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Public Goods and Public Bads

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Public Goods and Public Bads

Abstract

In many empirically relevant situations agents in different groups are affected by the provision of a public characteristic in divergent ways: While for one group it represents a public good, it is a public bad for another group. Applying Cornes' and Hartley's (2007) Aggregative Game Approach, we analyze a general model, in which such contentious public characteristics are present and are provided cooperatively. In particular, we establish neutrality results w.r.t. redistribution and growth of income, infer the effects of preference changes and coalition building and present a technology paradox. Finally, we compare the outcome of voluntary provision of the contentious public characteristic with the Pareto optimal solution highlighting a potential conflict between equity and efficiency in this case.

JEL-Codes: C720, H410.

Keywords: public goods, public bads, voluntary provision, neutrality.

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This paper is a revised and considerably extended version of Cornes and Rübbelke (2012) then entitled "On the private provision of contentious public characteristics".

1. Introduction

It is a common phenomenon that members of different groups are simultaneously affected by some economic activity but have opposing preferences concerning its consequences. Climate protection is usually considered to be a global public good whose provision is beneficial for all countries in the world. This conceptualization, however, ignores that global warming – within some limits and apart from catastrophic outcomes producing grave losses for all countries – might be welfare improving for some regions and countries. Countries like Canada or Russia may benefit from a higher temperature, e.g. through reduced heating costs, increased agricultural output and improved prospects for the tourism industry, which implies that climate protection can become a public bad for these countries. Therefore, the effects of climate policy are “contentious” so that a conflict of interest between the beneficiaries and the victims of greenhouse gas abatement arises.

In the field of environmental economics, opposing utility effects are not restricted to climate policy. In general, environmental policies are disadvantageous for agents who do not share “green preferences” underlying these policies but yet have to bear part of their cost. E.g., Bostedt (1999) has observed that, within Sweden, many lovers of nature consider the Swedish wolf as a public good. For reindeer herders in the North it is a public bad instead since the wolf preys on the migrating reindeers.

Contentious public characteristics are also present in a lot of fields outside environmental economics: While charitable giving is regarded as a public good by the altruistic donors, it is rejected by others emphasizing its potentially adverse economic effects. In the context of foreign aid prominent examples for such a critical attitude towards transfers are Collier (2007) and Deaton (2013), who are afraid of deteriorating performance incentives on the part of the recipients in developing countries, waste of money through bad governance and corruption of the ruling elites. But also arms races between enemy countries (see, e.g., Bruce 1990, or Ihuri, 2000) or lobbyism in support of opposing political goals (see, e.g., Ihuri and Kameda, 2015) can be interpreted from the perspective of contentious public characteristics.

In the presence of contentious public characteristics, the beneficiaries and the victims often have the possibility to counteract each other: While the beneficiaries, as

“augmenters” of the public characteristic, can increase the level of the public characteristic (and have an incentive to do so), the victims, as “depleters” of the public characteristic, can reduce it through countervailing measures. An example for such opposing activities appears in the context of climate change: While the countries that benefit from a lower global temperature may abate greenhouse gas emissions the countries, which are negatively affected by mitigation measures, might instead purposefully increase greenhouse gas emissions or conduct geo-engineering², e.g., through albedo modification, in order to increase global temperature. Other examples are obviously given by arms races and lobbying activities.

In economic theory, the simultaneous occurrence of public characteristics that are beneficial for some and adverse for others has only been treated in quite specific settings until now (Ihori, 2000, and Ihori and Kameda, 2015), i.e. by assuming Cobb-Douglas preferences for the agents involved. Using the ideas of the Aggregative Game Approach as conceived by Cornes and Hartley (2007) it becomes, however, possible to generalize in a straightforward way some of the already known results and, more importantly, to infer new effects for contentious characteristics, which can be augmented by one group and depleted by another. Such an analysis will be conducted in this paper whose structure will be as follows: After presenting the theoretical setting in Section 2, we describe in Section 3 the non-cooperative Nash equilibria of voluntary provision of the contentious public characteristics. By taking up a central issue in public good theory, the effects of income changes and income redistribution on these Nash equilibria are analyzed in Section 4, which in particular leads to some novel neutrality results to increases of income. Extending some findings of Ihori (2000) and Ihori and Kameda (2015), preference changes and coalition building then are considered in Section 5. In Section 6, we establish a paradoxical effect caused by improvements of the victims’ depleting technology, which results in utility losses for both the augmenters and the depleters. Some of the effects, which arise in case of contentious public characteristics, are illustrated by examples with Cobb-Douglas preferences in Section 7. In Section 8 we describe the Pareto optimal solutions and compare their welfare properties to those of the Nash equilibrium. This also enables us to identify

² See Sandler (2016) for a characterization of different geo-engineering approaches and their game-theoretic analysis.

some problems of international cooperation in the presence of contentiousness of public characteristics. Finally, in Section 9 we conclude and hint at some possible extension of the analysis.

2. The Model Framework

We assume that there are two groups I and J of agents which either benefit or suffer from the aggregate level G of a public characteristics PC.

Group I (of size m) contains the PC-beneficiaries. Each agent $i \in I$ is characterized by its initial endowment (“income”) w_i^I and its utility function is $u_i^I(c_i^I, G)$, which is defined for all private consumption levels $c_i^I \geq 0$ of agent i and all $G \geq 0$ and has the standard properties, i.e. it is twice differentiable, quasi-concave and strictly positive increasing both in c_i^I and G (which indicates that G is a public good for each agent $i \in I$). Then indifference curves in a c_i^I - G -diagram are downward sloping and convex (see Figure 1).

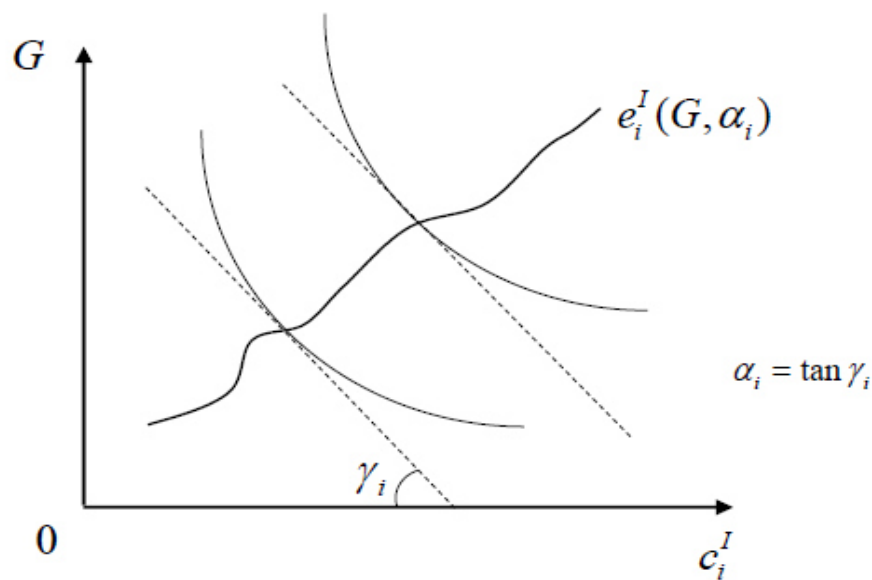


Figure 1

For any agent $i \in I$ and any given $\alpha_i > 0$ the (income) expansion path $c_i^I = e_i^I(G, \alpha_i)$ connects all points where agent i 's marginal rate of substitution between the private

and the public good is equal to α_i so that his indifference curves have slope $-\alpha_i$. Assuming non-inferiority for the private and the public good ensures that the expansion paths are well defined and upward sloping.

