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Julio Davila, Jan Eeckhout, César Martinelli. Bargaining over public goods. Documents de travail du Centre d'Economie de la Sorbonne 2008.41 - ISSN : 1955-611X. 2008. <halshs-00289435>

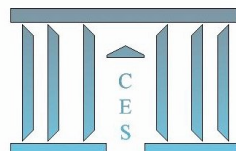
**HAL Id: halshs-00289435**

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Submitted on 20 Jun 2008

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## **Bargaining over Public Goods**

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**2008.41**



CENTRE NATIONAL  
DE LA RECHERCHE  
SCIENTIFIQUE

# BARGAINING OVER PUBLIC GOODS

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2008

**ABSTRACT.** In a simple public good economy, we propose a natural bargaining procedure whose equilibria converge to Lindahl allocations as the cost of bargaining vanishes. The procedure splits the decision over the allocation in a decision about personalized prices and a decision about output levels for the public good. Since this procedure does not assume price-taking behavior, it provides a strategic foundation for the personalized taxes inherent to the Lindahl solution to the public goods problem.

## 1. INTRODUCTION

The private provision of public goods in general leads to inefficient allocations in a competitive market environment. This inefficiency is often attributed to a missing market. If *personalized* markets could be created that individually price the public good for each agent, then a competitive equilibrium could implement an efficient allocation. For an economy with public goods, this outcome is known as a Lindahl equilibrium. Typically, however, a Lindahl equilibrium is deemed unrealistic because of a serious shortcoming: in the personalized markets upon which it rests the agents are assumed to have a price-taking behavior. But unfortunately, by the personalized nature of those markets, there is only one single agent on the demand side in each of them, which makes price-taking behavior of this single agent an utterly unrealistic assumption. On contrast, we propose in this paper a bargaining procedure that leads (without the need of assuming price-taking behavior) to an outcome arbitrarily close to a Lindahl allocation as the cost of bargaining vanishes. As a matter of fact, the two only agents of our model (for the sake of simplicity) have quite on the contrary a lot of market power.

In the case of a missing market (as it happens in the presence of a public good), one way to allocate the surplus left unappropriated is through Coasian bargaining. As pointed by Coase, as long as there remain gains from trade the parties involved have incentives to get together and strike a deal. The main feature of such bargaining is that it is decentralized (no benevolent government must intervene), and the extent to which the surplus can be allocated to the parties depends on the details of the bargaining protocol and on whether the bargaining is costly or not.

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The study of this type of bargaining in legislatures has already been addressed in Baron and Ferejohn (1989), where a model is presented in which one of the different possible ways to divide a given pie is chosen by a vote according to the majority rule. It turns out that typically there exist many equilibria for this procedure. Banks and Duggan (2000) present a far more general model in which the space of alternatives is a compact, convex subset of a multidimensional Euclidean space. They consider arbitrary voting rules and prove the existence of stationary equilibria, the upper hemicontinuity of equilibrium proposals in structural and preference parameters, and a core equivalence result. While several of these bargaining set-ups encompass economies with public goods, they differ from our own set-up in that ours implicitly imposes constraints on what the proposer is able to offer to other agents. We believe these constraints reflect in a natural way the sharing of power in a bargaining situation over both the output level and the financing of a public good. At any rate, as a consequence of imposing such constraints on the offers, the bargaining protocol considered here allows to attain (in the limiting case of vanishing bargaining costs) the outcome that would result from completing the markets that are missing because of the presence of a public good, but without resorting to the heroic assumption of price-taking behavior with respect to personalized prices.

Specifically, in order to formalize the Coasian procedure of extracting rents, we propose a sequential bargaining as a collective decision making process. Its sequential nature reflects a realistic feature of the power of setting the agenda of the negotiation. The proposal and acceptance decisions are endogenous. Agents can reject a proposal and have it modified in their turn. Because of the cost of any delay in reaching an agreement, the bargaining outcome will in general be inefficient thus reflecting the power of setting the agenda: when there is impatience for reaching an agreement, the agent who makes an offer that is accepted will extract more rents at the cost of inefficiency. As the impatience or cost of a delay vanishes, those rents disappear and the allocation is efficient and independent of who had the power of setting the agenda.

In this paper we show that, despite the fact that output decisions for public goods and their mode of financing are often the result of a political process rife with opportunities for strategic behavior, the Lindahl allocations can be implemented without assuming price-taking behavior with respect to personalized prices. This is obtained precisely through a *strategic* bargaining of the parties over the financing of the public good.<sup>1</sup> In order to show this we take here a first step towards modelling the political process behind output and financing decisions with regard to public goods as a sequential bargaining game of complete information.

Specifically, we consider an economy with any finite number of public goods and private goods (not necessarily the same number of each). There are two agents in this economy who take turns alternately (as in Rubinstein (1982)) to propose a maximum level of provision of each of the public goods and a way to split between them the cost of financing any level of the public goods to be provided up to the

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<sup>1</sup>The mixed competitive mechanisms proposed in Groves and Ledyard (1977) obviously can efficiently allocate private and public goods to coincide with the Lindahl allocation (see also Tian (1989)). However, those direct mechanisms both rely on a centralized mechanism designer and they may involve complicated mechanisms. The virtue here is that an efficient allocation of private and public goods is obtained through a decentralized bargaining procedure. It is simple: it relies explicitly on personalized contributions (taxes) and incorporates the notion that agenda setters have power to extract more rents when bargaining is costly.

proposed maxima (this amounts to proposing personalized prices or taxes). The other agent can then either accept or reject the proposal. In case of acceptance, this other agent chooses the amount of each public good to be provided (subject to the maximum amount offered in the proposal). Each agent pays for the public goods according to the personalized prices agreed upon. The levels of public goods and their financing are fixed thereafter so the game is effectively over. If instead the other agent rejects the proposal, then it is his turn to make a proposal himself of a new maximum amounts and personalized prices, and so on.

