s_{xy}\eta)}{1 + (\theta + r)(1 - s_{xy}\eta)}. \tag{A11}$$

A.4 Determination of the Optimal Matching Behaviour

Substituting (A2), (A3) and (A4) into (A2), dividing by $U_x > 0$ and shortening $s_{xy}\eta$ simply to s, we obtain

$$\begin{aligned}
&(1+r)(1-\gamma_{ij})\frac{\partial a_j}{\partial b_i} + a_j\{1 - \frac{[(1-s)\theta + 1](1+r)}{1 + (\theta + r)(1-s)}\} \\
&+\frac{1+r}{1-\theta}\{-(b_i - \gamma_{ij})\frac{\partial a_j}{\partial b_i} - \frac{a_j r(1-s)]}{1 + (\theta + r)(1-s)}\} \\
&+\theta\frac{1+r}{1-\theta}\{(b_i - \gamma_{ij})\frac{\partial a_j}{\partial b_i} + \frac{a_j r(1-s)}{1 + (\theta + r)(1-s)}\} = 0.
\end{aligned} \tag{A12}$$

Rearranging terms yields

$$\frac{\partial a_j/\partial b_i}{a_j} = \frac{r(1-s)[1+r+\theta]+rs}{(1+r)(1-b_i)[1+(1-s)(\theta+r)]}. \tag{A13}$$

In order to get the optimal b_i that satisfies (A2) we must determine the expression $\partial a_j/\partial b_i$ more precisely. We first have to solve equations (16) simultaneously. Then we obtain

$$a_j = \frac{a_j^* - \gamma_{ji}a_i^*}{1+(n-2)\gamma_{jj}-(n-1)\gamma_{ji}\gamma_{ij}}. \tag{A14}$$

To get the expression for (n-1) countries we have to multiply the equation above simply by (n-1):

$$(n-1)a_j = \frac{a_j^* - \gamma_{ji}a_i^*}{\frac{1}{n-1}+\frac{n-2}{n-1}\gamma_{jj}-\gamma_{ji}\gamma_{ij}}. \tag{A15}$$

Differentiation with respect to b_i yields

$$(n-1)\frac{\partial a_j}{\partial b_i} = \frac{(\frac{\partial a_j^*}{\partial b_i} - \frac{a_i^*\partial\gamma_{ji}}{\partial b_i}) - (n-1)a_j(\frac{n-2}{n-1}\frac{\partial\gamma_{jj}}{\partial b_i} - \frac{\gamma_{ji}\partial\gamma_{ij}}{\partial b_i} - \frac{\gamma_{ij}\partial\gamma_{ji}}{\partial b_i})}{\Delta} \tag{A16}$$

where

$$\Delta = \frac{1}{n-1}+\frac{n-2}{n-1}\gamma_{jj}-\gamma_{ji}\gamma_{ij}$$

Using (16) and (22), this becomes

$$\begin{aligned}(n-1)\frac{\partial a_j}{\partial b_i} \quad &= \frac{1}{\Delta}[\frac{(\epsilon-1)a_j^*}{1+r}+\frac{a_i^*\gamma_{ji}(1-s)}{1+(\theta+r)(1-s)}] \\ &-\frac{(n-1)a_j}{\Delta}[\frac{1}{1+(\theta+r)(1-s)}][\frac{n-2}{n-1}(1-s)(1-\gamma_{jj}) \\ &-\gamma_{ji}[(1-s)\theta+1]+\gamma_{ij}\gamma_{ji}(1-s)].\end{aligned} \tag{A17}$$