Group J (of size n) contains the PC-victims, which are harmed by the PC. Agent $j \in J$ has the income w_j^j and its private consumption is denoted by c_j^j . Its utility function is $u_j^j(c_j^j, G)$, which is defined for all $G \leq \bar{G} \leq \infty$ and is twice differentiable, quasi-concave and increasing in c_j^j but decreasing in G (which indicates the public bad property of G for each agent $j \in J$) and quasi-concave. In a $c_j^j - G$ -diagram, indifference curves are upward sloping and convex (see Figure 2).

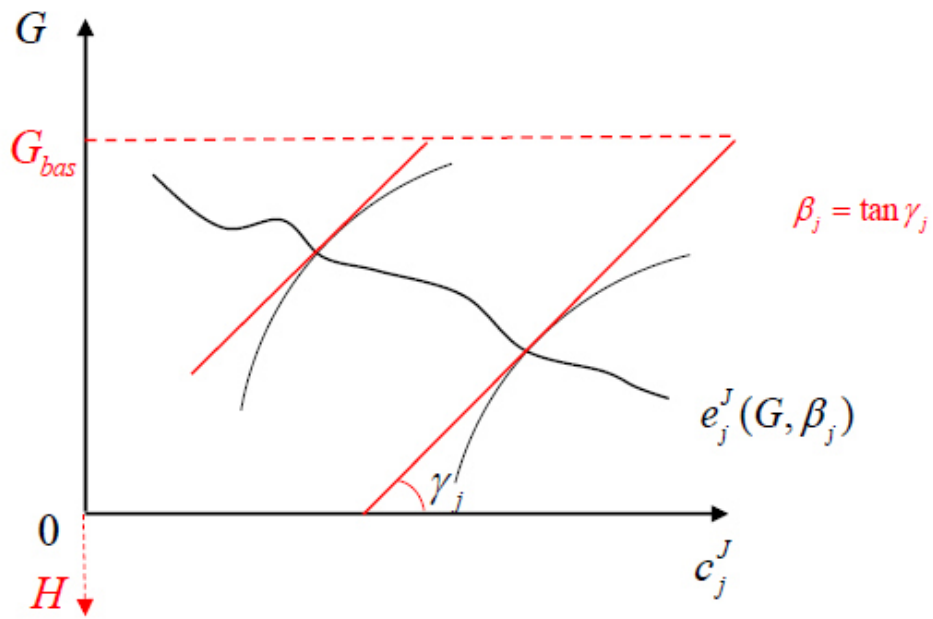


Figure 2

For any agent $j \in J$ and any marginal rate of substitution $mrs_j = \beta_j > 0$ the expansion path $c_j^j = e_j^j(G, \beta_j)$, which is assumed to be defined for all $G \in (0, \bar{G})$, connects all points where indifference curves have slope β_j . Throughout the paper, we will assume that these expansion paths are downward sloping, which can be motivated as follows: Given preferences $u_j^j(c_j^j, G)$ and some $G_{bas} < \bar{G}$, we define an auxiliary utility

function by letting $v_{jG_{bas}}^J(c_j^J, H) := u_j^J(c_j^J, G_{bas} - H)$ for total reductions $H \in [0, G_{bas}]$ of the PC. H is a public good for each agent $j \in J$ since G is a public bad. If H now is assumed to be non-inferior for $v_{jG_{bas}}^J(c_j^J, H)$ putting Figure 2 upside down directly shows that the expansion path $e_j^J(G, \beta_j)$ must be downward sloping below G_{bas} .

As in the standard public good model, we assume that an agent $i \in I$ can produce G by a linear technology so that all members of group I are the PC-augmenters. If agent $i \in I$ has the augmenting productivity a_i , it can generate $a_i z_i^I$ units of G if it spends $z_i^I = w_i^I - c_i^I$ units of its initial endowment for PC-provision (i.e. greenhouse gas abatement in the case of climate change). Inversely, any agent $j \in J$ can reduce/"deplete" total PC-supply by $b_j z_j^J$ units when it spends $z_j^J = w_j^J - c_j^J$ of its initial endowment for such defensive measures. Thus, b_j denotes the depleting productivity of agent $j \in J$.

Under these technological assumptions for both groups of agents total PC-supply G is given by

$$(1) \quad G = \sum_{i=1}^m a_i z_i^I - \sum_{j=1}^n b_j z_j^J .$$

Following condition (1) the feasibility constraint for an allocation with PC-supply G and the private consumption vectors (c_1^I, \dots, c_m^I) and (c_1^J, \dots, c_n^J) becomes

$$(2) \quad G + \sum_{i=1}^m a_i c_i^I - \sum_{j=1}^n b_j c_j^J = \sum_{i=1}^m a_i w_i^I - \sum_{j=1}^n b_j w_j^J ,$$

where $c_i^I \leq w_i^I$ for all $i \in I$ and $c_j^J \leq w_j^J$ holds for all $j \in J$. Based on (2) it is now possible to characterize interior non-cooperative Nash, equilibria by means of expansion paths.

3. Characterization of Nash Equilibria with Voluntary Contributions to the Public Characteristics

In the spirit of the Aggregative Game Approach (see, e.g., Cornes and Hartley, 2007) interior Nash equilibria NE, at which $z_i^I > 0$ for all $i \in I$ and $z_j^J > 0$ holds for all $j \in J$, we define for all $G \in (0, \bar{G})$

$$(3) \quad \Phi(G) := G + \sum_{i=1}^m a_i e_i^I(G, a_i) - \sum_{j=1}^n b_j e_j^J(G, b_j).$$

The function $\Phi(G)$ will be key for formulating and proving the following result on NE.

Proposition 1: Assume that there is an aggregate PC-level \hat{G} which fulfils the condition

$$(4) \quad \Phi(\hat{G}) = \sum_{i=1}^m a_i w_i^I - \sum_{j=1}^n b_j w_j^J,$$

and that $e_i^I(\hat{G}, a_i) < w_i^I$ holds for all $i \in I$ and $e_j^J(\hat{G}, b_j) < w_j^J$ holds for all $j \in J$. Then the allocation $(\hat{c}_1^I, \dots, \hat{c}_m^I; \hat{c}_1^J, \dots, \hat{c}_n^J; \hat{G})$, which has $\hat{c}_i^I = e_i^I(\hat{G}, a_i)$ for all $i \in I$ and $\hat{c}_j^J = e_j^J(\hat{G}, b_j)$ for all $j \in J$, is the unique interior NE.

Proof: (i) The allocation $(\hat{c}_1^I, \dots, \hat{c}_m^I; \hat{c}_1^J, \dots, \hat{c}_n^J; \hat{G})$ is an interior NE since it is feasible according to condition (2) and each agent $i \in I$ is in a Nash position. The reason is that contributing $\hat{z}_i^I = w_i^I - e_i^I(\hat{G}, a_i)$ to the PC ensures that its marginal rate of substitution coincides with its agent-specific marginal rate of transformation a_i . Analogously, each agent $j \in J$ attains a Nash position by contributing $\hat{z}_j^J = w_j^J - e_j^J(\hat{G}, b_j)$ to the PC. (ii) The allocation $(\hat{c}_1^I, \dots, \hat{c}_m^I; \hat{c}_1^J, \dots, \hat{c}_n^J; \hat{G})$ is the only interior NE since PC-supply in any interior NE has to fulfil condition (4): Only then the budget constraint (2) is satisfied

and each agent is in a Nash equilibrium position. The level \hat{G} as defined by (4), however, is unique because $\Phi(G)$ is strictly monotone increasing in G . This follows as each expansion path $e_i^l(G, a_i)$ is increasing and each $e_j^j(G, b_j)$ is decreasing in G .