Within this set-up we show that, as the discount factors of each agent in the economy converge to one (no matter how), the allocation of any stationary subgame perfect equilibrium converges to a Lindahl equilibrium allocation. Specifically, we show first that, for infinitely patient agents (i.e. for discount factors equal to 1), the set of Lindahl allocations coincides with the set of stationary subgame perfect equilibrium allocations of the alternating-offers bargaining game described above. Then we establish the upper hemicontinuity of the correspondence mapping, to each pair of discount factors, the set of stationary subgame perfect equilibrium allocations of the bargaining game, and in particular its upper hemicontinuity for discount factors  $\delta^A = \delta^B = 1$ . The conclusion then follows from these two results.

In this simple set-up, unanimity plays an important role in our modelling. In effect, a tax proposal can be adopted only if it is acceptable to every agent. This has the virtue of conferring a Wicksellian character to the Lindahl solution to the public goods problem. In effect, in a classical contribution to the theory of public finance, Wicksell [9] proposed unanimity as the criterion for just taxation. The game we propose incorporates the need of achieving consensus to effect tax proposals that to some extent may characterize budgetary procedures in political regimes with multiple checks and balances or in parliamentary democracies without a majority party. Inefficiencies associated with bargaining are shown to disappear as agents become increasingly patient. Thus, a Wicksellian procedure turns out to be consistent with a Lindahl result. Of course, this result depends on the assumption of complete information.

## 2. THE MODEL

We consider first a public good economy consisting of only two agents  $A$  and  $B$ , but an arbitrary number  $n + m$  of goods:  $n$  private goods  $x_1, \dots, x_n$  and  $m$  public goods  $y_1, \dots, y_m$ . The agents are infinitely lived and time is discrete. For each agent  $i = A, B$ , let  $x^i \in \mathbb{R}_+^n$  be  $i$ 's consumption of the private good, and let  $y \in \mathbb{R}_+^m$  be their common consumption of the public good. The agents have preferences over the two types of goods represented by standard utility functions  $u^A(x^A, y)$  and  $u^B(x^B, y)$ .<sup>2</sup> The agents are endowed with amounts  $e^i$  (with total endowment  $e = e^A + e^B$ ) of the private goods, and as a normalization, we assume the initial amount of the public goods is zero. A linear technology  $M \in \mathbb{R}^{n \times m}$  allows to produce each public good  $y_j$  by means of the private goods, requiring  $m_{ij}$  units of private good  $x_i$  for each unit of  $y_j$ , for all  $i = 1, \dots, n$ .

We consider an alternating-offers bargaining game. In any given period prior to an agreement, an agent  $i$  makes an offer consisting of a vector  $p_i = (p_{xi}, p_{yi})$  of prices for the other agent (in terms of, say, the private good  $x_1$ ) and an upper

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<sup>2</sup>That is to say  $C^2$ , monotone, differentiable strictly quasi-concave, non-negative utility functions that are well-behaved at the boundary of  $\mathbb{R}_+^{n+m}$ .

bound  $q_i$  to the contribution of private goods to the provision of public goods or, equivalently, to the provision of public goods itself. After receiving an offer the other agent can either accept it or reject it. In case of acceptance, the accepting agent chooses his consumption of private goods and the quantities of public goods to be provided subject to the accepted prices  $p_i$  and upper bound on trades  $q_i$ .

This procedure is repeated until a proposal is accepted. The utility of each agent  $i$  is discounted in each iteration by a positive discount factor  $\delta^i$  not bigger than 1. The utility of never reaching an agreement is 0.

At this point it is worth observing that the right to make a proposal can be thought of as a *property right* over the surplus from the public good. The details of those property rights will certainly matter when bargaining is costly —as we will show below. However, one of our findings is that the way in which property rights are assigned does not matter when the cost of a delay disappears.

### 3. THE STATIONARY SUBGAME PERFECT (SSP) EQUILIBRIUM ALLOCATIONS

We consider first the stationary subgame perfect equilibria without delay of this game (i.e. an equilibrium in which no agent has incentives to reject the offer received). Such equilibria are characterized by an offer  $(p_A, q_A)$  of a vector of prices and a maximum amount for the contributions of private goods or the provisions of public goods that  $A$  offers to  $B$  and a similar offer made by  $(p_B, q_B)$ , such that, for instance,  $(p_A, q_A)$  maximizes the utility that  $A$  obtains from  $B$ 's immediate acceptance of his offer  $(p_A, q_A)$ , subject to the constraint that it is indeed in  $B$ 's interest to accept  $(p_A, q_A)$ , i.e.  $(p_A, q_A)$  solves

$$\max u^A(e - \tilde{x}^B(p_A, q_A) - M\tilde{y}^B(p_A, q_A), \tilde{y}^B(p_A, q_A)) \quad (1)$$

subject to the constraint

$$\begin{aligned} u^B(\tilde{x}^B(p_A, q_A), \tilde{y}^B(p_A, q_A)) \geq \\ \delta^B u^B(e - \tilde{x}^A(p_B, q_B) - M\tilde{y}^A(p_B, q_B), \tilde{y}^A(p_B, q_B)) \end{aligned} \quad (2)$$

given  $p_B, q_B$  —where  $\tilde{x}^B(p_A, q_A), \tilde{y}^B(p_A, q_A)$  is the solution to

$$\begin{aligned} \max u^B(x, y) \\ p_A \cdot (x - e^B, y) \leq 0 \\ \|(x - e^B, y)\| \leq q_A,^5 \end{aligned} \quad (3)$$

— and symmetrically for  $(p_B, q_B)$ . That is to say,  $A$ 's offer maximizes the utility that  $A$  will derive from  $B$ 's immediate acceptance of the offer, provided that the offer is such that  $B$  is interested indeed in accepting immediately the offer.

