JUSTIFYING THE LINDAHL SOLUTION AS AN OUTCOME OF FAIR COOPERATION

WOLFGANG BUCHHOLZ
WOLFGANG PETERS

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Abstract

The Lindahl equilibrium is mostly motivated by a rather artificial price mechanism. Even though the analogy to a competitive market has been emphasised by Lindahl himself his approach does not directly explain the normative ideas, which are behind this concept. In the present paper we therefore show how the Lindahl equilibrium can be deduced from some simple equity axioms that in particular are related to the equal sacrifice principle and a non-envy postulate as norms for distributional equity. Fairness among agents with different preferences is taken into account by considering their marginal willingnesses to pay as virtual prices. In this way it might also become more understandable why the Lindahl solution can be perceived as an outcome of fair cooperation.

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Wolfgang Buchholz
Department of Economics
University of Regensburg
93040 Regensburg
Germany
wolfgang.buchholz@wiwi.uni-regensburg.de

Wolfgang Peters
Department of Economics
European University Viadrina
Postfach 1786
15207 Frankfurt (Oder)
Germany
peters@euv-frankfurt-o.de

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1. Motivation

The Lindahl equilibrium is one of the most prominent concepts in the theory of public goods that, in the context of the intensified interest in transnational public goods as combating global warming, has attained more attention in the last years[1]. According to Lindahl's concept every agent acts as a cost-share taker who, being confronted with an adequately chosen individualised price, wants to consume the same amount of the public good. The allocation characterised in this way is Pareto efficient and thus the Lindahl solution is quite parallel to a competitive market equilibrium for private goods. The attractiveness of Lindahl's construction mainly lies in this analogy, which is mostly used to provide the motivation for the concept[2]. Based on a purely artificial price mechanism this usual justification of the Lindahl equilibrium, however, is not directly linked to the allocation problem as stated by Lindahl (1919/1958) himself: How much of a public good should be provided and how should the costs of the public good be shared among the agents such that the resulting allocation can be considered as "just" and can thus be expected as the outcome of a "free agreement" between the agents involved?

In the literature there are a few attempts to bridge this gap and to provide an alternative motivation for the Lindahl equilibrium referring to equity or fairness concepts. In Silvestre's (1984) voluntariness approach the Lindahl outcome was identified as an allocation in which no agent would prefer to get a reduction of public-good supply accompanied by a proportional reduction of its contribution to the public good. Sato (1987), by a specific construction, characterized the Lindahl solution as an envy-free allocation in which no agent would want to interchange its position with someone else. Van den Nouweland, Tijs and Wooders (2002) motivate the Lindahl solution by a consistency requirement, and in the approach of Bilodeau and Gravel (2004), Lindahlian cost sharing turns out to be a special case of a general class of cost-sharing rules that fulfil some Kantian maxim of equal treatment.

Notwithstanding these contributions it is not quite transparent what the normative underpinnings of the Lindahl solution are that should make it appealing as a potential outcome of fair cooperation. In this note we therefore want to show how in the standard public-good model with a summation technology (like in Bergstrom, Blume and Varian, 1986, and Cornes and Sandler, 1996) the Lindahl solution can be based directly on simple equity conditions the most well-known of which is the benefit principle. Following its classical interpretation, eve-

[1] Some prominent examples are Chichilnisky and Heal (1994), Sandler (2004) and in particular Uzawa (2003).
[2] For details see Atkinson and Stiglitz (1980, pp. 509-512), Myles (1995, pp. 271-277) and Cornes and Sandler (1996, pp. 201-203).

ryone should pay for a public good according to his marginal willingness to pay. For each individual this means a "quid pro quo"-exchange as it is given in competitive markets for private goods. In this paper we want to show in addition that, in the case of public goods, the benefit principle can be related to equity norms concerning the distribution of public-good contributions among the parties. So, in particular, we assume that in the solution agreed upon each agent should carry the same burden for financing the public good after differences in willingness to pay have been taken into account. It turns out that this postulate for distributional equity combined with Pareto efficiency leads to the Lindahl equilibrium without invoking a Walrasian auctioneer. The relationship between equity postulates and the Lindahl equilibrium partly seems to be some kind of "common knowledge" in the theory of public goods. The aim of this paper is to make the intuition behind more explicit and thus to give a more transparent and sound normative foundation of the Lindahl solution.