QED

Existence of an interior NE is guaranteed under rather general conditions, which is shown by the subsequent Proposition 2.

Proposition 2: For all combinations of agent-specific utility functions $(u_1^I, \dots, u_m^I; u_1^J, \dots, u_n^J)$ and productivity parameters $(a_1, \dots, a_m; b_1, \dots, b_n)$, there are sets of income distributions $(w_1^I, \dots, w_m^I; w_1^J, \dots, w_n^J)$ so that any given $\tilde{G} \in (0, \bar{G})$ becomes the PC-level in an interior NE.

Proof: First, we choose a vector $(\Delta_1^I, \dots, \Delta_m^I; \Delta_1^J, \dots, \Delta_n^J)$ of positive and negative PC-contributions so that $\tilde{G} = \sum_{i=1}^m a_i \Delta_i^I - \sum_{j=1}^n b_j \Delta_j^J$. Second, we choose income levels $w_i^I = e_i(\tilde{G}, a_i) + \Delta_i^I$ for all $i \in I$ and $w_j^J = e_j(\tilde{G}, b_j) + \Delta_j^J$ for all $j \in J$. Then condition (4) is clearly satisfied for $\hat{G} = \tilde{G}$.

QED

4. Effects of Income Redistribution and Income Growth

Starting from an interior NE we consider transfers between two agents, which throughout this section, are kept so small that interiority is preserved. In this way we incorporate public bads in the familiar analysis of effects of income transfers in voluntary public good provision (see Bergstrom, Blume and Varian, 1986, and Cornes and Sandler, 1996, pp. 163 – 165).

Proposition 3: (i) An income transfer from an agent $k \in I$ to an agent $l \in J$ leads to a falling aggregate PC-level in NE. Welfare of all agents in group I decreases and welfare of all agents in group J increases.

(ii) The same effects as in (i) result from a transfer within group I that goes from an agent i_1 with a high augmenting productivity a_{i_1} to an agent i_2 with a lower productivity a_{i_2} and from a transfer within group J that goes from an agent j_1 with a low depleting productivity b_{j_1} to an agent j_2 with a higher productivity b_{j_2} .

Proof: (i) An income transfer Δ from an agent $k \in I$ to an agent $l \in J$ reduces the right hand side of (4) by $-(a_k + b_l)\Delta$. As the function $\Phi(G)$ is increasing PC-supply then has to fall to some \hat{G}' to restore equilibrium according to condition (4). The monotonicity properties of the expansion paths also imply that private consumption of each agent $i \in I$ falls to $\hat{c}_i' = e_i^l(\hat{G}', a_i) < e_i^l(\hat{G}, a_i) = \hat{c}_i^l$, while consumption of each agent $j \in J$ increases to $\hat{c}_j' = e_j^l(\hat{G}', b_j) > e_j^l(\hat{G}, b_j) = \hat{c}_j^l$ as a result of the transfer (see Figure 3). The claimed welfare effects thus directly follow from the properties of the utility functions $u_i^l(c_i^l, G)$ and $u_j^l(c_j^l, G)$.

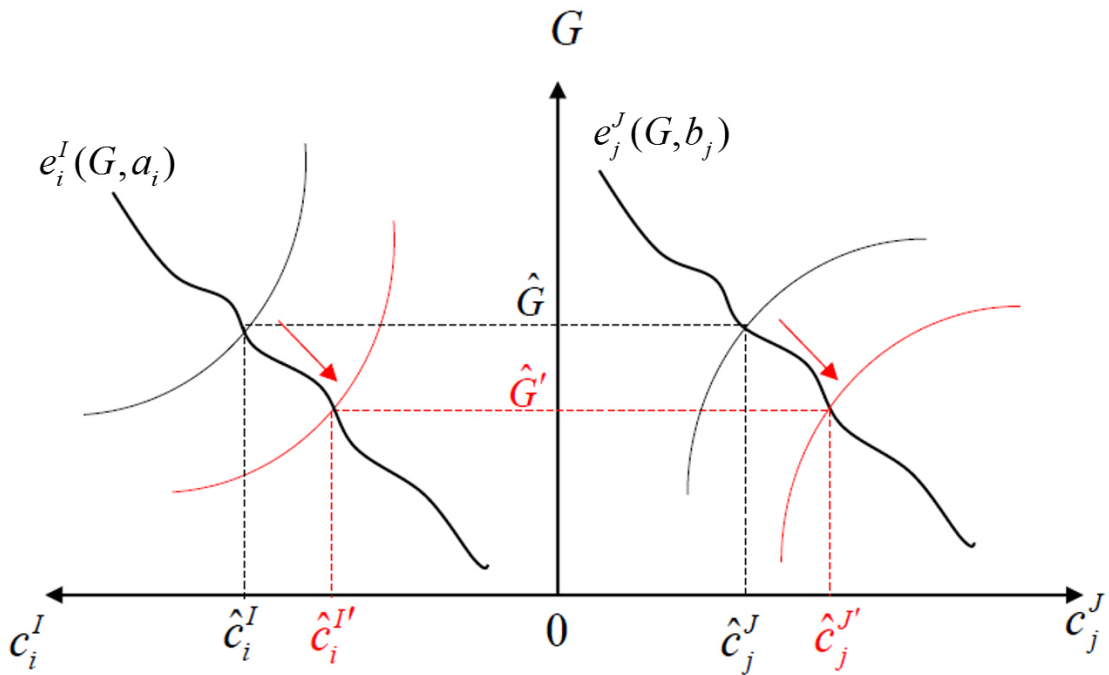


Figure 3

(ii) The proof is analogous to that of part (i).

QED

Proposition 3 (ii) generalizes effects of income redistribution that have been analyzed by Buchholz and Konrad (1995) and Ihuri (1996), where agents for whom PC is a public bad have been absent. Proposition 3, moreover, yields some neutrality results, which are closely related to those established by Warr (1983) and Bergstrom, Blume and Varian (1986) for conventional public good economies.

Proposition 4: An income transfer from an agent $i_1 \in I$ ($j_1 \in J$) to an agent $i_2 \in I$ ($j_2 \in J$), who has the same productivity, i.e. $a_{i_2} = a_{i_1}$ ($b_{j_2} = b_{j_1}$), leaves the interior NE unchanged.

Proof: The assertion directly follows from condition (4) as such a transfer leaves the right hand side of (4) unchanged. QED

However, as a new form of neutrality a “neutral growth property” may occur in the case of contentious public characteristics. This “super neutrality” (Ihuri and Kameda, 2015, p. 9) is in a broader sense reminiscent of the immiserizing growth phenomenon as observed by Cornes and Sandler (1989, 1996, pp. 166 – 170) for public good economies, since an improvement of the feasibility constraint does not entail an increase of utilities.