Note however that a SSP equilibrium without delay can equivalently be characterized by the *allocations* effectively offered by the agents. In effect, conditional to immediate acceptance, an offer by  $A$  of  $(p_A, q_A)$  amounts to offering  $B$  the bundle  $(\tilde{x}^B(p_A, q_A), \tilde{y}^B(p_A, q_A))$ , which is characterized by satisfying the condition

$$(u_x^B(x^B, y), u_y^B(x^B, y)) \begin{pmatrix} x^B - e^B \\ y \end{pmatrix} \geq 0. \quad (4)$$

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<sup>5</sup> The choice of the norm is inessential.

Conversely, any bundle  $(x^B, y)$  satisfying the previous inequality is solution to  $B$ 's problem above for some offer  $(p_A, y_A)$  by  $A$ . This fact is established in Lemma 1 in the Appendix.

As a consequence, A SSP equilibrium without delay can also be characterized by allocations  $(x_A^A, x_A^B, y_A)$  and  $(x_B^A, x_B^B, y_B)$ , proposed by  $A$  and  $B$  respectively, such that  $(x_A^A, x_A^B, y_A)$  solves

$$\begin{aligned} & \max u^A(x^A, y) \\ & (u_x^B(x^B, y), u_y^B(x^B, y)) \begin{pmatrix} x^B - e^B \\ y \end{pmatrix} \geq 0 \\ & u^B(x^B, y) \geq \delta^B u^B(x_B^B, y_B) \\ & x^A + x^B + My = e^A + e^B \end{aligned} \tag{5}$$

given  $(x_B^A, x_B^B, y_B)$ , and  $(x_B^A, x_B^B, y_B)$  solves

$$\begin{aligned} & \max u^B(x^B, y) \\ & (u_x^A(x^A, y), u_y^A(x^A, y)) \begin{pmatrix} x^A - e^A \\ y \end{pmatrix} \geq 0 \\ & u^A(x^A, y) \geq \delta^A u^A(x_A^A, y_A) \\ & x^A + x^B + My = e^A + e^B \end{aligned} \tag{6}$$

given  $(x_A^A, x_A^B, y_A)$ .

#### 4. THE LINDAHL ALLOCATIONS

A Lindahl equilibrium allocation  $(x^A, x^B, y)$  is characterized by satisfying that

- (1) the allocation is feasible, i.e.  $x^A, x^B, y \geq 0$  and

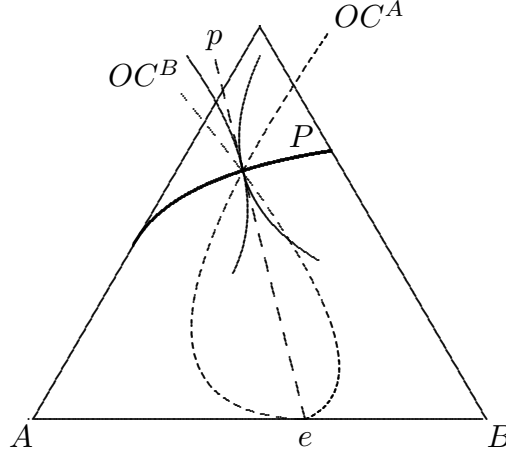
$$x^A + x^B + My = e^A + e^B \tag{7}$$

- (2) it allocates to each agent  $i$  his demand  $(x^i, y)$  at his personalized relative prices (implicitly equal to the marginal rates of substitution determined by his marginal utilities at  $(x^i, y)$ ), i.e. for  $i = A, B$ ,

$$(u_x^i(x^i, y), u_y^i(x^i, y)) \begin{pmatrix} x^i - e^i \\ y \end{pmatrix} = 0. \tag{8}$$

For the case of one private good and one public good, Lindahl Equilibrium allocations can be represented in a Kolm triangle, the public goods equivalent of the Edgeworth box of a private goods exchange economy (see Figure 1 below). The orthogonal distance from any point within the triangle to each of its sides represents each agent's allocation of the private good ( $x^A$  and  $x^B$ ), while the vertical distance to the base of the triangle represents their *common* consumption  $y$  of the public good. The triangular form accounts for the linear production technology: an increase in the quantity of public goods produced implies an proportional decrease in the quantity of private goods that remain for consumption. Thus, at the initial endowment  $e$  there is no provision of the public good.

Figure 1



The personalized prices  $p^A$  and  $p^B$  represent the terms of exchange of one unit of public good for  $p^A$  units of the private good from agent  $A$  and  $p^B$  units of private good from agent  $B$ . A balanced budget where the total contributions equal the total cost of production of the public good implies that for all  $y$ ,  $\sum_{i=1}^I p^i y = y$ . For a given price schedule  $p$ , the offer curve  $OC^i$  gives the optimal amount of public good and private good demanded by agent  $i$  at those terms of trade. An intersection of the offer curves represents then optimal quantities of the public good and the private good consumed by the agents given a vector of personalized prices that balances the budget. This corresponds to a Lindahl equilibrium allocation. There are of course other efficient allocation represented by the Pareto set  $P$ , but they are not attainable by means of price schedules starting from the initial endowment  $e$ .