Next, we consider the symmetry conditions of equilibrium of identical countries. Thus we set γ equal to a common γ, $b_i = b_j = b$, and $a_i^* = a_j^* = a^*$. Equation (A3) becomes

$$(n-1)a_j = \frac{a^*(1-\gamma)}{\Delta} \tag{A18}$$

where

$$\Delta = (1-\gamma)[\gamma + \frac{1}{n-1}]. \tag{A19}$$

From the reaction coefficient we can deduce

$$1-\gamma = \frac{(1-b)[s(1-\theta)+\theta]}{1+(1-s)(\theta+r)}. \tag{A20}$$

We set the denominator of the equation above equal to δ:

$$\delta = 1 + (1-s)(\theta + r).$$

Now, we can substitute (A5) into (A2); we employ equations (A5) and (A7), which we developed under the symmetry conditions of equilibrium:

$$\begin{aligned}\frac{r}{(1+r)(1-b)} \quad &= \{\frac{(\epsilon-1)\delta}{1+r} + \gamma(1-s)\}\frac{1}{(1-b)[\theta(1-s)+s]} \\ &-\frac{1}{\Delta\delta}\{\frac{n-2}{n-1}(1-s)(1-\gamma) - \gamma[(1-s)\theta + 1] \\ &+\gamma^2(1-s)\} \end{aligned} \tag{A21}$$

Multiplying both sides of the equation above by $(1-b)$ we obtain

$$\begin{aligned}\frac{r}{1+r} \quad &= \{\frac{(\epsilon-1)\delta}{1+r} + \gamma(1-s)\}\frac{1}{\theta(1-s)+s} \\ &-\frac{1-b}{\Delta\delta}\{\frac{n-2}{n-1}(1-s)(1-\gamma) - \gamma[(1-s)\theta + 1] \\ &+\gamma^2(1-s)\} \end{aligned} \tag{A22}$$

Now, we consider that $\delta/(1+r) = 1 - \frac{rs-\theta(1-s)}{1+r}$:

$$\begin{aligned}&\frac{r}{1+r} = \{(\epsilon-1) - \frac{(\epsilon-1)[rs-\theta(1-s)]}{1+r} + \gamma(1-s)\}\frac{1}{\theta(1-s)+s} \\ &-\frac{1-b}{\delta\Delta}\{\frac{n-2}{n-1}(1-s)(1-\gamma) - \gamma[(1-s)\theta+1] + (1-s)\gamma^2\}. \end{aligned} \tag{A23}$$

Since because of (A6) and (A7) it holds that $\frac{1-b}{\delta\Delta} = \frac{1}{[s(1-\theta)+\theta][\gamma+\frac{1}{n-1}]}$, equation (A6) can be expressed:

$$\begin{aligned}\frac{r}{1+r}[\theta(1-s) \quad &+ \quad \epsilon s] + \frac{\theta(1-s)(1-\epsilon)}{1+r} \\ &= \quad \epsilon - 1 + \gamma(1-s) - \frac{1}{\gamma + \frac{1}{n-1}}\{(1-s)\gamma^2 \\ &- \quad \gamma[(1-s)\theta + 1] + \frac{n-2}{n-1}(1-s)(1-\gamma)\}. \end{aligned} \tag{A24}$$

From the definition of γ it follows that

$$r = \frac{\gamma - 1 + s + \theta\gamma(1-s)}{\frac{1}{n-1} - (1-s)[\gamma - \frac{n-2}{n-1}] + \frac{(1-s)\theta}{n-1}}. \tag{A25}$$

By transformations we get

$$\frac{r}{1+r} = \frac{\gamma + (1-s)(\theta\gamma - 1)}{[\gamma + \frac{1}{n-1}][s + (1-s)\theta]} \tag{A26}$$

and

$$\frac{1}{1+r} = \frac{\frac{1}{n-1} - (1-s)[\gamma - \frac{n-2}{n-1}] + \frac{1-s}{n-1}\theta}{[(1-s)\theta + s][\gamma + \frac{1}{n-1}]}. \tag{A27}$$