Proposition 5: Assume that income of an agent $k \in I$ is increased by $\Delta_k^I \geq 0$ and income of an agent $l \in J$ is increased by $\Delta_l^J \geq 0$. Then the aggregate PC-level rises (remains unchanged, falls), utility of all augmenters $i \in I$ rises (remains unchanged, falls) and utility of all depleters $j \in J$ falls (remains unchanged, rises) in the NE if

$$(5) \quad a_k \Delta_k^I > b_l \Delta_l^J \quad (=, <).$$

Proof: In the first (second, third) case the right hand side of (4) increases (remains constant, decreases). The proof then follows the same lines of reasoning as that of Proposition 3. QED

It is a direct consequence of Proposition 5 that if productivity is the same for all agents, i.e. $a := a_1 = \dots = a_m = b_1 = \dots = b_m := b$, growth neutrality results when total income of both groups is increased by the same amount irrespective of how these income increases are distributed among the members of each group.

5. Effects of Preference Changes and Coalition Building

Keeping endowment levels fixed, we now, as a first step in this section, explore the effects that arise when either some agent $k \in I$ is substituted by some other agent with higher preferences for the public good, or, alternatively, that some agent $l \in J$ is substituted by an agent that suffers less from the public bad and thus has a lower preference for a reduction of the PC. Our analysis in this section will provide some generalization of the results by Ihuri (2000) and Ihuri and Kameda (2015), which are restricted to the case of Cobb-Douglas preferences.

As usual, an agent $k \in I$ is said to have a higher preference for the PC when his utility function changes from the originally given $u_k^I(c_k^I, G)$ to a new one $\tilde{u}_k^I(c_k^I, G)$ for which at any point (c_k^I, G) the marginal rate of substitution is smaller. Then indifference curves for $\tilde{u}_k^I(c_k^I, G)$ are everywhere flatter than those for $u_k^I(c_k^I, G)$, which indicates that agent k is willing to sacrifice a higher amount of private consumption for a marginal increase of PC-supply. Looking at Figure 1 and observing the convexity of indifference curves then immediately shows that, for any given marginal rate of substitution α_i , the expansion path moves closer to the G -axis when the utility function is changing in this way, i.e. $\tilde{e}_k^I(G, \alpha_k) < e_k^I(G, \alpha_k)$ for all $G > 0$ (see, e.g., Buchholz and Sandler, 2016, for details).

Analogously, for an agent $l \in J$ a change of its utility function from the original $u_l^J(c_l^J, G)$ to a new one $\tilde{u}_l^J(c_l^J, G)$ will reflect a lower preference for avoiding the public bad if in Figure 2 the indifference curves get steeper everywhere. Now concavity of k 's indifference curves implies that, for any given marginal rate of substitution β_l , the change of preferences moves the expansion paths away from the G -axis, i.e. $\tilde{e}_l^J(G, \beta_l) > e_l^J(G, \beta_l)$ holds for all $G > 0$.

Proposition 6: Assume that either the preferences of agent $k \in I$ for the PC get stronger or that preferences of an agent $l \in J$ for avoiding the PC get weaker. Then PC-supply in the NE becomes higher in both cases. In the first case, utility of all augmenters $i \in I / \{k\}$ rises in the NE while utility of all agents $j \in J$ falls. In the second case, utility of all augmenters $i \in I$ rises while utility of all agents $l \in J / \{l\}$ falls.

Proof: The change of the expansion paths of agent k and agent l , which follows from the assumed preference changes, leads to a new function $\tilde{\Phi}(G)$ as defined by (3), for which $\tilde{\Phi}(G) < \Phi(G)$ holds for all $G > 0$. As $\tilde{\Phi}(G)$ is strictly monotone increasing, PC-supply then has to rise after the change of preferences in order to satisfy the equilibrium condition (4). When the preference change occurs in group I the NE-position of all augmenters $i \in I / \{k\}$ moves to the right on their expansion paths so that their utility clearly rises. At the same time, all depleters $j \in J$ move to the left on their expansion paths so that their utility falls. The proof of the second case with a preference change in group J proceeds in an analogous way. QED

As a second step in this section, we analyze how the equilibrium solution changes when the members either of group I or of group J cooperate and, after having formed a coalition, jointly determine their (positive or negative) PC-contribution³. The cooperating group then plays Nash against the still non-cooperating members of the other group. To facilitate the exposition we now assume that both groups are completely homogeneous, i.e. that all augmenters have the same income w^I and the same utility function $u^I(c_i^I, G)$ (with expansion paths $e^I(G, \alpha_i)$), and that all depleters have the same income w^J and the same utility function $u^J(c_j^J, G)$ with expansion paths $e^J(G, \beta_j)$. Additionally, $a_i = b_j = 1$ for all $i \in I$ and all $j \in J$ is assumed for the augmenting and depleting productivities.

³ For an analysis of coalition building in a standard public good economy without depleters see Hattori (2015) and Buchholz and Eichenseer (2017).

In order to find the new equilibrium, which results after partial cooperation within one of the groups, we first of all examine how optimal reactions change through partial cooperation: Look at group I and assume that the aggregate level of the depleting activities by group J is Z^J . In a symmetric reaction, where all augmenters bear the same cost of PC-provision, group I as a coalition determines the PC-contribution of any agent $i \in I$ by maximizing aggregate utility $mu^i(w^i - z^i, mz^i - Z^J)$. If this optimization problem has an interior solution, a member of group I attains a position in which her marginal rate of substitution between the private and the public good is equal to m . This implies that a collective reaction by group I that leads to a positive PC-contribution will put each of its members on the expansion path $e^I(G, m)$. When the agents in group J act non-cooperatively, their position in an interior solution, however, still is on the expansion path $e^J(G, 1)$. In analogy to condition (4) the PC-level \hat{G}_{PI} in an interior equilibrium with partial cooperation by group I then is determined by the condition

$$(6) \quad \Phi_{PI}(\hat{G}_{PI}) := \hat{G}_{PI} + me^I(\hat{G}_{PI}, m) - ne^J(\hat{G}_{PI}, 1) = mw^I - nw^J.$$

When instead the depleter group J cooperatively determines its reaction to the PC-contributions by group I , it is shown by a similar argument that the position of any agent $j \in J$ in an interior solution must lie on the expansion path $e^J(G, m)$ so that in this case the PC-level \hat{G}_{PJ} is characterized by the condition

$$(7) \quad \Phi_{PJ}(\hat{G}_{PJ}) := \hat{G}_{PJ} + me^I(\hat{G}_{PJ}, 1) - ne^J(\hat{G}_{PJ}, n) = mw^I - nw^J.$$

Based on the equilibrium conditions (6) and (7) we obtain the following result on the effects of partial cooperation.

Proposition 7: Assume that group I and group J both are homogeneous and that an interior equilibrium is attained when one of these groups forms a coalition and cooperatively determines its PC-contribution.

(i) If the augments group I cooperates, public good supply is higher and utility of the members of group J is lower in the partial cooperation equilibrium than in the original NE without cooperation. The welfare effect for the cooperating group I is ambiguous.

(ii) If the depleter group J cooperates, public good supply is lower and utility of the members of group I is higher in the partial cooperation equilibrium than in the original NE without cooperation. The welfare effect for the cooperating group is ambiguous.