## 5. SSP EQUILIBRIUM ALLOCATIONS ARE LINDAHL ALLOCATIONS WHEN $\delta^A = \delta^B = 1$

First we show that for infinitely patient agents, that is to say, when the discount factors  $\delta^A$  and  $\delta^B$  are 1, the Lindahl equilibrium allocations, and only these allocations, are offered at a stationary subgame perfect equilibrium of the bargaining game above.

**Theorem 1.** *When  $\delta^A = \delta^B = 1$ , at every SSP equilibrium with immediate acceptance the agents' offers lead to the same allocation which is, moreover, the allocation of a Lindahl equilibrium. Conversely, every Lindahl equilibrium allocation is the allocation offered by the two agents at some SSP equilibrium without delay.*

*Proof.* Let  $(x_A^A, x_A^B, y_A)$  and  $(x_B^A, x_B^B, y_B)$  be the feasible allocations resulting from  $B$ 's (resp.  $A$ 's) acceptance of  $A$ 's (resp.  $B$ 's) offer of price and maximum provisions of public goods at a SSP equilibrium with immediate acceptance for infinitely many patients. That is to say, let  $(x_A^A, x_A^B, y_A)$  and  $(x_B^A, x_B^B, y_B)$  be such that



(1)

$$\begin{aligned}
(x_A^A, x_A^B, y_A) &\in \arg \max_{x^A, x^B, y} u^A(x^A, y) \\
(u_x^B(x^B, y), u_y^B(x^B, y)) &\begin{pmatrix} x^B - e^B \\ y \end{pmatrix} \geq 0 \\
u^B(x^B, y) &\geq u^B(x_B^B, y_B) \\
x^A + x^B + My &= e^A + e^B \\
&\text{given } (x_B^A, x_B^B, y_B)
\end{aligned} \tag{9}$$

(2)

$$\begin{aligned}
(x_B^A, x_B^B, y_B) &\in \arg \max_{x^A, x^B, y} u^B(x^B, y) \\
(u_x^A(x^A, y), u_y^A(x^A, y)) &\begin{pmatrix} x^A - e^A \\ y \end{pmatrix} \geq 0 \\
u^A(x^A, y) &\geq u^A(x_A^A, y_A) \\
x^A + x^B + My &= e^A + e^B \\
&\text{given } (x_A^A, x_A^B, y_A).
\end{aligned} \tag{10}$$

Then necessarily, from the first-order conditions, there exist multipliers  $\lambda^A, \mu^A, \lambda^B, \mu^B \geq 0$  and  $\nu^A, \nu^B$  such that

$$\begin{aligned}
&\begin{pmatrix} u_x^A(x_A^A, y_A) \\ 0 \\ u_y^A(x_A^A, y_A) \end{pmatrix} + \lambda^A \begin{pmatrix} 0 \\ u_x^B(x_A^B, y_A) \\ u_y^B(x_A^B, y_A) \end{pmatrix} \\
&+ \mu^A \begin{pmatrix} 0 \\ u_x^B(x_A^B, y_A) + u_{xx}^B(x_A^B, y_A)(x_A^B - e^B) + u_{yx}^B(x_A^B, y_A)y_A \\ u_y^B(x_A^B, y_A) + u_{xy}^B(x_A^B, y_A)(x_A^B - e^B) + u_{yy}^B(x_A^B, y_A)y_A \end{pmatrix} \\
&+ \sum_{i=1}^n \nu_i^A \begin{pmatrix} e_i \\ e_i \\ m_{i.}^t \end{pmatrix} = 0
\end{aligned} \tag{11}$$

where  $m_{i.}^t$  is the  $i$ -th row of  $M$  transposed as a column, or equivalently, eliminating the multipliers  $\nu_i^A$

$$\begin{aligned}
&\begin{pmatrix} u_x^A(x_A^A, y_A) \\ M^t u_x^A(x_A^A, y_A) - u_y^A(x_A^A, y_A) \end{pmatrix} = \lambda^A \begin{pmatrix} u_x^B(x_A^B, y_A) \\ u_y^B(x_A^B, y_A) \end{pmatrix} \\
&+ \mu^A \begin{pmatrix} u_x^B(x_A^B, y_A) + u_{xx}^B(x_A^B, y_A)(x_A^B - e^B) + u_{yx}^B(x_A^B, y_A)y_A \\ u_y^B(x_A^B, y_A) + u_{xy}^B(x_A^B, y_A)(x_A^B - e^B) + u_{yy}^B(x_A^B, y_A)y_A \end{pmatrix}
\end{aligned} \tag{12}$$

and similarly

$$\begin{aligned}
&\begin{pmatrix} u_x^B(x_B^B, y_B) \\ M^t u_x^B(x_B^B, y_B) - u_y^B(x_B^B, y_B) \end{pmatrix} = \lambda^B \begin{pmatrix} u_x^A(x_B^A, y_B) \\ u_y^A(x_B^A, y_B) \end{pmatrix} \\
&+ \mu^B \begin{pmatrix} u_x^A(x_B^A, y_B) + u_{xx}^A(x_B^A, y_B)(x_B^A - e^A) + u_{yx}^A(x_B^A, y_B)y_B \\ u_y^A(x_B^A, y_B) + u_{xy}^A(x_B^A, y_B)(x_B^A - e^A) + u_{yy}^A(x_B^A, y_B)y_B \end{pmatrix}
\end{aligned} \tag{13}$$