2. Axiomatic Characterisations of the Lindahl Solution

We consider a standard public-good economy with n agents. Each agent i has an exogenously given income y_i. Preferences are characterized by the utility function $u_i(x_i, G)$ where $x_i \geq 0$ denotes agent i's private consumption and $G \geq 0$ is the provision level of a public good. All utility functions are assumed to have the usual properties: they are strict monotonously increasing in both types of consumption, twice continuously differentiable for $(x_i, G) > 0$, strictly quasi-concave, and the private as well as the public good are non-inferior. By $g_i = y_i - x_i$ we denote agent i's contribution to the public good, which is the part of i's income that is spent for providing the public good. By assuming a linear technology, which transforms one unit of private into one unit of public consumption, we can normalise $mrt = 1$. Thus any feasible allocation fulfils

$$G = \sum_{i=1}^{n} g_i \tag{1}$$

which is a self-financing condition and corresponds to a balanced public budget.

For any $(x_i, G) > 0$ agent i's marginal rate of substitution between the public and the private good is denoted by $p_i(x_i, G) = \frac{\partial u_i / \partial G}{\partial u_i / \partial x_i}$. Or, putting it differently, $p_i(x_i, G)$ measures agent i's marginal willingness to pay for the public good at (x_i, G).

Given n agents with preferences represented by $(u_1, ..., u_n)$ and strictly positive income levels $(y_1, ..., y_n)$ the *mechanism L* defines a vector of Lindahl prices $(p_1^L, ..., p_n^L)$ such that, if G^L denotes public-good supply in the Lindahl equilibrium, each agent i maximises utility $u_i(y_i - p_i^L G, G)$ by choosing the public-good level G^L and then has private consumption $x_i^L = y_i - p_i^L G^L$. If we additionally assume that the indifference curves of all agents do not intersect both axes, normality implies existence and uniqueness of the Lindahl allocation $(x_1^L, ..., x_n^L, G^L)$[3]. In contrast to L, let M denote some *general* allocation mechanism which, for given preferences $(u_1, ..., u_n)$ and strictly positive income levels $(y_1, ..., y_n)$, appoints a specific allocation $(x_1^M, ..., x_n^M, G^M)$ that is self-financing according to (1): $\sum_{i=1}^{n} g_i^M = G^M$. Additionally, we suppose that the selected allocation is interior ($0 < x_i^M < y_i$ for all i, and $G^M > 0$). This assumption characterises minimal fairness requirements, as it excludes two rather strange financing conditions for the public good. On the one hand, agent i must not suffer from having no private consumption. Hence, the mechanism M does not allow a full exploitation of agent i through the other agents. On the other hand, each agent does not get a free lunch and thus has to bear at least a small cost share of financing the public good.

Besides feasibility, we now want to impose some additional properties which the mechanism M should fulfil. As we are interested in an efficient and somehow fair mechanism, these conditions are meant to incorporate some basic normative ideas. The first axiom is the uncontroversial efficiency postulate.

Efficiency (EF): The allocation $(x_1^M, ..., x_n^M, G^M)$ is Pareto optimal.

The axiom **EF** implies that for the allocation picked out by M the Samuelson condition holds, such that the sum of marginal rates of substitution of the n agents equals the marginal rate of transformation:

[3] For an elementary proof of this result see Buchholz, Cornes and Peters (2005).

$$\sum_{i=1}^{n} p_i(x_i^M, G^M) = 1. \tag{2}$$

The other class of axioms we are now going to formulate reflects equity considerations, which refer to agents' contributions (or cost shares) when financing the public good. To base equity directly on the individual contributions g_i^M measured in units of the private good is clearly inappropriate, as this would not take different preferences for the public good into account - which does not seem fair. Spending the same amount of income for the public good means a higher subjective burden for an agent who does not receive much benefit from the public good and thus has a low willingness to pay for it[4]. A fair mechanism has to incorporate such concerns. To correct for the effect of different individual valuations, contributions have to be converted into commensurable equivalents before an equity maxim can reasonably be applied. This transformation is done in a standard way by applying the marginal rates of substitution of the different agents as virtual public-good prices[5].

Equity may now be captured in various ways, so first by directly imposing the benefit principle[6] in its classical interpretation. As an equity maxim related to the Lindahl solution this is closest to the existing literature.

Benefit Principle (BP): Under the mechanism M

$$g_i^M = p_i(x_i^M, G^M)G^M \tag{3}$$

holds for all individuals.