Proof: (i) Normality and convexity of indifference curves implies that $e^I(G, m) < e^I(G, 1)$ for all $G > 0$. Therefore, $\Phi_{PI}(\hat{G}_{PI}) = mw^I - nw^J < \Phi(\hat{G}_{PI})$. Since the function $\Phi(G)$ as defined by (3) is strictly monotone increasing and the PC-level \hat{G} in the original NE is characterized by $\Phi(\hat{G}) = mw^I - nw^J$, we clearly have $\hat{G}_{PI} > \hat{G}$ for PC-supply and $\hat{c}_{PI}^J = e^J(\hat{G}_{PI}, 1) < e^J(\hat{G}, 1) = \hat{c}^J$ for private consumption of a depleter. With a higher PC-level and lower private consumption an agent in group J then is clearly made worse off through cooperation within group I . Concerning utility of the agents in group I there are two opposing effects: On the one hand they benefit from cooperation as the PC-level rises. But on the other hand they lose because their private consumption becomes smaller as the increase of the PC-level is accompanied by higher defensive measures of the depleter group J . Which of these two countervailing effect dominates is not a priori clear.

(ii) The proof is completely analogous to that of part (i).

QED

The changes of positions, which result for the members of both groups when group I forms a coalition, are visualized in Figure 4.

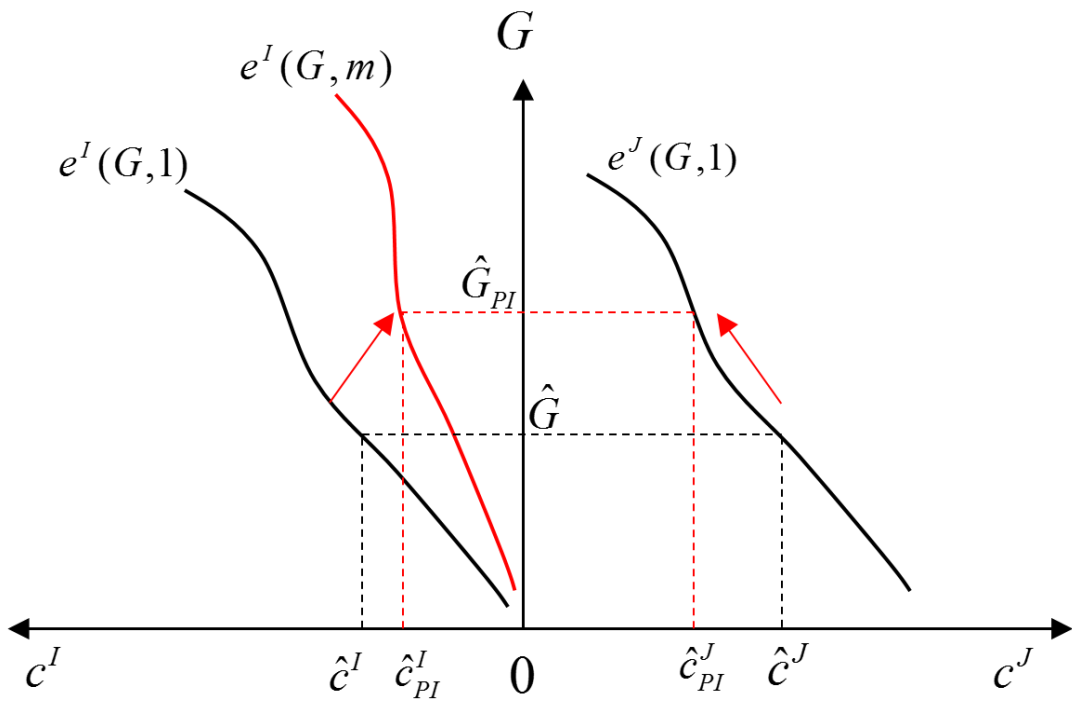


Figure 4

The fact that group I may also lose by forming a coalition is confirmed through an example with Cobb-Douglas preferences in Section 7. There, we will also consider the case in which not only one group but both groups I and J cooperate, and show that the outcome in this case may be Pareto-inferior to the original NE without cooperation.

6. A Technology Paradox

In this section we show that it is possible that the invention and application of a depleting technology by the members of group J , which can be used to reduce the PC-level and its harmful effects, does not necessarily benefit group J and may, in the end, make both groups worse off⁴.

⁴ In the standard model of private public good provision without depleters Buchholz and Konrad (1994) and Iori (1996) have also shown a paradoxical technology effect, as an agent may lose utility when it applies a technology with a higher public good productivity. There, however, a technological improvement does not lead to a Pareto inferior outcome.

Proposition 8: Assume that all members of group I and J have identical preferences, income levels and productivities. The productivity of each member of group I is $a = 1$, while the members of group J either have the ability to deplete the PC with the productivity $b = 1$ (Scenario 1) or do not have this ability, i.e. $b = 0$ (Scenario 2). Then for any size m of group I there exist income levels \hat{w}^I and \hat{w}^J for the members of each group so that the NE for $b = 1$ is Pareto inferior to that for $b = 0$ if the size n of group J is not too large.

Proof: The intricate proof proceeds in several steps.

(i) Let, as in the section before, $e^I(G,1)$ and $e^J(G,1)$ denote the expansion paths for the agents in group I and group J , respectively, given the productivities $a = b = 1$. Then fix some PC-level $\tilde{G} \in (0, \bar{G})$. For any $m \geq 1$ define initial income levels $\tilde{w}^I = e^I(\tilde{G}, 1) + \frac{\tilde{G}}{m}$ and $\tilde{w}^J = e^J(\tilde{G}, 1)$. Now consider the allocation with PC-supply \tilde{G} and private consumption levels $(\tilde{c}^I, \dots, \tilde{c}^I) = (e^I(\tilde{G}, 1), \dots, e^I(\tilde{G}, 1))$ and $(\tilde{c}^J, \dots, \tilde{c}^J) = (e^J(\tilde{G}, 1), \dots, e^J(\tilde{G}, 1))$ where the PC-contribution of each member of group I is $\tilde{z}^I = \frac{\tilde{G}}{m}$, while group J does not pursue any depleting activities, i.e. $\tilde{z}^J = 0$. Given income levels \tilde{w}^I and \tilde{w}^J this allocation is clearly feasible according to condition (1) for all sizes n of group J and all productivities $b \geq 0$, i.e. especially for $b = 1$ and $b = 0$.

(ii) Starting from this allocation income of each agent in group I is increased marginally by dw^I and, simultaneously, income of each agent in group J by $dw^J = \frac{m}{n} dw^I$.

When $a = b = 1$, the NE and hence utility of all agents $i \in I$ and $j \in J$ does not change as a result of these income changes, which directly follows from growth neutrality as established in Proposition 5.

(iii) We now examine how in the case $b = 0$ utility of the agents in group I and group J will change due to this simultaneous increase of income in both groups. Then we are in a standard situation of voluntary public good contribution by group I without

any depleting activities by group J . Given the income w^I of each agent $i \in I$, PC-supply \hat{G}_I in such a NE is characterized by

$$(8) \quad \hat{G}_I + me^I(\hat{G}_I, 1) = mw^I.$$

Differentiating (8) w.r.t. w^I and letting $e'_I := \frac{\partial e^I(G, 1)}{\partial G}$ at the fixed \tilde{G} yields a marginal change \hat{G}'_I of PC-supply at \tilde{w}^I , which is

$$(9) \quad \hat{G}'_I = \frac{m}{1 + me'_I} dw^I.$$

As normality implies $e'_I > 0$, we have $\hat{G}'_I > 0$. Hence, the agents in group I are moving outwards their respective expansion paths $e^I(G, 1)$ due to the increase of income so that their utility clearly rises.