Assume that  $(x_A^A, x_A^B, y_A) \neq (x_B^A, x_B^B, y_B)$ . Since at a SSPE with  $\delta^A = 1 = \delta^B$  the constraints

$$\begin{aligned} u^A(x_B^A, y_B) &\geq u^A(x_A^A, y_A) \\ u^B(x_A^B, y_A) &\geq u^B(x_B^B, y_B) \end{aligned} \quad (14)$$

are binding<sup>3</sup> (and hence both allocations are on the same indifference surface for both agents),<sup>4</sup> then none of these two allocations can be efficient while being different. Therefore the efficiency condition that

$$\begin{pmatrix} u_x^A(x^A, y) \\ u_y^A(x^A, y) \end{pmatrix} \text{ and } \begin{pmatrix} u_x^B(x^B, y) \\ M^t u_x^B(x^B, y) - u_y^B(x^B, y) \end{pmatrix} \quad (15)$$

are collinear cannot hold neither at  $(x_A^A, x_A^B, y_A)$  nor at  $(x_B^A, x_B^B, y_B)$ . In particular, there exist  $h, k$  such that

$$\frac{u_{y_k}^A(x_B^A, y_B)}{u_{x_h}^A(x_B^A, y_B)} < \frac{\sum_{i=1}^n m_{ik} u_{x_i}^B(x_B^B, y_B) - u_{y_k}^B(x_B^B, y_B)}{u_{x_h}^B(x_B^B, y_B)} \quad (16)$$

(a similar argument applies if the inequality holds the other way), then (13) above cannot be satisfied for non-negative multipliers (in the case the inequality is reversed it is condition (12) above that cannot be satisfied for non-negative multipliers).

In effect, since  $(\lambda^B, \mu^B)$  must solve (13) above, then it must also solve

$$\begin{aligned} \left( \sum_{i=1}^n m_{ik} u_{x_i}^B(x_B^B, y_B) - u_{y_k}^B(x_B^B, y_B) \right) &= \lambda^B \left( u_{x_h}^A(x_B^A, y_B) \right. \\ &\quad \left. + \mu^B \left( u_{x_h}^A(x_B^A, y_B) + u_{x_h x_h}^A(x_B^A, y_B)(x_B^A - e^A) + u_{y_k x_h}^A(x_B^A, y_B)y_B \right) \right. \\ &\quad \left. u_{y_k}^A(x_B^A, y_B) + u_{x_h y_k}^A(x_B^A, y_B)(x_B^A - e^A) + u_{y_k y_k}^A(x_B^A, y_B)y_B \right) \end{aligned} \quad (17)$$

so that in particular  $\mu^B$  is

$$\mu^B = \frac{\begin{vmatrix} u_{x_h}^A(x_B^A, y_B) & u_{x_h}^B(x_B^B, y_B) \\ u_{y_k}^A(x_B^A, y_B) & \sum_{i=1}^n m_{ik} u_{x_i}^B(x_B^B, y_B) - u_{y_k}^B(x_B^B, y_B) \end{vmatrix}}{\begin{vmatrix} u_{x_h}^A(x_B^A, y_B) & u_{x_h}^A(x_B^A, y_B) + u_{x_h x_h}^A(x_B^A, y_B)(x_B^A - e^A) + u_{y_k x_h}^A(x_B^A, y_B)y_B \\ u_{y_k}^A(x_B^A, y_B) & u_{y_k}^A(x_B^A, y_B) + u_{x_h y_k}^A(x_B^A, y_B)(x_B^A - e^A) + u_{y_k y_k}^A(x_B^A, y_B)y_B \end{vmatrix}}. \quad (18)$$

Since  $\mu \geq 0$  necessarily and the numerator is strictly positive according to (16), so must be the denominator. But this denominator is equivalent to the following expression which in fact happens to have the opposite sign,

$$\begin{aligned} &(-u_{y_k}^A(x_B^A, y_B) \quad u_{x_h}^A(x_B^A, y_B)) \\ &\cdot \left[ \begin{pmatrix} u_{x_h}^A(x_B^A, y_B) \\ u_{y_k}^A(x_B^A, y_B) \end{pmatrix} + \begin{pmatrix} u_{x_h x_h}^A(x_B^A, y_B) & u_{x_h y_k}^A(x_B^A, y_B) \\ u_{y_k x_h}^A(x_B^A, y_B) & u_{y_k y_k}^A(x_B^A, y_B) \end{pmatrix} \begin{pmatrix} x_B^A - e_h^A \\ y_{kB} \end{pmatrix} \right] \leq 0 \end{aligned} \quad (19)$$

<sup>3</sup>For instance, since  $(x_A^A, x_A^B, y_A)$  satisfies  $Du^A(x^A, y)(x^A - e^A, y) \geq 0$  (agent  $A$  will never choose at equilibrium to let  $B$  ask for a provision of public goods bigger than the one necessary to attain  $A$ 's demand at the implicit prices), then necessary  $u^B(x_A^B, y_A) \leq u^B(x_B^B, y_B)$  holds as well.