This axiom means that every individual has to spend that share of its income for the public good, which – according to the individual's marginal willingness to pay – is equivalent

[4] See already Wicksell (1896/1958, p. 77) for this argument where he identified the group with small willingness to pay to the public good with the "lower class".
[5] For a fundamental criticism of using marginal valuations for comparing public-good contributions, however, see Brennan (1976, 1981).
[6] For a general discussion of the benefit principle see already Wicksell (1896/1958), Musgrave (1959, pp. 61-89) and more recently Sandler (2004, pp. 77-79), referring especially to the provision of international public goods, and Silvestre (2004, pp. 535-536).

to the amount of the public good provided under M [7]. In the sense of "value and counter-value", everyone pays what he gets. On competitive markets for private goods this benefit principle is automatically fulfilled which provides the basis for considering market exchange as just.

It is an important message of the present paper that **BP** can be deduced from other equity axioms that are related to concepts of a fair burden sharing among individuals, i.e. to distributional equity relative to the individual contributions.

Proportional Contributions (PC): Under the mechanism M

$$\frac{g_i^M}{g_j^M} = \frac{p_i^M(x_i^M, G^M)}{p_j^M(x_j^M, G^M)} \tag{4}$$

holds for all pairs of individuals.

This axiom means that the cost shares of the agents in financing the public good are proportional to their marginal willingness to pay[8]. The higher an agent's willingness to pay of an agent, the higher is the contribution to the public good he should make if mechanism M is applied. In this sense, everyone pays according to his preferences for the public good which-seems to be a fair cost-sharing rule when agents are different.

Lindahl (1919/1958, pp. 171-172) gave some algebraic treatment of the special case where the utility functions are quasi-linear, i.e. $u_i(x_i, G) = x_i + f_i(G)$. Then condition (4) requires that cost shares are proportional to the individual marginal utilities $f_i'(G^M)$ of the public good at G^M. As for quasi-linear preferences income effects do not matter, Lindahl's example focuses on differences in individual tastes.

[7] Sandler (2004, p. 78) interprets the benefit principle in this way by saying that it "requires that a good's recipients pay their marginal willingness to pay (MWTP)". To Sandler this is one of the "essential principles that guide taxation at the national level and can be applied to TPGs [transnational public goods, *W. B. and W. P.*] at the supranational level". See also Wicksell (1896/1958, p. 75) who proposes "rejecting any public expenditure, along with its companion tax levy, which failed to render each taxpayer a service corresponding to his payment. Justice would thereby be done at least to the extent that each man received his money's worth." A critical discussion of this specific version of the benefit principle is given by Hines (2000) who also suggests another interpretation of the benefit principle. See also Kaplow (2003, esp. pp. 8-9) for a discussion of the benefit principle.

[8] Moulin (1995, p. 243 and pp. 286-288) interprets this condition as being some other version of the benefit principle, but doesn't take it as a starting point for characterising Lindahl equilibria. An illuminating discussion of the normative background of this cost-sharing rule is also in Moulin (1995, pp. 22-26). Moulin's (1987) own approach for making a selection among Pareto-optimal public good allocations by egalitarian-equivalent cost sharing can be interpreted as still another version of the benefit principle (see Hines, 2000).

If agent j has a stronger preference for the public good than agent i, i.e. if $f_j'(G) > f_i'(G)$ holds for all $G > 0$, then condition (4) implies $g_j^M > g_i^M$. This conforms to an intuitive requirement of vertical equity as the agent with the higher interest in the public good has to pay more for it if **PC** is assumed.

As a contrasting example consider the case where the agents have general but identical preferences. Then vertical equity demands that the agent with the higher income makes a higher contribution to the public good, which – as a normative postulate – can also be interpreted as a variant of the venerable ability-to-pay-principle. If **PC** is assumed it follows from (4) that mechanism M has this property in case of normal preferences. (See the Appendix for a precise proof.) So in a public-good economy the axiom **PC** implies a close relationship between two essential norms for just taxation or just burden sharing: the benefit principle on the one hand and the ability-to-pay principle on the other.

The axiom **PC** can also be reformulated in a somewhat different way.

Equality of Sacrifice (ES): Under the mechanism M

$$\frac{g_i^M}{p_i^M(x_i^M, G^M)} = const. \tag{5}$$

holds for all individuals.

This axiom means that, under the mechanism M, everyone bears the same burden when financing the public good. Before a comparison of individual contributions is made the monetary contribution g_i^M of each agent i is normalised through an adjustment for different preferences such that the individual burden is measured in public-good equivalents. This axiom implies an "equal sacrifice" in private consumption for all agents involved.