(iv) Concerning the utility changes of the agents in group J , whose income is marginally increased by $dw^J = \frac{m}{n} dw^I$, we recall that private consumption of an agent in group J must always equal its initial endowment if $b = 0$, i.e. if no depleting technology exists. Normalizing $\frac{\partial u^J}{\partial c^J}(\tilde{w}^J, \tilde{G}) = \frac{\partial u^J}{\partial G}(\tilde{w}^J, \tilde{G}) = 1$ and applying (9), utility of an agent in J thus changes by

$$(10) \quad \frac{du^J}{dw^I} = \frac{\partial u^J}{\partial c^J} \frac{dw^J}{dw^I} + \frac{\partial u^J}{\partial G} \frac{dG}{dw^I} = \frac{m}{n} - \frac{m}{1 + me'_I}.$$

In the case $b = 0$ the income increase thus makes an agent $j \in J$ better off if

$$(11) \quad n < 1 + me'_I.$$

(v) Let $\hat{n}(m) \geq 1$ be the largest cardinal number, which satisfies condition (11) and which exists as the right-hand side of (11) exceeds one. From continuity of all functions involved, it follows that for any group size $n \leq \hat{n}(m)$ the members of group J will benefit also from a non-marginal increase of income that leads to income levels \hat{w}^J and \tilde{w}^J , for which $m(\hat{w}^J - \tilde{w}^J) = n(\hat{w}^J - \tilde{w}^J)$ holds and which are lying not too far above \tilde{w}^I and \tilde{w}^J .

(vi) By construction, for $b = 1$ and $b = 0$ the NE are the same, if the income levels initially are \tilde{w}^I and \tilde{w}^J . If incomes are \hat{w}^I and \hat{w}^J instead, all agents have the same utility in the NE for $b = 1$ as in the original NE for the income levels \tilde{w}^I and \tilde{w}^J . In the NE for $b = 0$, however, the members of both groups are better off given these higher incomes. QED

Condition (11), which appears in the proof of Proposition 7, indicates when the technological paradox is more likely to occur. Keeping the size m of the augmentser group I fixed, it holds that the larger the size n of group J is the smaller becomes the increase in private consumption of these agents, which results in case $b = 0$ when income increases and the conditions for growth neutrality in case $b = 1$ are satisfied. Consequently, being deprived of depleting abilities is more attractive for a small group J . According to condition (11), the same holds true if e'_I is large, i.e. if in the $c^I - G$ -diagram the expansion paths of the agents in group I are relatively flat. Then in case $b = 0$ the increase of PC-supply, which harms group J , is small when the income of group I rises.

7. A Cobb-Douglas Example

7.1 The NE with Full Non-Cooperation

Like in the previous section assume that groups I and J are homogeneous and of size m and n , respectively. Each agent $i \in I$ has income $w^I = 1$, the utility function $u^I(c^I, G) = c^I G$ and the productivity parameter $a = 1$. The expansion path for the marginal rate of substitution α is $e^I(G, \alpha) = \frac{G}{\alpha}$. Each agent $j \in J$ also has the income

$w^j = 1$. Its utility function is $u^j(c^j, G) = c^j(\bar{G} - G)$ with $\bar{G} = 1$. For the marginal rate of substitution β the expansion path then is $e^j(G, \beta) = \frac{1-G}{\beta}$ as the ratio of the partial derivatives of $u^j(c^j, G)$ is $-\beta$ along this line. In the basic scenario the depleting productivity of any agent $j \in J$ is also assumed to be $b = 1$.

Condition (4), which characterizes PC-supply in an interior NE for $a = b = 1$, turns into

$$(12) \quad \Phi(\hat{G}) = \hat{G} + m\hat{G} - n(1 - \hat{G}) = m - n,$$

which gives

$$(13) \quad \hat{G} = \hat{c}^I = \frac{m}{1+m+n} \quad \text{and} \quad \hat{c}^J = 1 - \hat{G} = \frac{1+n}{1+m+n}$$

for the levels of PC-supply and private consumption in both groups. The allocation described by (13) indeed characterizes an interior NE for all group sizes m and n since $\hat{c}^I < 1 = w^I$ and $\hat{c}^J < 1 = w^J$. In this NE the members of group I and group J then have utility

$$(14) \quad \hat{u}^I = \hat{c}^I \hat{G} = \hat{G}^2 = \left(\frac{m}{1+m+n} \right)^2 \quad \text{and} \quad \hat{u}^J = \hat{c}^J \hat{G} = (1 - \hat{G})^2 = \left(\frac{1+n}{1+m+n} \right)^2.$$

Thus the augmenters are better off than the depleters, i.e. $\hat{u}^I \geq \hat{u}^J$, if and only if $m \geq n + 1$.

7.2 Coalition Building

In this sub-section we start by determining the equilibrium outcome, which results when the augments group I builds a coalition that cooperatively determines its PC-contribution whereas the agents in the depleter group J still act non-cooperatively.

According to condition (6) public good supply \hat{G}_{PI} in the NE with such unilateral cooperation is for any size $m \geq 2$ of the cooperating augmenter group I given by

$$(15) \quad \hat{G}_{PI} + m \frac{\hat{G}_{PI}}{m} - n(1 - \hat{G}_{PI}) = m - n.$$

Consequently,

$$(16) \quad \hat{G}_{PI} = \frac{m}{2+n}, \quad \hat{c}_{PI}^I = \frac{\hat{G}_{PI}}{m} = \frac{1}{2+n} \quad \text{and} \quad \hat{c}_{PI}^J = 1 - \hat{G}_{PI} = \frac{2+n-m}{2+n}$$

is obtained for public good supply and private consumption in this equilibrium, which is interior if $m \leq n+1$ and thus $\hat{c}_{PI}^J > 0$ holds. Utility of the agents in group I and group J then is

$$(17) \quad \hat{u}_{PI}^I = \frac{m}{(2+n)^2} \quad \text{and} \quad \hat{u}_{PI}^J = \left(\frac{2+n-m}{2+n} \right)^2.$$

Obviously, $\hat{G}_{PI} < \hat{G}$ if $m \geq 2$, which gives $\hat{u}_{PI}^J = (1 - \hat{G}_{PI})^2 < (1 - \hat{G})^2 = \hat{u}^J$. For a comparison of the utility levels, which a member of group I attains in the original NE and the partial cooperation equilibrium, we note that

$$(18) \quad \hat{u}_{PI}^I < \hat{u}^I \quad \Leftrightarrow \quad \left(\frac{1+m+n}{2+n} \right)^2 < m.$$

The expression on the left-hand side of the second inequality in (18) is falling in n and thus – for all $m \geq 2$ and $n \geq m-1$ as the condition for interiority – cannot exceed $\left(\frac{1+m+m-1}{2+m-1} \right)^2 = \left(\frac{2m}{m+1} \right)^2 < m$ for all $m \geq 2$. This shows that partial cooperation of group I makes all agents worse off.