<sup>4</sup>Note that for this step to hold true it is crucial to have the equality of the discount factors  $\delta^A$  and  $\delta^B$  to 1.

since the first scalar product is null and the Hessian of  $u^A$  at  $(x_B^A, y_B)$  is semi-definite negative in the space orthogonal to the gradient of  $u^A$  at  $(x_B^A, y_B)$  and hence also to any  $(0, \dots, 0, x_{hB}^A - e_h^A, 0, \dots, 0, y_{kB}, 0, \dots, 0)$  orthogonal to  $(u_x^A(x_B^A, y_B), u_y^A(x_B^A, y_B))$ , i.e. for all  $(x_{hB}^A - e_h^A, y_{kB})$  such that

$$u_{x_h}^A(x_B^A, y_B)(x_{hB}^A - e_h^A) + u_{y_k}^A(x_B^A, y_B)y_{kB}^A = 0 \quad (20)$$

(note that in this case  $(-u_{y_k}^A(x_B^A, y_B), u_{x_h}^A(x_B^A, y_B))$  is collinear to  $(x_{hB}^A - e_h^A, y_{kB})$  up to a positive constant).

Therefore  $(x_A^A, x_A^B, y_A) = (x_B^A, x_B^B, y_B)$  necessarily, i.e. whenever  $\delta^A = 1 = \delta^B$  at a SSP equilibrium with immediate acceptance the two agents offer the same allocation. Let then  $x^A, x^B, y$  be the common allocation offered at a SSP equilibrium when  $\delta^A = 1 = \delta^B$ , i.e. such that

$$(1) \quad x^A + x^B + My = e^A + e^B \quad (21)$$

$$(2) \quad \begin{aligned} (x^A, y) &\in \arg \max u^B(e - \hat{x}^A - M\hat{y}, \hat{y}) \\ (u_x^A(\hat{x}^A, \hat{y}), u_y^A(\hat{x}^A, \hat{y})) \begin{pmatrix} \hat{x}^A - e^A \\ \hat{y} \end{pmatrix} &\geq 0 \\ u^A(\hat{x}^A, \hat{y}) &\geq u^A(e - x^B - My, y) \\ &\text{given } x^B, y \end{aligned} \quad (22)$$

$$(3) \text{ and } \begin{aligned} (x^B, y) &\in \arg \max u^A(e - \hat{x}^B - M\hat{y}, \hat{y}) \\ (u_x^B(\hat{x}^B, \hat{y}), u_y^B(\hat{x}^B, \hat{y})) \begin{pmatrix} \hat{x}^B - e^B \\ \hat{y} \end{pmatrix} &\geq 0 \\ u^B(\hat{x}^B, \hat{y}) &\geq u^B(e - x^A - My, y) \\ &\text{given } x^A, y \end{aligned} \quad (23)$$

Assume that

$$(u_x^A(x^A, y), u_y^A(x^A, y)) \begin{pmatrix} x^A - e^A \\ y \end{pmatrix} > 0 \quad (24)$$

Then, since both  $u^A$  and  $u^B$  are concave,

$$\begin{aligned} (x^A, y) &\in \arg \max u^B(e - \hat{x}^A - M\hat{y}, \hat{y}) \\ u^A(\hat{x}^A, \hat{y}) &\geq u^A(e - x^B - My, y) \\ &\text{given } x^B, y \end{aligned} \quad (25)$$

Therefore, there exists  $\lambda > 0$  such that

$$\begin{aligned} \begin{pmatrix} u_x^A(x^A, y) \\ u_y^A(x^A, y) \end{pmatrix} &= \lambda \begin{pmatrix} u_x^B(x^B, y) \\ M^t u_x^B(x^B, y) - u_y^B(x^B, y) \end{pmatrix} \\ &= \lambda \begin{pmatrix} I_n & 0 \\ M^t & -I_m \end{pmatrix} \begin{pmatrix} u_x^B(x^B, y) \\ u_y^B(x^B, y) \end{pmatrix} \end{aligned} \quad (26)$$

But since

$$(1) \quad x^A + x^B + My = e^A + e^B \quad (27)$$

$$(2) \quad (u_x^A(x^A, y), u_y^A(x^A, y)) \begin{pmatrix} x^A - e^A \\ y \end{pmatrix} > 0 \quad (28)$$

and

$$(3) \text{ for some } \lambda > 0, \quad (u_x^A(x^A, y), u_y^A(x^A, y)) = \lambda^{-1} (u_x^B(x^B, y), u_y^B(x^B, y)) \begin{pmatrix} I_n & M \\ 0 & -I_m \end{pmatrix}, \quad (29)$$

then

$$(u_x^B(x^B, y), u_y^B(x^B, y)) \begin{pmatrix} x^B - e^B \\ y \end{pmatrix} < 0!! \quad (30)$$

contradicting (3) above. Therefore

$$(u_x^A(x^A, y), u_y^A(x^A, y)) \begin{pmatrix} x^A - e^A \\ y \end{pmatrix} = 0 \quad (31)$$

and similarly

$$(u_x^B(x^B, y), u_y^B(x^B, y)) \begin{pmatrix} x^B - e^B \\ y \end{pmatrix} = 0 \quad (32)$$

i.e., the allocations proposed by both agents at a SSP equilibrium is on both agents' offer curves so that it is a Lindahl equilibrium allocation.