The following result shows how these axioms can be combined to justify the Lindahl solution.

Proposition: The following characterizations of the allocation mechanism M are equivalent:

(i) $M = L$

(ii) M fulfills **BP**

(iii) M fulfills **PC** and **EF**

(iv) M fulfills **ES** and **EF**

Proof: (i) $\Rightarrow$ (ii): This is obvious according to the properties of L.

(ii) $\Rightarrow$ (i): Given M**,** let each individual i be confronted with the individual public-good price $p_i^M := p_i(x_i^M, G^M)$. Then, by **BP** and $g_i^M = y_i - x_i^M$, we have $y_i = x_i^M + p_i^M G^M$, i.e. (x_i^M, G^M) lies on the budget line of individual i given y_i and p_i^M. As $p_i^M = p_i(x_i^M, G^M)$ the consumption bundle (x_i^M, G^M) is utility maximising for agent i. Given the price vector $(p_1^M, ..., p_n^M)$ all price-taking agents would then choose the same public-good level G^M. As the Lindahl equilibrium is uniquely determined, then $G^M = G^L$ and p_i^M must be equal to agent i's Lindahl price p_i^L such that $M = L$ holds.

(ii) $\Rightarrow$ (iv): **ES** trivially follows from **BP** if we take G^M as the constant on the right hand side of (5). Combining the self-financing condition (1) and **BP** implies

$$G^M = \sum_{i=1}^{n} g_i^M = \left(\sum_{i=1}^{n} p_i(x_i^M, G^M) \right) G^M$$

such that cancelling G^M on both sides gives the Samuelson condition and thus **EF**.

(iv) $\Rightarrow$ (ii): It follows from **EF** (i.e. the Samuelson formula (2))**,** **ES** and the self-financing constraint (1) that for each agent i the constant term on the right hand side of (5) must be identical to the public-good supply G^M:

$$\frac{g_i^M}{p_i(x_i^M, G^M)} \underset{\mathbf{EF}}{=} \left(\sum_{j=1}^{n} p_j(x_j^M, G^M) \right) \frac{g_i^M}{p_i(x_i^M, G^M)}$$

$$\underset{\mathbf{ES}}{=} \sum_{j=1}^{n} g_j^M \underset{(1)}{=} G^M = const. \qquad (6)$$

Thus, (5) implies (3).

(iii) $\Leftrightarrow$ (iv): Obvious. QED.

That (i) implies (ii), has already been observed by Lindahl (1919/1958 p. 173) in the special case of quasi-linear preferences and has been taken up by the subsequent literature (see Musgrave, 1959, p. 77). The converse [(ii) $\Rightarrow$ (i)] seems to be some folk theorem in the theory of public goods (see, e.g., Musgrave, 1985, p. 17) for which an explicit statement highlighting the normative significance of "equality in exchange", however, is hard to find[9]. The other result stated in the Proposition [(iv) $\Rightarrow$ (ii)] says that the benefit principle in its standard version can, in the case of public-good allocation, also be interpreted as a consequence of a conceptually different normative judgement that focuses on a balanced burden sharing among the parties. Thus, the main message of the present paper is that there exists a close relationship between distributive justice, the traditional benefit principle, and consequently with the Lindahl concept.

Note that in contrast to the conventional characterization of the Lindahl solution Pareto optimality is not an implication but an assumption in conditions (iii) and (iv) of the Proposition. Without **EF** the equity axioms **ES** (or **PC**) alone would not entail the Lindahl solution. Just look at the case in which there are two completely identical agents. This symmetry implies that **ES** and **PC** are fulfilled when both agents make identical contributions. However, the Lindahl equilibrium is a distinct element within the whole set of symmetric allocations.

In the special case with two agents, condition (iv) of the Proposition can be illustrated in the standard diagram, where we depict agents' cost shares g_1 and g_2 on both axes (see Cornes and Sandler, 1996, p. 202). The g_1-g_2-combinations along the line P_1P_2 represent all Pareto optima where both agents' indifference curves touch each other. The common tangent of these indifference curves on the P_1P_2-line has a slope, which is measured by $\frac{p_2(y_2 - g_2, g_1 + g_2)}{p_1(y_1 - g_1, g_1 + g_2)}$[10]. Then, **PC** together with **EF** defines that point (g_1^M, g_2^M) on the P_1P_2-

[9] For some more detailed theoretical discussion on the relationship between the benefit principle and Lindahl equilibrium see Aaron and Mc Guire (1970).