The case that the depleter group J forms a coalition while the members of group I act non-cooperatively can be treated in an analogous way, whose treatment will therefore be omitted here. Instead, we will consider the case, in which cooperation takes place within both groups. PC-supply \hat{G}_{TS} in an interior NE with cooperation in both groups then is characterized by the condition

$$(19) \quad \hat{G}_{TS} + me^I(\hat{G}_{TS}, m) + ne^J(\hat{G}_{TS}, n) = \hat{G}_{TS} + m \frac{\hat{G}_{TS}}{m} + n \frac{1 - \hat{G}_{TS}}{n} = m - n,$$

which gives

$$(20) \quad \hat{G}_{TS} = \frac{1 + m - n}{3}, \quad \hat{c}_{TS}^I = \frac{\hat{G}_{TS}}{m} = \frac{1 + m - n}{3m} \quad \text{and} \quad \hat{c}_{TS}^J = \frac{1 - \hat{G}_{TS}}{3n} = \frac{2 + n - m}{3n}$$

and

$$(21) \quad \hat{u}_{TS}^I = \frac{(1 + m - n)^2}{9m} \quad \text{and} \quad \hat{u}_{TS}^J = \frac{(2 + n - m)^2}{9n}.$$

An interior solution now is attained only under very special conditions, i.e. if $m = n$ or $m = n + 1$. For these two cases it is easily checked that $\hat{u}_{TS}^I < \hat{u}_{PI}^I$. A comparison with (17), moreover, directly shows that also $\hat{u}_{TS}^J < \hat{u}_{PI}^J$, i.e. that cooperation within both groups leads to a further reduction of all agents' utility as compared to the outcome with only partial cooperation in group I .

7.3 The Technology Paradox

If no depletion technology is available, i.e. if $b = 0$, condition (8), which in this case characterizes PC-supply in the NE, turns into

$$(22) \quad \hat{G}_I + m\hat{G}_I = m,$$

which gives

$$(23) \quad \hat{G}_I = \hat{c}_I^I = \frac{m}{1+m} \quad \text{and} \quad \hat{c}_I^J = w^J = 1.$$

Utility of the agents in group I and group J then is

$$(24) \quad \hat{u}_I^I = \hat{x}_I^I \hat{G}_I = \hat{G}_I^2 = \left(\frac{m}{1+m} \right)^2 \quad \text{and} \quad \hat{u}_I^J = w^J (1 - \hat{G}^J) = \frac{1}{1+m}.$$

Comparing the NE for $b = 1$ and $b = 0$ first of all confirms that $\hat{G}_I = \hat{x}_I^I > \hat{G} = \hat{x}^I$ so that $\hat{u}_I^I > \hat{u}^I$, i.e. the members of the augmentser group I attain a higher utility level if no depletion technology exists. Concerning the members of the depleter group J we have $\hat{x}^J < \hat{x}_I^J = 1$, and comparing (14) and (24) yields

$$(25) \quad \hat{u}_I^J > \hat{u}^J \quad \Leftrightarrow \quad \frac{1}{1+m} > \left(\frac{1+n}{1+m+n} \right)^2.$$

This condition boils down to

$$(26) \quad n < (1+m)^{\frac{1}{2}} \quad \text{or} \quad m > n^2 - 1.$$

Condition (26) in particular shows that the technological paradox always occurs, if the depleter group J is a singleton, i.e. $n = 1$. If group J is of an arbitrary size n , it follows from (26) that both groups will suffer from the application of a depleting technology with $b = 1$ when the augmentser group I is sufficiently large.

8. Pareto Optimal Solutions

Consider any allocation $(c_1^I, \dots, c_m^I; c_1^J, \dots, c_n^J; G)$ at which there are members of both groups making a strictly positive PC-contribution, i.e. at which $z_i^I > 0$ holds for some

$i \in I$ and $z_j^J > 0$ holds for some $j \in J$. If we reduce z_i^I by some sufficiently small Δ and simultaneously z_j^J by $\frac{b_j}{a_i} \Delta$, PC-supply remains the same while private consumption of agent i and agent j increases. Thus a Pareto improvement results from such a simultaneous reduction of the augmenting and depleting PC-contributions of both agents. Therefore, each allocation in which at least one agent in group J takes defensive measures cannot be Pareto optimal. Hence, the Pareto optimal allocations PA are characterized by the following result.

Proposition 9: An allocation $(c_1^{I^*}, \dots, c_m^{I^*}; c_1^{J^*}, \dots, c_n^{J^*}; G^*)$ with $z_i^I > 0$ for all $i \in I$ is a PA if and only if $c_j^{J^*} = w_j^J$ for all $j \in J$ and the Samuelson condition holds for group I , i.e. $\sum_{i=1}^m \frac{a_i}{\alpha_i(c_i^{I^*}, G^*)} = 1$, where $\alpha_i(c_i^{I^*}, G^*)$ denotes agent i 's marginal rate of substitution between the private and the public good at $(c_i^{I^*}, G^*)$.

Proof: That $c_j^{J^*} < w_j^J$ holds in a PA for some $j \in J$ is excluded by the argument above. Given $c_j^{J^*} = w_j^J$ for all $j \in J$, Pareto optimality of an allocation with $c_i^{I^*} < w_i^I$ for all $i \in I$ is characterized by the Samuelson condition as in the standard public good model. QED

Proposition 9 shows that active defensive measures of group J aiming at improving welfare of its members are not compatible with Pareto optimality. In each Pareto optimal allocation the PC-victims in group J are deprived of the possibility to defend themselves, which causes a conflict between optimality and distributional objectives. In particular, it therefore becomes possible that the members of group J are better off in the NE than in any Pareto optimal solution.

For a further exploration of this issue we again assume that both groups I and J are homogeneous w.r.t. income and preferences and that $a_i = b_j = 1$ holds for all $i \in I$ and $j \in J$. In the following, PC-supply, private consumption and the utilities of agents

are made dependent on the size m of the augmentser group I while the size n of the depleter group J is fixed.

According to Proposition 8 the symmetric Pareto optimal solution SPA with PC-supply $G^*(m)$ is the Lindahl equilibrium of public good provision by group I combined with zero depleting activities by group J , i.e. $c^{I*}(m) = e^I(G^*(m), m)$, $c^{J*}(m) = w^J$ and the budget constraint $G^*(m) + mc^{I*}(m) = mw^I$. We now compare the agents' utility levels $u^{I*}(m)$ and $u^{J*}(m)$ in this SPA with the NE-utilities $\hat{u}^I(m)$ and $\hat{u}^J(m)$.

Proposition 10: (i) $u^{I*}(m) > \hat{u}^I(m)$ holds for all $m \in \mathbb{N}$.

(ii) $u^{J*}(m) < \hat{u}^J(m)$ holds, if

(a) the size m of the augmentser group I is large, or

(b) the income levels of the members of both groups are small.

Proof: (i) As $e^I(\hat{G}(m), 1) < w^I$ from the interiority assumption it follows from the NE-condition (4), i.e. $\hat{G}(m) + me^I(\hat{G}(m), 1) - ne^J(\hat{G}(m), 1) = mw^I - nw^J$, that

$$(27) \quad \hat{G}(m) + me^I(\hat{G}(m), 1) < mw^I.$$

As $e^I(G, 1)$ is increasing in G (27) implies that $\hat{G}_I(m) > \hat{G}(m)$ and thus $\hat{u}_I^I(m) = u^I(\hat{G}_I(m), e^I(\hat{G}_I(m), 1)) > u^I(\hat{G}(m), e^I(\hat{G}(m), 1)) = \hat{u}^I(m)$. Then the assertion follows since $u^{I*}(m) > \hat{u}_I^I(m)$, which is a consequence of Pareto optimality (and symmetry) of the Lindahl equilibrium.