Substitution of (A6) and (A7) into (A4) yields

$$0 = \gamma\{(1-s)[1 + \frac{\theta}{s} - \theta]\} + \theta\frac{1-s}{s(n-1)}\{(n-2)[s - \epsilon s] + n\epsilon - n$$

$$-(1-s)[(1-\epsilon)\theta - 1]\} + \epsilon(1-s) + \frac{\epsilon - 1}{n-1} - \frac{n-2}{n-1}(1-s). \tag{A28}$$

The right hand-side of this equation is positively related to γ. From (A5) it follows:

$$\begin{aligned} \gamma^* &= \frac{\frac{\theta}{s(n-1)}\{n - (1-s)[(\epsilon-1)\theta + 1] - (n-2)[s - \epsilon s] - n\epsilon\}}{1 + \frac{\theta}{s} - \theta} \\ &+ \frac{\frac{1-\epsilon}{(n-1)(1-s)} - \epsilon + \frac{n-2}{n-1}}{1 + \frac{\theta}{s} - \theta}. \end{aligned} \tag{A29}$$

The sign of the right hand-side of (A5) is the same as the sign of the left-hand side of (A2).
Thus, the sign of $\frac{\partial U}{\partial b}$ is negative if $\gamma < \gamma^*$ and positive if $\gamma > \gamma^*$. Finally, we consider the relationship between γ and b. From equation (A5) we get

$$\frac{\partial r}{\partial \gamma} = \frac{1 + \theta(1-s) + r(1-s)}{\frac{1}{n-1} - (1-s)[\gamma - \frac{n-2}{n-1}] + \frac{(1-s)\theta}{n-1}} = \frac{\delta}{\zeta}. \tag{A30}$$

with

$$\zeta = \frac{1}{n-1} - (1-s)[\gamma - \frac{n-2}{n-1}] + \frac{(1-s)\theta}{n-1}.$$

For the nominator δ to be positive a sufficient condition is that $r > -1$ or $b > -\frac{1}{n-1}$ respectively. Since $\zeta \geq 0$ if

$$1 + \frac{s}{(1-s)(n-1)} + \frac{\theta}{n-1} \geq \gamma, \tag{A31}$$

a sufficient condition in order to get a positive denominator of (A3) is that $1 \geq \gamma$ or $1 \geq b$ respectively. The implication that if $1 \geq \gamma$ then $1 \geq b$ can be deduced from equation (A5). Thus, for the economically senseful range for the matching rate we obtain that $\partial r/\partial\gamma = (n-1)\partial b/\partial\gamma > 0$.

B Investigation of the Leakage-Effect

Proposition: The reaction functions of the single countries are the more steep the larger the estimates on the impure public good's generation of the private characteristic become on stage two, given the decision about the matching rates in stage one.

This proposition will be proven for the economically relevant range of b exclusive its upper limit $b = 1$, since in this case, the slopes of the reaction functions obviously coincide in the pure as well as in the impure public good case.
With the proof of the aforementioned proposition we automatically proof that the leakage-effect is smaller in an impure public good case than in the pure public good case and all the other impure public good cases with lower θ (for $-\frac{1}{n-1} < b < 1$).

Proof: From equation (9) we can derive the effect of an increase of country i's flat contribution on the flat rate of country j:

$$\frac{\partial a_i}{\partial a_j} = -\gamma_{ij}. \tag{B1}$$

Thus, country i reacts with a drop in its flat rate by γ_{ij}. By the derivation of the reaction coefficient for θ we get

$$\frac{\partial \gamma}{\partial \theta} = \frac{(1-s)^2[b^2(n-1) - b(n-2) - 1]}{[1 + (\theta + r)(1-s)]^2} < 0 \tag{B2}$$

for all $b \in \;]-\frac{1}{n-1}, 1[$. As we can see the reaction coefficient becomes the lower the larger the the amount of the private characteristic provided by an additional unit of the impure public good 'GHG abatement measures'. Thus, the slope of the reaction functions become more steep with rising private characteristic. Therefore, the leakage-effect declines.

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