[10] This is obtained by solving the identity $\frac{dg_1}{dG} = \frac{dg_1}{dg_1 + dg_2} = p_1$ for $\frac{dg_2}{dg_1} = \frac{1 - p_1}{p_1} = \frac{p_2}{p_1}$ where the last equality follows from the Samuelson condition.

line for which the tangent to both indifference curves passes through the origin (see Figure 1)[11].

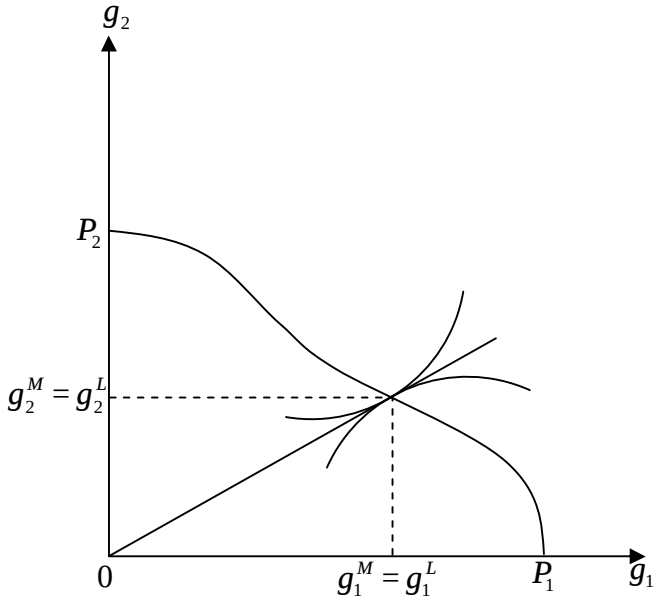

Figure 1

The axioms underlying the Proposition can slightly be weakened. So **BP** can be substituted by the postulate that under a mechanism M the inequality

$$g_i^M \leq p_i(x_i^M, G)\, G \tag{7}$$

holds for each agent. This means that no one should pay more for the public good than what he receives as a public-good equivalent. If condition (7) is now combined with **EF** we obtain condition (3), as otherwise $G^M = \sum_{i=1}^{n} g_i^M \leq \sum_{i=1}^{n} p_i(x_i^M, G^M)\, G^M = G^M$ would not hold. By the Proposition, this implies $M = L$. In the special case of a linear technology as considered here, condition (7) is equivalent to Silvestre's (1984) voluntariness postulate: Define $s_i^M := g_i^M / G^M$ as agent i's public-good cost share under M. Given (7), agent i prefers (x_i^M, G^M) over all points on the budget line $x_i + s_i^M G = y_i$ for which $G < G^M$. These points can be described by $(y_i - l\, g_i^M, l\, G^M)$ where $l \in [0,1)$, such that agent i, starting from

[11] Starting from condition (iv) this graphical presentation does not make use of Lindahlian reaction curves that, however, are needed to prove existence of the Lindahl solution in the diagram.

(x_i^M, G^M), does not want to have a proportional reduction of public-good supply and its individual contribution to the public good. This, however, is just Silvestre's voluntariness axiom.

The axiom **ES** can be relaxed in a similar way by postulating that for any pair of agents the inequality

$$g_i^M \leq \frac{p_i(x_i^M, G^M)}{p_j(x_j^M, G^M)} g_j^M \tag{8}$$

is valid for the allocation chosen by mechanism M. By simply interchanging the indices i and j it is clear that (8) implies (5) and thus **ES**. Condition (8) says that no agent i would prefer to have the contribution level g_j^M attributed by M to some other agent j when i, being confronted with this hypothetical choice, is simultaneously forced to take differences in marginal willingness to pay into account.

With this interpretation axiom **ES** becomes a non-envy postulate[12]: Given the allocation mechanism M no one wants to change roles to get the contribution level of someone else if he simultaneously has to respect the other's preferences. In this way the parties are treated quite symmetrically. Under this fairness proviso, no one can legitimately protest against the conditions that are imposed on him in the cooperative arrangement through the mechanism M. This gives some reason to identify the Lindahl solution with the outcome of fair cooperation without using Lindahl's own bargaining model that is based on a rather specific and "unconvincing" construction (Silvestre, 2004, p. 528). If the parties are fairness-oriented in a strict sense they will not accept an offer that removes them to a less advantageous position relative to the other parties[13]. In voluntary agreements, which are reached by truly fair negotiations, there is no tolerance for unilateral privileges. Only then can we legitimately suppose equal bargaining power with the parties, which has also been a crucial element in Lindahl's (1919/1958) approach[14].