(ii-a) For all m , public good supply in an interior NE is smaller than \bar{G}_1^I , which is defined by $e^I(\bar{G}_1^I, 1) = w^I$: Otherwise an agent $i \in I$ could not be in a NE position with $\hat{c}^I(m) < w^I$ (see, e.g., Andreoni, 1988). The lowest utility level an agent $j \in J$ can attain in an interior NE hence is $\hat{u}^J = u^J(e^J(\bar{G}_1^I, 1), 1)$. Let us define \underline{G}^J by $u^J(w^J, \underline{G}^J) = \hat{u}^J$ (see Figure 5).

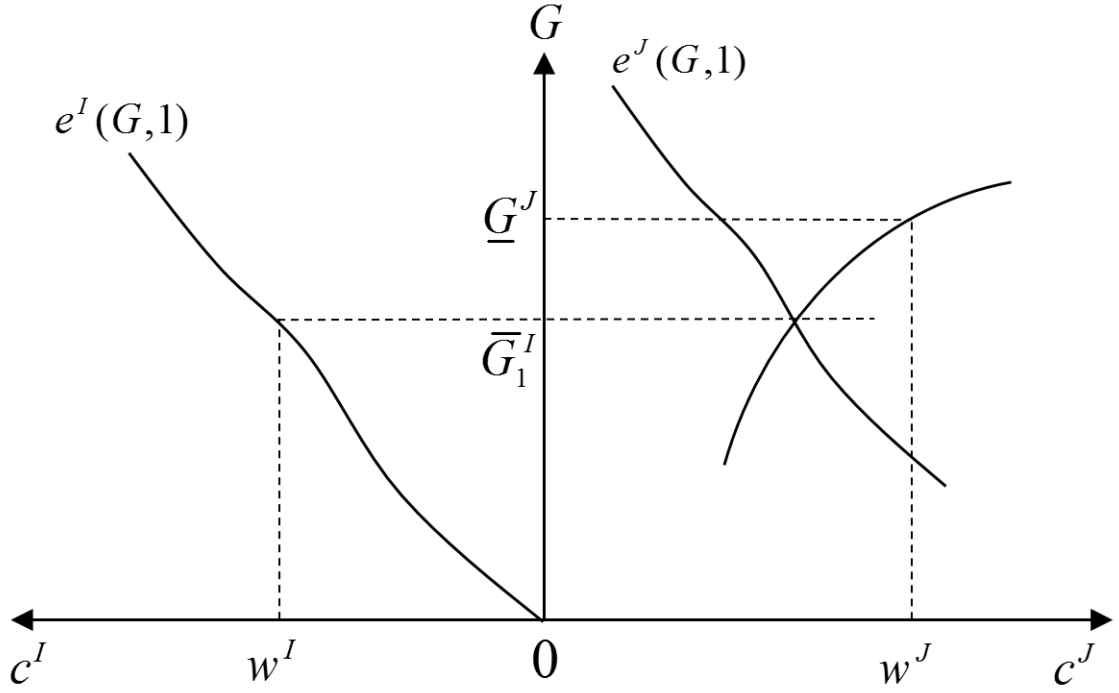


Figure 5

Since there clearly exists some \underline{m} so that $G^*(\underline{m}) > \underline{G}^J$ holds⁵, we have $G^*(\underline{m}) > G^*(\underline{m})$ and thus $u^{J^*}(\underline{m}) := u^J(w^J, G^*(\underline{m})) < u^J(w^J, \underline{G}^J) = \underline{u}^J < \hat{u}^J(\underline{m})$ holds for all $m \geq \underline{m}$.

(ii-b) Given $(\hat{c}^I(m), \hat{c}^J(m), \hat{G}(m))$ as the interior NE for the original income levels w^I and w^J , we define new income levels $\tilde{w}^I = e^I(\hat{G}(m), 1) + \frac{\hat{G}(m)}{m}$ and $\tilde{w}^J = e^J(\hat{G}(m), 1)$, for which $(\hat{c}^I(m), \hat{c}^J(m), \hat{G}(m))$ is also the NE. Let $\tilde{G}^*(m)$ be PC-supply in the Lindahl equilibrium of group I given \tilde{w}^I . The allocation $(\tilde{c}^{I^*}(m), \tilde{c}^{J^*}(m), \tilde{G}^*(m))$ with $\tilde{c}^{I^*}(m) = e^I(\tilde{G}^*(m), m)$ and $\tilde{c}^{J^*}(m) = \tilde{w}^J$ then is the SPA for \tilde{w}^I and \tilde{w}^J . From $\tilde{G}^*(m) > \hat{G}(m)$, we obtain $u^J(\tilde{w}^J, \tilde{G}^*(m)) < u^J(\tilde{w}^J, \hat{G}(m))$ so that, given \tilde{w}^I and \tilde{w}^J , utility of an agent $j \in J$ is lower in this SPA than in the given NE. From continuity the same holds for all income levels w^I slightly above \tilde{w}^I and all w^J slightly above \tilde{w}^J . QED

⁵ Choose \underline{m} so that the budget line $G = -mc^I + mw^I$ cuts the indifference curve passing through (w^I, \underline{G}^J) .

The intuition behind Proposition 10 (i) is that the augmenting agents benefit from the transition from NE to SPA because they cooperatively provide PC and depleting measures by group J are absent. The depleting agents, however, lose by the transition from NE to SPA when either – due to a large size of group I – their additional harm through an increased PC-level is large or when – due to low incomes and small depleting activities – their gain from saving depleting expenses is rather low.

A practical consequence of Proposition 10 is that there may be a conflict between efficiency and distribution, which hampers cooperation on PC-supply. Since – given the conditions in Proposition 10 – the SPA would harm group J as compared to the NE, the members of this group J are not willing to approve an agreement leading to SPA. This impasse may be avoided and a SPA may be made acceptable also for the depleter group J if income is redistributed from group I to group J . In this way, on the one hand, private consumption of the agents $j \in J$ is increased and, on the other hand, the harm inflicted on group J is reduced since normality of the public good for the members of group I implies that they will provide less of the PC in their Lindahl equilibrium when their income falls.

9. Conclusion

At the methodological level, we have demonstrated how the standard tools of public good theory can also be used to include public bads in the analysis and to determine equilibrium solutions in this more general framework. Concerning substance, we have shown that in the case of contentious public characteristics the traditional redistribution neutrality of voluntary public good provision is accompanied by growth neutrality as a new form of neutrality implied by income changes. Moreover, a specific technology paradox arises as an improvement of the depletion technology in the group of victims may make all agents worse off in the Nash equilibrium. Pareto optimality requires the non-application of any defensive activity but without some redistribution of income such a Pareto optimal solution might not be acceptable for the members of the depleter group.

Extensions of the analysis could be made by conducting additional comparative statics w.r.t. productivity parameters and group sizes. We could also consider preferences for which the public characteristic is a public good for an agent up to a certain provision level but then turns into a public bad. In this case interesting situations may occur when, due to some parameter changes, agents may switch from the beneficiary group to the victim group and vice versa. These issues will be topics of future research.

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