Conversely, let  $x^A, x^B, y$  be the allocation of a Lindahl equilibrium, i.e. such that

$$(1) \quad x^A + x^B + My = e^A + e^B \quad (33)$$

$$(2) \quad (u_x^A(x^A, y), u_y^A(x^A, y)) \begin{pmatrix} x^A - e^A \\ y \end{pmatrix} = 0 \quad (34)$$

(3) and

$$(u_x^B(x^B, y), u_y^B(x^B, y)) \begin{pmatrix} x^B - e^B \\ y \end{pmatrix} = 0. \quad (35)$$

Let  $(p_A, q_A)$  be  $((u_x^B(x^B, y), u_y^B(x^B, y)), y)$  and, similarly, let  $(p_B, q_B)$  be the vector  $((u_x^A(x^A, y), u_y^A(x^A, y)), y)$ , so that  $x^A = \tilde{x}^A(p_B, q_B)$ ,  $x^B = \tilde{x}^B(p_A, q_A)$  and  $\tilde{y}^A(p_B, q_B) = y = \tilde{y}^B(p_A, q_A)$ . Then it can be easily checked that the Lindahl allocation  $(x^A, x^B, y)$  is the outcome of the following SSP equilibrium profile of strategies:

(1)  $A$  offers  $(p_A, q_A)$  whenever he has the opportunity to do so, and accepts only offers  $(p, q)$  such that

$$u^A(\tilde{x}^A(p, q), \tilde{y}^A(p, q)) \geq \delta^A u^A(\tilde{x}^A(p_B, q_B), \tilde{y}^A(p_B, q_B)) \quad (36)$$

(2)  $B$  offers  $(p_B, q_B)$  whenever he has the opportunity to do so, and accepts only offers  $(p, q)$  such that

$$u^B(\tilde{x}^B(p, q), \tilde{y}^B(p, q)) \geq \delta^B u^B(\tilde{x}^B(p_A, q_A), \tilde{y}^B(p_A, q_A)). \quad (37)$$

QED

## 6. CONVERGENCE OF SSP EQUILIBRIUM ALLOCATIONS TO LINDAHL ALLOCATIONS AS $\delta^A, \delta^B \rightarrow 1$

In the relevant case in which bargaining entails some frictions, so that the factors by which the agents discount future utilities are strictly smaller than 1, any SSP equilibrium allocation is still arbitrarily close to a Lindahl allocation if agents are patient enough. This is a consequence of the upper hemicontinuity of the correspondence of SSP equilibrium allocations with respect to the agents' discount factors, as Theorem 2 next establishes.

**Theorem 2.** *Every SSP equilibrium allocation converges to a Lindahl allocation as  $\delta^A, \delta^B \rightarrow 1$ .*

*Proof.* Consider the correspondence  $\Phi$  defined as

$$\begin{aligned} \Phi(x_A^A, x_A^B, y_A, x_B^A, x_B^B, y_B; \delta^A, \delta^B) = \\ \arg \max_{0 \leq x^A, x^B, y} u^A(x^A, y) \times \arg \max_{0 \leq x^A, x^B, y} u^B(x^B, y) \\ \left. \begin{array}{l} Du^B(x^B, y) \quad x^B - e^B \\ y \end{array} \right) \geq 0 \quad \left. \begin{array}{l} Du^A(x^A, y) \quad x^A - e^A \\ y \end{array} \right) \geq 0 \\ u^B(x^B, y) \leq \delta^B u^B(x_B^B, y_B) \quad u^A(x^A, y) \geq \delta^A u^A(x_A^A, y_A) \\ x^A + x^B + My = e^A + e^B \quad x^A + x^B + My = e^A + e^B \\ \text{given } (x_B^A, x_B^B, y_B) \quad \text{given } (x_A^A, x_A^B, y_A) \end{aligned} \quad (38)$$

where  $Du^i(x^i, y)$  stands for  $(u_x^i(x^i, y), u_y^i(x^i, y))$ , for all  $i = A, B$ . Note that, by the Theorem of the Maximum,

$$\begin{aligned} \arg \max_{0 \leq x^A, x^B, y} u^A(x^A, y) \\ \left. \begin{array}{l} Du^B(x^B, y) \quad x^B - e^B \\ y \end{array} \right) \geq 0 \\ u^B(x^B, y) \geq \delta^B u^B(x_B^B, y_B) \\ x^A + x^B + My = e^A + e^B \\ \text{given } (x_B^A, x_B^B, y_B) \end{aligned} \quad (39)$$

is a compact-valued, upper hemicontinuous correspondence that depends explicitly on  $x_B^B, y_B$ , and  $\delta^B$  but also trivially on  $x_B^A$  and  $x_A^A, x_A^B, y_A, \delta^A$ .<sup>5</sup> And similarly for agent  $A$ 's problem. Therefore,  $\Phi$  is the cartesian product of compact-valued, upper hemicontinuous correspondences, and hence it is compact-valued and upper hemicontinuous itself.<sup>6</sup>

<sup>5</sup>Since  $u^A$  depends continuously on  $x^A, y$  and also trivially on  $x_A^A, x_A^B, y_A, x_B^A, x_B^B, y_B, \delta^A, \delta^B$ , and the correspondence defined by the constraints

$$\begin{aligned} \Omega^A(x_A^A, x_A^B, y_A, x_B^A, x_B^B, y_B, \delta^A, \delta^B) = \left\{ (x^A, x^B, y) \in \mathbb{R}^{2n+m} \mid \begin{array}{l} Du^B(x^B, y) \quad x^B - e^B \\ y \end{array} \geq 0 \right. \\ \left. \begin{array}{l} u^B(x^B, y) \geq \delta^B u^B(x_B^B, y_B) \\ x^A + x^B + My = e^A + e^B \end{array} \right\} \end{aligned}$$

is continuous and compact-valued.

<sup>6</sup>See Lemma A1 in Dávila-Eeckhout (2008).