[12] For another more complicated application of Varian's (1974) non-envy approach to public-good provision see Sato (1987) who uses the special and intricate notion of *L*-fairness but also uses marginal willingness to pay as the basis of comparison.

[13] In this spirit is also the short remark by Romer (1995, p.14): "For once interpersonal bargaining occurs, then notions of fairness may be required to describe its outcome, as a bargainer may refuse to accept an offer because he views it as unfair, a conclusion he may reach, inter alia, by making some comparison of his gain compared with his adversary's."

[14] So Lindahl (1919/1958, p. 169) states that if a "party has defended its own interests better than the other parties… power is not distributed evenly."

3. Conclusion

The purpose of the Lindahl concept is to find a cooperative solution for a public-good economy that is voluntarily accepted by all agents involved. Unanimous approval over public-good supply, however, can only be expected when the parties consider the underlying cost-sharing rule as equitable. Even though fair burden sharing played a central role in Lindahl's own reasoning and the ensuing discussion of his approach, maxims concerning distributional equity are not explicitly used as the starting point for a motivation of the Lindahl equilibrium. Therefore, our analysis first of all should be helpful for elucidating the Lindahl solution as a "normative concept" (see Varian, 1978, p. 200, and Inman, 1987, p. 681). Moreover, in this way the Lindahl allocation mechanism might be brought more into line with fair cooperation, which Lindahl actually had in mind[15].

Considering provision of international public goods, like mitigating climate change, negotiation over public goods among independent agents has become a much more important topic in public-good theory as compared to the traditional situation in which public goods are provided by a single government. From this perspective Lindahl's thought experiment is not only of theoretical but also of practical interest as it might improve our understanding of how a bargaining solution on public goods might look like when fairness is seen as a prerequisite for an agreement.

Implementing the Lindahl solution, however, requires knowledge on the preferences of the agents involved, i.e. on their willingness to pay (see Cornes and Sandler, 1996, pp. 214-221, for a detailed discussion on this problem). From the very beginning the Lindahl concept has been plagued with this inherent problem of an efficient provision of public goods. This explains why a vast theoretical and empirical literature on preference revelation has emerged since awareness of environmental problems has increased. Concerning international public goods in particular the question arises whether the problem of asymmetric information becomes more or less serious when only a small number of governments is involved in negotiations. Discussing this quite controversial question[16] is outside the framework of this paper, which concentrates on motivating the Lindahl solution as a cooperative outcome under ideal conditions usually assumed in the literature.

[15] See Musgrave (1959, pp. 63-77) for an illuminating review of the history of economic thought concerning the relationship between contractual arrangements, or, specifically the "contract theory of the state", and equity according to the benefit principle. In particular, Musgrave in this context refers to A. Smith's first principle of taxation.

[16] For arguments that might be relevant in this context see e.g., Musgrave (1959, p. 80) and Johansen (1977).

Appendix

Axiom PC and Ability to Pay

In the case of identical preferences $p(x_i, G)$ denotes the common *mrs*-function of all agents. It follows from normality that $p(x_i, G)$ is increasing in x_i given any arbitrary level of G such that private consumption and the marginal willingness to pay for the public good change in the same direction (see already Kovenock and Sadka, 1981). As a consequence, the axiom **PC**, i.e. condition (4), implies that $g_j^M > g_i^M$ holds if and only if $x_j^M > x_i^M$. If agent j has a higher income than agent i $(y_j > y_i)$ this gives $g_j^M > g_i^M$ and $x_j^M > x_i^M$ since otherwise $g_j^M + x_j^M = y_j \leq g_i^M + x_i^M = y_i$ would be obtained.

As a by-product of these considerations we immediately get the result that no "rank-reversal" can occur when a mechanism M satisfying **PC** and **EF** (and henceforth $M = L$) is applied: $y_j > y_i$ implies $x_j^L > x_i^L$ and thus $u(x_j^L, G^L) > u(x_i^L, G^L)$. Thus, in the Lindahl equilibrium the agent with the higher income enjoys the higher welfare level. Therefore, an important objection raised by Brennan (1976, 1981) against the Lindahl solution is not valid when preferences are normal. (See also the short remark in Hines, 2000.)

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