Consider the correspondence  $\Gamma$  of fixed points of  $\Phi$  as a function of  $\delta^A, \delta^B$ , i.e.

$$\Gamma(\delta^A, \delta^B) = \left\{ (x_A^A, x_A^B, y_A, x_B^A, x_B^B, y_B) \in \mathbb{R}^{2(2n+m)} \mid \right. \\ \left. (x_A^A, x_A^B, y_A, x_B^A, x_B^B, y_B) \in \Phi(x_A^A, x_A^B, y_A, x_B^A, x_B^B, y_B; \delta^A, \delta^B) \right\}. \quad (40)$$

Since  $\Phi$  is compact-valued and upper hemicontinuous, then the correspondence mapping to each pair  $(\delta^A, \delta^B)$  the fixed points of  $\Phi(\cdot, \cdot, \cdot, \cdot, \cdot, \cdot; \delta^A, \delta^B)$  is upper hemicontinuous.<sup>7</sup>

Finally, note that  $\Gamma$  is the correspondence of SSP equilibrium allocations (without delay). Since this correspondence is upper hemicontinuous, in particular at  $(\delta^A, \delta^B) = (1, 1)$  and, according to Theorem 1,  $\Gamma(1, 1)$  is the set of Lindahl allocations, then the claim follows.

QED

## APPENDIX

**Lemma 1.** *If  $(x, y)$  solves*

$$\begin{aligned} \max u(x, y) \\ p \cdot (x - e, y) &\leq 0 \\ \|(x - e^B, y)\| &\leq q_A \end{aligned} \quad (A.1)$$

*then*

$$Du(x, y) \begin{pmatrix} x - e \\ y \end{pmatrix} \geq 0 \quad (A.2)$$

*and conversely, if  $x$  satisfies (A.2) then there exist  $p, q$  for which  $x$  solves (A.1).*

*Proof.* Since  $x$  solves (A.1), then there exist  $\lambda, \mu \geq 0$  such that

$$\begin{aligned} Du(x, y) &= \lambda p + \mu(x - e, y) \\ \lambda p \cdot (x - e, y) &= 0 \\ \mu[(x - e)^t(x - e) + y^t y - q^2] &= 0 \end{aligned} \quad (A.3)$$

Therefore,

$$\begin{aligned} Du(x, y) \cdot (x - e, y) &= \lambda p \cdot (x - e, y) + \mu(x - e, y) \cdot (x - e, y) \\ &= \mu(x - e, y) \cdot (x - e, y) \geq 0 \end{aligned} \quad (A.4)$$

Conversely, if  $x, y$  satisfies  $Du(x, y)(x - e, y) = 0$ , let

$$\begin{aligned} \lambda &= 1 \\ \mu &= 0 \\ p &= Du(x, y) \\ q^2 &= (x - e, y)(x - e, y). \end{aligned} \quad (A.5)$$

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<sup>7</sup>See Lemma A3 in Dávila-Eeckhout (2008).

If  $x, y$  satisfies  $Du(x, y)(x - e, y) > 0$ , let

$$\begin{aligned}
\lambda &> 0 \\
\mu &= \frac{Du(x, y)(x - e, y)}{(x - e, y)(x - e, y)} \\
p &= \frac{1}{\lambda} \left[ Du(x, y) - \frac{Du(x, y)(x - e, y)}{(x - e, y)(x - e, y)}(x - e, y) \right] \geq 0,^6 \\
q^2 &= (x - e, y)(x - e, y).
\end{aligned} \tag{A.6}$$

Q.E.D.

**Lemma 2.**

If  $a \in \mathbb{R}_{++}^n$  and  $b \notin \mathbb{R}_+^n$  are such that  $ab > 0$ , then

$$a - \frac{a \cdot b}{b \cdot b} b \geq 0. \tag{A.7}$$

*Proof.*

We provide the proof for the case  $n = 2$ . The general case is then established applying this case in the 2-dimensional space spanned by the vectors  $a$  and  $b$ .

Since  $a \in \mathbb{R}_{++}^2$  and  $ab > 0$ , then  $b \notin -\mathbb{R}_+^2$ . Since  $b \notin -\mathbb{R}_+^2$  and  $b \notin \mathbb{R}_+^2$ , then  $b_1 b_2 < 0$ . Assume, without loss of generality that  $b_1 < 0$  and  $b_2 > 0$ . Note first that, for all  $a \in \mathbb{R}_{++}^2$ , the inequality  $a - \frac{a \cdot b}{b \cdot b} b \geq 0$  holds if, and only if,

$$\frac{a}{\|a\|} - \frac{b}{\|b\|} \cos \widehat{ab} \geq 0. \tag{A.8}$$

Since  $a \in \mathbb{R}_{++}^2$ ,  $ab > 0$ , and  $b_1 < 0$ , then it trivially holds

$$\frac{a_1}{\|a\|} - \frac{b_1}{\|b\|} \cos \widehat{ab} \geq 0. \tag{A.9}$$

Moreover, since  $b_1 < 0$ , then

$$b_1 \left( \frac{a_1}{\|a\|} - \frac{b_1}{\|b\|} \cos \widehat{ab} \right) \leq 0 \tag{A.10}$$

but since, for any  $a, b \in \mathbb{R}^n$ , it holds

$$\sum_{i=1}^2 \frac{b_i}{\|b\|} \left( \frac{a_i}{\|a\|} - \frac{b_i}{\|b\|} \cos \widehat{ab} \right) = 0, \tag{A.11}$$

then

$$b_2 \left( \frac{a_2}{\|a\|} - \frac{b_2}{\|b\|} \cos \widehat{ab} \right) \geq 0 \tag{A.12}$$

and finally, since  $b_2 > 0$ , hence

$$\frac{a_2}{\|a\|} - \frac{b_2}{\|b\|} \cos \widehat{ab} \geq 0. \tag{A.13}$$

Q.E.D.

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<sup>6</sup> This is a consequence of Lemma 2 below

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